

**Applications of Modular Construction Techniques for Habitability Spaces in Naval Ship Design and Production**

by

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Submitted to the Department of Ocean Engineering in Partial Fulfillment of the Requirements for the Degrees of

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and

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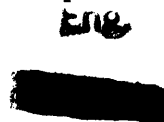
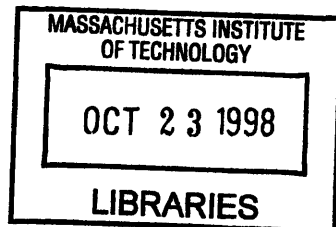
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## **ABSTRACT**

Traditional construction methods for habitability spaces in naval ships, particularly aircraft carriers, are manpower intensive and expensive. In response to decreasing defense spending, the Navy is considering methods to improve the affordability of aircraft carriers. Modular construction techniques for habitability spaces offer potential costs savings.

Although cruise ship builders have utilized modular construction techniques for almost 30 years, these modules do not meet Navy survivability requirements. The Navy's Affordability Through Commonality (ATC) program is developing new joiner bulkhead systems and modular sanitary spaces to meet Navy performance requirements. However, very little is known about the cost benefits and area and weight penalties for using habitability modules in aircraft carriers.

An arrangement design project was carried out on a new aircraft carrier design to quantify the cost, area, and weight benefits and penalties for using modular habitability spaces. With the assumptions made in this research, the results show that modular habitability spaces offer a 15 percent cost benefit, but suffer a 7-15 percent area penalty and 8-13 percent weight penalty. A plan for testing modular construction techniques on a new aircraft carrier is also presented. While modular construction techniques have many benefits in cruise ships, the benefits for aircraft carriers are more limited, and depend on the characteristics of the individual design.

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## **1.0 Introduction**

Today's Navy is facing many new challenges. Although the cold war is over, the U.S. Navy must continue to meet commitments around the world. Since the end of the cold war in 1988, the U.S. Navy has been called upon for a variety of missions. These include traditional forward presence and diplomacy missions, actual combat operations, peacekeeping, and humanitarian missions.

For all of these missions, the Navy relies on the power and flexibility of aircraft carriers. Whenever there is a global crisis, the U.S. relies on carrier battle groups to represent the nation's interests. The *Nimitz* class aircraft carriers form the backbone of the current carrier fleet. At over 1,000 feet in length, these nuclear powered ships are the largest naval ships ever built. With an airwing of over 85 aircraft, they have incredible power and flexibility.

While the need to keep forces around the world is as important as ever, it is not possible to continue to maintain defense spending at past levels. And the power of the aircraft carrier does not come without a price. A new *Nimitz* class aircraft carrier costs over 4 billion dollars, without aircraft. Over the 50 year life of the carrier, life cycle costs will come to another 15 billion. Considering the tremendous cost of aircraft carriers and shrinking budgets, it is extremely important to identify ways to improve affordability in future carriers.

One method for improving affordability is to increase common elements between different ship classes. This is the goal of the Navy's Affordability Through Commonality (ATC) project. By designing a range of standard modules, the ATC group hopes to reduce design and construction costs. In addition, improved standardization will reduce crew training and maintenance costs. Among the ideas the ATC group is investigating are habitability modules. Habitability modules include sanitary spaces and berthing quarters. To date, the ATC group has developed a prototype of a modular crew sanitary space, which it is planning to install on the new LPD-17 amphibious ship.

The idea of habitability modules is not new. Kvaerner Masa-Yards, a world leading commercial shipbuilder in Finland, has used modular cabins in its cruise ships for many years. By building modular cabins off the ship, they can begin outfitting work earlier in the construction process. In addition, building the cabins in a specialized factory is quicker and less expensive than assembling them on the ship. The cabins are sent to the shipyard as completed units and inserted into the ship at the outfitting pier. Kvaerner claims they have reduced their outfitting expenses almost 50% by switching to modular cabins.<sup>1</sup>

In some ways, aircraft carriers have much in common with cruise ships. Modern cruise ships displace over 70,000 tons – almost as much as a nuclear powered aircraft carrier. In addition, cruise ships must provide magnificent food and accommodations for up to 3,000 passengers. All of these requirements force cruise ships to devote large areas to cabins and restaurants. Aircraft carriers are also extremely manpower intensive, requiring over 6,000 crew members. While the comfort level is different, many of the fundamental berthing, sanitary, and messing requirements are similar. If modular habitability spaces have cut costs in the cruise ship business, is it possible they will also make aircraft carriers more affordable?

Just as there are similarities, there are huge differences. An aircraft carrier's primary mission is to operate aircraft. As a combatant, an aircraft carrier must also be able to survive damage and continue to operate. Several questions must be addressed to accurately evaluate the application of modular construction techniques for habitability spaces in an aircraft carrier. To answer these questions, it is first necessary to outline the requirements for the construction of habitability spaces on a naval ship. The requirements for nonstructural bulkheads and sanitary spaces are found in *the U.S. Navy General Specifications*, sections 621 and 644 respectively. These sections outline

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<sup>1</sup> Bosworth, Michael and Hough, Jeffrey, "Improvements in Ship Affordability." SNAME Transactions, Vol. 101, September 1993.

material selection, design, and shock and fire resistance characteristics for habitability spaces.

It is also important to examine current habitability construction methods. Currently, habitability spaces are “stick built” on board the carrier at the outfitting pier. This method is well known, but expensive. Even using preoutfitting – doing outfitting work on-block – can significantly reduce labor costs. It is necessary to identify why the work is done on-ship, and what physical and scheduling limitations could affect modular construction techniques.

After examining the advantages and disadvantages of current outfitting methods, it is possible to evaluate alternative construction methods. The ATC program is developing a new joiner bulkhead system. While this system does not use self supporting modules, it incorporates producibility improvements designed to reduce costs. In addition to Navy efforts, it is useful to examine commercial modular habitability systems. The ATC program is relatively young, while Kvaerner has been building modules for almost thirty years. The more experienced commercial sector may have some valuable lessons for the Navy.

Because habitability modules are a new concept in the Navy, very little is known about the relative trade-offs. It is expected that modules will carry weight and area penalties, while potential cost benefits are unknown. Advantages in commercial shipbuilding do not always carry over to the naval shipbuilding process. For example, cruise ships have large, uninterrupted decks for passenger cabins. As a result, modular cabins fit into the available space without significant area penalties. However, habitability spaces on naval ships are often located in unusual locations which are not well suited for modules. Using modular habitability spaces in these compartments leaves unused area. But this area penalty has never been quantified. Weight penalties and cost benefits are also unknown.

To answer these questions, modular habitability spaces are integrated into a concept design of the Navy’s next aircraft carrier, the CVX. The concept design was developed

by third year students in the Naval Ship Construction and Engineering program at MIT. This design project focuses on the officer berthing spaces in the CVX design, and presents a methodology for quantifying the weight and area penalties, as well as cost benefits of modular construction techniques. The impact of system design on total ship design and effectiveness is also examined.

After examining the integration of modular construction techniques into a new design, a plan is presented for testing modular installation techniques in a small area on CVN-77, the last *Nimitz* class carrier. The test program is necessary to establish the technical feasibility of modular construction techniques for aircraft carriers before full scale installation in a new carrier. Finally, the application of modular habitability spaces in other types of naval ships is examined. Although aircraft carriers are the best suited to modular construction techniques because of their physical dimensions and large crew size, several other naval ship types could also benefit.

## **2.0 Requirements for the Construction of Habitability Spaces on Naval Ships**

Naval vessels are among the most complex machines in the world, with millions of parts. On a one for one basis, U.S. Navy vessels are generally acknowledged as the most technologically advanced and capable warships in the world. However, building vessels to these high standards requires a rigorous design and construction process. The construction of U.S. Navy vessels is governed by a comprehensive set of requirements, evolved and developed over a long period of time. These requirements are based on years of in-service experience, and are intended to insure the high quality and survivability of U.S. ships. While these specifications might seem overly burdensome compared to commercial shipbuilding requirements, they were originally developed for specific performance-based reasons. It is, therefore, necessary to fully review and understand these requirements before considering alternative methods.

The construction of habitability spaces in U.S. Navy ships is governed by the *General Specifications for Ships of the U.S. Navy*. There are separate sets of specifications for joiner bulkheads and sanitary spaces. Joiner bulkhead requirements are found in *Section 621, Nonstructural Bulkheads and Partitions*. Sanitary space requirements are found in *Section 644, Sanitary Spaces and Plumbing Fixtures and Fittings*.

### **2.1 Specifications for Construction of Nonstructural Bulkheads**

Each ship class has its own ship specifications, based on the general specifications. The LPD-17 specification, Section 621, is representative of nonstructural bulkhead requirements and is presented here for several reasons. The LPD-17 is the newest ship class in the U.S. Navy, and its specifications reflect the most recent thoughts on nonstructural bulkhead requirements. (Section 621 of the LPD-17 specification is dated April 1996.) It is anticipated the LPD-17 specifications will be representative for a range of future naval vessels. A summary of the specification is presented here, and the complete specification is found in Appendix A.

## **Summary of Nonstructural Bulkhead and Partition Requirements for LPD-17**

### **2.1.1 Definitions**

**Nonstructural bulkheads are bulkheads which do not contribute directly to the strength of the hull and do not support decks.**

### **2.1.2 General**

**Nonstructural bulkheads are of three general types: joiner bulkheads, expanded metal bulkheads, and non-load bearing lightweight plate. Bulkheads for bounding and subdividing such spaces as offices, passages, quarters, foodservice spaces, pantries, and medical and dental spaces shall be joiner type.**

**Nonstructural bulkheads attached to portions of decks subject to helicopter landing or vehicle and forklift motion and all joiner bulkheads shall have a rattle proof deflection joint along the top edge to permit deck vertical deflection of +/- 50 mm without damage to the bulkhead.**

**Nonstructural bulkheads shall be stiffened locally in way of furniture and other articles supported from or attached to the bulkheads as required. Where equipment is mounted on nonstructural bulkheads, the analysis of design loads shall consider ship motion factors.**

### **2.1.3 Joiner Bulkheads**

**Joiner bulkheads shall be GRP/NOMEX, non-filled, sandwich constructed panels. The GRP/NOMEX honeycomb panel consists of a paintable phenolic resin impregnated fiberglass face sheet over an aramid fiber honeycomb core. The honeycomb core dimension shall be 6 mm hexagonal shaped cell size with a core density of 50 kg/m<sup>3</sup>. Overall panel thickness shall be 15.88 mm, including the decorative face sheets. Where decorative sheathing is required, face sheathing shall be 0.68 to 0.94 mm thick High Pressure Plastic Laminate (HPPL) or stainless steel (CRES 304), and meet fire performance standards of CRD-104.**



Bottom edge joints in dry spaces shall be sealed with a commercial quality, all-purpose, paintable adhesive/caulking compound. Bottom and vertical edge joints in wet spaces shall be sealed with silicone sealant AMS 3362. Where acoustic or thermal insulation is required, the insulation shall be attached to the bulkhead and the HPPL finished material shall be omitted.

If possible, joiner bulkheads shall be located in line with stanchions. Construction of bulkheads which separate air conditioned from non-air conditioned areas shall be of fume-tight construction. Bulkheads of darkrooms, staterooms, and the Quiet Room and similar spaces shall be constructed so as to exclude light.

#### **2.1.4 Coamings**

Coamings shall be 150 mm high, 5 mm thick steel, ASTM A36, painted, and of non-watertight construction. Watertight coamings shall be installed between adjoining wet spaces. Coamings for nonstructural bulkheads shall also be of semi-watertight construction when bounding a space likely to have water or oil upon the deck, when used to protect stores or deck equipment against mop or water leakage from adjoining spaces where liquids are stowed for operating mechanical systems, or when provided for rat-proofing. Tightness classifications and welding requirements are as follows:

##### **2.1.4.1 Non-watertight coaming**

Where a coaming serves as a boundary between adjoining dry spaces, the coaming shall be intermittently welded on both sides when making connections to the deck and the vertical structure at the end of the coaming.

##### **2.1.4.2 Semi-Watertight Coaming**

Where a coaming serves as a boundary between a wet space and a dry space, the coaming shall be continuously welded on the wet side boundary and intermittently welded on the dry side.

#### **2.1.4.3 Watertight Coaming**

Where a coaming serves as a boundary between adjoining wet spaces, the coaming shall be continuously welded on both sides.

#### **2.1.5 Intermittent Welding**

As a minimum, intermittent welding shall consist of a bead of weld 25 mm long, with adjacent beads spaced not greater than 150 mm apart.

#### **2.1.6 Overheads**

In addition to the requirements for nonstructural bulkheads in section 621, section 637 specifies which areas are to receive overhead sheathing. Currently, staterooms and offices are not scheduled to receive overhead sheathing. In all applications, sheathing shall be installed in a manner which will not impede damage control efforts. Full visibility and accessibility shall be provided for damage control fittings and other vital system components requiring access for inspection, maintenance, and operation. Installation of overhead sheathing for humidity control and protection of insulation shall be provided in shower and shower drying areas. Installation for aesthetic purposes shall be confined to Flag and Commanding officer quarters, quarters of officers or equivalent rank, Executive officer quarters, chapels, wardroom messrooms, CPO messrooms, and lounges.

#### **2.1.7 Shock**

Although shock requirements are not outlined in section 621, all joiner bulkheads must meet grade B shock requirements. Grade B shock qualification allows for loss of function, but requires equipment not come adrift. In addition, all furniture in spaces which will be occupied during general quarters (marine berthing compartments) must also meet grade B shock requirements.

## **2.2 Construction of Habitability Spaces**

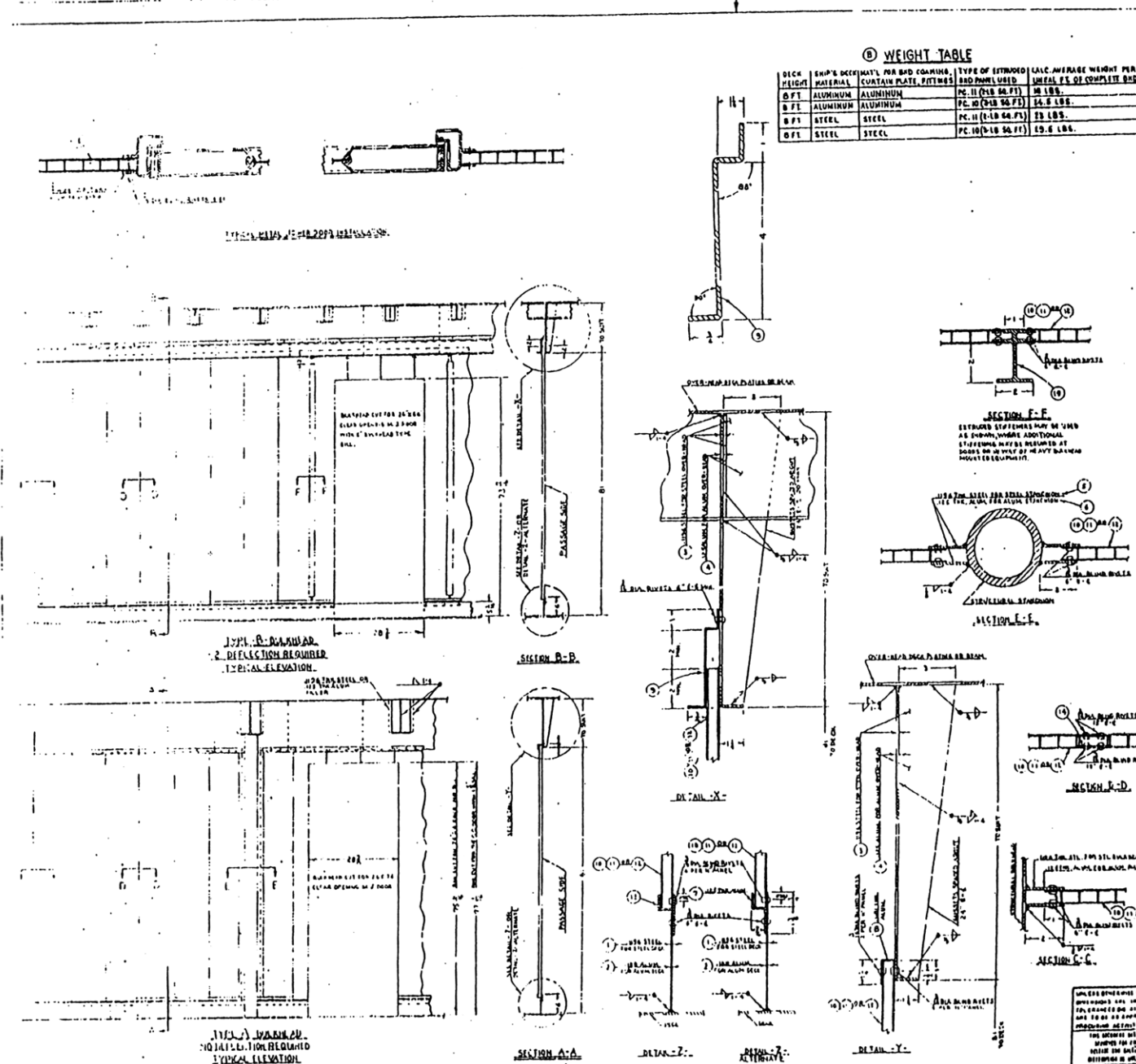
There are three types of joiner bulkheads: extruded bulkheads, honeycomb bulkheads, and stiffened sheet metal bulkheads. There are NAVSHIP detailed drawings for each of these joiner bulkhead types. The general construction and installation procedure and details are summarized here. Figure 2-1 illustrates current joiner bulkhead designs.

Extruded and Honeycomb bulkhead systems use a 6 inch (150 mm) flat bar coaming welded directly to the deck. There is either a Z-clip or H-clip attached near the top of the coaming. The joiner bulkhead panel rests either between the Z-clip and the coaming or inside the H-clip, and is fastened to the coaming. An alternative coaming system utilizes a U-channel welded directly to the deck. The joiner panel is inserted into the channel and fastened. Stiffened sheet metal joiner bulkheads are fastened directly to a 6 inch flat bar coaming, without Z or H-clips.

Curtain plates are used to form the upper boundary of a compartment and are usually 30 inches high with gussets attached 24 inches center to center. Curtain plates are secured by welding them to the underside of the overhead deck. If the curtain plate is attached to the underside of a structural member, additional stiffness is provided by welding an angle bracket to the curtain plate. Curtain plate must conform to the tightness requirements for the particular space (i.e. fume-tight, light tight, etc). This is more difficult, since a curtain plate is penetrated by pipes, cableways, and HVAC ducts and notched in way of stiffeners. All curtain plate penetrations must be sealed to meet particular tightness requirements.

Installation of both coamings and curtain plate begins by scribing the piece to fit the installation location. After scribing, the coamings or curtain plate are cut to fit along the structure, leveled, and welded to the structure. Once in place, the curtain plate obstructs the installation of piping, HVAC, and electrical subsystems. Each penetration requires a unique seal to maintain the integrity of the compartment. Installing curtain plate is even more difficult if the subsystems are already in place, and the plate must be installed

Figure 2-1 - Current Joiner Bulkhead Design



**(B) WEIGHT TABLE**

| DECK HEIGHT | SHIP'S DECK MAT'L FOR BHD COUPLING CURTAIN PLATE FITTINGS | TYPE OF EXTRUDED BHD PANEL USED | CALC. AVERAGE WEIGHT PER LINEAL FT. OF COMPLETE BHD |
|-------------|---|---------------------------------|---|
| 0 FT        | ALUMINUM  | PC. 11 (1-18 96.71)             | 18 LBS.   |
| 6 FT        | ALUMINUM  | PC. 10 (1-18 96.71)             | 14.5 LBS.   |
| 8 FT        | STEEL   | PC. 11 (1-18 96.71)             | 18 LBS.   |
| 0 FT        | STEEL   | PC. 10 (1-18 96.71)             | 13.6 LBS.   |

**REVISIONS**

| NO. | DESCRIPTION  | DATE    | BY | APP. |
|-----|--|---------|----|------|
| A   | REVISED BHD'S AUTHORITY FROM INTER-OFFICE MATR'L AND CONTROL LABEL TO BULKHEAD WEIGHT TABLE ADDED BY AUTHORITY OF JFONCON FROM NAUTIC CODE 6181F TO CODE 114 NAVSHIP TONON ON 7 JAN 1931 | 1/7/31  | JV | JV   |
| B   | AUTHORITY NAUTIC LTR 431 SER. 411 OF 3 NOV 1938 ADDED. NOTE FOR DOCUMENT RELEASE, SALE AND DISTRIBUTION  | 11/1/38 | JV | JV   |

**NOTES (A)**

- BULKHEAD SHALL BE IN GENERAL ACCORDANCE WITH SECTION 9-10-2 OF THE GENERAL SPECIFICATIONS FOR BULKHEAD BHD'S OF THE U.S. NAVY.
- WELDING SYMBOLS DEFINED IN AMERICAN WELDING SOCIETY E.C. 22 OF '33.
- DETAILS NOT SHOWN ON THIS DRAWING OR PARTS NO. 1, ARE CONSIDERED TO BE A MATTER OF DEVELOPMENT TO SUIT LOCAL CONDITIONS.
- BULKHEAD SECTION ON THIS DRAWING IS NOT SHOWN TO BE SHOWN BY OTHER BULKHEADS FOR VERT. SPACES RELATE TO BE IN ACCORDANCE WITH REF. DWG. NO. 3.
- THE USE OF HARD SOLD FASTENERS, SUCH AS BOLTS AND NUTS, OR OTHER SIMILAR FASTENERS, WHICH ARE AT LEAST EQUAL IN STRENGTH TO THE SPECIFIED FASTENERS, AS AN ALTERNATE METHOD OF FASTENING IS ACCEPTABLE.
- TYPE OF FASTENER IS TO BE EQUIVALENT TO THE NATIONAL ONE WHEN USED.
- WELDING BULKHEAD FITTINGS IN LAY OF MATERIAL, NOT SHOWN ON THIS DRAWING ARE DETAILED ON REF. DWG. NO. 8.
- THE ALUMINUM ASSOCIATION STANDARDS FOR EXHAUSTED 6-06'S SHALL APPLY TO ALL BULKHEADS UNLESS OTHERWISE NOTED HEREIN.
- PATENT NOTICE:** THE U.S. GOVERNMENT HAS A PATENT-PATENT RIGHTS IN HAND TO THE INVENTIONS INCORPORATED AND CLAIMED IN U.S. PATENT APPLICATION SERIAL NO. 98,818 OWNED BY REVEL, COPPER AND BRAD. THE ONLY FOR THE BENEFIT OF MANUFACTURERS OF THE ITEMS CALLED FOR ON THIS DRAWING OTHER FOR THE GOVERNMENT OR FOR USE IN EQUIPMENT TO BE DELIVERED TO THE GOVERNMENT.
- TYPE 'C' AND 'B' BULKHEADS SHOWN ON REF. DWG. NO. 1 ARE USUALLY PRIMARILY IN SENIOR OFFICERS QUARTERS, LOCAL 'A' APPROXIMATE CAPTAINS AND ADMIRAL QUARTERS WHICH ARE GENERALLY FINISHED INCLUDING BULKHEADS WITH A DECORATIVE 'T' TYPE MATERIAL.

**LIST OF MATERIAL CONTAINED ON SHEET NO. 1**

| ITEM NO. | DESCRIPTION        | QUANTITY | DETAILS ON SHEET NO. |
|----------|--------------------|----------|----------------------|
| 1        | 1/2" BHD CAP       | 1        | 1                    |
| 2        | 1/2" BHD COLUMN    | 1        | 1                    |
| 3        | 1/2" BHD STIFFENER | 1        | 1                    |
| 4        | 1/2" BHD SUPPORT   | 1        | 1                    |
| 5        | 1/2" BHD COLUMN    | 1        | 1                    |
| 6        | 1/2" BHD STIFFENER | 1        | 1                    |
| 7        | 1/2" BHD SUPPORT   | 1        | 1                    |
| 8        | 1/2" BHD COLUMN    | 1        | 1                    |
| 9        | 1/2" BHD STIFFENER | 1        | 1                    |
| 10       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 11       | 1/2" BHD COLUMN    | 1        | 1                    |
| 12       | 1/2" BHD STIFFENER | 1        | 1                    |
| 13       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 14       | 1/2" BHD COLUMN    | 1        | 1                    |
| 15       | 1/2" BHD STIFFENER | 1        | 1                    |
| 16       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 17       | 1/2" BHD COLUMN    | 1        | 1                    |
| 18       | 1/2" BHD STIFFENER | 1        | 1                    |
| 19       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 20       | 1/2" BHD COLUMN    | 1        | 1                    |
| 21       | 1/2" BHD STIFFENER | 1        | 1                    |
| 22       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 23       | 1/2" BHD COLUMN    | 1        | 1                    |
| 24       | 1/2" BHD STIFFENER | 1        | 1                    |
| 25       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 26       | 1/2" BHD COLUMN    | 1        | 1                    |
| 27       | 1/2" BHD STIFFENER | 1        | 1                    |
| 28       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 29       | 1/2" BHD COLUMN    | 1        | 1                    |
| 30       | 1/2" BHD STIFFENER | 1        | 1                    |
| 31       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 32       | 1/2" BHD COLUMN    | 1        | 1                    |
| 33       | 1/2" BHD STIFFENER | 1        | 1                    |
| 34       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 35       | 1/2" BHD COLUMN    | 1        | 1                    |
| 36       | 1/2" BHD STIFFENER | 1        | 1                    |
| 37       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 38       | 1/2" BHD COLUMN    | 1        | 1                    |
| 39       | 1/2" BHD STIFFENER | 1        | 1                    |
| 40       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 41       | 1/2" BHD COLUMN    | 1        | 1                    |
| 42       | 1/2" BHD STIFFENER | 1        | 1                    |
| 43       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 44       | 1/2" BHD COLUMN    | 1        | 1                    |
| 45       | 1/2" BHD STIFFENER | 1        | 1                    |
| 46       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 47       | 1/2" BHD COLUMN    | 1        | 1                    |
| 48       | 1/2" BHD STIFFENER | 1        | 1                    |
| 49       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 50       | 1/2" BHD COLUMN    | 1        | 1                    |
| 51       | 1/2" BHD STIFFENER | 1        | 1                    |
| 52       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 53       | 1/2" BHD COLUMN    | 1        | 1                    |
| 54       | 1/2" BHD STIFFENER | 1        | 1                    |
| 55       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 56       | 1/2" BHD COLUMN    | 1        | 1                    |
| 57       | 1/2" BHD STIFFENER | 1        | 1                    |
| 58       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 59       | 1/2" BHD COLUMN    | 1        | 1                    |
| 60       | 1/2" BHD STIFFENER | 1        | 1                    |
| 61       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 62       | 1/2" BHD COLUMN    | 1        | 1                    |
| 63       | 1/2" BHD STIFFENER | 1        | 1                    |
| 64       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 65       | 1/2" BHD COLUMN    | 1        | 1                    |
| 66       | 1/2" BHD STIFFENER | 1        | 1                    |
| 67       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 68       | 1/2" BHD COLUMN    | 1        | 1                    |
| 69       | 1/2" BHD STIFFENER | 1        | 1                    |
| 70       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 71       | 1/2" BHD COLUMN    | 1        | 1                    |
| 72       | 1/2" BHD STIFFENER | 1        | 1                    |
| 73       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 74       | 1/2" BHD COLUMN    | 1        | 1                    |
| 75       | 1/2" BHD STIFFENER | 1        | 1                    |
| 76       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 77       | 1/2" BHD COLUMN    | 1        | 1                    |
| 78       | 1/2" BHD STIFFENER | 1        | 1                    |
| 79       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 80       | 1/2" BHD COLUMN    | 1        | 1                    |
| 81       | 1/2" BHD STIFFENER | 1        | 1                    |
| 82       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 83       | 1/2" BHD COLUMN    | 1        | 1                    |
| 84       | 1/2" BHD STIFFENER | 1        | 1                    |
| 85       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 86       | 1/2" BHD COLUMN    | 1        | 1                    |
| 87       | 1/2" BHD STIFFENER | 1        | 1                    |
| 88       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 89       | 1/2" BHD COLUMN    | 1        | 1                    |
| 90       | 1/2" BHD STIFFENER | 1        | 1                    |
| 91       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 92       | 1/2" BHD COLUMN    | 1        | 1                    |
| 93       | 1/2" BHD STIFFENER | 1        | 1                    |
| 94       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 95       | 1/2" BHD COLUMN    | 1        | 1                    |
| 96       | 1/2" BHD STIFFENER | 1        | 1                    |
| 97       | 1/2" BHD SUPPORT   | 1        | 1                    |
| 98       | 1/2" BHD COLUMN    | 1        | 1                    |
| 99       | 1/2" BHD STIFFENER | 1        | 1                    |
| 100      | 1/2" BHD SUPPORT   | 1        | 1                    |

**REFERENCE DRAWINGS**

| DRAWING NO. | TITLE                                      | DATE      |
|-------------|--|-----------|
| 1           | METAL JOINER BULKHEAD BULKHEAD SECTION 2-F | 10-1-1931 |
| 2           | METAL JOINER BULKHEAD BULKHEAD SECTION 2-F | 10-1-1931 |
| 3           | METAL JOINER BULKHEAD BULKHEAD SECTION 2-F | 10-1-1931 |

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONS ARE TO BE AS SHOWN BY DIMENSION LINES THE WEIGHTS ARE TO BE APPROXIMATE WEIGHTS FOR INFORMATION ONLY

**DEPT. OF THE NAVY**  
WASHINGTON, D. C.  
SYSTEMS COMMAND  
805 1749247 OF 3

**METAL JOINER BULKHEADS**  
DOUBLE FACED, EXTRUDED  
TYPE-A AND TYPE-B  
SCALE: 1/4" = 1'-0"

around existing systems. While installing coamings requires on-ship welding, installing curtain plate is worse, as it requires time-consuming overhead welding.<sup>2</sup>

Panel installation is facilitated by riveting Z or H-clips to the top of the coamings. Because of requirements to accommodate relative motion between decks, deflection joints are installed at the panel's upper connection points. For extruded and honeycomb joiner bulkhead panels, the deflection joint is composed of a Z-clip riveted directly to the curtain plate. The bottom of the joiner panel rests in the clip on the coaming, and the panel's upper edge floats between the Z-clip and the curtain plate. If the joiner panel does not require a deflection joint, a Z-clip is still used, but the panel is riveted to the clip and curtain plate. Stiffened sheet metal bulkheads not requiring deflection joints are riveted directly to the coaming and curtain plate.

For honeycomb bulkheads, panel to panel connection is accomplished with an H-post. The panel ends slide into the H post and are fastened to the post. Honeycomb panels are attached to structural bulkheads with a U-channel. The U channel is welded to the structural bulkhead, and the panel end slides into the U channel and is fastened. Intersecting honeycomb panels use either a U channel or a T post. The U channel is fasten perpendicularly to one panel. The other panel end slides into the U channel and is fastened. Corners are built using a rounded 90 degree corner post that fastens to both panels.

Extruded bulkhead panels are fastened to each other using a joiner tube. Each panel slides over half of the joiner tube, and is riveted in place. Panel intersections are built by attaching a U channel to the side of one panel, and sliding the other panel over the U-tube. A T-intersection extrusion is used at the intersection of three extruded panels.

Stiffened sheet metal panels are fastened together by folding both ends of each sheet to form channels. The channels are then fastened together. Alternatively, one end of the

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<sup>2</sup> NAVSEA 03R & NAVSEA 03H, "Affordability Through Commonality (ATC) Furniture Standardization and Stateroom Concepts – Integrated Joiner Bulkhead System." Page 2. Undated.

panel can be folded into an L shape. The channel end of one panel is then fastened to the L-end of the adjacent panel.

Currently, joiner bulkhead panels are manufactured in standard sizes. Ship outfitters must cut and fit joiner bulkhead panels in the field to meet individual compartment dimensions.

Furniture installation is a major part of habitability space construction. While the installation process varies for different types of furniture, it follows this general process. The foundation is scribed to fit the installation location, cut, leveled, and welded to the deck. Each type of furniture has a unique foundation, and can only be used with that furniture piece. Flashing is also installed around each piece of furniture for rat-proofing purposes. Furniture is then brought to the space in kit form, and assembled in place on the foundation.

### **2.3 Specifications for Construction of Sanitary Spaces**

The LPD-17 specification, Section 644, is representative of sanitary space requirements for future U.S. Naval vessels and is presented here. (Section 644 of the LPD-17 specification is dated March 1996) The specification was written after the Affordability Through Commonality program was developed and takes into account some of those lessons. (See Chapter 4) A summary of the specification is presented here, and the complete specification is found in Appendix B.

#### **Summary of Sanitary Space Requirements for LPD-17**

##### **2.3.1 Materials**

The sanitary space bulkhead panels and partitions are to be constructed of 1.27 mm thick CRES formed flush panels. The bulkhead panels shall be supported by a CRES framework. The individual panels and partitions shall be removable in a non-progressive manner from the inside of the sanitary space. Where exposed to view, the outside of the

sanitary spaces shall have flush finished panels. The material and finish of exterior panels is in accordance with the adjacent space. These panels are not required where the sanitary space boundary abuts ship structure or another sanitary space.

### **2.3.2 Erection**

Sanitary space erection and attachment of components and accessories shall be by Huck bolts, CRES machine screws or bolts with nuts or press nuts as applicable. Components and accessories shall be mounted and fully supported by bulkhead panels, framework, or partitions. Panels shall be reinforced or doubled in way of fittings. Panel joints shall be sealed by neoprene gaskets.

### **2.3.3 Ceilings**

Ceilings shall be provided. Panels shall be CRES or aluminum, progressively interlocking and rattle free. The first and last panel shall be fixed into position by machine threaded captive fasteners. Ceiling panels shall be removable from the inside of the sanitary space. The underside of the ceiling shall be not less than 2.0 m from the steel deck. Curtain plates and fascia plates shall be provided separately or in combination, as needed, to separate the volume above the sanitary space from adjacent spaces.

### **2.3.4 System Hookup**

Ventilation and Electrical systems serving the sanitary space shall be installed behind the bulkhead panels and above the ceiling panels. Within the space, piping systems for potable water, vacuum waste collection, and lavatory plumbing drains and vents shall be grouped to minimize the number of connections to the ship's systems and concealed behind removable bulkheads and ceiling panels.

### **2.3.5 Access**

Access panels shall be provided for access to systems serving the sanitary space for inspection, maintenance and repair. Quick-acting hinged access panels shall be provided for access to damage control fittings which are concealed by the bulkhead panels or ceiling.

### **2.3.6 Emergency Wash Facilities**

**Includes eye/face and deluge shower eye/face units. The specification outlines which spaces must have these units, maximum and minimum water pressures, alarms, and information labels.**

### **2.3.7 Shock**

**Joiner bulkheads and panels surrounding troop, troop officer, and SNCO sanitary spaces shall meet grade B shock requirements.**

### **2.3.8 Other**

**Section 644 also provides dimensional requirements for showers, combined shower and drying areas, water-closets, and lavatories. Locations for latches, hooks, ventilation terminals, and lights are also specified. Drinking water coolers are covered in section 644d. The location and makes of fixtures and fittings is also shown.**

## **2.4 Construction of Sanitary Spaces**

**Sanitary spaces have traditionally been built in much the same manner as other living spaces. The biggest differences were the additional piping runs required for the plumbing fixtures and the different panel facing material (CRES). Actual installation of joiner bulkheads was done in the same manner as for other living spaces as described above. However, the LPD-17 specifications for sanitary spaces were developed after the Affordability Through Commonality program developed a Modular Crew Sanitary Space (MCSS). The MCSS concept is intended to minimize on ship outfitting time through the use of standard, preoutfitted panels. The LPD-17 specifications referenced here reflect the lessons learned and recommendations of this program. While the specification reflects these production considerations, it still reflects the original performance-based requirements.**



## **2.5 Assessment of Current Habitability Space Specifications**

The specifications for nonstructural bulkheads for crew living spaces reflect a different approach than the specifications for the sanitary spaces. While the two specifications do not have conflicting requirements, it is also apparent the sanitary space specifications were designed to coincide with modular construction techniques. For example, while the MCSS requirements specified panels must be removable in a non progressive manner, that issue was not addressed in the nonstructural bulkhead section. Traditional joiner bulkhead systems do not use standardized panel widths, and are not designed for easy removal. In addition, there are no requirements for quick action access panels for damage control fittings in the nonstructural bulkhead specification. Nevertheless, by examining the similarities of the two specifications, it is still possible to summarize the vital requirements for habitability spaces.

Within the two specifications, a few items merit emphasis. The sanitary space specification requires individual panels and partitions must be removable in a non-progressive manner from inside the module. This is necessary to allow for easy maintenance, inspection, and damage control without taking down all the panels to access the desired area. Also important is the requirement for fixtures and components to be mounted and fully supported by bulkhead panels, framework, or partitions, as opposed to deck mounting. While this increases the complexity of the panel mounting system, it has several advantages. This arrangement supports both pre-outfitted panel construction methods as well as full modular construction. In addition, it is anticipated that a panel mounted fixture able to move with the panel under load or shock will be more resistant to damage.

Nonstructural bulkhead requirements for other habitability spaces do not specify standardized panel sizes or require bulkhead mounted furniture. However, just as the sanitary space specification require CRES faced panels, the nonstructural bulkhead specification requires HPPL or CRES facing. In addition, 50 kg/m<sup>3</sup> low density GRP or NOMEX cores are specified to reduce panel weight.

In a departure from the traditional approach, the LPD-17 sanitary spaces use false ceilings. The false ceilings reduce cost significantly by reducing the need for numerous curtain plates.<sup>3</sup> In the past, however, the Navy has generally refused to use false ceilings for several reasons. In a shock situation, ceiling panels can fall or become projectiles, increasing damage and endangering crew. Furthermore, ceiling panels restrict access to overhead piping and electrical runs, which is important for maintenance and damage control. To counteract the problems of false ceilings and panels, the specification requires quick acting hinged access panels for all damage control fittings. This is a reasonable compromise that allows the benefits of weight reduction while mitigating the damage control problems.

While the sanitary spaces are currently scheduled to receive false ceilings, the offices and crew living spaces are not. Section 637 of the LPD-17 specification indicates where overhead sheathing is to be applied. This again demonstrates that the LPD-17 is a transition ship, based on traditional methods but incorporating some advanced techniques. And while there is a reluctance to use false ceilings, false decks and uninspectable void spaces are prohibited.<sup>4</sup> Corrosion is the primary concern for these spaces.

The last major issue is shock. There are three categories for shock resistance in the U.S. Navy. To meet Grade A shock requirements, the equipment must maintain 100% function after a shock load. Grade B shock qualification allows for loss of function, but requires the equipment not come adrift. Grade C qualification has no requirements.

The joiner bulkheads and sanitary space panels are required to meet Grade B shock requirements. Because the LPD-17 is an amphibious assault ship, it has a large complement of marines. During general quarters, the marines are stationed in their

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<sup>3</sup> NAVSEA 03R & NAVSEA 03H, "Affordability Through Commonality (ATC) Furniture Standardization and Stateroom Concepts – Integrated Joiner Bulkhead System." Page 3. Undated.

<sup>4</sup>Interview with Shawn Izenon, Naval Architect, NAVSEA 03H, conducted by Gene Miller, March 16, 1998.

berthing compartments. The joiner bulkhead panels and furniture for these compartments must meet grade B shock qualifications to protect the marines stationed there. While the sanitary spaces are unoccupied during general quarters, these spaces are located adjacent to marine berthing areas. Therefore, the sanitary space panels must meet grade B shock qualification to protect the marines stationed in adjacent compartments. In general, spaces which are unoccupied during general quarters and do not have mission-related equipment do not have any shock requirements. Nevertheless, there is a desire to provide as much shock resistance as possible for the fixtures inside these spaces. This is to reduce replacement costs for fixtures which would otherwise be destroyed during the shock test on the first ship of class.

Table 2-1 summarizes the specifications for sanitary and crew living spaces. While the sanitary space specifications are based on section 644 and the crew living space specifications are based on section 621, some specifications are derived from additional sources.

| <b>Category</b>               | <b>Sanitary Space,<br/>Based on Section 644</b>                                       | <b>Crew Living Spaces,<br/>Based on Section 621</b>   |
|-------------------------------|---|---|
| <b>Materials</b>              | CRES formed flush panels, removable in non-progressive manner from inside compartment | GRP/NOMEX honeycomb panel; 15.88 mm thick; fiberglass, HPPL, CRES faces                         |
| <b>Coamings</b>               | Watertight Coamings – full length weld  | Non-watertight or semi-watertight, depending on adjacent space. Intermittent or continuous weld |
| <b>Fixtures /Furniture</b>    | Bulkhead Mounted  | Provision for bulkhead mounting, with additional local stiffening                               |
| <b>False Deck/Void Spaces</b> | No  | No  |
| <b>Ceilings</b>               | Yes, with provision for quick access panels to damage control fittings                | Generally No, See Section 637 for complete list   |
| <b>Shock</b>                  | Bulkheads grade B   | Bulkheads grade B, Furniture in Marine crew spaces meet Grade B                                 |

Table 2-1 – Summary of Sanitary Space and Crew Living Space Specifications

### 3.0 Aircraft Carrier Construction

#### 3.1 *Nimitz* Class Aircraft Carriers

The *Nimitz* class aircraft carrier is the ultimate symbol of American naval power. These vessels are 1092 feet long, 252 feet wide on the flight deck, and displace over 97,000 tons full load. With over a 100 million parts and two nuclear reactors, they take over seven years to build. The two nuclear reactors generate steam for a 260,000 SHP power plant, driving the vessel at over 30 knots at full speed. The *Nimitz* class carrier can carry 85 aircraft, and is equipped with all the necessary hanger, maintenance, and support equipment of a military airbase. In addition, she carries an extensive suite of electronics, communication, and radar systems.<sup>5</sup> Figure 3-1 is a picture of a *Nimitz* Class Aircraft Carrier.

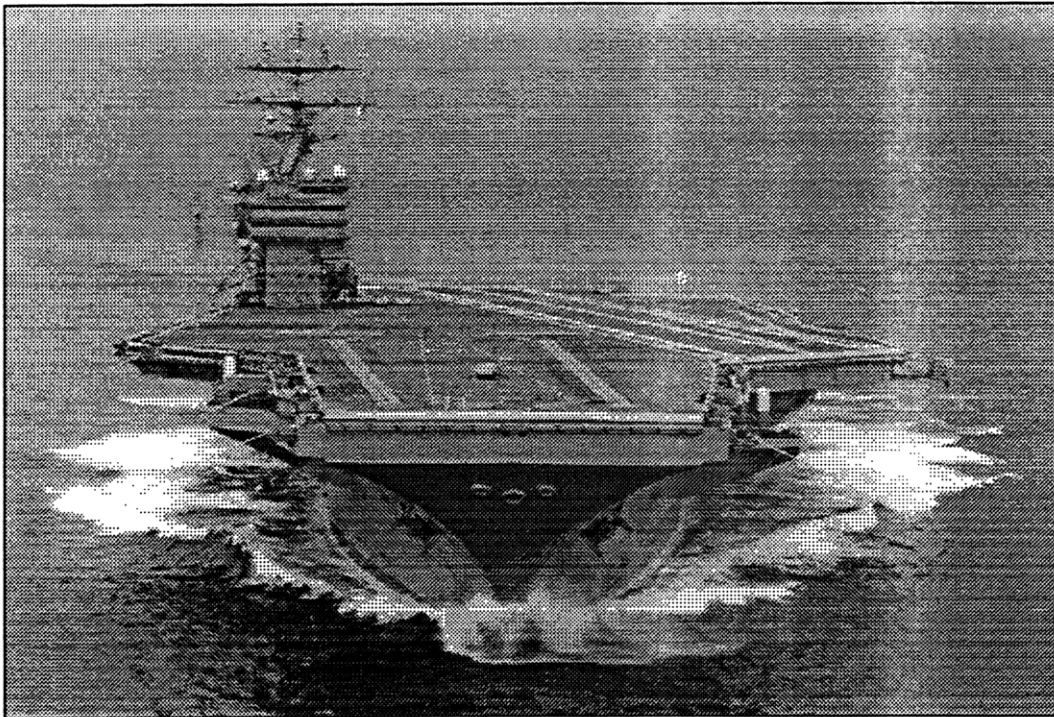


Figure 3-1 - A *Nimitz* Class Aircraft Carrier

<sup>5</sup> Sharpe, Captain Richard, Editor, *Jane's Fighting Ships 1997-1998*, pp807, Butler and Tanner Limited, Great Britain, 1997.

The first vessel of the class, *Nimitz*, was delivered by Newport News Shipbuilding (NNS) in 1975. Since then, NNS has completed seven *Nimitz* class carriers, has two more under construction, and one more planned.

### **3.2 Newport News Shipbuilding, Inc.**

Newport News Shipbuilding is the only facility in the world currently capable of building a nuclear powered aircraft carrier the size of the *Nimitz*. It is therefore important to understand the Newport News's history, facilities, and capabilities. Newport News Shipbuilding is America's largest privately-owned shipyard. Started in 1886, NNS has delivered more than 800 commercial and naval vessels, including 29 aircraft carriers. In addition to the two *Nimitz* class carriers currently under construction (CVN-75 and 76), NNS is building a series of double hull product tankers, and is in the process of converting two commercial ships into strategic sealift ships. NNS also performs commercial and naval repair and overhaul work on a regular basis.

The shipyard itself is located on 550 acres along the James River, near Hampton Roads, VA. Its facilities include eight dry docks, two outfitting berths, and four outfitting piers; an 11-acre automated steel fabrication center, a 130,000 sq. ft module outfitting facility; a foundry complex, and 300,000 sq. ft of machine shops. Two of these dry docks are used in the construction and refueling of *Nimitz* Class aircraft carriers. New carriers are built in Dry Dock 12. This dry-dock is the largest in the western hemisphere, at over 2100 feet in length, and features a 900 ton capacity crane, also the most capable in the western hemisphere.<sup>6</sup> Dry Dock 12 is currently divided in two, with Double Eagle tankers under construction on the river side, and the *Ronald Reagan* (CVN-76) under construction on the inboard side. This dry dock has a 30' 6" draft limitation, so it is used exclusively for the construction of new carriers.<sup>7</sup> New carriers are launched before their draft exceeds

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<sup>6</sup> Newport News Shipbuilding, Facts and Figures. Public Relations Kit, December 1997.

<sup>7</sup> Michael Powell, "CVX Modular Berthing." Briefing to Alan Brown and Gene Miller, NNS, Feb. 20, 1998.

this limit. Completed aircraft carriers do not meet the draft limitations of Dry Dock 12, and must use Dry Dock 11.

While Dry Dock 11 was originally used to build new aircraft carriers, it is the only dry dock at Newport News capable of accommodating a completed *Nimitz* Class aircraft carrier. Therefore, it is now used for overhauling and refueling existing nuclear-powered carriers. Dry Dock 11 only has a 310 ton crane, which is not capable of making some of the larger lifts currently used in the construction process for new carriers.

### 3.3 Habitability Spaces in Aircraft Carriers

Obviously, running a complex vessel of this size is a manpower intensive job. A *Nimitz* class aircraft carrier has a crew of over 6000, and a breakdown is given in Table 3-1.<sup>8</sup> Of these, about half are associated with the air wing.

| <b>AIRCRAFT CARRIER CREW BREAKDOWN</b> |             |
|--|-------------|
| Enlisted                               | 5050        |
| Marine                                 | 60          |
| Marine 1 <sup>st</sup> Sargent         | 1           |
| Chief Petty Officers                   | 347         |
| Officers                               | 567         |
| <b>TOTAL ACCOMMODATIONS</b>            | <b>6025</b> |

Table 3-1 – Aircraft Carrier Crew Breakdown

In addition to bunk spaces for the crew, galley, washroom, office, and recreational spaces are all necessary, and take up a significant amount of space. However, finding this space in an aircraft carrier design is a difficult task.

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<sup>8</sup> Michael Powell, "CVX Modular Berthing." Briefing to Alan Brown and Gene Miller, NNS, Feb. 20, 1998.

### **3.4 Carrier Arrangement Design Hierarchy**

The traditional design spiral begins with a concept design, which attempts to translate mission requirements into naval architectural and engineering characteristics. Based on the mission requirements, the first step is to estimate the vessel's proportions and preliminary powering requirements. From the proportions, a lines plan and body plan are developed. Hydrostatics and floodable length curves are developed from the lines and body plan. Hull and Machinery arrangements are developed next, followed by structural design and powering. Once this is complete, a lightship weight estimate is created for intact and damaged stability studies. Finally, a cost estimate is developed. The cost estimate is used to determine whether to proceed with the program and to evaluate different concept designs. If the program proceeds, the spiral is repeated to develop a preliminary design.

The preliminary design locks in controlling factors such as length, beam, deadweight, and horsepower. The preliminary design serves as a foundation for the development of the contract design. The contract design loops around the spiral again, developing many of the features of the ship's design. This stage includes model testing, structural detail design, and the final general arrangement. The final general arrangement fixes the volumes and areas for each space, and defines their location in relation to other spaces and systems. The final stage is the detail design. The detail design is not so much an iteration that loops around the spiral, but rather the development of construction instructions which are passed from engineer to shipbuilder.

While an aircraft carrier follows the traditional design spiral, within the spiral the development of general arrangements follows a definite hierarchy. The carrier's primary mission is to operate combat aircraft, and this is the first design priority, the mission requirement. As a result, aircraft launching, recovery, arming, and maintenance facilities are the most important systems in the ship's design. The electronic, radar, and communication systems needed to coordinate the airwing are also in the highest level of



the design hierarchy. These systems will dictate the location and size of the flight deck, hanger deck, magazines, weapons elevators, and some control facilities.

The ship propulsion and protection systems are in the next level of the design hierarchy. This includes the nuclear reactors, propulsion turbines and shafting, and power generation systems. Protection systems, both active (self defense missile systems and point defense guns) and passive (internal subdivision and structural protection systems) are also on this level. These requirements will dictate structural design and dominate the internal arrangements of the carrier's lower decks.

The preliminary design of an aircraft carrier considers all of the systems in the two highest design hierarchy levels. Because these are the most important systems, they need and require the "preferred" spaces in the carrier. "Preferred" spaces are those with the most regular geometry, best protection, or easiest access to the flight deck. Design trade-offs between systems in these levels are considered individually and carefully.

Toward the bottom of the design hierarchy are support and habitability systems. Within this level, briefing and mission-related office spaces have the highest priority. Galley and bunk spaces are next, and sanitary spaces are last. As a result of their low position in the design hierarchy, these systems are put in the remaining spaces after all the mission critical systems have been designed and placed. This often results in the assignment of habitability spaces to oddly shaped, difficult to access, and widely-separated locations.

Tanks and void spaces are unusual in the aircraft carrier arrangement design hierarchy. On one hand, they are at the bottom of the hierarchy because they can fit in any unusual space left over after every other system is positioned. On the other hand, they must still meet certain requirements. Double bottom tanks and some wing tanks serve a secondary function as armor for critical spaces, and must be arranged and built accordingly. In addition, the tanks must have enough capacity to carry the required amounts of aviation and diesel fuel to meet mission requirements. So while designers can usually allocate tanks and void spaces at the end of the arrangement design process,

they must still meet important requirements. Figure 3-2 illustrates the arrangement hierarchy.

### 3.5 Layout of Habitability Spaces

Figures 3-3 through 3-8 show the general arrangements of the Gallery Deck, 01, 02, Main deck, Second deck, and Third deck of the CVN 75, U.S.S. Theodore Roosevelt. The flight deck is located above the gallery deck, while the nuclear reactor and propulsion systems are located below the Third Deck. The majority of the habitability spaces are located on these six decks.

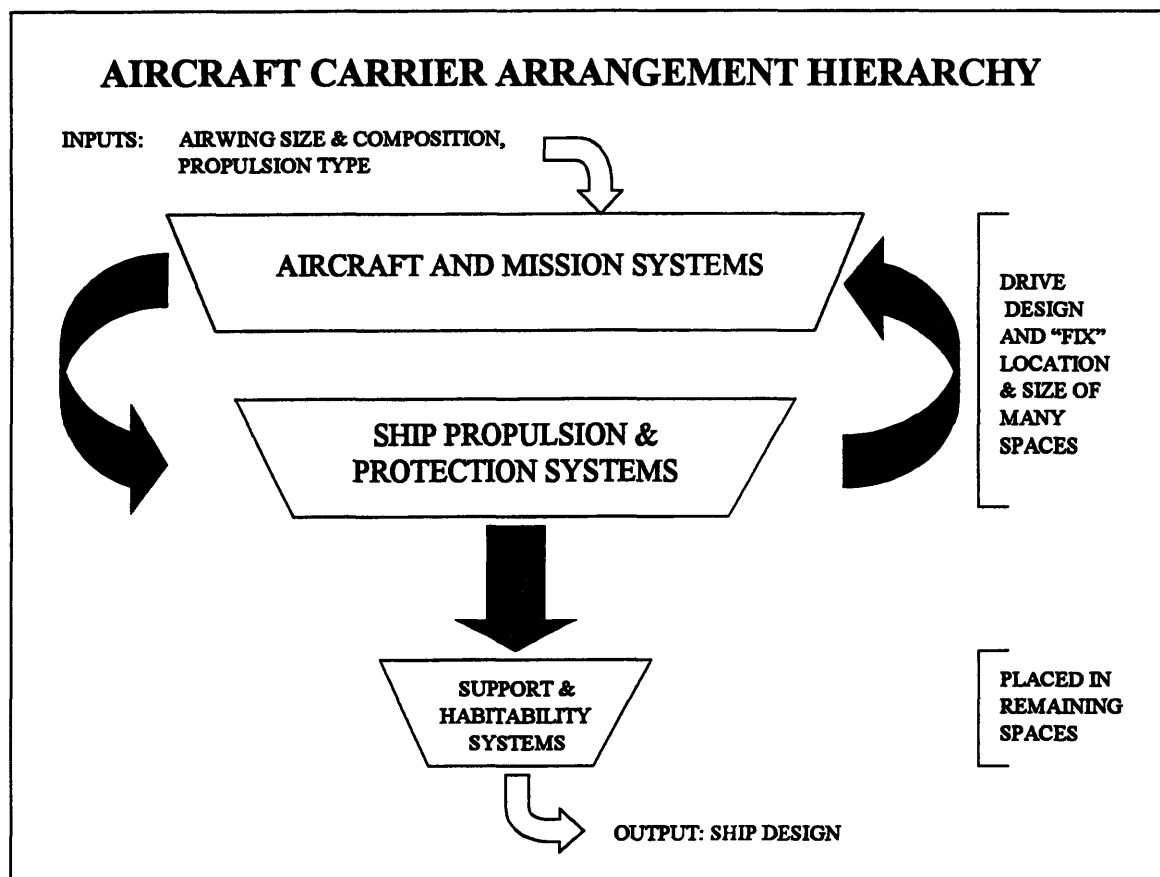


Figure 3-2 – Aircraft Carrier Arrangement Hierarchy.

### **3.5.1 Gallery Deck**

The gallery deck contains significant berthing and galley space. Crew living spaces dominate the forward and aft-most quarters of the deck, and there are some galley spaces forward. The middle half of the deck is dominated by weapons elevators, radar display spaces, and the Combat Information Center spaces, with some staterooms interspersed. Catapult systems are located both forward and amidships to port. Storerooms occupy the outboard areas through the middle half of the deck. This is one of the “busiest” decks on the carrier because of the variety of systems.

### **3.5.2 02 Deck**

The majority of the O2 level is open to the hanger bay. The anchor and line handling spaces are forward, and are immediately followed by crew spaces and staterooms. Storerooms are located outboard through the middle half of the deck, and more crew living spaces are located aft.

### **3.5.3 01 Deck**

The majority of the 01 level is open to the hanger bay. The windlass room and several storerooms are located forward, and are immediately followed by crew living spaces and avionics shops. Storerooms are located outboard through the middle half of the deck, and crew living spaces and more aviation shops.

### **3.5.4 Main Deck**

The hanger deck dominates the main deck level. Aviation shops are located forward and aft of the hanger bays. There are no living spaces on this level.

### **3.5.5 Second Deck**

The second deck is dominated by living and galley spaces. Crew living spaces are located both forward and aft, with galley and mess spaces throughout the middle half of the deck. The mess spaces also serve as alternate weapon assembly spaces. The ship’s hospital is also located on this deck.

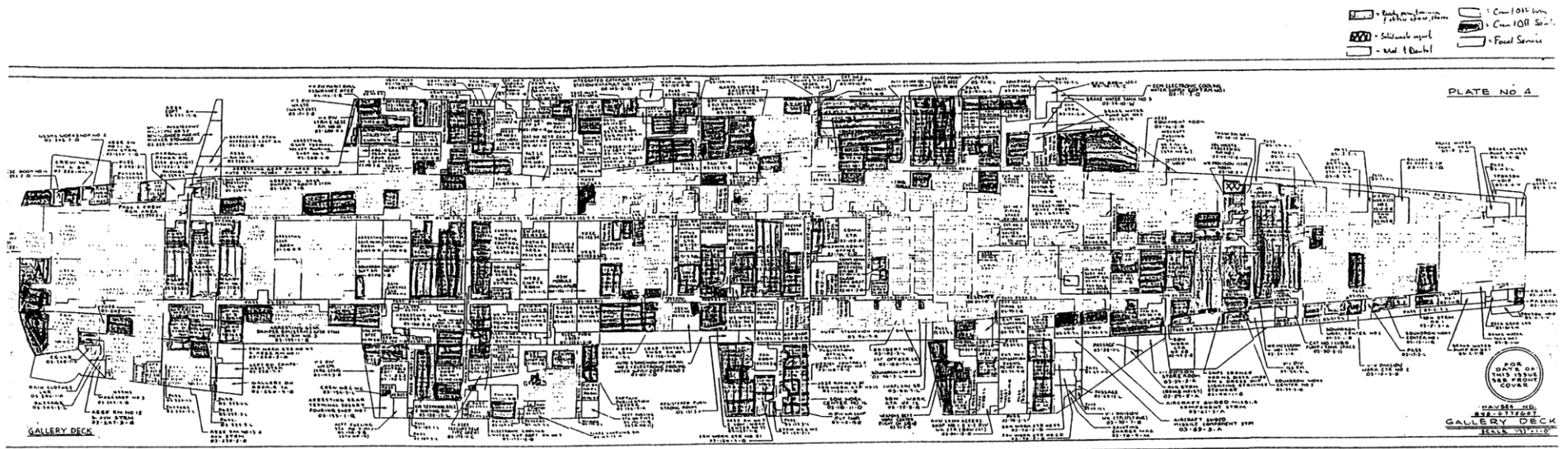


Figure 3-3 – Gallery Deck Arrangement

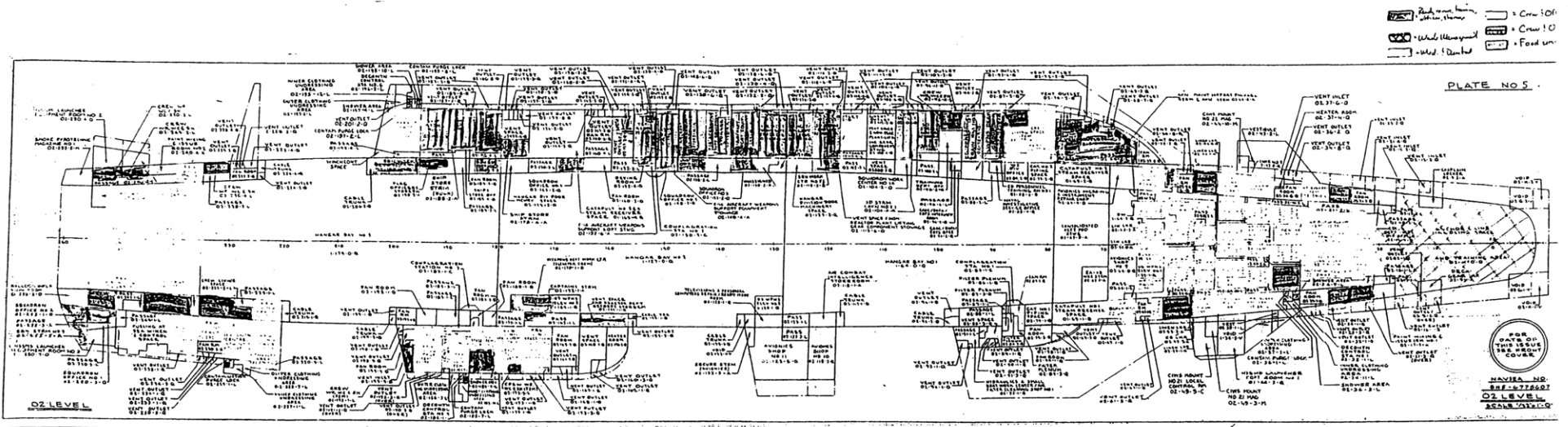


Figure 3-4 – 02 Deck Arrangement

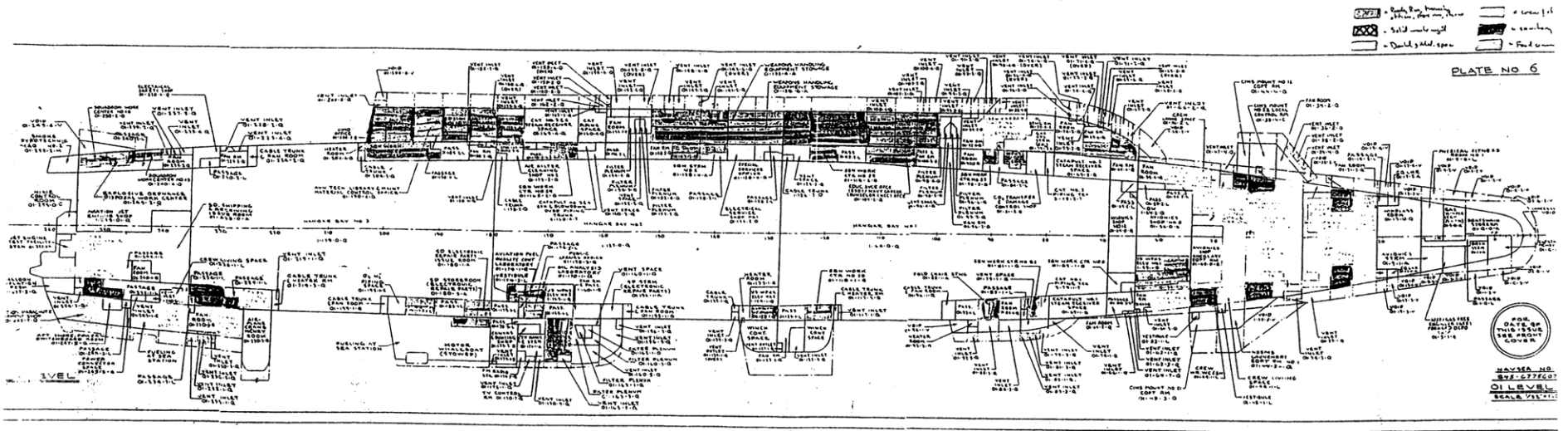


Figure 3-5 – 01 Deck Arrangement

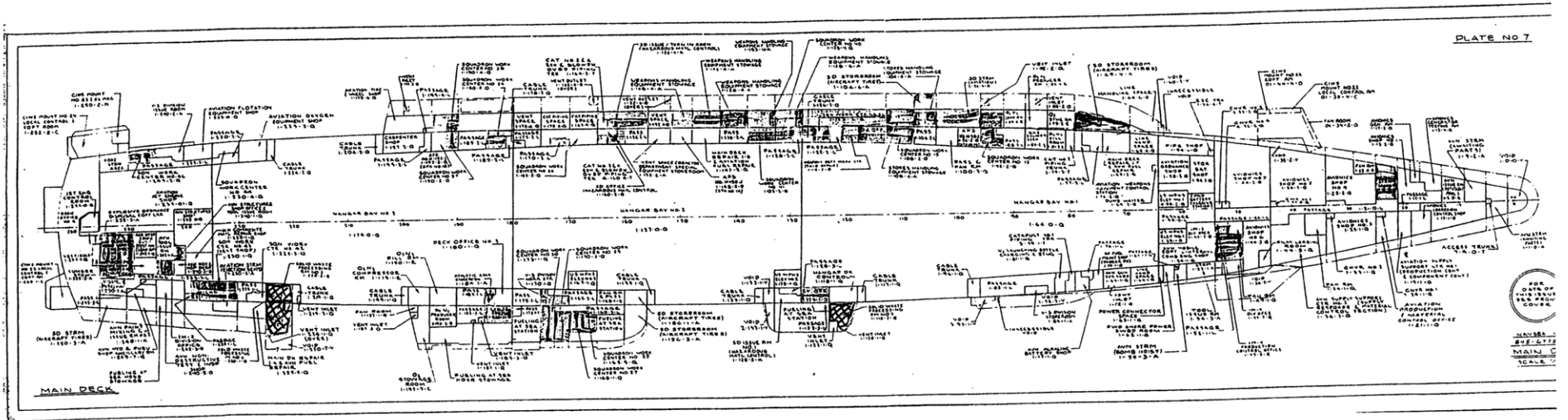


PLATE NO. 7

Figure 3-6 – Main Deck Arrangement





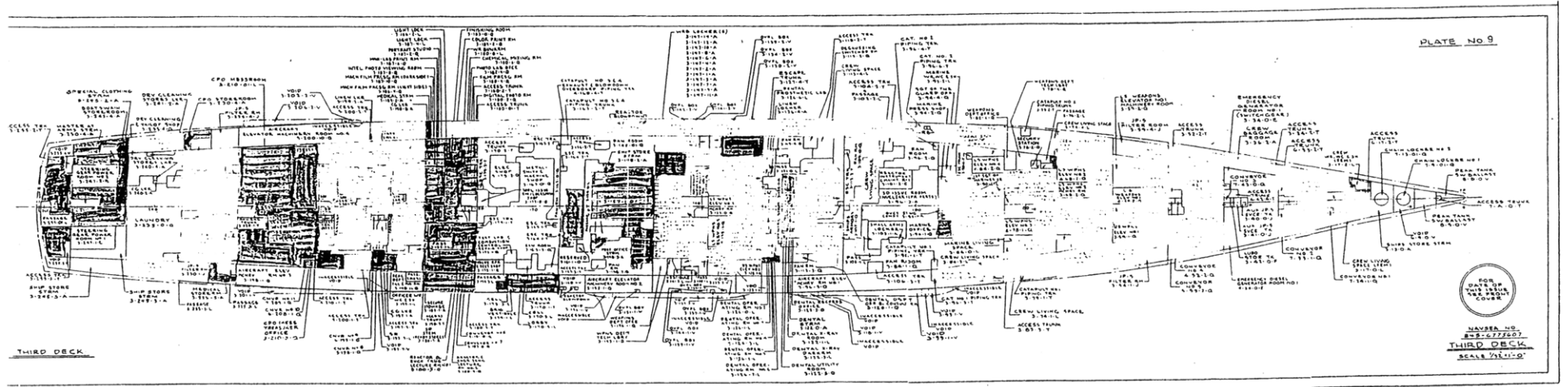


Figure 3-8 Third Deck Arrangement

### 3.5.6 Third Deck

Crew living spaces are interspersed with weapons elevators, generator rooms, fan rooms, and access trunks throughout the forward half of the deck. There are several machine shops, film labs, and mail rooms amidships, with more state rooms, crew living areas, galley, and laundry spaces aft.

### 3.5.7 Other Considerations in Habitability Space Design

While habitability spaces are placed primarily where space allows, they are considered to have a secondary purpose as protection for the vital parts of the ship. As a result, they tend to be located outboard and above such mission critical spaces as the combat information center, the hanger, and weapons elevators. Also, the original design for the lead vessel of the class is over 30 years old, and predates many environmental regulations. As a result, many sanitary spaces were located outboard to facilitate overboard discharges. While changes in environmental regulations now prohibit overboard discharge, the facilities have remained in the same locations. This necessitates long pipe runs to the furthest reaches of the ship.

## 3.6 Aircraft Carrier Construction Schedule

The design of a new aircraft carrier class begins approximately 10 years before the first contract award. Figure 3-9 shows a Typical Aircraft Carrier Construction Schedule.<sup>9</sup> Before an actual contract award, there is an advanced appropriation for long lead time material. This long lead time material includes the nuclear reactors. After contract award, it takes between seven and eight years until the finished carrier is delivered. Once the contract is awarded, major component procurement begins. This includes ordering the nuclear reactors and propulsion machinery. Steel fabrication begins three to six months after contract award, and equipment outfitting begins one year after contract award.

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<sup>9</sup> Michael Powell, "CVX Modular Berthing." Briefing to Alan Brown and Gene Miller, NNS, Feb. 20, 1998.

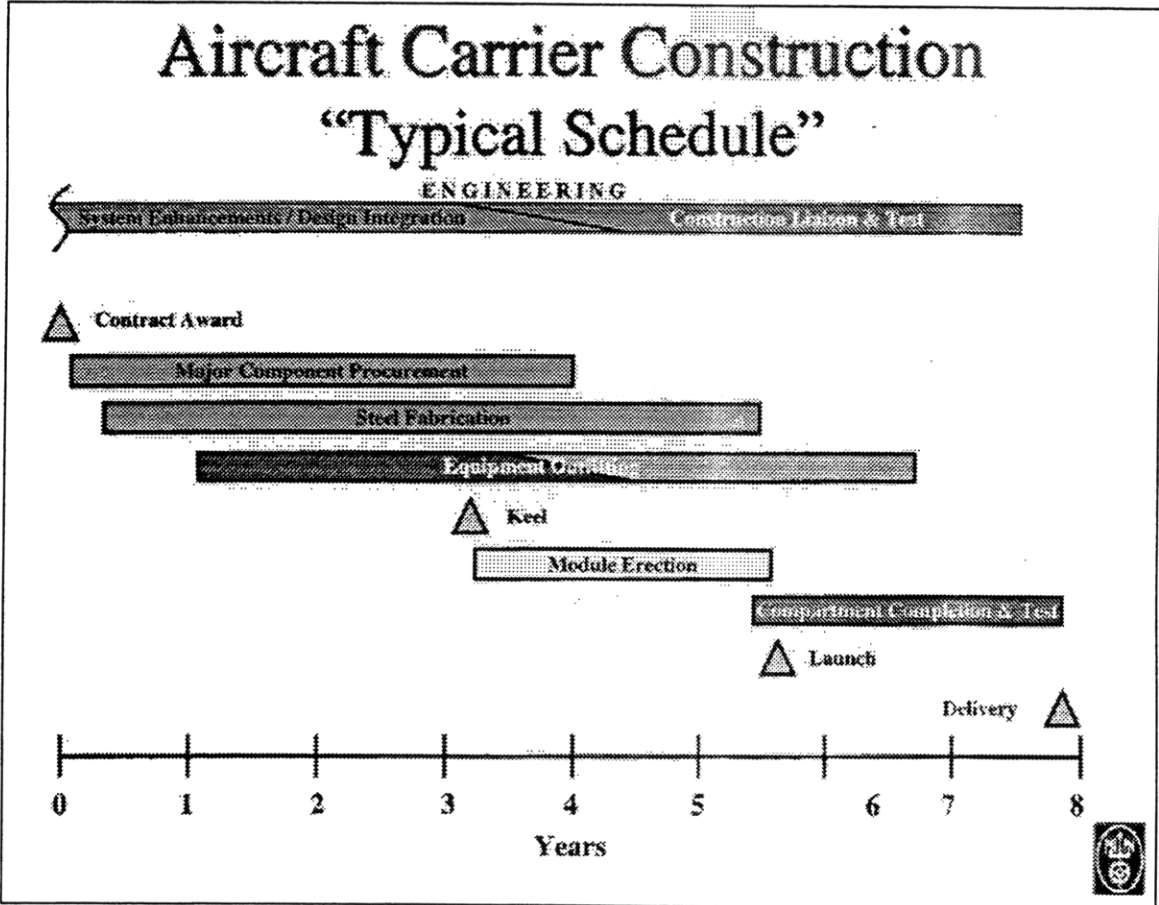


Figure 3-9 – Typical Aircraft Carrier Construction Schedule

The keel is laid in the graving dock three years into the project. The midship hull modules are erected first, while subsequent modules are installed aft and above. This is done so time critical machinery components, located aft, can be installed as early as possible. Module erection continues in the graving dock for about two and half years until launch. After the carrier is launched it is moved to the outfitting pier, where outfitting begins in full and system tests are conducted. The compartment completion and testing phase lasts two and a half years, and the carrier is delivered eight years after contract award.

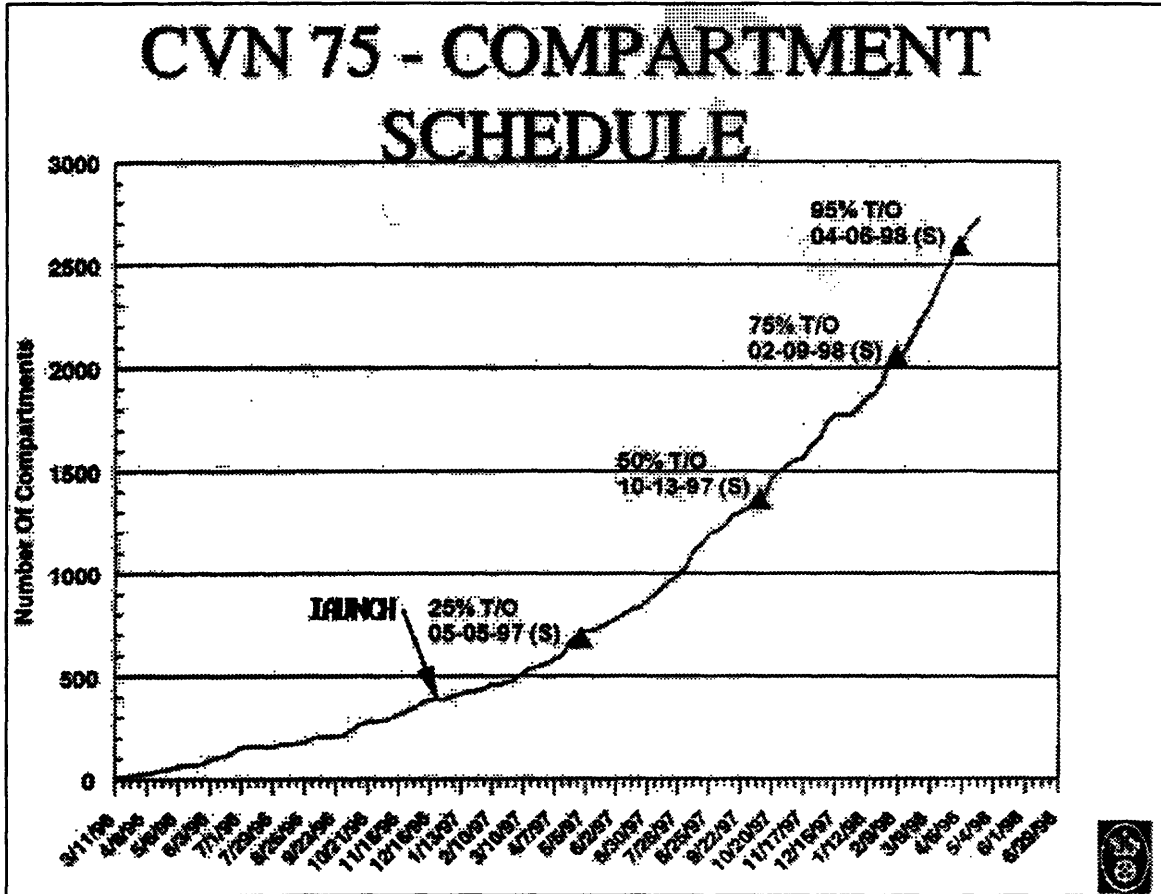


Figure 3-10 – Compartment Turnover Schedule

### 3.7 Construction of Habitability Spaces

Newport News does most of the outfitting for *Nimitz* class carriers after the carriers are launched. This is the traditional approach, using construction details developed in the 1950s. As can be seen in Figure 3-10, the carrier is launched with less than 20 percent of its compartments finished, or “turned-over.”

#### 3.7.1 Reasons For On Ship Outfitting

There are several reasons Newport News performs the outfitting of habitability spaces on ship. Aside from the fact Newport News has always done - and is “set up” for - on ship outfitting, it continues this method for several reasons. First, the outfitting is not on the

critical path. Dry-dock limitations restrict launching weight, which limits the amount of preoutfitting possible. It is unlikely these constraints will change. Finally, on ship outfitting offers Newport News the greatest construction, schedule, and ordering lead time flexibility.

#### 3.7.1.1 Critical Path

Outfitting the habitability spaces is not on the critical path. Before the ship is launched, construction of the stern section, including the propulsion shafting, and the installation of the nuclear propulsion equipment, drives the construction time. After launch, the main propulsion and nuclear systems testing forms the critical path. As a result, NNS concentrates all of its initial efforts on installing the propulsion systems and shafting, and does not preoutfit habitability spaces.

#### 3.7.1.2 Dry-dock Limitations

While new aircraft carriers are erected in Newport News' Dry Dock 12, the largest in the western hemisphere, the dock has a draft limitation of 30' - 6." New carriers are launched with just a few inches of clearance. Once a carrier is launched, it is not able to return to Dry Dock 12. As a result, there is little margin for the additional weight at launch associated with greater preoutfitting.<sup>10</sup> Newport News has another dry dock that is capable of handling fully outfitted aircraft carriers, although it is presently used only for nuclear refuelings.

#### 3.7.1.3 Flexibility

By outfitting the habitability spaces on ship, there is more flexibility in determining the exact layout of the spaces. This is useful as changing requirements for both the habitability and surrounding spaces might require changes in habitability space size and

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<sup>10</sup> Interview with Michael Powell, at Newport News Shipbuilding. Conducted by Gene Miller and Dr. Alan Brown. Feb. 20 1998.

arrangement. In addition, piping, electrical, and HVAC systems are often routed from point to point. As the construction process evolves and more systems are installed, additional systems must be fitted around existing installations. This results in an apparently haphazard overhead arrangement. Outfitting the spaces on ship allows workers to work around these unanticipated pipe and electrical runs and HVAC ducts.

On ship outfitting also offers schedule and ordering lead time flexibility. Preoutfitting requires careful planning up front to sequence when particular areas are outfitted. If the schedule is off and blocks are not ready, it can delay the entire erection schedule. Outfitting on ship does not carry the logistical and scheduling management burdens of preoutfitting. In addition, preoutfitting moves joiner material and furniture procurement up in the schedule. Since these items are not on the critical path, no matter when installed, there is no incentive to order these items any sooner than necessary. Because module erection begins over four years before delivery, preoutfitting would require ordering items at least four years before the ship is delivered. During these four years, space and arrangement requirements could change. By waiting to outfit habitability spaces until after launch, ordering decisions can be postponed by two or more years.

### 3.7.2 Habitability Space Construction Method

The carrier is launched with some of the piping and overhead ventilation ducting already installed in the habitability spaces. Installation of joiner bulkheads, coamings, and curtain plate is done after the carrier is moved to the outfitting pier. Coamings and curtain plates are first scribed to fit the installation location. The coamings and curtain plates are then cut to fit, leveled, and welded to the structure. Joiner bulkhead panels are then attached either directly to the coamings and curtain plates or with Z and H-clips, depending on the panel material and deflection requirements. The lagging work is also completed while the vessel is located at the outfitting berth. The lagging is installed after the structure is already completed in a space. Finally, the compartments are sealed off and painted. Painting causes major schedule disruptions.

The furniture is installed after the lagging is in place. Like the joiner bulkhead coamings, each foundation is scribed to fit, cut, leveled, and welded to the deck. Each type of furniture (i.e. lockers, bunks, desks, chairs, tables) has a unique foundation. Figure 3-11 shows a crew berthing space with the locker and bunk foundations in place.

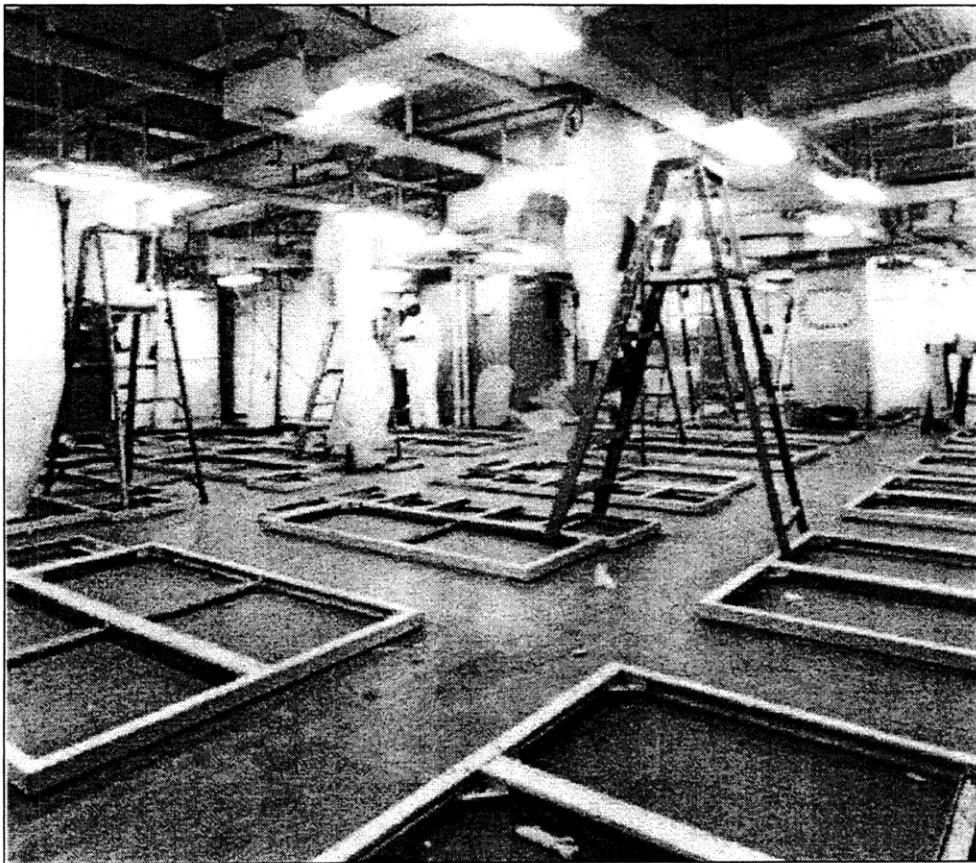


Figure 3-11 – Crew Berthing Space with Furniture Foundations Laid

Once the foundations are secure, the decks are leveled and the tile floor is laid down. Upon completion, the tile flooring is covered with protective sheets, and the furniture is brought into the compartment. The furniture is ordered from an independent vendor, and arrives unassembled in a “kit” form. Each bunk, locker, and table is then assembled, in position, by Newport News workers. A completed crew berthing space is shown in Figure 3-12.



Figure 3-12 – Completed Crew Berthing Space

Each crew berthing space may serve between 40 and 100 or more men. Crew living spaces are based on three bunk high units. The three bunk high units are arranged back to back, forming multiple six man semi-enclosures. Most bunks have under mattress storage, with additional stowage space in nearby lockers. Community head and shower facilities are located in separate, nearby spaces.

Officer Staterooms and common areas are completed in a similar method. Junior officer staterooms typically have two to four bunks, additional storage space in drawers and closets, and possibly a desk. Sanitary spaces are located in separate compartments. Junior officer staterooms have more individual space than the crew berthing spaces.



Senior officer staterooms have one bunk, storage space in drawers and closets, and a desk. These staterooms share a sanitary space with an adjacent stateroom. Often the officer staterooms have unique arrangements based on the geometry of the space available. Figure 3-13 shows an officer stateroom under construction.

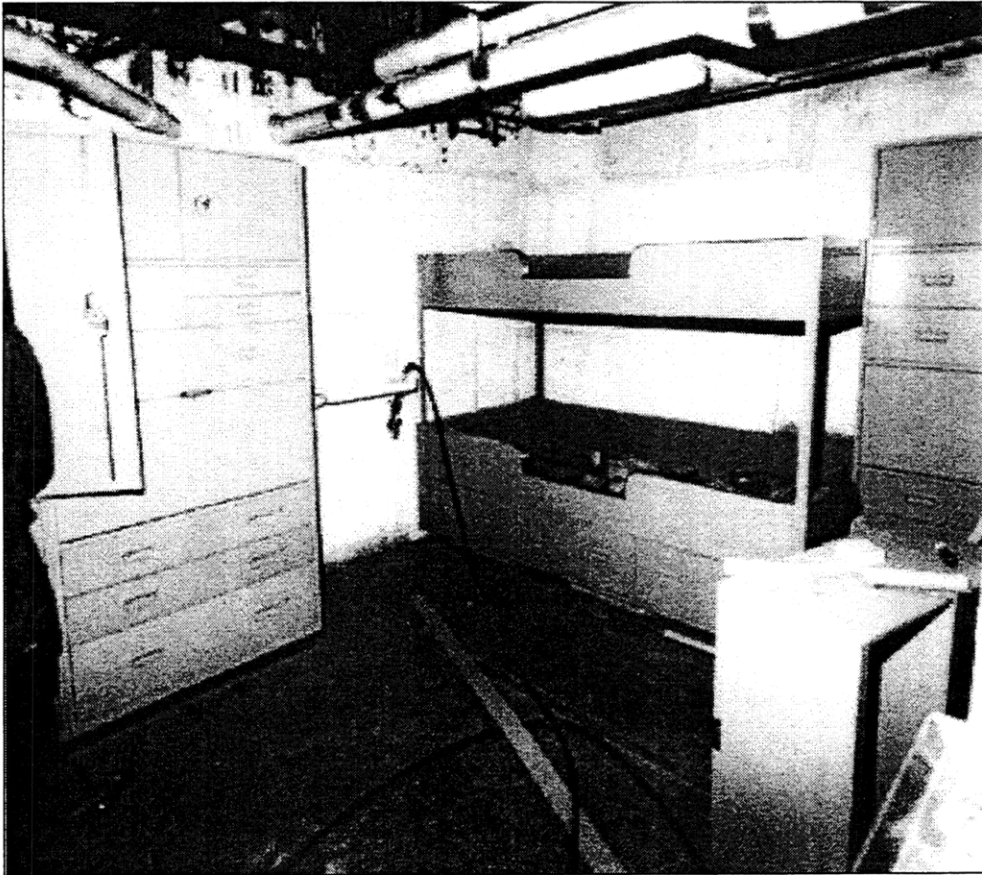


Figure 3-13 – Officer Stateroom Under Construction

While there is limited recreational space in berthing areas, separate common and recreational areas are often forced to share space with other equipment. Figure 3-14 depicts this interaction of function.

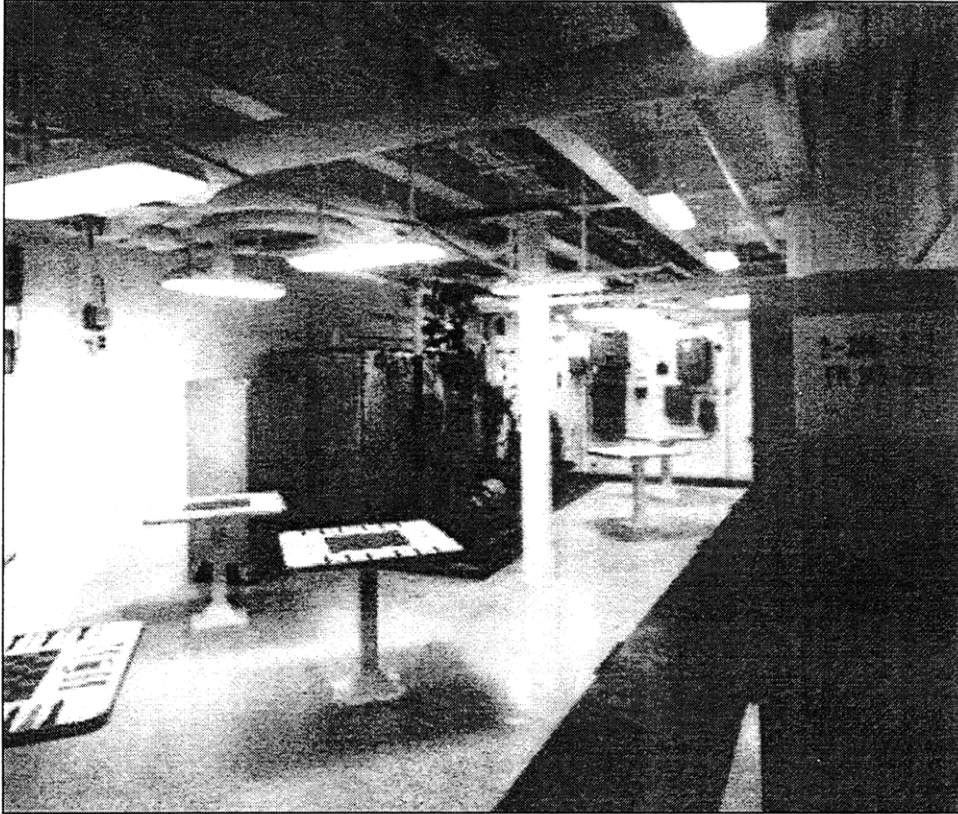


Figure 3-14 – Intermix of Function of Crew Recreational Spaces

Upon completion, the compartment is first inspected by Newport News, then the SupShip, and finally accepted by the crew. The crew actually moves aboard the vessel as habitability spaces become available, approximately 10-12 months after launch.

Sanitary spaces are also built with a similar procedure. Once the piping runs to the space are in place, the partitions are erected, the floor is leveled, tile flooring is laid down, and fixtures are installed. Figure 3-15 shows a sanitary space under construction, and Figure 3-16 shows a completed sanitary space. Because sanitary spaces are located in whatever unusual space remains, their arrangements are almost always unique.

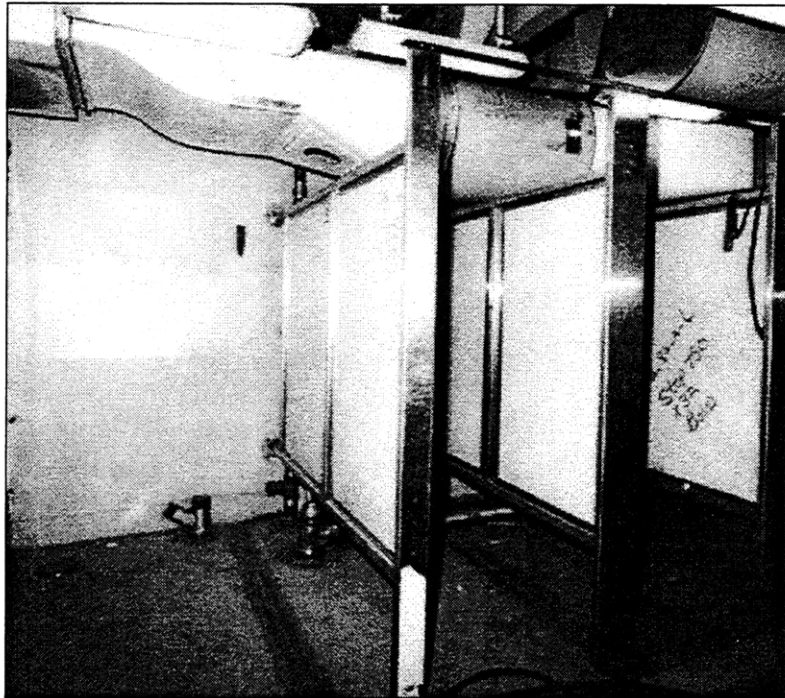


Figure 3-15 – Sanitary Space Under Construction

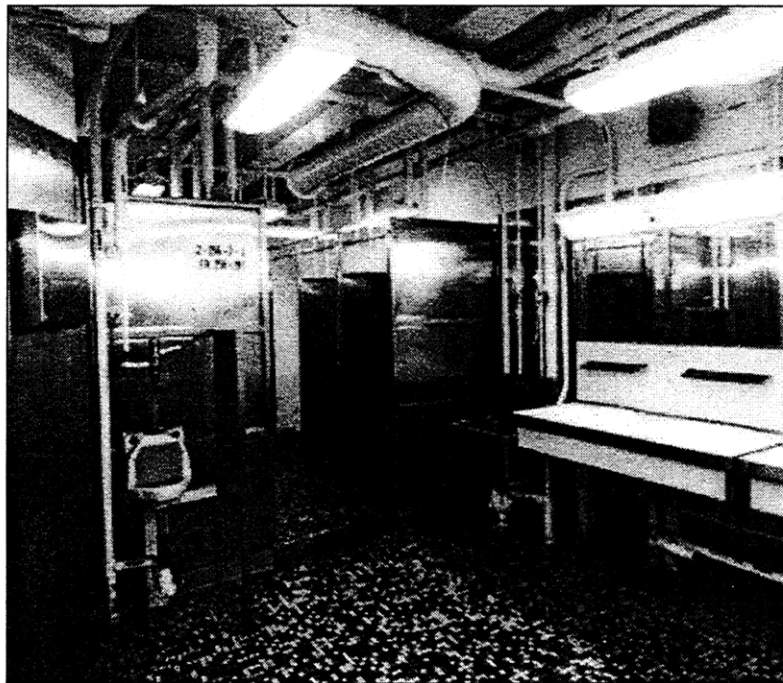


Figure 3-16 – Completed Sanitary Space

### **3.8 Assessment of Current Habitability Construction Methods**

The task of designing and building living spaces for 6,000 people on a warship is difficult, and while the existing methods work there is certainly room for improvement. This is true both on a strategic level (arrangement design and production) and a tactical, component level (i.e. furniture and curtain plate).

Many of the current difficulties in building habitability spaces are a direct result of the *Nimitz's* arrangement. Because each living space has a unique geometry, there is a tremendous amount of custom fitting of panels, brackets, foundations, coaming, and curtain plates. Building these spaces becomes a labor intensive process, as each piece must be individually sized, cut, and installed. And since each space is unique, it is difficult to establish a learning curve. These problems are common in all naval ships.

The current method of on-ship installation has many difficulties. For example, the installation of coamings, foundations, and curtain plate all requires extensive on ship fit up and welding. Curtain plate requires difficult overhead welding. Outfitters must either travel between the ship and a shop to custom cut each piece for installation or work in the sub-optimal conditions of a half finished ship. In addition, it is difficult to transport supplies and furniture kits to the final installation location through the carrier's many decks and hatches. And once the supplies are in the compartment for installation, there is only limited material handling equipment.

Preoutfitting, on the other hand, offers numerous advantages for building habitability spaces. In preoutfitting, the habitability spaces are constructed on unit or on block, before erection. In this method, all welding is performed in shop. By beginning assembly of blocks upside down, it is possible to eliminate overhead welding. And because the blocks are outfitted in a single, environmentally protected shop, it is easier to perform shop work such as cutting and grinding. Transporting supplies to location is easy, since at least one end of the block is usually left open for easy access. Overhead cranes can ease other material handling problems. Preoutfitting is used extensively on

commercial ships and other naval vessels, and is usually dependent on a shipyard's facilities and build strategy.

Throughout this process, one of the biggest problems is coordinating the many different types of labor required to outfit a habitability space. This includes sheetmetal workers, welders, pipefitters, electricians, and outside machinists. Since U.S. aircraft carriers are traditionally built on a systems basis, each trade is responsible for its own system, not a particular space. This often results in the installation of systems without consideration for other systems that need to run through the same areas. This results in a haphazard overhead arrangement. In the worst cases, previously installed systems must be ripped out and reinstalled. New zonal outfitting approaches can help reduce this problem. While installation interferences are a problem, so is the physical interference between the actual workers. Painting is a further complication, as it delays all other work in the compartment and restricts access and material flow to surrounding compartments. Construction of habitability spaces requires careful coordination between all the involved shops to avoid installation and work interferences. Any changes in the sequence can result in substantial increases in man-hours and costs.

On a component level, installing curtain plate is the most time and labor intensive process. In addition to the overhead welding, any overhead subsystems must penetrate the curtain plate. It is a very labor intensive process to cut a penetration, run the system through, and then reseal the penetration. In addition to the construction problems, the curtain plate is inherently heavy. While stability is not quite as large a problem on aircraft carriers as on smaller combatants, weight is still carefully controlled. It is possible to improve the current system by reducing the number of penetrations (a subsystem design issue which will ease installation) and reducing the need for curtain plate as a space boundary (a false ceiling system which will reduce weight).

Finally, there are many reasons to improve the current furniture system. Current furniture items come in odd shapes and sizes, which aggravates the habitability space arrangement problem. Bulkhead installers are forced to cut panels to nonstandard sizes to

accommodate the furniture. Furthermore, each piece of furniture has a unique foundation. Since each foundation is unique, there is no opportunity to mount different pieces on a standard foundation. If a compartment needs reconfiguring, the foundations must be ripped out, and the deck covering replaced. This makes it infeasible to reconfigure a compartment in most cases.

### **3.9 Opportunities From Newport News Commercial Shipbuilding**

In 1994, Newport News reentered the commercial shipbuilding market with its Double Eagle product tanker line. The yard secured contracts for nine of these vessels, of two separate but similar designs. The construction times for these vessels are measured in weeks, not years, so Newport News launched a major process redesign effort to become as competitive as possible in this business segment.

These efforts have focused on improving processes in five main areas: product development, production planning, materials management, steel fabrication, and outfitting.

For example, Newport News implemented zone and grand unit construction techniques where ship units flow through specified process lanes. The grand units weigh up to 900 tons and are 90% preoutfitted when they arrive at the dock. Just-in-time philosophies are used to aid the process. The shipyard has also changed the material acquisition process to shorten times from decision to delivery. Engineering, sourcing, and vendors are all working together before the order is placed, and a new bar-coding system is used to keep track of material.

Newport News is also emphasizing “Design-Build” teams to increase producibility. Team members include representatives from the customer, suppliers, sourcing, and production. Finally, efforts were made to improve data management with the development of a “Shared Data Environment.”

These efforts have resulted in significant improvements. Material processing time has been reduced by 75% since the first Double Eagle was started. The improvements in material processing have helped reclaim crowded storage areas, as 70% more production area is now available. Pipe preoutfitting has increased from just 3% to 45%. Finally, a more efficient build strategy has reduced the number of lifts in dock by 65% for the second flight of vessels. All of this has led to improved quality and shorter erection times. The first tanker took 10 months from keel-laying to launch. By the fourth tanker, the erection time was cut to just four and a half months.<sup>11</sup>

Newport News executives are optimistic that the lessons learned from the Double Eagle tankers will be applied to the Yard's Navy work. Certainly, many of the general preoutfitting lessons would improve the production of aircraft carriers. However, Newport News subcontracted the construction of the deck houses for the Double Eagle tankers to independent companies. The independent companies barged the deck houses to Newport News, where they were merely lifted onto the hull. Since all the habitability spaces are contained in the deck houses, Newport News did not gain any direct experience in preoutfitting habitability spaces. Newport News has since cancelled the construction of the last two tankers due to financial losses. This makes it unlikely that the NNS will apply many of the lessons from the Double Eagle tankers to the construction of habitability spaces in aircraft carriers.

### **3.10 Conclusions**

While aircraft carriers follow a traditional design spiral, the carrier is actually arranged according to a definite hierarchy. This hierarchy trades off aircraft and mission systems with ship propulsion and protection systems. Habitability spaces are not placed until after these more important systems are already fixed. As a result, habitability spaces are often located in difficult to access, strangely shaped areas, which complicates the construction process. The construction of habitability spaces is further inhibited because

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<sup>11</sup> Barlow, Kelly, "America's Largest Private Shipbuilder Makes Sweeping Changes in Manufacturing to Become Globally Competitive." *Manufacturing Magazine*, Virginia Edition, November 1997.

they are built on the ship after the ship is launched, where access is difficult. Today's habitability spaces require extensive fitting, cutting, and welding of many unique pieces. Finally, the existing furniture system is heavy, requires labor intensive installation, and is difficult to reconfigure. While the existing method of constructing habitability spaces is proven, it has many shortcomings which must be addressed.



## **4.0 Navy Programs to Improve the Construction of Habitability Spaces**

### **4.1 Affordability Through Commonality Program**

In response to the looming affordability crisis for Navy ships, the Naval Sea Systems Command instituted the Affordability Through Commonality (ATC) Program in 1992. The project's goal is "to improve the process by which the Navy will design, acquire, and support the future fleet by using commonality."<sup>12</sup> The ATC program seeks to achieve this goal through a three-pronged approach. This is a coordinated effort which includes developing common modules/interfaces across the fleet, creating common families of equipment, and by simplifying the design, acquisition, and support processes.

The ATC program is seeking to achieve its goals by reducing the time and complexity of current processes rather than identifying individual components for cost reductions. In this context, equipment modularization is the "determination and establishment of packaging and interface constraints on a system level. Standard interfaces are the foundation of common module designs. The products are the building blocks for building larger subassemblies."<sup>13</sup>

#### **4.1.1 ATC Approach to Modularity**

As evidenced by the *Nimitz* design, Navy ships are traditionally designed on a systems basis. While this is efficient from a design perspective, it lends itself to interferences during the actual construction phase. Interferences between systems often result in extensive rework and unique arrangements. An ATC module is intended to combine and physically group together standard components which operate together functionally. Assembled and connected together on a common foundation, these modules could be fabricated off the ship, or even outside of the shipyard. The module includes components

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<sup>12</sup> Hane, Gauthier, Lang, and Valsi, "Modularity in HM&E Systems." *Naval Engineers Journal*, May 1995. pp. 149.

<sup>13</sup> Bosworth, Michael and Hough, Jeffrey, "Improvements in Ship Affordability." *SNAME Transactions*, Vol. 101, September 1993.

from several systems, and is a service-based design approach as opposed to a systems-based approach. The unit is a unique entity for the procurement, fabrication, and erection phases of ship construction. However, in service logistics support is the same as if the equipment were purchased and installed piece-wise.

Ideally, these modules would be applicable to several ship types, not just a single class. This would increase standardization. The modules could be proportionally sized and equipped to meet the varying demands of different ship types. These module families are integral to the affordability through commonality approach.

Module design and definition is based on the system and the expected rate of technology change.<sup>14</sup> For example, a pump or generator module would be fully defined since the rate of technology change for that service is relatively slow. On the other hand, a combat systems module would have standard interfaces to allow upgrades as technology improves or mission requirements change. Most HM&E modules would more closely match the pump or generator example, and would be fully designed by the Navy. The Navy would provide a fully defined product drawing package, including components and interfaces, reducing the design load on the shipyard. The Navy could also use the same module in later ships, reducing future design time.

Individual shipyards have used modularity concepts in the past, particularly on large ship classes such as the FFG-7. By investing in up-front engineering and interface planning, shipyards have achieved cost and time savings by developing “packaged units” which they could fabricate in shops. However, these packaged units have been ship class specific. In order to achieve the full benefits of standardization by using these modules on many ship classes, the Navy must be involved to coordinate the shipyards’ efforts.

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<sup>14</sup> Hane, Gauthier, Lang, and Valsi, “Modularity in HM&E Systems.” *Naval Engineers Journal*, May 1995. pp. 151.

#### 4.1.2 ATC Advantages of Modularity

The ATC program identified several advantages of modular construction techniques. These included advantages in design, arrangements, fabrication, construction, and logistics support.

##### 4.1.2.1 Design

The modular-based design is a service-oriented approach. The design for each module would combine structural, piping, and electrical components and interfaces. This design work would only need to be done once for each service, and the module could then be applied to any ship that requires that service. And by developing a family of varying sizes and ratings, designers can use the same basic module in a variety of applications and ship types. Designers can combine these functional building blocks to create future designs, and have an easier time laying out piping and cabling arrangements and tracking weight.

##### 4.1.2.2 Arrangements

Some studies suggest that the ship designer must pay a weight and volume penalty to use modules. However, this penalty is difficult to quantify, and there have even been cases where modular construction techniques have produced more efficient arrangements than conventional approaches.<sup>15</sup> Because modules already include piping, electrical, and ventilation interfaces, the design of these systems in later phases is easier. Interferences and associated rework are reduced, saving time and money. More efficient systems routing can save weight by reducing cable and piping run lengths. Finally, designing the ship to use modules from the beginning can minimize any weight and volume penalties.<sup>16</sup>

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<sup>15</sup> Scott, Robert, Comments to the Paper by Michael Bosworth and Jeffery Hough, "Improvements in Ship Affordability." *SNAME Journal*, September 1993.

<sup>16</sup> Scott, Robert, Comments to the Paper by Michael Bosworth and Jeffery Hough, "Improvements in Ship Affordability." *SNAME Journal*, September 1993.

#### **4.1.2.3 Fabrication**

Construction of modules can take place in shops, which allows for faster, cleaner, and more accurate construction. In addition, the shop offers full accessibility to the module and better material handling systems. Finally, the module can be tested in the shop, reducing on-ship rework and repair.

#### **4.1.2.4 Construction**

The modules are built in shops in parallel with the vessel. This offers potential construction time savings, especially if outfitting work is on the vessel's critical path. These schedule savings reduce time-dependent overhead costs. The use of standard interfaces also reduces the number of unique arrangements, further saving on-ship outfitting time. In addition, the use of modules across many ship classes increases production numbers, taking advantage of the economies of mass production.

#### **4.1.2.5 Logistics**

The family-based module system will have common equipment, improving in-service logistics support. Common equipment through different ship classes will result in fewer unique spare parts. In addition, the use of common equipment reduces crew and maintenance training requirements. Finally, this standardization will reduce the number of required manuals, technical drawings, and maintenance records.

### **4.1.3 ATC Module Development**

Considering the advantages of modular construction, the ATC program initiated the development of three modules beginning in 1992. These were a standard fire pump module, a reverse osmosis desalination module, a modular crew sanitary space (MCSS).

## **4.2 Modular Crew Sanitary Space**

The modular crew sanitary space is an attractive application of modular technology for several reasons. Habitability spaces can account for up to 30% of a ship's interior.<sup>17</sup> Of the habitability spaces, sanitary spaces are some of the most outfitting-intensive areas. Sanitary space construction requires a wide range of trade skills which are difficult to coordinate in an on-ship installation. Furthermore, most current sanitary spaces have common equipment but unique arrangements. Finally, all ships have sanitary spaces, so a well designed module could be installed throughout the fleet. The ATC program office therefore decided the potential benefits of the MCSS warranted further development.

The first step was to determine the optimum size and configuration of the MCSS. The ATC program determined berthing and sanitary spaces should serve 42 sailors for several reasons. The 42 person capacity was in line with current department/division sizes. This module is also a reasonable size to manufacture, transport, and install. Although larger size modules were considered, they offered less arrangement flexibility, and were difficult to coordinate with the Women at Sea program.

### **4.2.1 Modular Sanitary Space Development**

While the MCSS was originally designed to serve 42 people, a panel concept was incorporated to increase flexibility. This involved the development of nine interchangeable panels. Each panel is 750 mm wide and contains a particular sanitary fixture. The panel width was selected to meet the human factors requirements for most sanitary fixtures (i.e. minimum required access width for particular fixtures). There are nine different panel types which builders can combine in almost any arrangement. The same panels that form the 42 man MCSS can be reconfigured into all sizes and arrangements giving the designer increased flexibility in laying out sanitary spaces. In

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<sup>17</sup> Hane, Gauthier, Lang, and Valsi, "Modularity in HM&E Systems." *Naval Engineers Journal*, May 1995. pp. 161.

addition, the ability to easily change out panels aids maintenance and reconfigurability. This is all possible because the sanitary space requirements dictate bulkhead, not deck, mounted fixtures.<sup>18</sup> Figure 4-1 shows the ATC Panelized Head Concept.

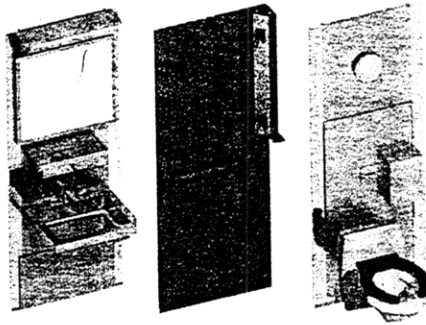


Figure 4-1 – ATC Panelized Head Concept

The ATC program selected Hopeman Brothers Manufacturing and Kvaerner Masa to build the prototype 42 person MCSS. The prototype was constructed in two parts. The first part was a five sided (no floor) clean side, which included sinks and shower stalls. (Figure 4-2) The second part was a six sided (floor included) dirty side, which included a sink and heads. (Figure 4-3) After undergoing testing, the ATC program decided to redesign the prototype MCSS module for several reasons.

Based on the lessons learned from the prototype, the ATC office made several changes to the MCSS design. The original design included a cleaning gear locker inside the module. Because the locker could fit more easily into nearby berthing spaces, it was removed from the module. Secondly, the six sided module (floor included) required a deck pan to accommodate prefabricated drains. This deck pan reduced the clear headroom in the module. The team therefore decided all future modules should be five sided (no floor), with all drain and flooring work completed after the module was landed on the ship.<sup>19</sup> Third, piping in the original module was based on the arrangement and grouping of

<sup>18</sup> Section 644, LPD-17 Ship Specification. NAVSEA, March 8, 1996.

<sup>19</sup> Hane, Gauthier, Lang, and Valsi, "Modularity in HM&E Systems." Naval Engineers Journal, May 1995. pp. 163.

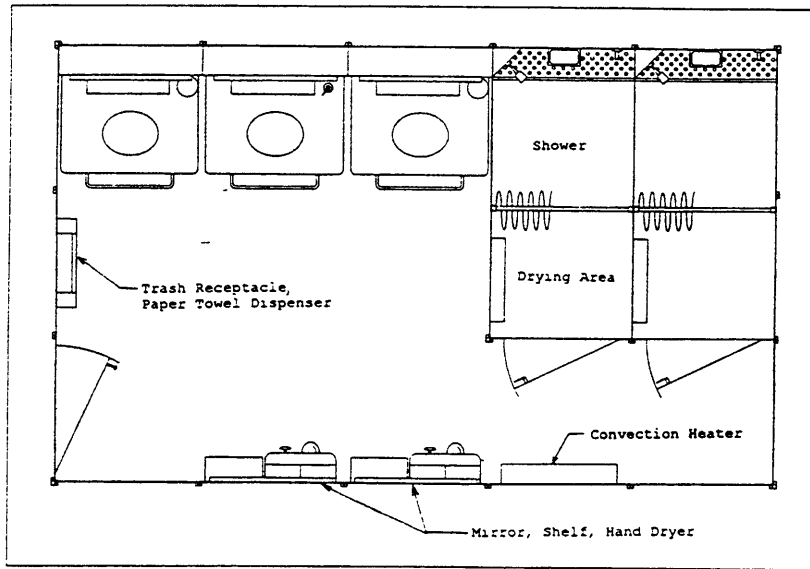


Figure 4-2 MCSS "Clean" Side

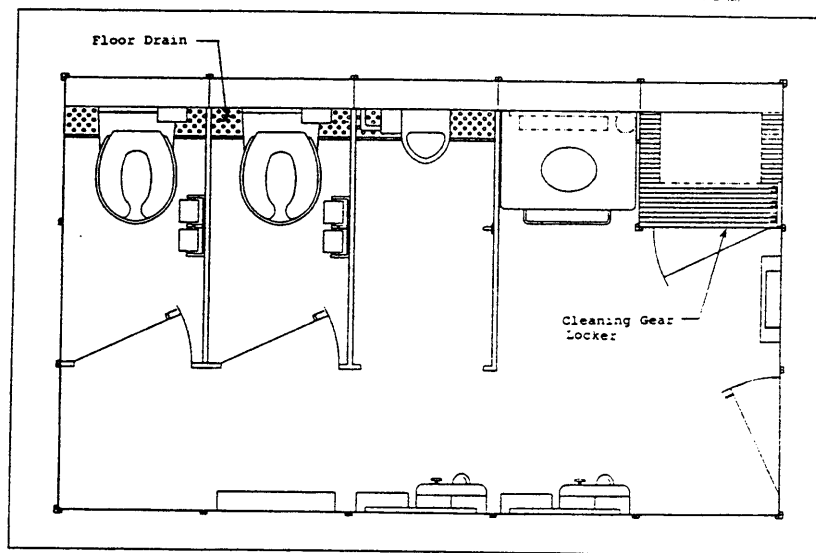


Figure 4-3 – MCSS "Dirty" Side

fixtures. This was changed so the piping arrangements behind each fixture were standardized, increasing commonality between panels and supporting the panelized construction concept. Finally, a standard water closet replaced the original urinal, increasing commonality and supporting the Women at Sea program. The redesigned configuration is shown in Figure 4-4.

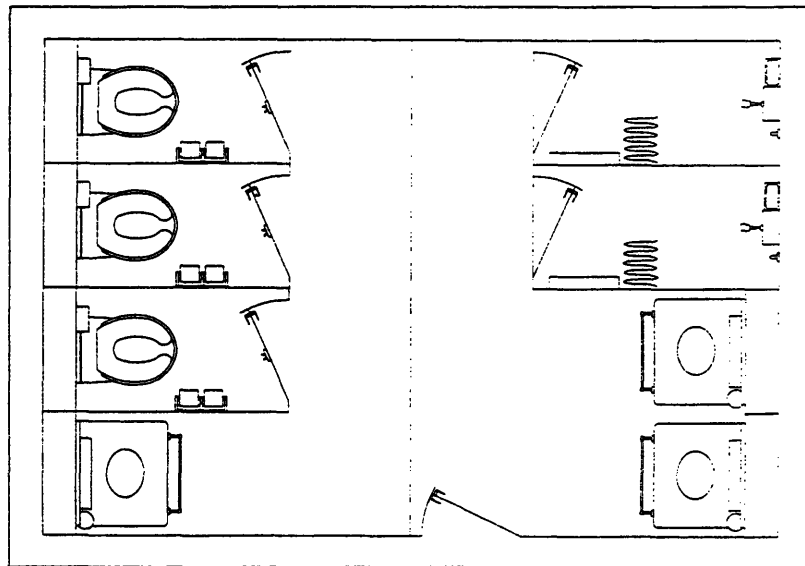


Figure 4-4 – Redesigned MCSS

#### 4.2.2 Modular Crew Sanitary Space Applications

The ATC program developed the MCSS for installation in the new LPD-17 class amphibious assault ships. While the MCSS can be installed as a complete module, the preoutfitted panel installation method is currently favored. The preoutfitted panel installation method is favored for several reasons. There are a variety of sanitary space sizes and configurations on the LPD-17. The outfitters can arrange the nine different panel sections as required to build a greater percentage of the sanitary spaces, where as the box module only comes in one size. In addition, since the MCSS box module is loaded onto the ship through “blue sky” lifts, installation requires careful coordination within the construction schedule. The preoutfitted panel installation schedule is more



flexible (i.e. does not require additional scheduling effort) than the box module, and can be installed during almost any stage of construction.

The box module also suffers penalties in transportation. Since the box module is shipped fully assembled (or nearly so), it is very volume intensive. Furthermore, the module requires additional structural stiffening material for shipment, which increases weight. On the other hand, manufacturers can ship the preoutfitted panels in a compact package, without additional structural material. For these reasons, current plans are to use preoutfitted panels to build the sanitary spaces on the LPD-17.

### **4.3 The Integrated Joiner Bulkhead System**

The ATC program office, in association with Turnbull Enterprises, Hopeman Brothers, and M. Rosenblat and Sons, has developed an Engineering Demonstration Model (EDM) for a Common Stateroom and Integrated Joiner Bulkhead System (IJBS). Partially based on the lessons of the MCSS, the IJBS is based on the preoutfitted panel installation method model. The IJBS is intended for use in any living space, and improves installation through the use of bulkhead mounted furniture. The ATC program is considering incorporating the concept into the LPD-17 design.

#### **4.3.1 Motivation for IJBS**

In developing the IJBS, the Accommodations IPT first identified the major cost drivers of current shipboard living space construction methods. Of the shortcomings identified earlier, there are four main cost drivers associated with the installation of joiner bulkheads, furniture, furnishings, distributive systems, and shipboard equipment in habitability spaces. First, the requirement to custom fit so many panels, brackets, foundations, and coamings is extremely time consuming, especially when installation is done on ship. Reducing the number of custom fittings will reduce man-hours and costs.

The second major cost driver is the installation of curtain plates. The curtain plate welding requires a large amount of hot work. In addition, curtain plating is very heavy and an obvious weight reduction target. The third major cost driver is on-ship hot work. In addition to the curtain plate, the hot work required to install coamings, furniture, and distributed system mounting brackets is labor intensive and very expensive. On-ship welding is the most time consuming, since welders must work in cramped, unfamiliar, and sub-optimal positions. It also damages previously applied coatings and requires touch-up painting.

Finally, current installation methods inevitably result in scheduling conflicts and work interferences. Installation of some systems depends on completion of other systems (i.e. you can not install joiner bulkheads until the coamings and curtain plates are in place). This requires schedule coordination between many different trades (shipfitters, machinists, pipefitters, welders, electricians, etc), which are under different managers. Scheduling conflicts can often lead to incorrect construction sequencing. When this occurs, previous work must be ripped out and later reinstalled. This also leads to unique arrangements, where systems are not installed to plan but rather to fit around other, already installed, systems. All of these problems are time consuming, affecting schedule and increasing cost.

In addition to reducing cost, the ATC program also examined methods to reduce the weight of the joiner bulkhead systems. Weight is always a critical issue on naval vessels, especially smaller combatants. Any reduction in habitability space weight increases the weight available for additional electronics and combat systems.

#### **4.3.2 IJBS Design**

The ATC Accommodations IPT designed the IJBS to address the major issues cited above. In addition, the system was designed to be consistent with the MCSS in terms of panel size, panel demounting features, and panel mounted fixtures. Finally, the IJBS was

designed to be structurally self sufficient, reduce weight, and minimize loose parts.

Based on these requirements, the IJBS incorporates the following design criteria:

- 1) Modular Components consistent with a 750 mm grid system
- 2) Easily assembled in the field without hot work (hot work limited to supports only)
- 3) Lightweight construction, fire resistant, non-toxic materials (current Navy standards)
- 4) Honeycomb panels may have aluminum, Nomex, or other suitable core material with GRP, aluminum, or CRES faces. Panels will be finished with extruded or formed edge profiles
- 5) Positive means of securing components in place. (To minimize vibrations and maintain integrity of system under ship motions and shock loads. Pop rivets are not acceptable fasteners).
- 6) Individually stiffened by use of extrusions
- 7) Deflection fittings between ceiling and bulkhead
- 8) Coamings that reduce installation labor
- 9) Components removable in a non-progressive manner
- 10) The ability to support bulkhead mounted accessories (furniture, miscellaneous items)
- 11) Use of suspended ceilings to minimize curtain plate
- 12) Compatible with curtain plate for special cases
- 13) Shock performance equal to existing bulkheads

#### 4.3.3 IJBS Installation

The IJBS is based on a formed metal “C” coaming. The deck is first leveled and sealed (as per the current practice) and the coaming is attached with either Nelson studs or tack-welded directly to the deck. Caulking is used to seal the coaming and prevent water leakage underneath the C plate.

Each 750 mm bulkhead panel is based on a lightweight honeycomb core, with reinforced aluminum extrusions. The panel is bolted to the coaming at the bottom, and slides into a deflection rail at the top. Each panel is approximately 30 mm thick, as opposed to 16 mm

in traditional joiner bulkhead panels. This extra thickness allows the use of a side extrusion. The panels attach to each other by overlapping these extrusions, forming a lap joint. Special intersection posts are used to join panels at the corners of the space. The overlapping extrusion joints prevent light and noise from passing through, and may be fastened together to increase structural integrity. The extrusions are sized with a void to receive bolts for installation and mounting furniture. The bulkhead system, coaming, and deflection joint are shown in Figure 4-5.

A suspended ceiling is used to partition spaces. The ceiling panels attach to the deflection rails (at the bulkhead edge) and a ceiling carrier (for support in the middle of the space). Overhead sway braces, attached to the overhead deck, support the deflection rails and ceiling carriers. The ceiling panels are of similar construction to the bulkhead panels. The ceiling system is shown in Figure 4-6.

Furniture is mounted directly to the bulkheads. All furniture items are designed to match the standard 750mm panel width, and are bolt mounted to the reinforced aluminum panel extrusions through factory drilled keyholes. The factory drilled keyholes are spaced at even intervals along the height of the extrusion, forming an adjustable height mounting system. Furniture is either bolted directly to the keyholes or to mounting plates that are bolted directly to the keyholes. Because furniture is cantilevered off the bulkhead, traditional foundations are no longer required. If a particular furniture item or piece of equipment is too heavy to mount on the bulkhead, a traditional foundation is used.

The current concept for the officer stateroom leaves an open space for the installation of a toilet/shower unit. The connection point for distributive systems is located in this area. The wiring for each system attaches at the single connection point, and runs atop the ceiling near the deflection rails. The HVAC system connects to a ceiling mounted terminal with a flexible hose.

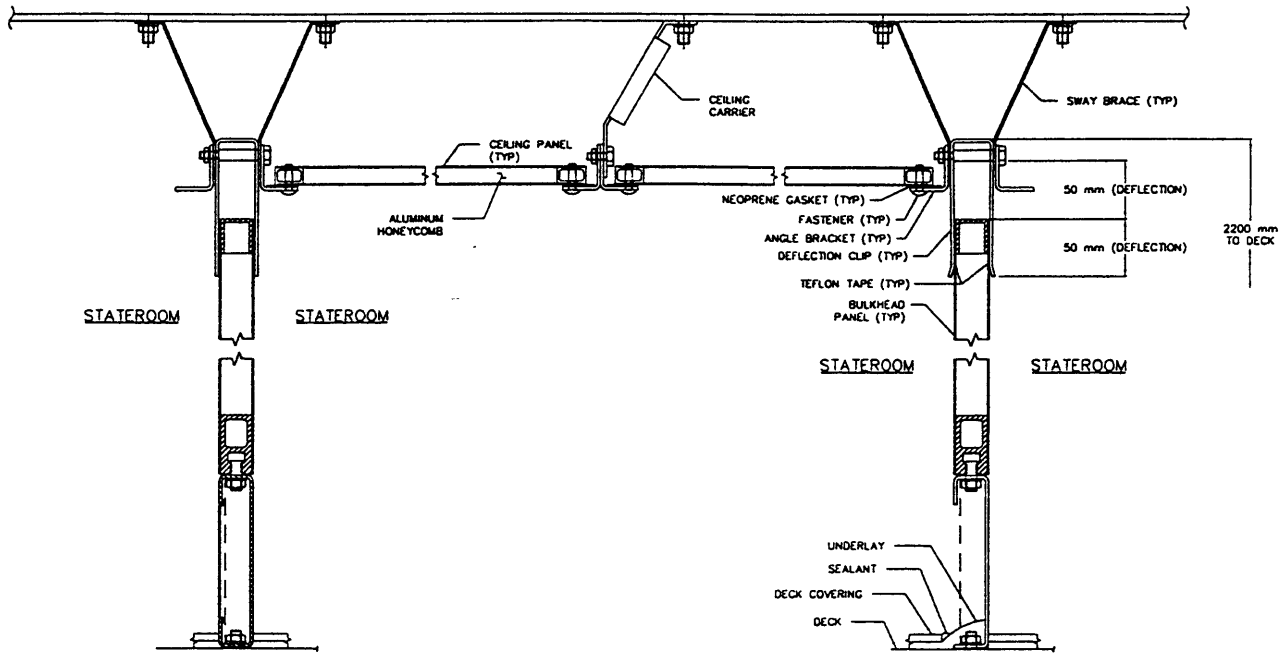


Figure 4-5 – IJBS Coaming, Panel, and Deflection Joint

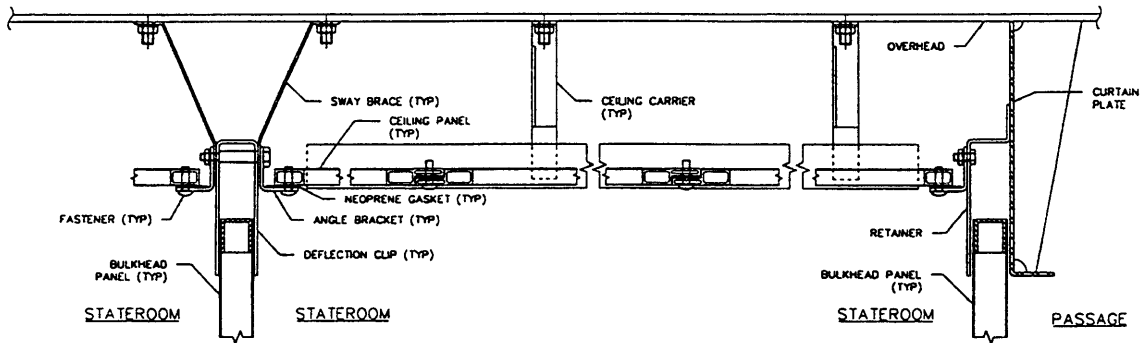


Figure 4-6 IJBS Ceiling System

#### 4.3.4 IJBS Assessment

The IJBS offers many weight and producibility advantages over the traditional joiner bulkhead system. The suspended ceiling forms a barrier between compartments usually separated by curtain plate, greatly reducing the need for curtain plate. The deflection clip and sway brace system, which takes the place of curtain plate, is significantly lighter. And because the overhead sway braces are not solid plates, it is no longer necessary to cut penetrations through overhead plates when running piping, electrical, or HVAC systems through a space. Finally, the sway braces require significantly less overhead welding than curtain plate, helping reduce expensive on-ship hot work. This overhead welding can be eliminated by using bolts or studs to secure the sway braces to overhead decks. Hot work on ship is further reduced by using Nelson studs to mount the coaming to the deck.

The demountable panel system also offers several advantages. Connecting the panels with overlapping side extrusions eliminates the need to install separate H posts for each panel joint. The panel overlap joints alternate, so every other panel can be removed individually. The rest of the panels can be removed by removing the adjacent panel. This allows easy access for maintenance and reconfigurability, while the current joiner bulkhead system is not nearly as easy to demount.

The panel extrusion furniture mounting system also offers significant advantages. The weight loads of the cantilevered furniture is transferred to the deck through the side extrusions. The panels are rigidly connected once they are secured to each other, the coaming, and the deflection joint. The ceiling system provides increased rigidity for the whole compartment. By securing the furniture to the bulkheads, it is no longer necessary to install furniture foundations. This eliminates the scribing, cutting, fitting, and welding processes required by the current system, also reducing on-ship hot work. Eliminating the foundations also saves weight. Finally, the IJBS furniture system has greater flexibility. It is relatively easy to reposition or replace the bulkhead mounted furniture pieces, since it does not require removing or replacing foundations and deck coverings.

And while the system requires less hot work on ship, it also reduces the number of parts, further easing installation. Because each panel is a standard width, the need to custom cut panels is eliminated, as long as the compartment is properly designed. This also reduces the need for rework and cosmetic “flashing.” The integral side extrusions eliminate the need for traditional H posts. Finally, the number of unique fasteners was minimized. All of these features reduces the difficulty of doing on-ship construction.

Some questions remain regarding the design of the coaming system. While the ATC office wants to bolt the coamings to the deck, it is unclear at this time whether that will be acceptable. Furthermore, there are questions regarding the coaming’s ability to resist damage and corrosion from everyday use. The “shoe” design for the connection point between the bottom of the bulkhead and the coaming is a water trap, which can lead to corrosion of the panel bottom and connection bolts.

One critical requirement for the IJBS is shock performance. In order for the Navy to accept this system, it must perform at least as well as current systems under a shock load. While the Navy has not tested the IJBS for shock, it incorporated several design features to provide shock isolation. The coaming and deflection joint system allows the bulkhead to move with the deck while remaining secured to the coaming. Each panel is bolted to the coaming with five long square head bolts. The bolts are connected in tension to provide maximum strength. The bolts are attached to a milled aluminum bar at the bottom of each panel, and the square heads provide maximum surface area at the connection points. The upper deflection joint meets Navy standards, allowing the panel to travel vertically up to 50mm. The joint isolates the bulkhead from the ceiling above, allowing for relative motion between decks. Finally, the sway braces which hold the deflection joint in place are designed to deflect or collapse if the force is too large, limiting damage to the bulkheads, ceiling, and overhead deck.

The ceiling remains an unanswered question. While the ceiling system is designed with sway braces to prevent damage in a shock load, the system is not tested. Falling ceiling

panels are potential projectiles during a shock load. On the other hand, if the ceiling panels are too difficult to remove, it is very difficult to inspect overhead systems or perform damage control operations. These conflicting requirements for ceiling integrity are potentially difficult to reconcile. One option is to avoid running overhead systems in spaces with false ceilings. Unfortunately, this is a difficult or impossible design problem for most ships. Another option is to include quick access panels in the ceiling panels. NAVSEA's damage control group currently only allows ceiling panels on a case by case basis, but continues to examine the issue.

#### 4.3.5 IJBS Program Status

Turnbull Enterprises completed an Engineering Demonstration Model of the IJBS officer stateroom in June 1997. The completed system was shipped to Hopeman Brothers and reassembled there. Even though it was the first time the system was erected, assembly was completed in 72 hours. Certain installation modifications were made since the module was erected in a warehouse, and not a ship. Because there was no "overhead deck," sway braces were simulated using turnbuckles attached to the ceiling.

Holes were drilled into the concrete floor to secure the coaming. The coaming installation process was not included in the 72 hour assembly time. While the trial installation successfully demonstrated the IJBS concept, it is not necessarily the equivalent of an on-ship installation. Space is more confined in a ship than a warehouse, and tools are more easily available in the warehouse. In addition, there were no other activities in adjacent spaces to simulate the disruption that often results from having many activities going on in a small area. The ATC program office is considering possibilities for incorporating the IJBS in the LPD-17 design.



## 5.0 Cruise Ship Construction

### 5.1 Introduction – The Cruise Ship Industry

Many of the outfitting problems in naval vessel construction are similar to those in the cruise ship industry. Cruise ships provide accommodations for up to 3,000 people in first class comfort. The competitive pressures of the market have led shipbuilders to develop innovative approaches to outfitting habitability spaces on these vessels. To understand the motivation and development of these innovative outfitting techniques, it is necessary to first examine the cruise industry and a typical cruise ship construction yard.

Today's cruise industry bears little resemblance to the transportation-oriented cruise industry of 40 years ago. There are two major classes within the industry: cruise ships and cruise ferries. Cruise ferries are typically smaller, and operate on short (one night) regular routes. These ferries load cars and trucks in lower decks and have accommodations for up to 1500 people. Cruise ships are typically larger (up to 3000 beds), cruise for longer periods of time (3 to 7 days), and focus on entertainment. Within the cruise ship class, there are four divisions: Contemporary (the largest vessels), Premium, Luxury, and Niche (the smallest vessels).<sup>20</sup>

Kvaerner Masa-Yards is one of the biggest cruise ship builders, with experience building a variety of cruise vessels for a variety of markets. Carnival's new *Fantasy* class cruise ships are representative of Contemporary cruise ships. The *Fantasy* is 260.6 m long, 31.5 m in beam, and over 70,000 gross tons. A 57,000 hp diesel electric propulsion plant is capable of driving the vessel at over 22 knots. (See Figure 5-1) The *Fantasy* class has 1,020 passenger cabins with a maximum capacity of 2,634 passengers, as well as 520 crew cabins for 980 crew members.<sup>21</sup> The vessels also have extensive restaurant, lounge, and entertainment facilities. Competition is fierce, and cruise operators discount tickets

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<sup>20</sup> Levander, Kai, "Technical Development of Cruise Ships." Kvaerner Masa-Yards Inc., Technology. 1996.

<sup>21</sup> "Fantasy Class Cruise Ships for Carnival Cruise Lines, Inc." Kvaerner Masa-Yards Brochure. 1996.

to increase load factor, relying on revenues from on-board shops, casinos, beverages, and shore-excursions to compensate.

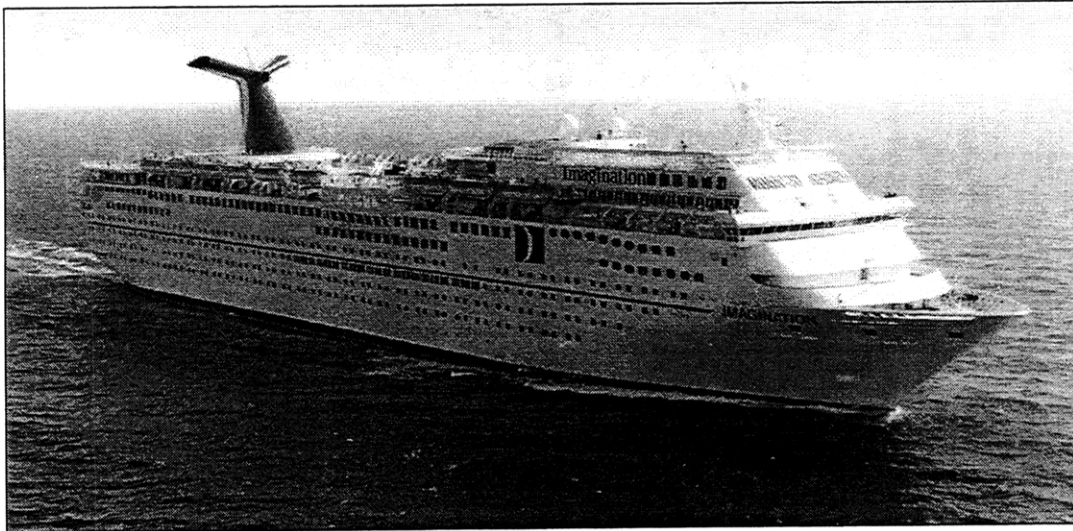


Figure 5-1 – *Fantasy* Class Cruise Ship

## 5.2 Kvaerner Masa-Yards

It is interesting to examine the production facilities of Kvaerner Masa-Yards, a world class cruise ship builder. Kvaerner Masa-Yards is a Finnish shipbuilding company with a long history of building many diverse, technically advanced, commercial ships. The Kvaerner Masa Yards group operates the Turku New Shipyard and the Helsinki New Shipyard, as well as the Piikkio Cabin Works and a technology group. Kvaerner assumed control of the yards in 1991 after the restructuring of Wartsila in 1989. The Kvaerner Masa-Yards group is part of Kvaerner Shipbuilding, which is in turn part of Kvaerner ASA, a diversified global business group.

Kvaerner Masa-Yards employs 4,700 people total, including 2,600 at the Turku New Shipyard, 1,800 at the Helsinki New Shipyard, and 200 at the Piikkio Cabin Works Factory. The yards have extensive experience building both Cruise and Ferry Passenger

Vessels, Icebreakers, Tankers, Gas Carriers, Ro-Ro Vessels, Off-Shore Support Vessels, and Finnish Naval Vessels.

The Helsinki New Yard was originally established in 1865. A recent 300 million dollar investment program has focused on modernization and training, and the yard is now one of the most modern and efficient yards in the industry. Because the yard is located in Helsinki and has limited real estate, process flow is highly refined and efficient. The yard specializes in passenger vessels and icebreakers. New construction is conducted in a 280.5 x 34 x 9.5m covered graving dock with a 300 ton crane.<sup>22</sup>

The Turku New Yard is one of the industry's newer yards, completed in 1974. It is one of the largest yards in Europe, and has a 365 x 80 x 10 m newbuilding dock equipped with a 600 ton gantry crane.<sup>23</sup> The Turku Yard specialized in large, technically demanding projects, including LNG carriers, special tankers, and cruise liners. Recent investment programs have included a production plant for spherical LNG tanks and indoor production facilities for steel production and block assembly.

The Piikkio Cabin Works factory is located near Turku, and is an independent profit center. The Cabin Works has provided module cabins for shipyards in Germany, Spain, and the UK, as well as Finland. The factory is capable of producing 5000 modules a year, and has also supplied cabins to the offshore and civil industries.<sup>24</sup>

### **5.3 Cruise Ship Design Method**

Design development begins with an owner's specification. These specifications are typically two to three pages, and outline passenger capacity, number of cabins, and cabin size. Specifications are often heavily based on previous ships. Occasionally, some operators will have their own architect prepare a set of general arrangement drawings. One of the biggest problems in these cases is insuring the drawings meet safety and

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<sup>22</sup> "Kvaerner Masa-Yards," Kvaerner Masa-Yards Brochure, 1997.

<sup>23</sup> "Kvaerner Masa-Yards," Kvaerner Masa-Yards Brochure, 1997.

<sup>24</sup> "Kvaerner Masa-Yards," Kvaerner Masa-Yards Brochure, 1997.

regulatory requirements. More often, the shipyard is able to start with a “clean sheet of paper.” In this case, the naval architect uses a parametric-based tool to determine necessary volumes and areas based on the owner’s requirements.

In creating a new design the first consideration is the placement of water-tight and fire-tight bulkheads. Modern cruise ships are designed to meet two compartment and probabilistic damaged stability criteria. The next step is to place the main escapes and main stairways based on the water-tight and fire-tight bulkhead locations. Once the escapes and stairways are located, the main engines and machinery rooms are designated. Design of the ship’s passenger, luggage, crew, provision, and waste systems begins at this point. The logistics flow patterns are the most important factor in designing the layout of these spaces.

Cruise ships must comply with many rules and regulations. They must meet International Maritime Organization (IMO) and Safety of Life at Sea (SOLAS) requirements for stability, unsinkability, fire safety, life saving equipment, and escape ladders. In addition, they must meet classification society rules for structural dimensions, and International Labor Organization (ILO) standards for crews quarters. Finally, they must meet any flag state safety requirements.

#### **5.4 Layout of Habitability Spaces**

Once the bulkheads, stairs, and machinery are located, the habitability spaces receive prime consideration in a cruise ship. As a result, cabins are located in the “prime” areas of the ship. These spaces are large and regularly shaped, easily accessible, and located near each other. Three or four decks can often have identical arrangements.

There are four primary considerations in laying out these spaces. As mentioned above, the logistics flow pattern is the most important factor. An arrangement with clear, straight, passageways and easy access to stairs and elevators is important. The next requirement is to arrange the cabins in-line, both horizontally and vertically (from one

deck to the next). This allows for straight pipe and electrical runs and eases the traffic flow problem.

The third consideration is the structural arrangement. Before the cabins are inserted, the passenger decks are large, open spaces, and need pillars for structural support. These pillars can not be placed more than 8 meters apart for vibration reasons.<sup>25</sup> The structural design must try to minimize the impact of these pillars on cabin layout. These pillars also affect the installation of modular cabins. Finally, the cabin layout must maximize outside cabins to meet increasingly demanding owners. Figure 5-2 shows the layout of a passenger deck in the *Fantasy*.

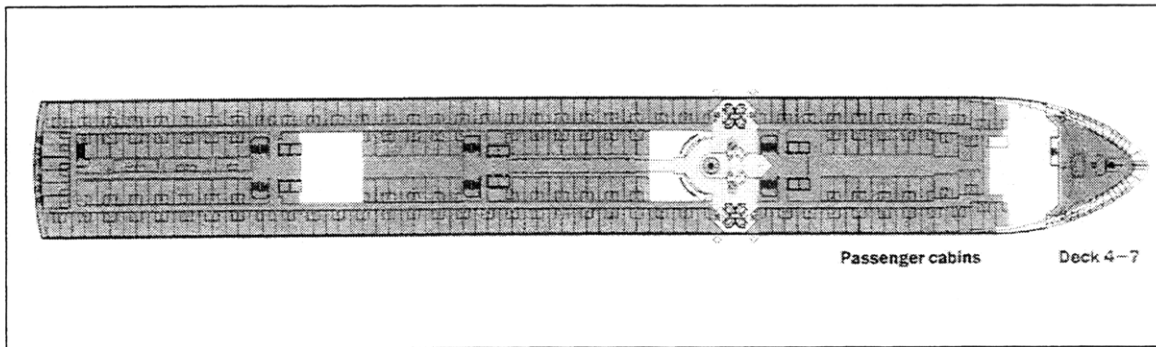


Figure 5-2 – Passenger Deck Layout on *Fantasy*

## 5.5 Modular Cabins

### 5.5.1 Motivation for Modular Cabins

A typical cruise ship takes two years to complete from contract award to delivery. Figure 5-3 shows a traditional schedule. In the traditional schedule, the first six months is devoted to planning. The next six months are devoted to steel work and hull construction. The superstructure is built in the third quarter, and finally all the outfitting is finished in the last quarter, on board the ship.

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<sup>25</sup> Interview with Heikki Sipila, Manager, Ship Design, by Gene Miller. At Kvaerner Masa-Yards, Helsinki, Finland, Feb. 22, 1998.

In this method, the outfitting is on the critical path. Since outfitting cannot begin until the superstructure is complete, all the cabins must be completed, from start to finish, in six months or less. There are inevitably problems completing so many cabins in such a short time. This leads to delivery problems, and since the work is hurried, quality often becomes a problem. Poor finishes can lead to expensive upkeep and rework. The modular cabin concept was developed to remove accommodation outfitting from the critical path.

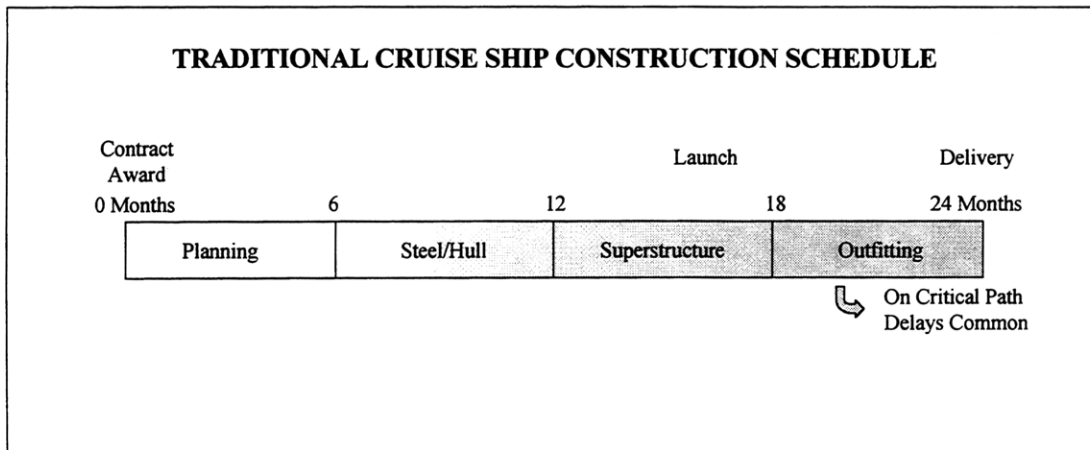


Figure 5-3 - Traditonal Cruise Ship Construction Schedule

### 5.5.2 Modular Accommodation Based Development Schedule

In a modular accommodation based schedule, ship construction begins and proceeds as normal. Instead of performing time-consuming outfit work exclusively on ship, the cabins are built in a separate facility, in parallel to the vessel. Shortly after the ship contract is signed, the architect and the cabin producer begin to build a mock-up. Once the mock-up is accepted, the factory begins planning production and ordering materials. Module production begins three to six months after the mock-up is accepted. As modules are completed they are sealed and delivered to the shipyard. When the ship reaches the appropriate point in construction, the modules are inserted into the ship and hooked up to plumbing and electrical systems. This approach removes the time consuming accommodation outfitting process from the critical path. Figure 5-4 details the modular cabin based cruise ship construction schedule.

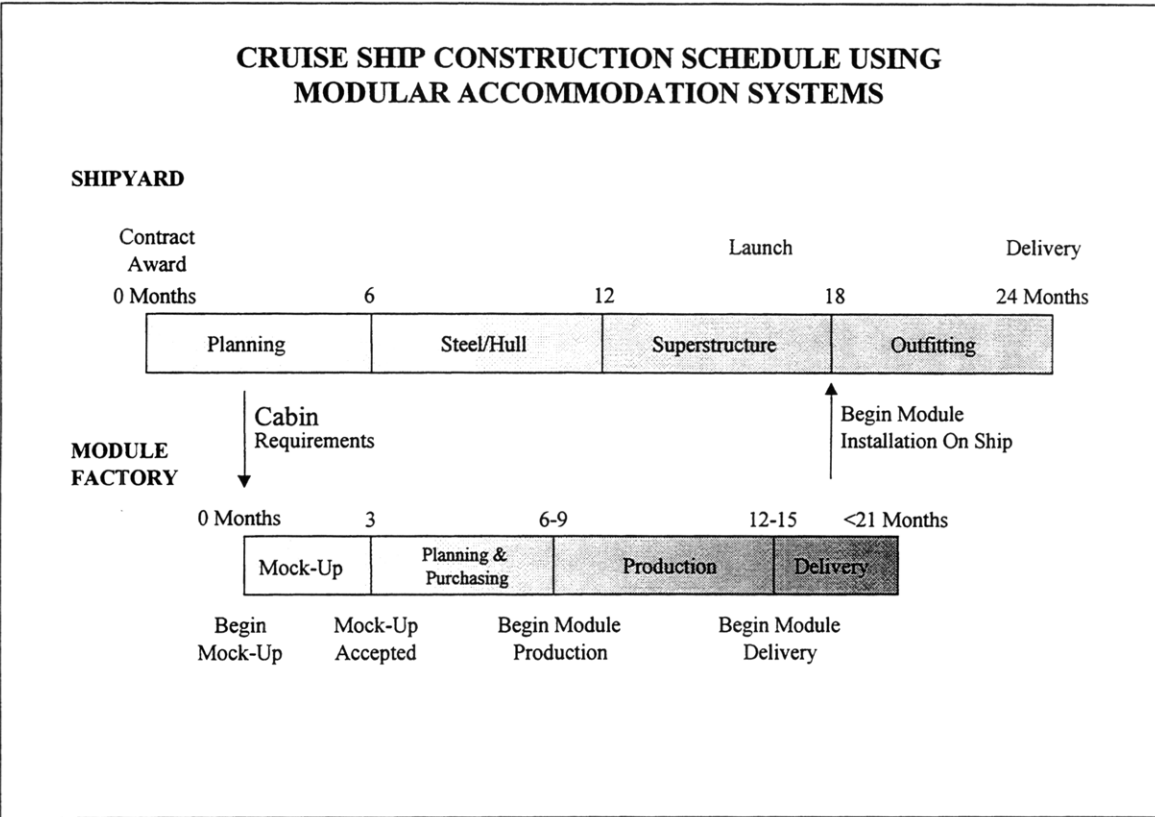


Figure 5-4 – Modular Cabin Based Cruise Ship Construction Schedule

### 5.5.3 Module Design and Mock-Up

Within the first few months after the order for a new cruise ship is made, the ship owner and architect begin to develop the cabin modules. While the overall number, location, and size of cabins are already fixed by the ship design, the internal arrangements of each cabin are still undecided. In this first stage, the Cabin Factory works with the architect to develop a cabin mock-up. This process usually takes three to six months to complete, depending on the complexity of the arrangement, the material selection, and the architect’s resolve. The owner then approves the mock-up, after which time no changes are allowed. Any changes made after this point could result in schedule delays and price increases.

Cabin units are designed to meet individual customer requirements. While Piikkio offers a series of standard module designs, most clients, especially in the cruise industry, have unique requirements and tastes. The cabin design can feature a variety of layouts, and a variety of wall and ceiling coverings, shower room accessories, sanitary fittings, light fittings, and furniture can be specified. This ability to build individual cabin designs allows the factory to compete with the more flexible on-ship outfitting approach.

#### 5.5.4 Module Construction

Each WAS (Wetmodule and Accommodation System) prefabricated cabin unit is a floorless, self supporting unit. Figure 5-5 shows the layout of a typical crew module for an offshore application. Cabin walls and ceilings are assembled from panels built at the factory. Figure 5-6 shows a section through a panel.

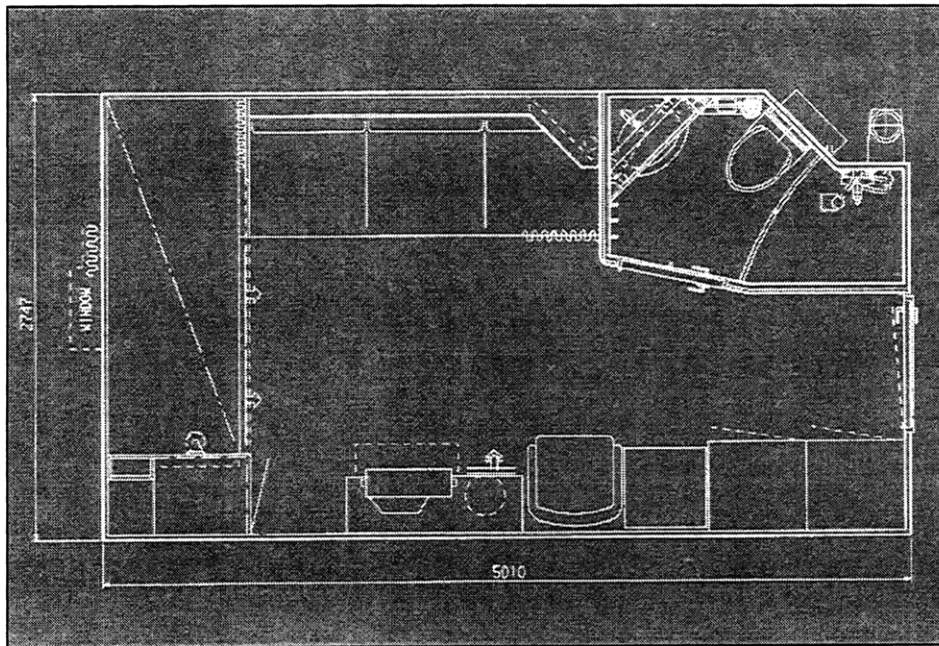


Figure 5-5 – Typical Offshore Crew Module Layout



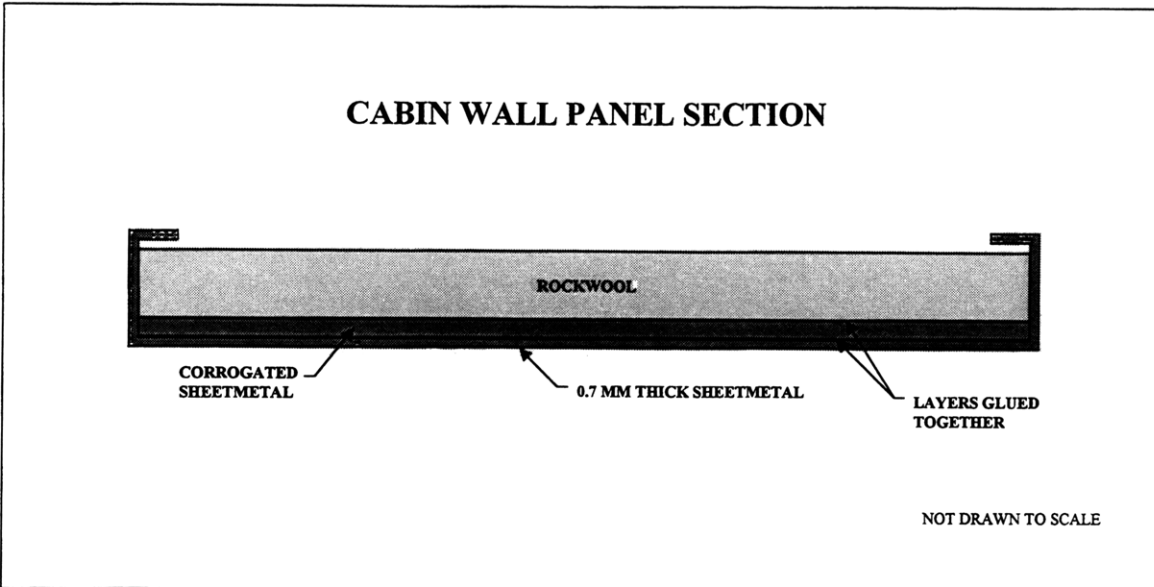


Figure 5-6 – Cabin Wall Panel Section

The factory's panel line is capable of fabricating panels up to 900 cm wide. The panel's surface is made of 0.7 mm thick sheet metal. A corrugated sheetmetal sheet is glued to the back of the panel's surface to provide strength and rigidity. Stiff mineral wool sheets (density of 220 kg/m<sup>3</sup>) are then glued to the corrugated sheet to provide fire and noise insulation. The panels are then joined to each other with hat-shaped sheet metal pieces, as shown in Figure 5-7. The panels are also bolted to the lower structural frame.

Structural support is provided by the lower structural frame and upper structural frame. The lower structural frame is a 30 mm x 30 mm steel tube. The bathroom unit is built on a steelplate floor pan. The floor of the bathroom unit also provides structural rigidity for the unit. While the ceiling panels do provide additional structural rigidity, Piikkio has recently introduced a prototype ceilingless cabin module which does not require additional structural supports once installed.

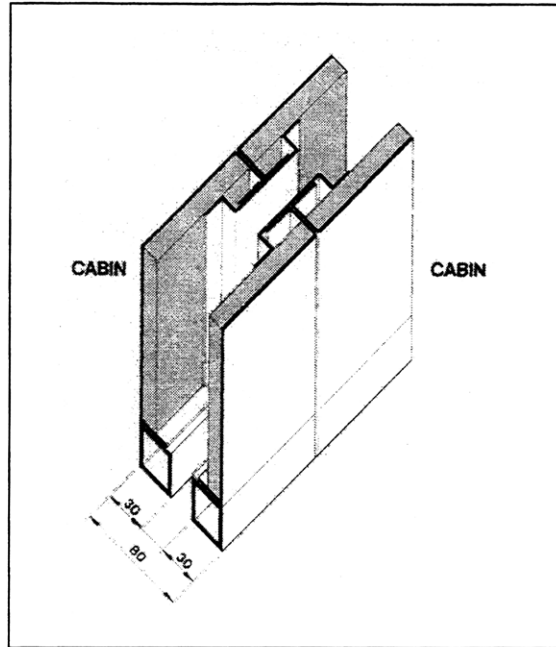


Figure 5-7 – Panel Joining Method

Each module is built with all connection points for air conditioning, electrical, water supply, and sewage systems in one location. One corner of each bathroom is cut off in a V-shape to allow access to all the connection points. When installed on board, two cabins are placed with their V-corners back to back, forming an access space. Figure 5-8 shows the system connection points for a module.

Once the panels are erected, the furniture is installed. Because the units have no floors, all furniture is secured to the wall panels. While the wall panels are able to support small loads, steel angles are used for reinforcement for heavier furniture. Loose items such as chairs are placed in the bathroom unit for transit. Electronics such as TVs are not installed at the factory.

Ordering lead times for materials and cabin furnishings varies with design. Lighting fixtures and marble for the bathrooms are the longest lead time items, requiring up to eight months.

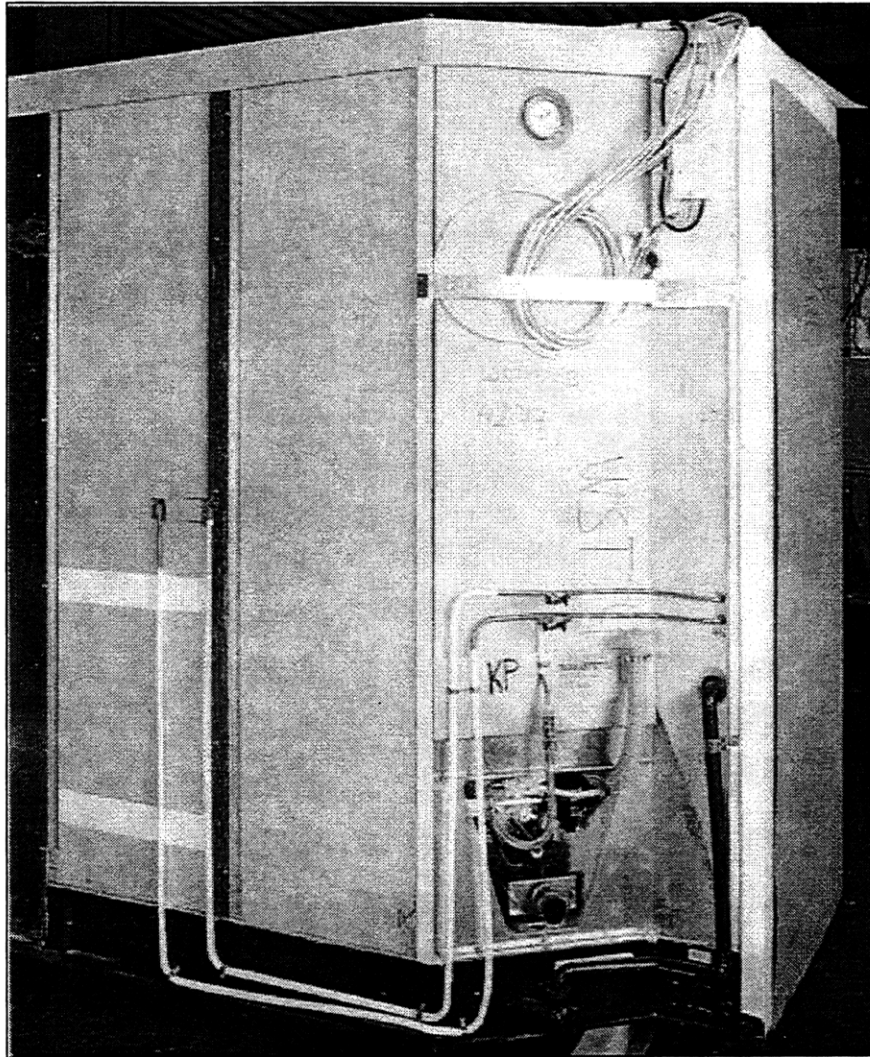


Figure 5-8 – Module System Connection Points

#### 5.5.5 Module Transportation

The modules are given special structural reinforcements before shipping and lifting. A diagonal steel bar is attached to the lower frame on the corner opposite the bathroom unit. Depending on the requirements, another bar can be attached to the lower frame, stretching across the width of the module. These bars provide rigidity during lifting and transport, and are removed before the cabin is installed. Each module is sealed in a weather-proof wrapping before it is shipped to its destination. The modules are loaded

on wooden pallets in the shop. The modules remain on their wooden pallet throughout the shipping process, and can be transported by truck, rail, or barge. Piikkio has shipped modules from Finland to locations as far away as the United Kingdom. Figure 5-9 shows a module being lifted.

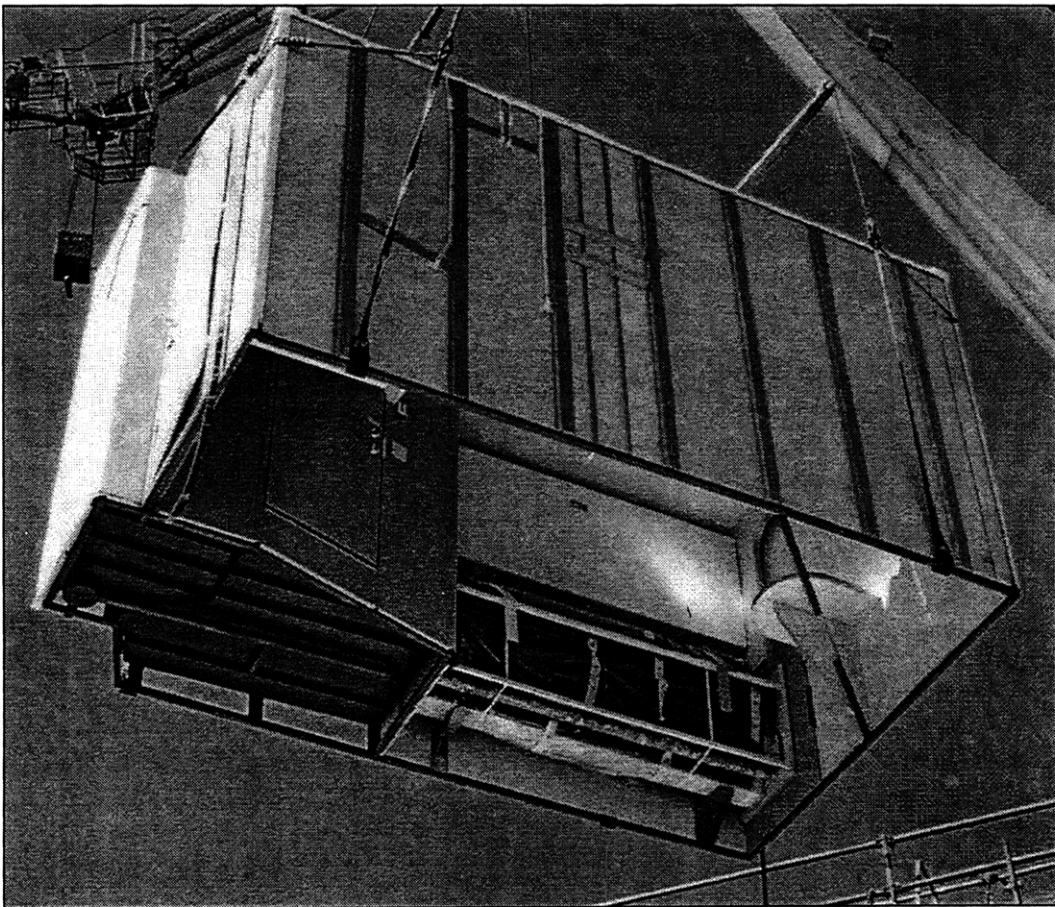


Figure 5-9 – Lifting a Module

#### 5.5.6 Installation on Ship

The Piikkio Cabin Works is not responsible for the installation of their modules. The shipyard either installs the modules themselves or hires experienced sub-contractors. The biggest challenge in installing the modules is establishing a logistical plan. This plan must coordinate the arrival of the right modules with the progress of the ship's construction.

When the steel construction of the deckhouse is ready, and the main piping, electrical, and ventilation runs have been installed, the cabin area is cleared. The module installation locations are then marked on the deck. The cabin modules are then lifted onto the ship through an opening in the ship's side. There are several methods for lifting the modules. One method uses a spreader bar, which is attached to four lifting hooks. The hooks are secured to the lower frame of the module. This is the method shown in Figure 5-9. In another method, the modules are rolled onto wooden pallets. The crane lifts the pallets to the opening, and the module is just rolled off the pallet onto the ship.

The cabins are moved to their final locations with the help of wheeled transferring devices. (See Figure 5-10) The number of devices required depends on the weight of the module. A typical module uses three dollies, as shown in Figure 5-11. One device spans the width of the cabin and is attached to special lifting slots in the lower frame of the module. The other two dollies are attached to the module on the entryway side. The devices then lift the module one to two cm, allowing a three man crew to roll the module into place. The dollies can either be installed shore side and lifted with the module, or installed after the module is placed on the ship.

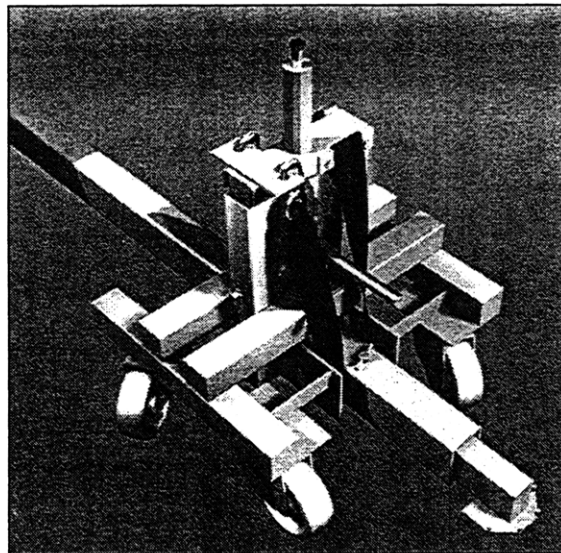


Figure 5-10 – Close up of Lifting Dolly

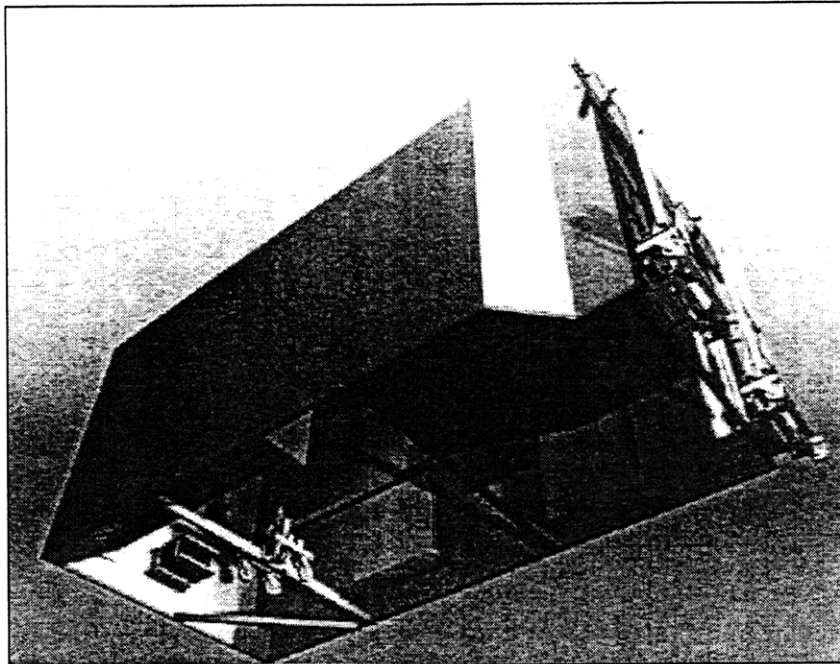


Figure 5-11 – Arrangement of Lifting Dollies on Module

Once the module is in place, the dollies lower the cabin to the deck. There are several ways to secure the module to the deck. The module can be glued, tack welded, or nailed to the deck. The window box is then installed, and the piping, electrical, and ventilation systems are hooked up. An experienced four man crew can install ten to twenty cabin modules a day. While modules are most often installed “on-ship” using this method, they can also be installed on block.

While this method of module installation is most common, it is also possible to install the modules with “blue-sky” lifts. In this method, the cabin is lifted by crane directly into its final location. This method is potentially faster as it eliminates the need to attach lifting dollies and roll the cabin into position. However, in this method the cabins must be installed before the overhead deck is in place. This requires careful planning and coordination, and is not always feasible from a scheduling perspective.

### **5.5.7 Module Design and Installation for Restricted Areas**

Often times, the structural design of a ship will prevent the installation of full size modular cabins. There are several methods for installing cabins in these restricted spaces.

When the structural pillars are too closely located to allow a module to be rolled into position, a bellows design can be used. In this method, one wall of the cabin folds into the rest of the cabin. Although the module is built with a missing window, ceiling panel, and wall panel, the length of the cabin is reduced 75 cm. After the compressed cabin is rolled into place, the last wall is folded out, and the missing components are installed.

In other cases, large cabins can be divided into two separate modules. Another design with a rising ceiling allows installation through low overhead areas. In a worst case situation, the module can be shipped as a “flat pack” where the individual panels are erected in place on the ship. This method is only used when no other access to a spot is possible.

### **5.5.8 Reconfigurability**

The modular cabin system is as reconfigurable as “stick-built” systems. They are no more difficult to disassemble in the field than other systems, and it is even possible to remove entire modules. This could actually be an advantage in future overhauls.

## **5.6 Advantages of Modular Accommodation Systems**

Modular accommodation systems offer several advantages, including reduced outfitting time, weight, cost, and quality.

As discussed earlier, prefabricated modular cabins reduce the required on board outfitting. This onboard outfitting has caused schedule delays and quality problems in

past cruise ship construction programs. By building the cabins off-ship in a dedicated factory, work can begin early in the construction schedule. When the construction of the deckhouse is ready, the fully outfitted modules are quickly and easily installed, making it possible to meet tight schedules.

Because the modules are built in a specially-dedicated factory, their construction process is carefully monitored. All modules are weighed before they leave the factory to insure they meet requirements. This manufacturing control offers potential weight savings. A two man crew cabin module for an offshore platform weighs 1500 kg. Of this, about 1/3 of the weight is the bathroom, 1/3 the cabin, and 1/3 the furniture. For special applications, the cabin weight can be reduced even more by using lighter materials, such as aluminum. For the same performance (fire category, sound insulation, finish), a modular cabin weighs 10-20% less than a traditional “stick built” cabin.<sup>26</sup>

Modular cabins can also cost less than their traditional stick built competitors. The Piikkio Cabin Works is able to focus on building modular cabins, as opposed to a shipyard which must deal with many varied activities. Additionally, building the cabin in a workshop with good lighting, easy access, and better worker coordination requires significantly fewer hours than building the same space on ship. A two man crew cabin module (8 to 9 m<sup>2</sup>) costs approximately 10,000 USD.<sup>27</sup>

Finally, modular cabins are of higher quality than competing systems. The cabin is manufactured under better working conditions with special workshops. Compared to the disorderly conditions onboard an outfitting ship, it is much easier to create a quality product. Because the cabins are built under identical conditions at the factory, their quality is more uniform. Finally, the prefabricated cabin can be locked after it is installed to prevent damage during the rest of the construction process.

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<sup>26</sup> Interview with Kari Ruusunen, Naval Architect, Piikkio Cabin Works, by Gene Miller. At Kvaerner Masa-Yards Piikkio Cabin Works Factory, Turku, Finland, Feb. 24, 1998.

<sup>27</sup> Interview with Kari Ruusunen, Naval Architect, Piikkio Cabin Works, by Gene Miller. At Kvaerner Masa-Yards Piikkio Cabin Works Factory, Turku, Finland, Feb. 24, 1998.



## **5.7 Advantages of Competing Systems**

The primary competitor of the modular cabin system is the traditional method of on-ship erection of accommodation spaces. Despite its drawbacks, this method does have several advantages.

Because outfitting does not begin until 18 months into the construction process, material purchasing decisions can be postponed. In addition, the on-ship method is more flexible for accommodating design changes or construction irregularities. This method also allows shipyards to use the local labor pool. Finally, many shipyards are already organized for the traditional system, and do not have any motivation to change.

## **6.0 Evaluation of Modular Habitability Spaces in New Aircraft Carrier Designs**

In order to quantitatively analyze and evaluate the use of modular habitability spaces in a new aircraft carrier design, it is necessary to develop a total concept design. A ship is an integrated system, and it is impractical to examine only habitability spaces without considering the arrangement of other important systems. Without considering the total ship arrangement, any design analysis of modular habitability spaces is incomplete. This chapter examines the integration of modular habitability construction techniques into a concept design for a next generation aircraft carrier, and discusses the associated design, construction, weight, and cost tradeoffs.

### **6.1 Ship Design**

It was decided to examine the application of modular habitability spaces in a new aircraft carrier design for several reasons. The *Nimitz* class is a thirty year old design, and the Navy is actively beginning the design of a new aircraft carrier class, the CVX. In addition, aircraft carriers are some of the most man-power intensive ships in the fleet, and require the greatest areas for habitability spaces. Because of these large areas, an aircraft carrier is most likely to enjoy the benefits of modular construction. Finally, the aircraft carrier presents the best opportunities for economies of scale.

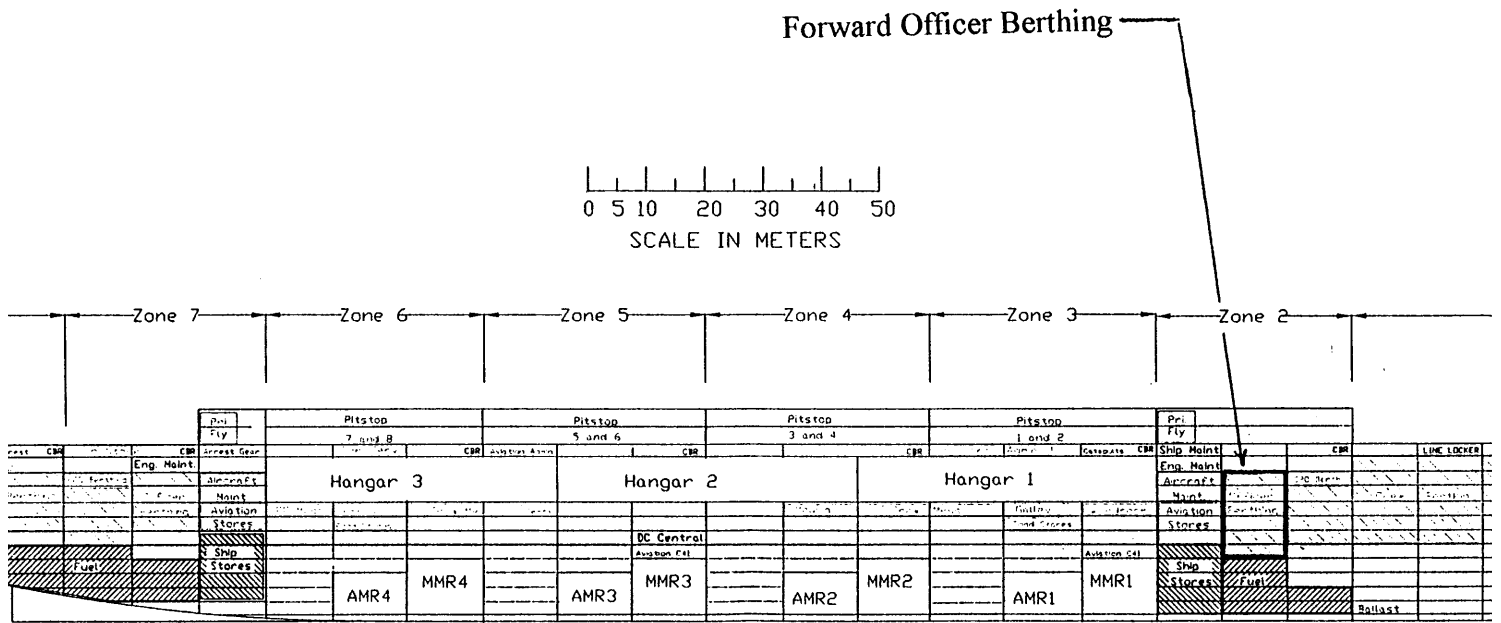
The U.S. Navy program at the Massachusetts Institute of Technology is a three year long program that concludes with a year long design project. The current third year naval officers are developing a concept design for a new aircraft carrier, so it was decided to coordinate the modular habitability space investigation with their concept design. After considering the implications of eight design variants, the officers chose to develop a concept design of a conventionally powered carrier operating a 60 aircraft conventional and short take-off and landing airwing. A comparison of the concept aircraft carrier and the *Nimitz* class is shown in Table 6-1.

| Comparison of Concept Design and <i>Nimitz</i> Class Aircraft Carriers |                |                     |
|--|----------------|---------------------|
| Category   | Concept Design | <i>Nimitz</i> Class |
| LBP  | 305 m          | 317 m               |
| LOA  | 317 m          | 332.8 m             |
| Beam (Waterline)   | 40.5 m         | 40.8 m              |
| Depth  | 30.6 m         | -                   |
| Draft  | 11.5 m         | 11.9 m              |
| Displacement (Full Load)   | 95540.3 MT     | 98500 MT            |
| Propulsion   | Gas Turbine    | Nuclear Steam Plant |
| Airwing  | 60 aircraft    | 85+ aircraft        |
| Crew Size  | 3645           | 6025                |

Table 6-1 – Aircraft Carrier Comparison

It is evident from the table the concept design is for a slightly smaller carrier than the *Nimitz*. The biggest differences are the decrease in crew size and the increase in fuel tankages. The conventional power plant requires the increase in fuel capacity. The reduction in crew is the result of using a smaller airwing with its associated reduction in manpower, as well as improvements in automation (based on the Smart Ship program). Because crew size is 40% lower while displacement is only 3% lower, the concept design requires proportionally less space be dedicated to habitability areas. The inside profile of the concept design is shown in Figure 6-1.

As a result of concurrent engineering, the design incorporates a number of features that facilitate the use of modular habitability spaces. This contrasts with the *Nimitz* class which has several arrangement features that prevent the use of modules. The *Nimitz* class has habitability spaces spread throughout the length of the ship on multiple decks, with no real coordination of these spaces between decks. On the gallery deck, the habitability



## INBOARD PROFILE

Figure 6-1 – CVX Concept Design Used For Modular Habitability Space Study

spaces are arranged around the catapult machinery, arresting gear machinery, weapons elevators, multiple storerooms and many other mission critical systems. Similar problems exist in other decks, with weapons elevators commonly running through habitability spaces. These systems, while obviously necessary, prevent the clean, unimpeded, systematic arrangement required to make modules feasible.

The concept design addresses these issues with several innovative features. The gallery deck is devoted entirely to housing flight deck machinery for the catapults and arresting gear, and does not include any habitability spaces. It is not necessary to position crew habitability spaces on the gallery deck because of there is sufficient area in other places of the ship. The habitability spaces are located at the forward and aft ends of the ship, between the 02 level and the fifth deck. This positioning groups all the habitability spaces together, in line both horizontally and vertically. The habitability spaces are homogeneous, and are not interrupted by other mission systems as in the current *Nimitz* arrangement. The concept design also uses a long, radar cross section reducing island with an integrated “pitstop” system. Weapons elevators are spread along the length of the island, which covers approximately the middle third of the ship.

## **6.2 Habitability Space Arrangement**

For this investigation, it was decided to focus on one particular area of the ship. It was decided to analyze the forward officer quarters for several reasons. One of the first considerations is the design of the actual module. While there are no designs for a Navy officer stateroom module, an officer stateroom is more like current commercial module designs than either crew or CPO berthing spaces. In addition, the IJBS demonstration model is for an officer stateroom. Based on this previous work and similarities, it was decided the officer stateroom was most favorable to modular construction.

In addition, the officer quarters were chosen because they are the aftmost of the forward habitability spaces. This reduces the potential problems of hull shape curvature that become worse further forward. In these ways, this test case represents a naval ship “best

case” arrangement for using habitability modules. Testing the best case sets an “upper limit” performance measure – if modules can not work in this case, they are unlikely to work in any naval ship arrangement. More specifically, this arrangement can help quantify the area and weight penalties for using modules.

It was decided to increase the transverse bulkhead spacing outside of the machinery spaces. Although the current spacing is 11.1 meters, the design team plans to increase spacing to 12.5 meters in the next design iteration to achieve a more producible design. The 12.5 meter spacing facilitates an even side shell stiffener spacing of 2.5 meters, enhancing producibility. In addition, while the lengthening is not necessary to incorporate a modular habitability system, it allows an easier arrangement for either an IJBS or modular system based on a 750mm grid system. It is not expected that increasing the spacing will cause damaged stability problems.

### **6.3 Module Design**

Once the compartments are defined, a conceptual module is developed. For the purposes of this study, the module is based on a combination of Kvaerner’s commercial two man offshore crew module and the IJBS. The module consists of IJBS style 750 mm wide honeycomb panels with aluminum extrusions. Furniture is similar to the IJBS, and cantilevered off the bulkhead panels. This allows all the furniture to be installed in one lift with the rest of the module. The ceiling system uses a similar honeycomb panel system.

Like the commercial offshore crew module, the model module is floorless, but has an integrated coaming system. Unlike the commercial module, the model uses an U clip to provide a positive force on the bottom of the bulkhead panel. A 3.0 m by 0.75 m Toilet/Shower module is integral with the stateroom module. Overall, the module is 5.25 meters long (7 x 750 mm panels) by 3 meters wide (4 x 750 mm panels) and 2 meters tall. Figure 6-2 outlines the module dimensions.

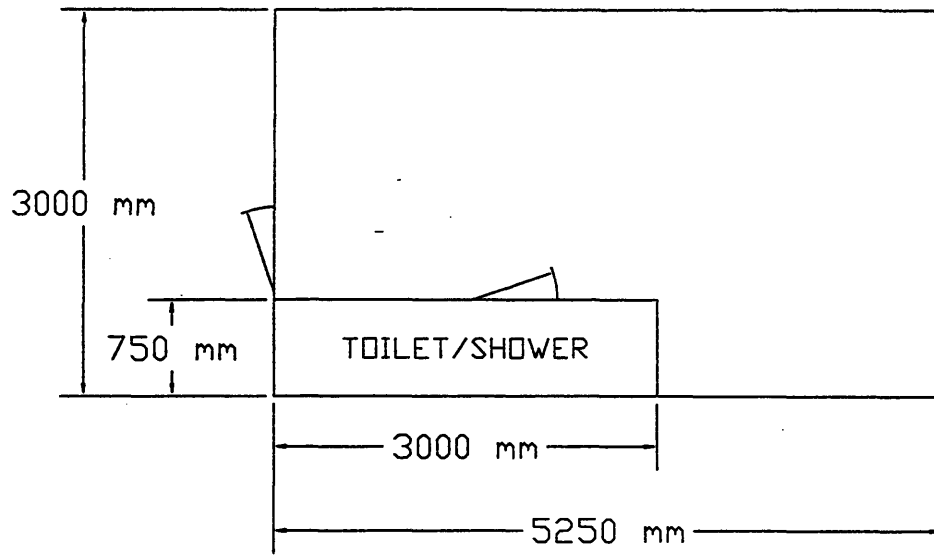


Figure 6-2 – Notional Officer Module for CVX Concept Design

In this case, a left hand and right hand version of the module are used to allow toilet showers in adjacent units to fit side by side. Because the module size is standard and uses a grid mounting system, it is easy to reconfigure each module depending on specific requirements. For example, a senior officer stateroom could have only one bunk installed, while a junior officer stateroom could have three or four bunks installed by removing other furniture pieces. This “customization” would be relatively easy to accomplish in the factory, the biggest concern is coordinating the arrival of the right module at the shipyard at the correct time.

The current module design integrates a toilet shower unit into every stateroom. It is not necessary to have separate toilet/showers for all officer cabins. This results in extra piping, higher acquisition and maintenance costs, and extra weight. Another variation of the module could replace the toilet shower unit with additional bunks. A modular sanitary space, based on the commonly sized module (in this case 5.25 x 3.0 x 2.0 m), would satisfy the head requirements.

This is only a conceptual design, meant to explore the feasibility of using modules from an overall arrangement sense. Specific details of the construction are not addressed, and future designers will have to develop these details before attempting an actual installation.

#### 6.4 Structural Allowances

The first step in developing the compartment arrangements is to identify possible structural interferences. Even though the concept design did not perform a detailed structural analysis of the habitability areas, it is still necessary to estimate structural arrangements to ensure the modules fit without interference. The ship arrangement allows for 0.5 meter deep side shell frames and 0.2 meter deep transverse bulkhead stiffeners. The side shell frames are located on both the port and starboard side. The transverse bulkhead stiffeners are consistently located on the aft side of the transverse bulkheads, so only the stiffeners on the forward bulkhead interfere with the arrangement. Figure 6-3 illustrates the structural allowances. The deepest deck frame in the design is 0.3 meters, so there is a minimum 0.1 meter clearance between the module ceiling and the bottom of the overhead structure.

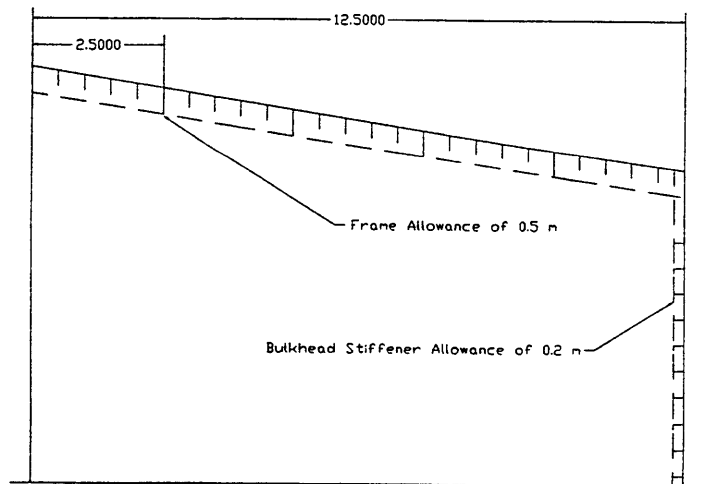


Figure 6-3 – Structural Allowances in Forward Officer Berthing Compartments



## 6.5 Passageway and Overhead Clearance

Minimum passageway widths are determined based on the “NAVSEA Design Practices and Criteria Manual.” Accordingly, “The minimum passageway width for personnel access is 36 inches clear of obstructions (fittings, equipment, structure, etc). In order to meet this requirement, 48 inch wide passageways are normally provided.”<sup>28</sup> A 1.25 meter (49.2 inches) allowance for main fore and aft passageways is used to meet this requirement. In addition, multiple passageways are recommended for survivability reasons. By placing one on either side of the vessel, there is still access if one side of the ship is on fire or flooded due to listing. A transverse passageway (again minimum 36 inches) linking the two main passageways is also provided. Minimum overhead clearances for passageways and berthing spaces are 6 feet 5 inches.<sup>29</sup> The modules are 2 meters (6 feet 6.7 inches) high, with a below ceiling clearance of over 6 feet 5 inches (ceiling panels are approximately 1 inch or 25 mm thick).

## 6.6 Module Arrangement

The two main options are to arrange the modules in two columns about a central transverse passageway; or in four rows about the two main longitudinal passageways. The two column approach was selected for several reasons. This arrangement accommodates more modules given this particular transverse bulkhead spacing. Based on preliminary arrangement drawings from the IJBS, it also allows berths to be placed longitudinally, as recommend by the NAVSEA Shipboard Habitability Design Criteria Manual.<sup>30</sup> Figures 6-4 and 6-5 show the arrangement drawings for the forward officer berthing compartments.

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<sup>28</sup> “NAVSEA Design Practices and Criteria Manual,” NAVSEA T9070-AB-PRO-010, pp. 11, Naval Sea Systems Command, Naval Architecture Sub Group, Washington, D.C. June 1985.

<sup>29</sup> “Shipboard Habitability Design Criteria Manual,” T9640-AB-DDT-010/HAB, pp. 9, Naval Sea Systems Command, Washington, D.C. Dec. 1995.

<sup>30</sup> “NAVSEA Design Practices and Criteria Manual,” NAVSEA T9070-AB-PRO-010, pp. 11, Naval Sea Systems Command, Naval Architecture Sub Group, Washington, D.C. June 1985.

Figure 6-4 - Arrangement of Forward Officer Berthing Compartments, 01 to Third Deck

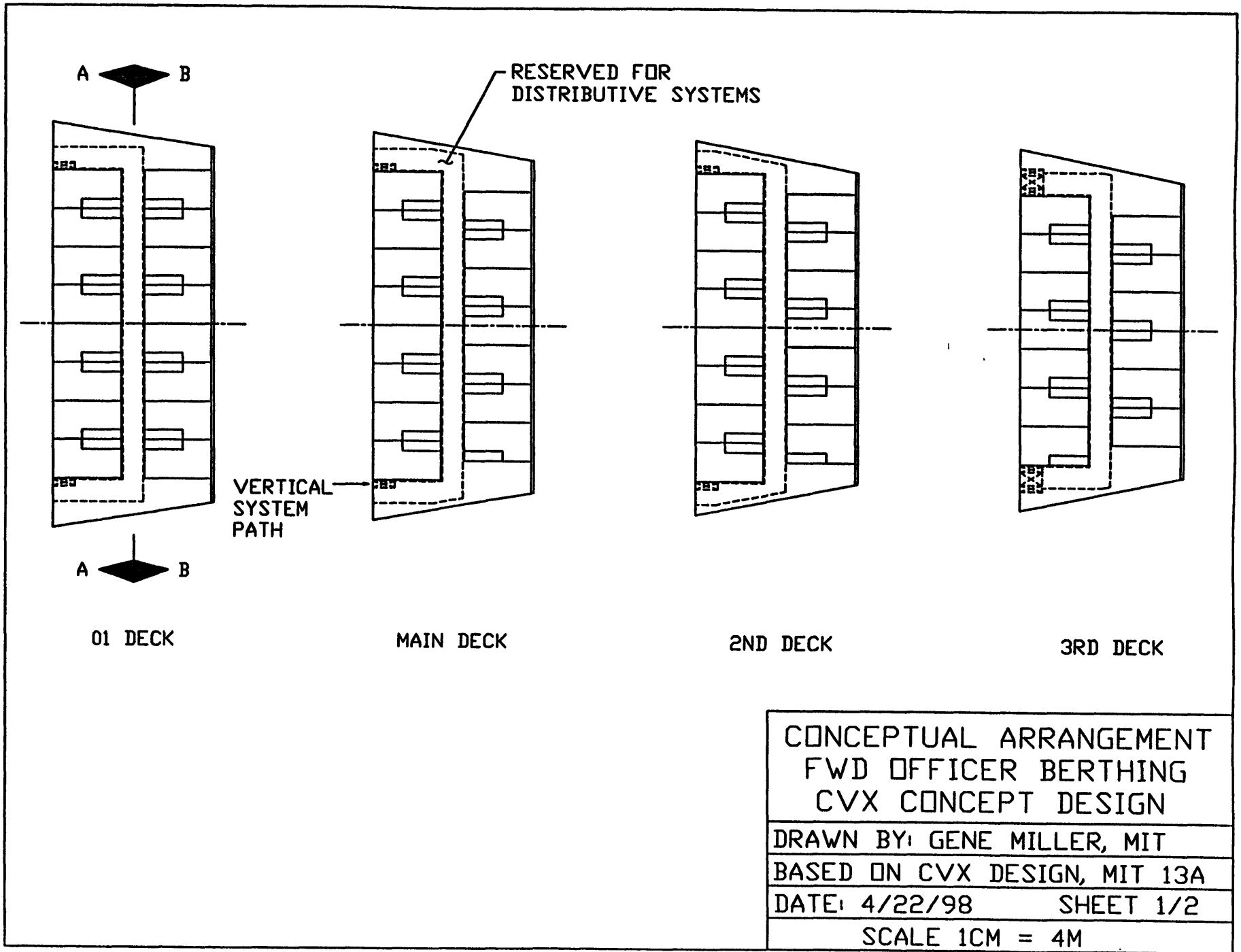
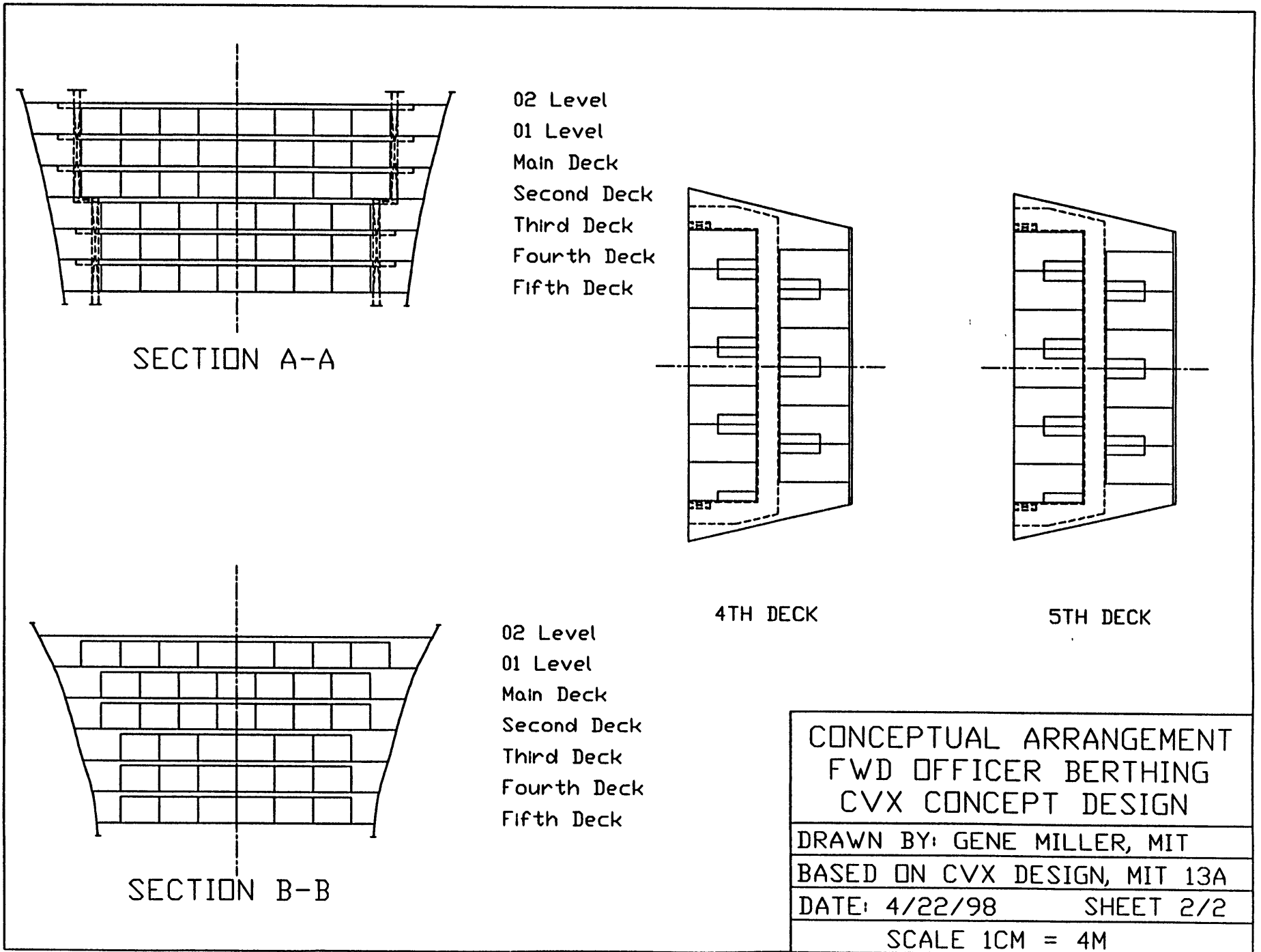


Figure 6-5 – Arrangement of Forward Officer Berthing Compartments, Fourth and Fifth Deck, and Sections A-A and B-B



The longitudinal passageways are located as far outboard as possible, against the side shell. This provides the widest separation between passageways, and follows the example of the forward berthing spaces on the gallery deck of the *Nimitz* Class carriers. To meet minimum passageway width requirement and the allowance for side shell structure, all modules were located at least 1.75 meters from the side shell. One column of modules is located directly along the aft transverse bulkhead, and another column is located 0.2 meters from the forward bulkhead, to accommodate the transverse bulkhead stiffeners. Where possible, modules are arranged so the toilet shower units in adjacent cabins are side by side. This arrangement results in a transverse passageway 1.8 meters wide. While this is significantly wider than required, the clear width is needed for housing the distributive systems.

## **6.7 Distributed Systems**

The concept design calls for the use of a zonal distributed system architecture. This is particularly important for incorporating habitability modules. Because of the restrictions on using sheathing in way of overhead systems, it is necessary to minimize overhead system runs. The zonal distributed system method accomplishes this goal by locating load centers, auxiliary, and ventilation modules in every zone of the ship. Figures 6-6 and 6-7 illustrate this concept for electrical, piping, and HVAC systems.<sup>31</sup> This eliminates the need to provide many longitudinal feeders stretching the length of the ship, reducing weight and clearing overhead space.

Redundant load centers, auxiliary, and ventilation module sets are placed in two separate compartments within each zone for survivability reasons. One set is located high in the ship on the port or starboard side, and the other set is located low in the ship on the opposite side. In this ship design, the habitability spaces occupy the middle decks, so the load centers, auxiliary, and ventilation modules do not interfere with the berthing compartment areas. Although the distributed system module sets are not located in the

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<sup>31</sup> MIT Naval Officer Professional Summer Notes, Dr Alan Brown.

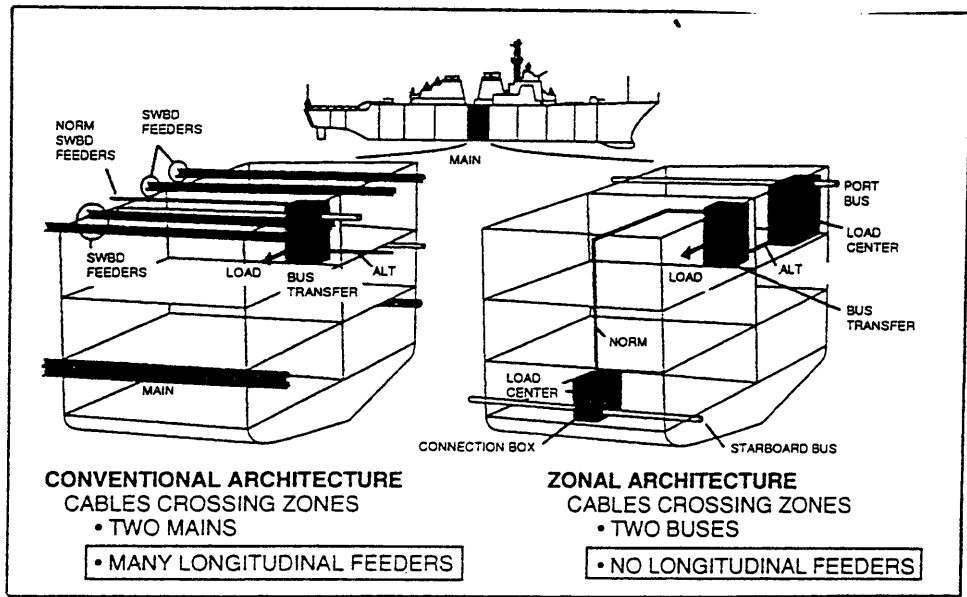


Figure 6-6 – Zonal Electrical Distributive Systems

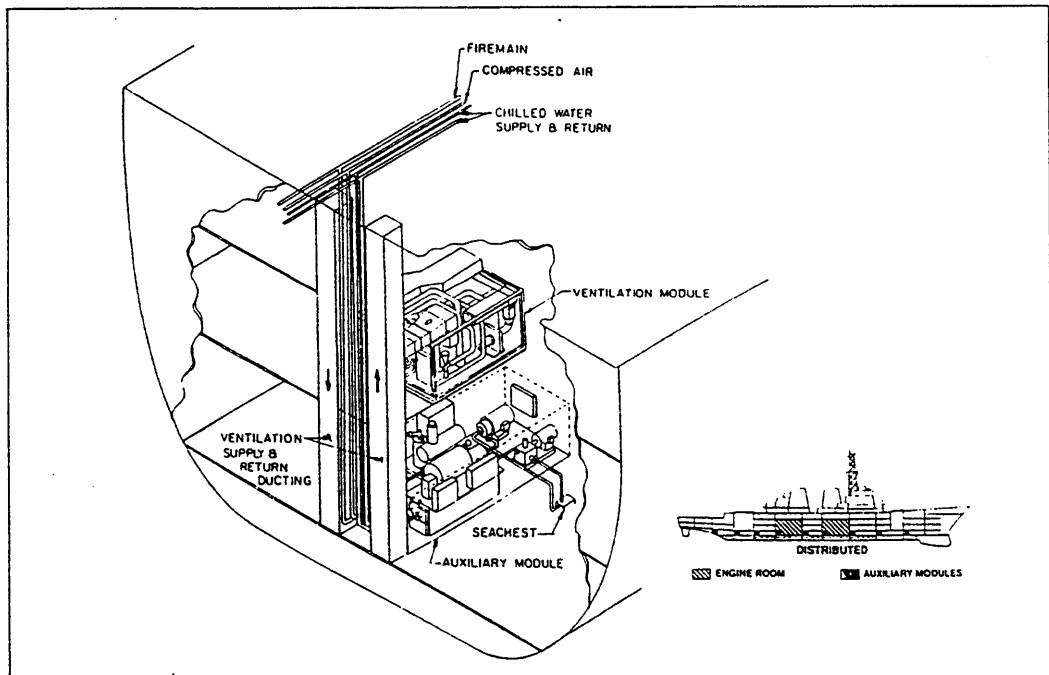


Figure 6-7 – Zonal Piping and HVAC Distributive Systems

berthing compartments, it was still necessary to provide space on each deck for the vertical and longitudinal feeders from the module sets to the staterooms. For damage control reasons, these feeders should not pass over any areas with overhead sheathing.

To minimize interference with staterooms and passageways, the vertical feeders are located aft, port and starboard, just outboard of the outer modules. An area 0.5 m wide by 1.7 meters long is allocated for the vertical system runs. The runs are straight from the 01 level to the second deck, where they are rerouted in slightly, and then run straight down from the third deck to the fifth deck. On every deck, the transverse passageway overhead is used to run HVAC, piping, and electrical connections to each module. This provides a clear area 0.4 meters deep and 1.7 meters wide in which to run the system hookups. The main longitudinal passageway overheads are used to connect the vertical system runs to the horizontal network. The distributed systems arrangement is indicated by the dashed lines in Figures 6-4 and 6-5.

## **6.8 Transportation and Production**

Ideally, a specialized factory similar to Kvaerner's Piikkio Cabin Module factory would produce the modules. There are several U.S. joiner companies located along the east coast capable of producing these modules. The modules are finished at the factory and wrapped for protection from the weather for transportation to the shipyard.

Transportation requirements and methods should be the same for naval and commercial modules.

Transporting the modules to the shipyard is a potential problem. The modules are 3.0 meters (9.8 feet) wide, so they are wide loads for highway transportation. Rail transportation is possible, but again subject to size restrictions along the route from the factory to the shipyard. It is also possible to transport the modules to the port nearest the factory, and then ship them to the shipyard. Kvaerner's Piikkio Cabin Module Factory uses trucks to transport its modules to Turku and Helsinki, both of which are relatively close (less than 200 km). For destinations further than that, they are palletized and

shipped to the destination. In the end, the best transport method depends on the proximity of the module factory to the shipyard, access to alternative transportation methods, and cost.

Transportation costs are higher for a completed module than for an equivalent “kit.” The module requires an angle bar for stiffening during transportation, adding slightly (less than 5%) to the total weight.<sup>32</sup> But the biggest penalty is the greater volume required to transport an erected module instead of a “flat pack” or “kit” containing all the same pieces. The impact of this extra volume depends greatly on the transportation distance and rate structure. This volume penalty will have a greater effect if the factory is located further away from the shipyard.

## **6.9 Module Installation**

There are two primary ways to install modular habitability spaces. “Blue sky” lifting is the preferred method, and is illustrated in Figure 6-8. In this method, the modules are delivered to the shipyard during hull erection. After the lower hull block is installed, the first series of cabin modules is lifted in place. For example, in this design after the hull block containing the fifth deck is erected, cranes lift the modules into position on the fifth deck. Installation proceeds from the centerline outward to minimize interferences between previously installed modules. After the modules are lifted in place, they are either welded or bolted to the deck. After all the modules for the fifth deck are in place, the fourth deck hull block is lifted into position on top of the fifth deck. When the fourth deck hull block is secured, the modules are installed in the same manner as before. This method continues until all the modules are installed and the hull is erected.

In this method, all the modules are installed before the ship is launched. Theoretically, this eliminates the need to do outfitting work in habitability spaces when the ship is on

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<sup>32</sup> Interview with Kari Ruusunen, Naval Architect, Piikkio Cabin Works, by Gene Miller. At Kvaerner Masa-Yards Piikkio Cabin Works Factory, Turku, Finland, Feb. 24, 1998.

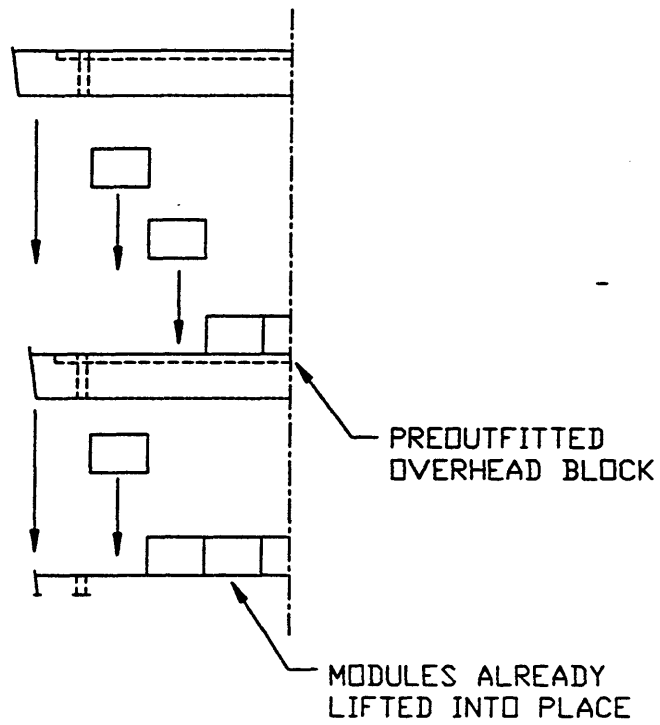


Figure 6-8 "Blue Sky" Method of Module Installation

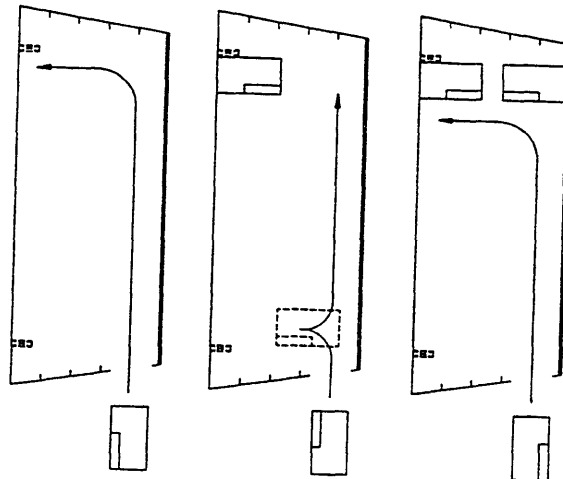


Figure 6-9 – Side Installation Method for Habitability Modules



the outfitting pier. The only remaining task is to hook up each module to the distributed systems running in the transverse passageway overhead.

The alternative method is to cut an opening in the hull, and slide the modules into each compartment. This is usually done while the ship is at the outfitting pier. After the opening is cut, several wheeled lifting devices are used to lift the module and roll it onto a pallet. The pallet is lifted into position next to the opening, and the module is rolled into the hull. The module is then rotated and rolled into position as necessary. This method is illustrated in Figure 6-9.

While the Blue Sky lift method has several advantages, it is not possible to use this method for an aircraft carrier. Although it is the simplest procedure for placing the modules into position without interference, it must be done early in the construction process. Each module requires a separate lift. This requires extra lifts, keeping the vessel in the expensive graving dock for a longer time. If the modules are behind schedule it delays the entire construction process, since all the modules must be in position before lifting the next block into position. The real limitation in this case is the draft limitation on the carrier construction dock at Newport News. It is assumed the weight limitations for the *Nimitz* also apply to this concept design, making it impossible to outfit the habitability spaces before launch.

Therefore, the current habitability space arrangement is designed to be completed using an opening in the side shell. This installation method is not practical for all ships. It requires a clear path from the side shell to the installation location, and room to maneuver the module into the proper orientation. This method is reasonable for this concept design since there are no interferences between the side shell and the module installation locations. It is proposed to use a 3.5 m opening, centered around the forward-most sideshell frame. This should allow enough room to slide the 3 meter wide modules into the hull while minimizing the rework required to patch the opening and frame after module installation is complete.

A total of six openings, one per deck, is required to install all of the officer berthing modules. Using modular berthing compartments for all crew members would require either cutting additional openings in the side shell forward, or cutting openings into the transverse bulkheads.

When the wheeled lifting devices are used, they lift the module approximately 2 centimeters.<sup>33</sup> In the concept design the deck height is 2.4 meters. When the module height and the additional clearance for the lifting device are considered, it is necessary to have a vertical clearance of 202 cm plus some margin. If a three cm (just over one inch) margin is used the overall required clearance is 205 cm. In this arrangement, workers have to wait until after the modules are installed to install any overhead systems that extend below 35 cm. (240-205 cm)

## **6.10 Evaluation**

After considering arrangement, distributive systems, production and installation, four fundamental questions remain. How do modular construction techniques for habitability space influence arrangement efficiency, weight, and cost? Does the modular based accommodation system meet the requirements of this design?

### **6.10.1 Arrangement Efficiency**

The CVX concept design arrangement provides a tool to answer the arrangement efficiency question. It is commonly believed that since module size and shape is constant, designers are unable to efficiently arrange small or unusual spaces. Using traditional construction methods, designers can use stepped bulkheads to utilize extra space in high curvature areas or otherwise use restricted spaces that would otherwise be too small to accept full size modules. However, by using a large, uninterrupted, area for

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<sup>33</sup> Interview with Kari Ruusunen, Naval Architect, Piikkio Cabin Works, by Gene Miller. At Kvaerner Masa-Yards Piikkio Cabin Works Factory, Turku, Finland, Feb. 24, 1998.

habitability spaces, this ship design and arrangement are intended to minimize these penalties.

An “arrangement efficiency percentage” is calculated for each compartment. This factor reflects the percentage of the total compartment area that is used by modules and required passageways. Required passageways include two longitudinal passageways, 1.25 m wide, and one transverse passageway, 1m wide, stretching two thirds the length of the forward transverse bulkhead. The 0.5 meter allowance for side shell stiffeners is considered unusable area, since it is difficult for a compartment to make effective use of these areas, with their deep frames. However, the 0.2 meter allowance for transverse bulkhead stiffeners is considered usable area, since these stiffeners are not as deep and many Navy ships have compartments that include these stiffeners. The arrangement efficiency percentage factors are shown in Table 6-2.

| Deck            | Total Area (m <sup>2</sup> ) | Module Area (m <sup>2</sup> ) | Passageway Area (m <sup>2</sup> ) | Other Used Area (m <sup>2</sup> ) | Total Used Area (m <sup>2</sup> ) | Arrangement Efficiency |
|-----------------|------------------------------|-------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|------------------------|
| 01              | 372.5                        | 252.0                         | 49.8                              | 14.4                              | 316.2                             | <b>84.9%</b>           |
| Main            | 352.5                        | 236.3                         | 48.6                              | 14.4                              | 299.2                             | <b>84.9%</b>           |
| 2 <sup>nd</sup> | 336.3                        | 236.3                         | 47.6                              | 14.4                              | 298.2                             | <b>88.7%</b>           |
| 3 <sup>rd</sup> | 322.5                        | 204.8                         | 46.8                              | 14.4                              | 265.9                             | <b>82.4%</b>           |
| 4 <sup>th</sup> | 306.3                        | 204.8                         | 45.6                              | 14.4                              | 264.7                             | <b>86.4%</b>           |
| 5 <sup>th</sup> | 301.3                        | 204.8                         | 45.4                              | 14.4                              | 264.5                             | <b>87.8%</b>           |
| <b>Total</b>    | <b>1991.3</b>                | <b>1338.8</b>                 | <b>283.5</b>                      | <b>86.4</b>                       | <b>1708.7</b>                     | <b>85.8%</b>           |

Table 6-2 – Arrangement Efficiency Percentage Calculations

Based on this comparison, the use of modules is only 86% efficient. While this indicates 14% of the area in the officer’s habitability spaces is wasted, the problem is not really so severe. The extra-wide transverse passageway is purposely designed to provide better access for overhead distributive systems. This extra width decreases arrangement

efficiency by 3.75–4 percent. Many passageways on current aircraft carriers, designed and built in the traditional manner, are wider than the minimum one meter wide. In addition, there are many locations in the officers berthing quarters that are not big enough to fit a module, but are large enough to accommodate storage closets, linen lockers, and other necessary services. If areas with at least 0.75 by 0.75 meter clearance are used for storage spaces (to be built on ship), the efficiency rating increases another 3 percent. When considering these factors, the arrangement efficiency rating could be as high as 93 percent. The biggest single loss is the space lost to the stiffeners on the forward transverse bulkhead, averaging 1.5 percent.

Another measure of arrangement efficiency is required area per officer. In the *Nimitz* design there are a total of 232 bunkrooms and staterooms to accommodate 567 officers, for an average occupancy rate of 2.44 officers per room. In the concept design, the forward officer spaces have a total of 85 modules. It is assumed the modules will be equipped with a different number of berths, based on whether the module will hold junior or senior officers. At an average occupancy rate of 2.44 officers per stateroom, the forward berthing spaces accommodate 207 officers, or 60 percent of the ships total officer complement. The total area of the forward spaces, minus non-berthing or sanitary used space (passageways, etc) is 1621.4 m<sup>2</sup>, which translates to an average 7.82 m<sup>2</sup> per officer. Because there is a toilet/shower unit in every stateroom, a higher area is used for sanitary spaces than otherwise necessary. It should be noted that in the *Nimitz* class, only 24 compartments have individual or shared toilet/shower units. If sanitary spaces are not included, the average berthing area is 6.89 m<sup>2</sup> per officer.

A comparison of this area requirement to current aircraft carriers is possible with the use of the aircraft carrier version of the U.S. Navy's advanced surface ship evaluation tool, ASSET. During the concept design process, the student design team created an ASSET model, which includes required area estimates for various ship functions, including habitability spaces. The ASSET tool is based on a regression analysis of data from a variety of previously constructed naval ships, providing a good tool for comparative purposes. The predicted officer berthing area requirement is 2095.3 m<sup>2</sup>, plus an

additional 206.2 m<sup>2</sup> for sanitary spaces. For 343 officers, this results in an average per person of 6.71 m<sup>2</sup> including sanitary spaces, and 6.11 m<sup>2</sup> without sanitary spaces.

Based on this area per officer comparison, the conventional arrangement requires only 86 percent as much area. If the sanitary spaces are not included in the comparison, the conventional arrangement requires only 89 percent as much area as the modular arrangement. These figures are similar to the results of the previously derived arrangement efficiency percentages.

### 6.10.2 Weight

Using the IJBS as a base line, it is possible to estimate the magnitude of weight penalties. The modules are floorless, like most commercial module designs. If the module incorporates a floor, it is necessary to remove the ship's deck structure underneath the module once the module is in place. Otherwise, there is an inaccessible void between the floor of the module and the deck, as well as extra weight. Even using floorless models, the modules suffer weight penalties in a naval design.

In order to lift and transport the modules, every module must have four walls. When the modules are placed next to each other in the ship, the adjacent modules form a double wall. This redundant wall results in a weight penalty. In addition, using an IJBS or traditional construction method allows installations to attach directly to structural bulkheads, eliminating the need for the "back" wall in the modules. The IJBS is designed to support furniture weights off both sides of the same panel. In the module arrangement, the bulkheads only need to support furniture on one side. Because of the reduced load requirements, it is possible to make the module panels thinner than a corresponding IJBS installation.

The complete weight estimate for a modular stateroom based on the IJBS components is in Appendix C. In summary, each module is estimated to weigh 2150 kg, with 840 kg for

material and structure, 560 kg for the toilet and shower area, and 750 kg for furniture. At 2.44 men per module, this equates to 881.1 kg per officer.

This weight estimate makes it possible to estimate the increased weight from using modules. The weight penalties are summarized in Table 6-3. In the base case, all panels located against a structural bulkhead and one side of a double sided wall are considered extra weight. In the second case, it is assumed that using a structural wall as a compartment boundary requires some extra weight for bulkhead coverings and a furniture mounting system. This extra weight is not required with a module since the structural bulkhead is not part of the compartment. In this case, the weight required to use a structural bulkhead as a compartment boundary reduces the extra weight for using “back” panels in the module by 10 percent. The last case considers the effect of reducing panel thickness and weight by a third on sides that only support furniture on one side. This includes all panels on the toilet/shower side and the back side. The front and non toilet/shower side panels also form passageway boundaries, and it is sometimes necessary to mount equipment in passageways (i.e. firefighting equipment, etc). In these cases, the panels have to support weight on both sides, so no weight reduction is possible.

| Deck            | Base Case - Weight For Double Panels | Consider Extra Weight for Using Structural Bulkhead | Reduce Double Panels Weight / Thickness 1/3. |
|-----------------|--------------------------------------|---|--|
| 01              | 12.2%                                | 11.6%   | 8.7%   |
| Main            | 12.3%                                | 11.7%   | 8.8%   |
| 2 <sup>nd</sup> | 12.3%                                | 11.7%   | 8.8%   |
| 3 <sup>rd</sup> | 12.1%                                | 11.5%   | 8.6%   |
| 4 <sup>th</sup> | 12.1%                                | 11.5%   | 8.6%   |
| 5 <sup>th</sup> | 12.1%                                | 11.5%   | 8.6%   |
| <b>Total</b>    | <b>12.2%</b>                         | <b>11.6%</b>  | <b>8.7%</b>                                  |

Table 6-3 – Summary of Weight Penalties for Using Modules

As shown in Table 6-3, the maximum weight penalty for using modules is 12.2 percent. If panel weight and thickness is reduced, it is possible to reduce the weight penalty to 8.7 percent. Since modules are built in a factory, careful attention is paid to manufacturing accuracy, and each module is weighed before leaving the factory. Because better quality control and uniform manufacturing processes are possible in a factory, modules can weigh less than an equivalent on ship installation. In fact, Kvaerner estimates that a commercial cabin module can weigh 10 to 20 percent less than an equivalent traditionally built cabin.<sup>34</sup> While this figure is based on experience with commercial systems, the weight reduction is derived from a process improvement which should be applicable to military as well as commercial installations. When this benefit is considered, it is possible there is no weight penalty for using modular habitability spaces.

### 6.10.3 Cost

Cost is difficult to quantify. Traditionally, the Navy has used weight-based cost models. If all alternatives weigh the same in a weight based model, they have the same predicted cost. These models disregard construction processes. There are currently efforts to move to process oriented cost models. However, these models are not fully developed, and there are currently no process based estimates available for habitability space outfitting costs.

While there are no process-based models available for this comparison, there is a general rule for estimating the relative cost of doing outfitting work at different construction stages. The eight-three-one rule predicts that for every dollar spent to do outfitting work on-unit, it would cost three times as much to do the same work on block, and eight times as much to do it on ship.<sup>35</sup> According to another estimate by Wilkens, et al., cost

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<sup>34</sup> Interview with Kari Ruusunen, Naval Architect, Piikkio Cabin Works, by Gene Miller. At Kvaerner Masa-Yards Piikkio Cabin Works Factory, Turku, Finland, Feb. 24, 1998.

<sup>35</sup> Barlow, Kelly, "America's Largest Private Shipbuilder Makes Sweeping Changes in Manufacturing to Become Globally Competitive," *Manufacturing Magazine*, Virginias Edition, November 1997.

estimates for outfitting at the erection site are approximately four to seven times higher than in-shop labor.<sup>36</sup>

Both the current outfitting method and the IJBS depend on on-block or on-ship outfitting. However, since launch weight limitations preclude on-block outfitting on aircraft carriers, all this work must be done on ship, where costs are highest. In this respect, the IJBS offers little acquisition cost saving potential over the current outfitting method. Modules, on the other hand, make it possible to move the majority of the work to the shop.

A basic cost comparison is made based on the eight-three-one rule. Table 6-4 summarizes the calculation and results. The first step is to develop a baseline cost estimate for the current outfitting method. Several joiner companies estimated 60 percent of the current costs of outfitting habitability spaces on aircraft carriers are labor related, and 40 percent are material related.<sup>37</sup> Following the 8:3:1 rule, labor rates cost 1 unit for in shop work, 3 units for on block work, and 8 units for on ship work. Since all habitability space outfitting work is done on ship, the total labor cost for the current method is 8 units (100% on-ship labor multiplied by 8 units/on-ship work = 8 units). Since labor costs are 60 percent of the total costs, the material costs are 5.33 units. In total, the current outfitting method costs 13.33 units.

The IJBS is compared next. The first question is how to reconcile differences in the material costs and amount of work required to install the IJBS instead of the traditional system. For example, while the reduction in curtain plate lowers material costs and work content, using a ceiling system increases material costs and work content. In addition, the IJBS uses panel sections with high strength integral aluminum extrusions that are more complicated to manufacture. Considering all these factors, it was decided to increase the material costs for the IJBS by 50 percent, to a total cost of 8 units. However, because the IJBS reduces on board painting, hot-work, and the need to install curtain

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<sup>36</sup> Wilkens, James R., Gilbert L. Kraine, Daniel H. Thompson, "Evaluating the Producibility of Ship Design Alternatives," *Journal of Ship Production*, August 1993.

<sup>37</sup> Interview with Dan Romanchuck, Vice President of Program Management and Engineering, Hopeman Brothers Marine Interiors, conducted by Gene Miller and Dr. Alan Brown, Waynesboro, VA, Jan



plate, the total labor content was reduced 25%. It is estimated that of the total labor, 15 percent is in shop (i.e. panels are precut, prefinished, etc), while 85 percent is still on the ship. This includes installing coamings, erecting the system, and installing furniture. This results in a total labor cost of 5.2 units, for a total cost of 13.2 units. This indicates there is a slight (less than one percent) cost advantage to using the IJBS. The material/labor split for this system is 61/39.

The material costs for the modular system are based on the weight penalties previously calculated. Since the modules weigh 12.2 percent more than the IJBS baseline system, the material costs increase by 12.2 percent, from 8.0 to 8.97 units. While the labor content in the IJBS is 25% less than the traditional method, using modules increases the labor content. While the modules enjoy the same labor reducing features of the IJBS, there is extra work that is not required in the installation of the IJBS. This includes maneuvering and securing the modules into position in the ship, and cutting and repatching the insertion points in the hull. When considered together, it is estimated the extra work required to install the modules is offset by the advantages of reduced on board painting and hot-work. Of this, 20 percent of the labor is performed on ship, including installing and hooking up the modules. The remaining 80 percent is done in the shop. This includes cutting the panels, erecting the modules, and installing the furniture. This results in a labor cost of 2.4 units. The total cost for the modular system is 11.37 units, approximately fifteen percent less than the current outfitting method. The material/labor split is 79/21.

| Category                       | Current Outfitting | IJBS        | Modular     |
|--------------------------------|--------------------|-------------|-------------|
| Material Costs <sup>1</sup>    | 0.40               | 0.60        | 0.67        |
| On Ship Labor                  | 100%               | 85%         | 20%         |
| In Shop Labor                  | 0%                 | 15%         | 80%         |
| Labor Costs <sup>1</sup>       | 0.60               | 0.39        | 0.18        |
| Material/Labor Ratio           | 40/60              | 61/39       | 79/21       |
| <b>Total Costs<sup>1</sup></b> | <b>1.0</b>         | <b>0.99</b> | <b>0.90</b> |

Note 1 – All cost categories normalized against the current outfitting method.

Table 6-4 – Cost Comparison of Alternative Outfitting Methods

As can be seen in this table, both the IJBS and Modular based methods enjoy considerable labor cost savings. However, if it were possible to move the on-ship outfitting to the on-block stage, these cost savings would drop significantly. For example, moving all outfitting from ship to block would cut labor costs by more than half for the current outfitting method. The IJBS and Modular methods, which derive their benefits from lower labor costs, lose this advantage and become 20 to 30 percent more expensive. Table 6-5 displays the results of moving the outfitting work to on-block.

| Category                       | Current Outfitting | IJBS        | Modular     |
|--------------------------------|--------------------|-------------|-------------|
| Material Costs <sup>1</sup>    | 0.40               | 0.60        | 0.67        |
| On Block Labor                 | 100%               | 85%         | 20%         |
| In Shop Labor                  | 0%                 | 15%         | 80%         |
| Labor Costs <sup>1</sup>       | 0.23               | 0.15        | 0.11        |
| Material/Labor Ratio           | 64/36              | 80/20       | 86/14       |
| <b>Total Costs<sup>1</sup></b> | <b>0.63</b>        | <b>0.75</b> | <b>0.78</b> |

Note 1 – All cost categories normalized against the current outfitting method.

Table 6-5 – Cost Comparison of Alternative Outfitting Methods Using  
On-Block Outfitting

This example illustrates several lessons. The cost of outfitting work in habitability spaces is very sensitive to the stage of construction and/or labor rates. While it is not possible to move the stage of outfitting work in a carrier, there are many other shipyards that use on-block outfitting while building other types of naval combatants. This indicates that it may not be cost efficient to use modules in a shipyard that is already doing early stage habitability space outfitting. This example also illustrates a possible lesson for aircraft carrier work tasking management. There are many joiner companies capable of doing the same outfitting work as the shipyard for an aircraft carrier. These companies, which specialize in joiner work, believe they can do the same outfitting work, at the same construction stage, for one-half to one-third the labor cost of the shipyards. These labor cost reductions are similar in magnitude to the savings from changing outfitting stage illustrated above. If this is the case, subcontracting the outfitting work, with no changes in design or material, would result in the greatest cost savings. Finally, all these cost figures reflect only acquisition and installation costs, not total life cycle costs. Given the poor maintenance characteristics of the current joiner system, the IJBS and modular systems should enjoy some total ownership cost benefits.

This cost estimate did not include the extra costs associated with transporting modules. As mentioned earlier, transporting a module will cost more than an equivalent “kit” because of the module’s added weight and volume. Transportation costs will vary significantly depending on the location of the manufacturing facility in relation to the shipyard. Although this is a potentially important cost element, it is impossible to estimate the magnitude of these penalties at this time.

### **6.11 Commercial Substitution**

The weight and cost estimates are based on a module system developed to meet current Navy standards for shock, survivability, and weight. It is interesting to compare the direct substitution of a commercial off the shelf (COTS) habitability module. This comparison is based on a Kvaerner-Piikkio Cabin Works Factory developed two man crew module. The basic module is 5 x 2.75 x 2.13 meters, weighs 1500 kg, and costs

10000 U.S. dollars. The weight distribution of the commercial module is 500 kgs for structure, 500 kg for the toilet/shower unit, and 500 kg for the furniture. For this comparison, the cabin is resized to the same dimensions as the previously examined module, 5.25 x 3 x 2 meters, and a nomex core is substituted for the standard mineral wool core to reduce weight. In addition, furniture weight is increased to reflect the requirement to house 2.44 men per module. A new weight estimate considers the reduced panel weight and increased furniture weight, and again calculates the weight penalty for using modules. Another estimate considers the possible weight savings for using commercial modules instead of the new Navy integrated joiner bulkhead system. Finally, a rough order of magnitude cost estimate is completed. In this case, the material costs for using commercial materials are estimated at 50 percent less than an IJBS based modular system. The results of this commercial substitution case are shown in Tables 6-6 and 6-7.

|  | Commercial Module | IJBS Module | IJBS          |
|--|-------------------|-------------|---------------|
| Module Weight                                | 1479 kg           | 2150 kg     | -             |
| Avg. Weight Penalty For Modules              | 6.4%              | 12.2%       | -             |
| Total Weight                                 | 125698 kg         | 182966 kg   | 160713 kg     |
| Total Weight Savings/Penalty vs. IJBS Module | 31.3% Savings     | -           | 12.2% Savings |

Table 6-6 – Weight Impacts of Commercial Module Substitution

| Category                       | Current Outfitting | Commercial Modules |
|--------------------------------|--------------------|--------------------|
| Material Costs <sup>1</sup>    | 0.4                | 0.34               |
| On Ship Labor                  | 100%               | 20%                |
| In Shop Labor                  | 0%                 | 80%                |
| Labor Costs <sup>1</sup>       | 0.6                | 0.18               |
| Material/Labor Ratio           | 60/40              | 65/35              |
| <b>Total Costs<sup>1</sup></b> | 1.0                | 0.52               |

Note 1 – All cost categories normalized against the current outfitting method.

**Table 6-7 – Cost Impacts of Commercial Module Substitution**

The weight and cost comparison results in Tables 6-6 and 6-7 indicate the commercial modules offer significant advantages. While commercial modules suffer a weight penalty from redundant panels, this penalty is only 6.4%. And compared to a standard integrated joiner bulkhead system installation, the commercial modules are almost 20 percent lighter. This is a result of a lightweight coaming and panel to panel connection system. While these costs are only estimates, a preliminary investigation indicates commercial module systems could offer 48% cost reductions over current outfitting methods. It is important to remember these commercial systems are not designed to meet Navy requirements. The coaming system is significantly simpler, but offers far less support to keep panels restrained in a shock. While commercial modules offer potentially significant weight and cost savings, their survivability properties are not known. Before a commercial system is used in a naval vessel, the Navy should conduct a shock test on a sample module.

Commercial modules might not have to meet shock requirements. Currently non-structural bulkheads must meet grade B shock requirements, primarily so they do not come adrift and damage mission critical systems located nearby. However, in this concept design arrangement, the habitability spaces do not share space with mission critical systems. In a shock situation there are no mission critical systems for the non-structural bulkheads to damage. Therefore, commercial modules might be acceptable even without meeting shock requirements. They must still meet fire requirements, but

current commercial systems already have very good fire resistance characteristics. Because Marines are stationed in their berthing areas during general quarters, the shock requirement can not be waived for marine habitability spaces.

## **6.12 Conclusions**

Like other decisions a naval architect must make, the use of habitability modules in naval ships involves many trade-offs. This design project utilized a concurrent engineering approach to create a favorable environment for using modules in habitability spaces. This approach is essential to develop an arrangement that addresses the needs of all systems. In this case, the habitability spaces are all positioned together in two groups, where past designs have spread these spaces throughout the ship. This arrangement is made possible by locating aircraft operation machinery in the gallery deck and by careful positioning of weapons elevators. By changing the location of both habitability and mission systems from previous designs, it is possible to develop an arrangement that better addresses the needs of both systems.

This arrangement offers many potential production benefits, regardless of which method or system the shipyard uses to build the habitability spaces. The spaces are in line vertically and horizontally, facilitating straight piping, HVAC, and other system runs. In addition, interferences between different shops and trades should be reduced since there are no other mission systems located in these areas. Specifically, this arrangement is well suited for modular construction techniques. The geometry of these spaces is limited only slightly by the hull's curvature, and there are no interferences to inhibit module installation.

The decision to use modules must trade-off cost savings with increased weight and area requirements. Based on the analysis of this particular carrier design, a module system built to Navy requirements can cost up to 10 percent less than current joinerwork systems. However, because modules have redundant walls and can not fit in some smaller spaces they incur weight and arrangement penalties. These area penalties can

range from 7 to 14 percent, depending on the criteria used. The weight penalties for redundant panels is up to 13 percent. It is possible to reduce these weight penalties by about five percent by using thinner, one sided panels. If shipyards are able to do a greater amount of preoufitting, or reduce labor costs through subcontracting, the cost of using modules can exceed current costs. Finally, a brief analysis indicated commercial based module systems potentially offer significant cost and weight savings or current Navy joinerwork systems. It is important to note, however, that these commercial systems are not designed to the same survivability standards.

## **7.0 Comparison and Assessment of Modular Habitability Spaces in New Design Aircraft Carriers and Cruise Ships**

There are several reasons to analyze the application of modular habitability spaces in cruise ships and aircraft carriers together. To determine which method of habitability space outfitting is best for aircraft carriers, it is necessary to consider a variety of issues. Arrangement, construction and installation issues, flexibility, and material ordering time are all important from a design and production perspective. The experiences of several commercial cruise-ship builders familiar with modular construction techniques offer possible construction and scheduling lessons.

In addition, understanding why modular construction techniques are used in cruise ships offers insight into what advantages modular habitability spaces can really offer carriers. This includes considering in service issues such as safety, human engineering, and reconfigurability, as well as survivability. Finally, these benefits are weighed together with cost and weight considerations to determine whether the best outfitting methods for cruise ships are necessarily the best for aircraft carriers.

### **7.1 Design and Production**

#### **7.1.1 Arrangement Process**

Cruise ships have relatively few limits on arrangement design. Designers first determine the required spacing and location of firetight and watertight bulkheads to satisfy classification and SOLAS rules. There is very little flexibility in meeting this requirement. The next step is to locate the escape routes and main stairwell. While these must also meet SOLAS requirements, there is more flexibility in their arrangement. An experienced designer can arrange these escapes and stairs to appear “natural” and not interfere with the arrangement of cabins.



After the bulkheads and escapes are located, the cruise ship designer arranges the propulsion and machinery spaces. While these spaces are important, they do not greatly interfere with the arrangement of habitability spaces because they are low in the ship. At this point the designer can arrange the passenger cabins, restaurants, and lounges. Since the cruise ship is in business to entertain its passengers, the passenger habitability spaces have the highest priority, and are therefore assigned to the best spaces. The structural arrangement of the ship must meet classification society rules, but designers have some flexibility to design the structure and arrangement together. In this manner, the supporting structure is sized and spaced to mesh with the cabin arrangement with minimal disruption. Cabins and structural columns are sized and spaced to fit with each other, and exhaust uptakes are routed to have minimal impact on cabin arrangement. Lounges, restaurants, and cabins are all located to insure good logistical flows, and trade-offs are made to insure the best overall arrangement. The crew cabins have a lower priority than the passenger cabins, and are located as low in the ship as possible to leave the best decks (and views) for passengers. But again, they are involved in the iterative process, with trade-offs resolved in favor of passenger comforts.

The habitability spaces are usually located high and in the middle of ship, where they avoid areas of hull curvature. Because these areas are large, uninterrupted spaces, it is easy to use a modular based cabin system without incurring large area and volume penalties. As Figure 5-2 illustrated, the boundaries of the passenger cabin decks have almost no curvature, resulting in an extremely efficient arrangement with consistently sized cabins. Cruise ships are therefore able to use modular arrangements with no apparent area penalties.

On the other hand, aircraft carriers do not have the large, uninterrupted areas for habitability spaces. The driving factor in aircraft carrier arrangement is the flight deck. This drives the dimensions and arrangement of most of the rest of the ship. The flight deck arrangement directly determines the location of catapults, arresting wires, and elevators. All of these systems affect the arrangement on other levels of the carrier. For example, the steam catapults extend below the flight deck into the gallery deck. Because

they extend several feet into the gallery level, they limit the flexibility in laying out those spaces. More importantly, the machinery required to launch and retract the catapults also takes up significant space on the gallery deck. And because there are catapults both forward and amidships, this machinery is distributed throughout the gallery deck. Meanwhile, extensive machinery is required to retract and reset the arresting wires between every landing. This machinery must be located directly below the flight deck, near the arresting wires. As a result, a large amount of space in the aft end of the gallery deck must be set aside for this machinery.

The elevators also influence arrangements. In the current *Nimitz* design, the elevators are located on the outboard edges of the flight deck. This minimizes the impact on internal arrangements and offers improved damage control. (Damaged elevators are out of the flight path of aircraft). However, these outboard elevators increase radar cross section and are directly exposed to the sea in heavy weather. Future carriers may have elevators located in the middle of the flight deck. This will have a large impact on arrangement, as areas between the flight deck and hanger deck must remain clear in way of the elevators. In addition, the gallery deck must accommodate air traffic control centers, command spaces, and other office spaces. Although these spaces are not as “fixed” as the catapult and arresting machinery, they are mission related spaces that are located early in the arrangement process. While these examples all affect the arrangement of the gallery deck, similar restrictions exist on other decks. The hanger is the biggest restriction on the next three levels. Its size is fixed by the airwing requirements. Because of its size requirements, the hanger bay commands the “prime” areas of those three decks. The preferred spaces on these levels have the most regular geometry, best protection, and easiest access to the flight deck.

The ship’s propulsion and protection systems are considered higher priorities than the habitability spaces. However, these systems are located in the lower levels of the aircraft carrier. Since habitability spaces are not located as low in the ship, the impact of propulsion arrangement decisions on habitability space arrangements is limited. This

could change for a conventionally powered aircraft carrier which requires larger exhaust uptakes and air intakes, influencing arrangements on upper decks.

Habitability spaces are at the bottom of the arrangement hierarchy. Because they are arranged after all other aviation and mission systems have been located, the preferred areas are no longer available. As a result, the habitability spaces are located in oddly shaped, difficult to access, and widely separated areas.

However, as the concept design project showed, it is possible to arrange a carrier so that habitability spaces are grouped together in large, uninterrupted areas. While the spaces are limited by the curvature of the hull, it is still possible to create a modular based arrangement at a small penalty. An aircraft carrier arranged to use modular habitability spaces will suffer a 5 to 15 percent area penalty. It is possible to reduce this penalty by optimizing bulkhead spacing for a pre-designed module where possible. Where it is not possible to change bulkhead spacing for strength or survivability reasons, naval architects can redesign the module to meet specific constraints. By using a module designed to fit within the structural constraints of the ship, it is possible to reduce the area penalty.

Traditional commercial and military joinerwork systems do not suffer any area penalties. They are the most flexible systems in terms of arrangement. While custom fitting panels to fit unusual arrangements carries higher installation costs, it allows designers to utilize the most possible area in a particular space. The proposed IJBS offers many of these flexibility advantages, although at higher installation costs.

### 7.1.2 Installation Stage and Construction Sequence

Outfitting work can occur at any of three stages – on-unit, on-block, or on-ship.

Prefabricated modular cabins are an example of on-unit outfitting. All the outfitting work (installing bulkheads, furniture, etc) is performed on the module, or unit. The completed unit is then inserted at one of the later outfitting stages, either on-block or on-ship.

Performing outfitting work on-unit is most efficient since construction can take place in a

factory. This allows complete access to every side of the unit, as well as easy access to tools, machinery, and material handling equipment.

On cruise ships, it is not usually possible to outfit habitability spaces on-block. The habitability spaces in a cruise ship are very plush, and easily damaged. More importantly, it is difficult to do on-block outfitting because of scheduling problems. Many of the fixtures in a fancy cruise ship, including marble counters and lighting fixtures, have a long ordering lead time. Because of the competitive nature of the cruise ship construction business, it is necessary to begin construction as soon as possible. Any on-block preoutfitting of habitability spaces must begin in the first six to nine months. It is not possible for the interior designers to finish designing the cabins and order materials within this time frame. As a result, habitability space outfitting is pushed to the end of the process.

However, when the outfitting work is forced on to the ship it becomes time consuming and expensive. More importantly, it becomes the critical path, and delivery is delayed until the outfitting work is complete. Modular cabins are therefore a good solution to cruise ship construction sequencing problems. By using modular cabins, most of the outfitting work is moved into the shop where it is less expensive. More importantly, because the outfitting work is done in a shop it begins sooner in the process and is accomplished in parallel to the ship construction.

By the time the modules begin to roll off the production line, it is too late to insert them into the ship with “blue sky” lifts. This forces shipbuilders to insert the modules into the side of the ship and roll them into position. This is done while the ship is at the outfitting pier. Even with modular cabins the outfitting is still the critical path, so every effort is made to continue to find ways to reduce outfitting time. Figure 7-1 shows the construction sequence for a cruise ship using prefabricated cabin modules.



Outfitting work is therefore completed at the end of the construction process, after the carrier is launched. While this outfitting work is done on-ship and is time consuming, it again is not on the critical path. Once the carrier is launched, attention is focused on completing system tests. This includes the nuclear reactors and propulsion systems, which again are the critical path. Because testing these systems takes take so long, outfitting time does not affect delivery time.

Modules do not offer nuclear powered aircraft carriers the same reductions in construction time as cruise ships. This reduction in construction time was the primary motivation for using modules in cruise ships. As a result, modules must offer other advantages to remain an attractive option for aircraft carriers. However, if the next aircraft carrier is conventionally powered, it is possible the outfitting work will become the critical path. In this case, modules will offer the same construction time reduction advantages for carriers.

Regardless of scheduling benefits, to use modulare habitability spaces aircraft carriers will have to use the same installation process as cruise ships, but for different reasons. Based on lead times in the commercial market, there is enough lead time to deliver modules to the shipyard before hull erection begins. While this makes scheduling blue sky installations possible, it is not physically possible because of the draft limitations of the graving dock. Therefore, the shipyard will have to open a hole in the side of the carrier to insert the modules, just like cruise ship builders. For different reasons, the construction sequence and installation method are very similar for aircraft carriers and cruise ships.

### 7.1.3 Producibility/Work on Ship

Both cruise ships and aircraft carriers enjoy the same producibility benefits by using modules. A ship that is arranged for modules enjoys the greatest producibility benefits. The modules are produced in a specialized factory, where tools and material handling

equipment are easily available. Installing the electrical wiring and piping in the shop also reduces the on-ship work required, reducing interferences between different trades. On-ship work is limited to installing and hooking up the completed module. Since the coaming and ceiling system is integral to the module, there is no need to fit, cut and install time intensive pieces. Welding work is limited to securing the module to the deck, and the use of studs or nails can potentially eliminate all hot work. All painting and finishes are installed in the factory, so there is no need for on-ship painting.

For difficult to access areas, it is necessary to use module kits. These kits include all required pieces, precut to the same dimensions as the other modules. Installing modules in kit form is easier than installing a traditional system since all the pieces are precut. Nevertheless, this increases work on the ship, raising costs. However, while the modules themselves are easy to install, they can have a negative impact on installation times for other systems. In a traditional design, module installation must occur early in the outfitting sequence so installers have a clear path to move the modules into position. Once the modules are in position they interfere with the installation of systems that must run through those areas. This problem is reduced if designers use a zonal distributive system arrangement that routes systems away from habitability space overheads.

There are four major problems with traditional habitability space outfitting methods. First, installers must cut the bulkhead panels, coamings, and curtain plates to fit each location. This requires fitting the pieces on-ship, but cutting them in off-ship shops. The second big problem is the on-ship hot work. Installers must clean and prep every surface, and then weld the coamings and curtain plate in location. The curtain plate is more difficult because of its overhead location. On ship hot work is expensive and interferes with other trades. Installing furniture and foundations is the third problem. Each piece of furniture has a unique foundation and requires more on-ship hot work. The final problem is painting. When a space is painted, it disrupts all other work in the compartment and limits the flow of people and material through the compartment. These problems are reduced with modules.

The new IJBS also reduces many of the producibility problems of current joiner systems. The IJBS uses pre-cut panels and a hanging ceiling concept that reduces curtain plate. In addition, the bulkhead mounted furniture system eliminates the need to install foundations. Finally, the panels are already finished, so painting on the ship is also reduced. While the IJBS has producibility advantages over current systems, it does not offer the advantages of modules.

#### 7.1.4 Material Ordering Time

There are advantages and disadvantages to earlier material ordering times. The current method allows shipyards to make material ordering times at the latest point in the construction schedule. Within the context of an eight year construction time for an aircraft carrier, habitability space outfitting work does not really begin until five years into the process. As a result, the shipyard does not have to make material ordering decisions until approximately four and a half years after contract award. (This assumes the longest lead time for habitability space components is one year.) The IJBS has a similar material ordering timeframe. Postponing material ordering decisions allows the greatest flexibility to change arrangements as requirements change.

For both cruise ships and carriers, the modular construction approach requires earlier material ordering decisions. Assuming the production and delivery time frames are similar for current commercial modules and a naval module, the builder must make planning and purchasing decisions about 18 months before module delivery and installation. This means material ordering decisions are made three and a half to four years after contract award, or about six to 12 months earlier than with the current system. While this is a disadvantage from a flexibility point of view, it has a potential advantage. Ordering materials earlier allows outfitting work to begin earlier, which is important if it is on the critical path.



## **7.2 In Service**

### **7.2.1 Human Engineering**

The degree of human engineering varies greatly between commercial and naval habitability systems. Cruise ships depend on quiet, comfortable cabins to satisfy customers. It is very important to use a habitability system which is attractive and provides maximum sound attenuation. Commercial modules use mineral-wool panel cores, which provide excellent sound and fire insulation. Further sound reduction is provided by leaving an air gap between cabins. This sound reducing system is natural for modular construction. Each cabin module has mineral wool wall panels, with an air gap between the next cabin. In this sense, the redundant walls between cabins are not extra weight in a cruise ship. They are part of a sound reduction system that is necessary to insure passenger comfort. Similar considerations go into the design of the module ceiling system. In addition to sound insulation, the ceiling in a modular system improves appearance by hiding overhead piping or electrical runs.

A Navy module will not incorporate all of the amenities of a cruise ship module. A honeycomb panel core is used instead of mineral wool for weight reasons. The honeycomb core does not provide nearly as good sound insulation as the mineral wool. Where it is necessary because of machinery noise, a layer of mineral wool can be installed to help reduce noise levels. However, the module system still provides some human engineering benefits. The redundant walls between modules improves noise reduction, and the module ceiling system is more attractive than the current system, which leaves the overhead open. The IJBS offers many of the same human engineering advantages as modules, without the redundant walls between compartments.

The current system is the worst from a human engineering perspective. The exposed overheads reveal an unattractive mess of piping, HVAC ducting, and electrical systems. In addition, there are no false ceilings to provide acoustic insulation from the overhead decks.

There are different comfort standards for cruise ships and aircraft carriers. Cruise ships depend on comfortable and quiet cabins to keep passengers happy. The double walls between modules serve as an excellent sound barrier, greatly increasing passenger comfort. A Navy module built with honeycomb panels does not offer the same noise performance of commercial modules, but is still an improvement over current Navy joiner systems.

### 7.2.2 Safety/Survivability

Survivability is the biggest obstacle to using commercial systems in Navy ships. Cruise ships do not have any shock requirements, although they must meet fire standards. In fact, the materials used in modern cruise ship modules provide very good fire protection. However, the method for securing the bulkhead panels to the coaming and overhead joint are relatively flimsy in comparison to a Navy system. It is unlikely the commercial module would survive a Navy shock test, although it has never been tested. Finally, the commercial modules use ceiling panels that do not allow quick access to overhead systems. This is a potential damage control problem, which can be reduced by rerouting systems away from cabin module overheads. In short, a commercial module is built to meet fire requirements, but is not likely to survive a shock load.

Any module used on a Navy ship must meet shock and damage control requirements. Navy habitability spaces are required to meet grade B shock requirements. Furniture in Marine berthing quarters is also required to meet grade B requirements. To meet grade B requirements, a system must survive a shock load without coming adrift, although loss of function is permissible. In order to meet this requirement, some sort of shock isolation system is necessary for the bulkhead panels. The use of a U, Z, or H clips in the coaming provides a positive force to keep panels in place under a shock load. An overhead deflection joint allows the panel to travel in the vertical direction. Using a deflection joint may also require attaching a sway brace to the overhead after the module is in

position. While this will increase installation work on ship, it will help the module meet shock requirements.

False ceilings are discouraged in naval ships because they block access to overhead systems. However, zonal distribution systems (as in the concept design) allow designers to locate all overhead system runs in the passageways. Since there are no false ceilings in the passageways, there is still easy access to damage control fittings. Without overhead systems above the modules, the false ceilings will not inhibit damage control efforts. If overhead access is required in special cases, it is possible to use quick action access panels in the ceiling system.

The current joiner system uses deflection joints to provide shock isolation for bulkhead panels, and offers unimpeded access to overhead systems. It is possible for a modular system to achieve the same survivability as the current Navy system, it is a matter of design and testing. The Navy also needs to test the bulkhead mounted furniture system.

### 7.2.3 Maintenance and Reconfigurability

Modules offer maintenance advantages for both cruise ships and aircraft carriers. The modules are based on demountable panel sections. Because the panels are demountable, it makes replacing damaged panels much easier than current joiner systems. In addition, it is easy to remove panels for inspection purposes. The new IJBS also has these maintenance advantages. The current joiner system is difficult to repair. In addition, the open overheads leave overhead systems and insulation vulnerable to damage. These maintenance costs make up a significant portion of the life cycle costs of the joiner system.

Reconfigurability is a more important issue for aircraft carriers than cruise ships. Cruise ships are only designed for a 20 to 25 year service life. Since most conversions and reconfigurations only occur when the ship changes owners, the original owner is not usually concerned with reconfigurability. On the other hand, an aircraft carrier is

designed to last fifty years. Over an aircraft carrier's fifty year life, it will undergo many modifications and reconfigurations. The habitability spaces are no different, as changing system and manning requirements will dictate changes to habitability spaces. As a result, reconfigurability is a consideration in the life cycle cost of aircraft carriers.

The current joiner system is difficult to reconfigure. The biggest problem is the furniture foundations. Furniture foundations are attached directly to the deck. Moving furniture pieces requires pulling up these foundations and retiling or resurfacing the deck in that area. To install the furniture in a new location, workers must remove the existing deck surfacing and install new foundations. And since each furniture type has a unique foundation, it is impossible to utilize existing foundations in reconfiguring spaces. In addition to the furniture problems, the current method can not reuse coamings and curtain plates.

The new IJBS offers much better reconfigurability. Because it does not use much curtain plate, there is less overhead rip-out and installation work. The IJBS's greatest reconfigurability advantage is the furniture system. Workers can easily dismount existing furniture since it is only bolted to the bulkhead mounting system. Existing furniture can be reused by installing it in a new location, or new furniture can be installed using the original mounting system. Finally, because the IJBS system is based on standard panels, it is easy to add or remove panels from an existing installation to change a compartment's dimensions.

A modular system also offers better reconfigurability performance than the current system. A Navy module based on the IJBS bulkhead mounted furniture system offers the same furniture reconfiguration advantages. Since the modules are also made of standard panels, they are no worse to reconfigure or disassemble than the IJBS or current system. It is even possible to remove or reposition the module as a complete unit, in a reverse of the installation procedure. This offers potential time savings, depending on the magnitude of the reconfiguration.

### **7.3 Weight**

Both cruise ships and naval ships have strict weight budgets. Navy ships have steel superstructures for survivability reasons. In addition, they also have a vast array of heavy electronics and radar arrays located high in the ship. This increases weight high in the ship, decreasing stability. A heavy armored flight deck adds to the stability problems on an aircraft carrier. As a result, aircraft carriers are very sensitive to any modifications that increase weight. Cruise ships have large, heavily outfitted superstructures, and must use lightweight aluminum superstructures to maintain adequate stability.

The redundant wall panels cause the biggest weight penalties in a modular system. Both the IJBS and current joiner systems use double faced panels for stateroom boundaries. With modules, the double wall contains a redundant panel that increases weight. In addition, modules place nonstructural bulkheads against structural bulkheads. In the IJBS and current systems, the structural bulkhead is used as the compartment boundary, saving weight. The concept design explored in the previous chapter suffered up to a 13 percent weight penalty for using modules. Before this extra weight is accepted, it is necessary to conduct another stability analysis.

As mentioned in the human engineering discussion, these redundant bulkheads are not considered extra weight in a cruise ship. In the cruise ship, noise reduction and passenger comfort are priorities. The redundant walls/air gap combination is such an effective sound reduction system, it is considered a necessary cost, and not a penalty.

Another concern for both commercial or Navy modules is the extra weight required to give the module enough structural integrity for transportation and installation. In commercial modules, two cross braces are attached to the module during transport to increase rigidity. However, these braces are removed once the module is installed, so there is no structural weight penalty once the module is installed. A Navy module should follow this model.

Kvaerner has actually experienced weight savings by using modules. Since the modules are built in a factory, the manufacturing and assembly processes are standardized and carefully monitored. Each module is weighed before it leaves the factory. For these reasons, Kvaerner feels modular cabins can weigh 10 to 20 percent less than an equivalent "stick built" cabin. If these weight savings were applied to a Navy module, it could counteract the penalty from redundant panels. This is a potentially vital weight savings which should be investigated further. Finally, commercial systems are often dismissed out of hand for weight reasons. In fact, in the concept design the weight estimate for the commercial module system is significantly less than the navy module (1479 Vs 2150 kg). While the commercial system does not have the survivability of the Navy system, it is worth investigating the reasons for the significant weight difference.

#### 7.4 Cost

Cost is one of the most difficult issues to quantify. Commercial modules run from \$10,000 for a two man crew cabin to \$50,000 for a first class stateroom in a cruise ship.<sup>38</sup> While a navy module more closely resembles the two man crew cabin, it is difficult to estimate the cost increase to meet survivability and weight requirements. Even if it were possible to estimate the cost of a Navy module, it is virtually impossible to determine the exact cost of current Navy joiner systems. The cost data is not broken down to the required level of detail, and if it were it would be proprietary.

In a commercial environment, Kvaerner has claimed they reduced outfitting costs 50 percent after switching to modular outfitting methods.<sup>39</sup> One argument is that this is a commercial example, and therefore the potential savings do not apply to a naval ship. However, Kvaerner did not switch materials or standards - they simply created a better process to do the same work. There is no reason why similar process improvements would not also result in cost savings, although the magnitude of savings will probably be

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<sup>38</sup> Interview with Unto Jalkanen, Vice-President, Sales and Marketing, Piikkio Cabin Works, by Gene Miller. At Kvaerner Masa-Yards Piikkio Cabin Works Factory, Turku, Finland, Feb. 24, 1998.

<sup>39</sup> Bosworth, Michael and Hough, Jeffrey, "Improvements in Ship Affordability." SNAME Transactions, Vol. 101, September 1993.

lower. The outfitting work is not on the critical path, so construction cycle time will not decrease. In addition, naval ships will not enjoy the benefits of bulk ordering. Even in an aircraft carrier, there are only 150-200 officer stateroom modules. In contrast, a single cruise ship has over a thousand modules. Based on the cost estimates from the previous chapter, it is still possible a navy module system could reduce habitability outfitting costs by 15 percent. While this is well below Kvaerner's 50 percent, it is certainly a sizable figure.

## **7.5 Conclusions**

Table 7-1 summarizes the advantages and disadvantages of using modules in cruise ships and aircraft carriers. It is important to note this is an evaluation of modular construction techniques from a systems point of view. This analysis does not consider the effects of modules on the total ship design. Nevertheless, it is still vital to understand the advantages and disadvantages of a system before attempting to integrate it into a total design.

Modular construction techniques have different impacts in cruise ships and aircraft carriers. In both cases, modules are more producible than traditional joiner systems, moving work off the ship and into the shop. Modules offer human engineering and maintenance advantages, as well as potential cost savings. While modules also reduce construction time in cruise ships, this advantage does not carry over to aircraft carriers because outfitting work is not on the critical path. While earlier material ordering times are a disadvantage for aircraft carriers, they are an advantage for cruise ships, since outfitting work can begin sooner.

Modules are well suited for installation in the large, uninterrupted areas dedicated to habitability systems in cruise ships. Because aircraft carrier habitability spaces have constrained geometry, using modules results in a 7-15 percent area penalty. In addition, the modules incur an 8 to 13 percent weight penalty in aircraft carriers. However, modules do not carry an effective weight penalty in cruise ships because of the need

for heavier, sound reducing walls. While commercial modules offer very good fire protection, they are not as strongly built as a military counterpart. A module built to Navy shock requirements is heavier than a commercial equivalent. A brief analysis of using commercial modules in an aircraft carrier suggests there are potential weight and cost benefits, however survivability remains unknown. These potential benefits might justify the cost of shock testing a commercial module. In conclusion, a modular system involves trading area and weight to improve habitability and reduce costs. Designers must evaluate the impact of these system characteristics on the total ship design to determine which construction method is best.



|  | <b>Aircraft Carrier</b>   |   |  | <b>Cruise Ship</b>   |
|--|---|---|--|--|
|  | <b>Current Joiner System</b>  | <b>Naval Module System</b>  | <b>Commercial Modules</b>  | <b>Commercial Modules</b>  |
| <b>Arrangement Process</b>             | Most flexible, build to fit any arrangement   | Requires large, uninterrupted spaces. These spaces are used for other systems, so habitability spaces put in worse spaces. Typical 7-15% area penalty                           | Same as Naval Modules. Typical 7-15% area penalty  | Requires large, uninterrupted spaces. These spaces are used for passenger cabins, so almost no area penalty to use modules                           |
| <b>Construction/Installation Stage</b> | On-ship because of graving dock weight limits.  | Module built in shop. Installed and hooked up on ship because of graving dock weight limits   | Module built in shop. Installed and hooked up on ship because of graving dock weight limits                                  | Module built in shop. Installed and hooked up on ship for schedule reasons.  |
| <b>Producibility/Work on Ship</b>      | Least producible, all work on ship  | Much more producible. Only installation and hookup on ship. Once in place, can interfere with installation of other systems.  | Much more producible. Only installation and hookup on ship. Once in place, can interfere with installation of other systems. | Much more producible. Only installation and hookup on ship. Once in place, can interfere with installation of other systems.                         |
| <b>Impact on Construction Time</b>     | None. Outfitting not on critical path for carrier   | None. Outfitting not on critical path for carrier   | None. Outfitting not on critical path for carrier  | Outfitting on critical path, decreases outfitting time and reduces delays  |
| <b>Material Ordering Time</b>          | Latest in construction process – 4.5 yrs after contract. Greatest flexibility to make changes.                    | Slightly earlier in process – 3.5 to 4 yrs after contract. Only advantage if outfitting is on critical path.  | Slightly earlier in process – 3.5 to 4 yrs after contract. Only advantage if outfitting is on critical path.                 | As early as possible, usually with 6 months of contract award. Allows outfitting to begin sooner, big advantage because outfitting on critical path. |
| <b>Human Engineering</b>               | Worst, poor sound reduction and unattractive open overheads   | Better, some sound reduction, more attractive   | Better, some sound reduction, more attractive  | Best, good sound reduction and attractive finishes.  |
| <b>Safety/Survivability</b>            | Good, bulkheads meet grade B shock, furniture in marine spaces must meet grade B shock also. Good fire resistance | Designed to same survivability standards as current joiner / furniture system. Overhead systems must be routed away from areas with false ceilings, or use quick access panels. | Worst. No shock resistance. Good fire protection.  | Only designed to meet fire regulations. Good fire resistance, no shock resistance. False ceilings w/o access panels.                                 |

|  |   |  |  |   |
|--|---|--|--|---|
| <b>Maintenance / Reconfigurability</b> | Poor, panels difficult to demount to repair. Difficult to rearrange furniture foundations | Better, panels demountable for repair. Furniture all bulkhead mounted, modules can be removed as complete unit.                        | Better, panels demountable for repair. Furniture all bulkhead mounted, modules can be removed as complete unit.                                  | Better, panels demountable for repair. Reconfigurability not a major concern in cruise ships.   |
| <b>Weight</b>                          | Current standard acceptable. Naval ships very weight sensitive.                           | Weight penalty for redundant panels when modules installed back to back. Estimated weight penalty of 8 to 13 percent.                  | Weight penalty for redundant panels when modules installed back to back. However, lighter construction reduces overall weight over 20 percent.   | Redundant panels not a penalty (provide sound reduction). Weight savings for building in factory, careful processes. Cruise ships not as weight sensitive as CVs. |
| <b>Cost</b>                            | Most expensive because of high on-ship labor costs. Material costs low.                   | Overall cost savings up to 10 percent because of reduced on-ship labor costs. Material costs higher. Added module transportation costs | Overall cost savings up to 44 percent because of reduced on-ship labor costs. Commercial material costs lower. Added module transportation costs | Kvaerner claimed a 50% reduction in outfitting costs after switching to modules.  |

Table 7-1, Summary of the Advantages and Disadvantages of Modular Habitability Spaces in Cruise Ships and Aircraft Carriers

## **8.0 Evaluating the Effects of Modular Habitability Systems on Total Ship Design**

To this point, the research has focused on evaluating modular habitability systems as a system. This was done by taking an existing design and carefully examining a small portion of the ship – the forward officer berthing spaces. This study quantified the advantages and disadvantages of using modular habitability systems. However, it is not possible to accurately judge the merits of a system without considering its effect on the total ship.

This is specifically true in the case of modular habitability systems, which offer cost savings at the price of extra weight and area. This research was necessary to quantify these costs and penalties. However, quantifying the cost savings and weight and area penalties is only the first step in the total evaluation. Based on this data, it is necessary to go back to the concept design and evaluate the total impact of using modular habitability systems.

Specifically, using modules incurs a 15 percent area penalty. What is the impact of increasing officer berthing area by 15 percent? Does the ship have to be longer to accommodate the extra area? Or are officer berthing areas such a small percentage of total required area that a 15 percent increase has almost no impact on overall size. The same questions apply for weight and cost. How much does a 13 percent increase in the weight of officer berthing spaces decrease stability or increase draft? Finally, how much does a 15 percent reduction in officer berthing space outfitting costs really reduce the ship's cost.

### **8.1 How To Do This Evaluation**

Using the quantitative results of this research, it is possible to use a ship synthesis program to evaluate the effects of using modules on the total ship. The Navy 13A design project used the ASSET program, which is capable of answering some of these questions. Starting with the synthesized concept design variant, the designer should increase the

officer berthing space area group by 15 percent, and the officer berthing space weight groups (SWBS 641) by 13 percent. After making these modifications, the designer must rebalance and resynthesize the concept design. It is then possible to estimate the total effects of using the modular system by comparing the overall dimensions and weight of the two designs.

Estimating the overall cost impact is a little more difficult. There are cost evaluation relationships for the single digit weight groups. However, these cost models are weight based. Designers need a way to apply the 15 percent cost savings to this number.

## 8.2 Possible Outcomes

The decision whether or not to use modular habitability systems will depend on the relative importance of weight, area, and cost of officer berthing spaces in the total ship. Tables 8-1 and 8-2 show how the relative importance of these items can influence the decision whether to use modules.

|        | System Benefit or Cost | Officer Berthing Space Impact On Total Ship<br><i>(This Is Only An Example!)</i> | Total Ship Benefit or Cost |
|--------|------------------------|--|----------------------------|
| Area   | +15%                   | 5%   | +0.75%                     |
| Weight | +13%                   | 2%   | +0.3%                      |
| Cost   | -15%                   | 1%   | -0.15%                     |

Table 8-1 – System Impact on Total Ship Design, Officer Berthing Spaces Important

|        | System Benefit or Cost | Officer Berthing Space Impact On Total Ship<br><i>(This Is Only An Example!)</i> | Total Ship Benefit or Cost |
|--------|------------------------|--|----------------------------|
| Area   | +15%                   | 1%   | +0.15%                     |
| Weight | +13%                   | 1%   | +0.13%                     |
| Cost   | -15%                   | 2%   | -0.3%                      |

**Table 8-2 – System Impact on Total Ship Design, Officer Berthing Spaces Unimportant**

The two examples shown in Tables 8-1 and 8-2 illustrate how the same system can have a different impact on total ship design, depending on the specific design. In the first case, the 0.75% and 0.3% total area and weight penalties are probably great enough to offset the 0.15% cost savings. This is especially true if the length and draft of the ship must increase to accommodate modules. If certain dimensions exceed critical limits (i.e. maximum draft to fit into certain harbors) then extra weight is completely unacceptable. Other dimension changes can also have far reaching effects. An increase in draft increases resistance and fuel costs. The increased fuel costs could offset the modules cost advantage.

On the other hand, if the total area and weight penalties are small in comparison to the cost savings, modules are very attractive. This is more likely if the area and weight increases do not increase the total ship size. For example, the concept design used for this research is not area limited, so the area penalty is not important in the decision whether to use modules. It is, however, draft limited. If the added weight increases draft too much, the ship has to become wider or longer to avoid exceeding the draft limit. This increase steel costs, again offsetting the modular system's cost savings. If the area and weight penalties do not have a large impact on the total ship design, modular habitability systems offer cost, maintenance, and human engineering benefits. The final decision will consider both risks and rewards. In addition to the impact on the total ship, there is always some risk with using a new system or construction method.

## **9.0 Incorporating Modular Construction Techniques into Current Aircraft Carriers and Other Naval Ships**

While modular construction techniques offer potential benefits for new aircraft carrier designs, Newport News is still building *Nimitz* class aircraft carriers. Construction has not even started on the last ship of the class, CVN-77. The Navy is looking for ways to advance the existing *Nimitz* design, and is planning to use CVN-77 as a transition ship to the new CVX. It is therefore important to find opportunities to test modular construction techniques in the CVN-77.

### **9.1 Testing Program**

Neither the U.S. Navy nor any U.S. shipbuilders have ever used modules in an actual ship construction program. It is therefore necessary to conduct a test program to: a) validate the technical feasibility of modular construction techniques in naval ships, b) quantify and confirm weight and area penalties, and cost savings, and c) gain experience in module design, installation, and total ship integration for future programs. The testing program should also be conducted in such a way to minimize risk for both the shipyard and navy.

The Navy is considering a redesign of the CVN-77 from the hanger deck up. There is an opportunity to coordinate a test program with this redesign. Even if the ship is not entirely redesigned, it is still early enough to design a test program to fit within the constraints of the present design. In addition, lessons from the CVN-77 are directly transferable to CVX, since they are both aircraft carriers.

## **9.2 Testing Objectives**

The testing program needs to accomplish several things:

- Design and produce a habitability module that meets Navy survivability performance requirements, while minimizing weight and area penalties
- Demonstrate the side insertion installation procedure is feasible for aircraft carriers
- Quantify weight and area penalties, if any, in an actual naval installation
- Minimize risk to the overall mission effectiveness, cost, and delivery schedule

The test program should only attempt to use modular systems in a small, controlled area. By only outfitting a small area of the ship with modules, it is possible to demonstrate the technical capability to build and install modules while reducing the potential risk. The potential effects of unanticipated weight increases and area penalties are minimized. If they exceed tolerable limits, it is easier to cancel the test, and replace the modules with traditional joiner systems.

Unfortunately, this sort of test program will not display significant cost savings. Since the test program will only build and install a few modules, the research and development costs will be a proportionally higher percentage of the total costs. In addition, the test program will not enjoy the economies of scale of a full production program.

### **9.3 Test Plan**

Officer staterooms are the logical first candidates for modular construction techniques. The officer stateroom more closely resembles existing commercial module designs than crew or CPO quarters. The officer staterooms are also most consistent with modular construction techniques. Crew and CPO berthing spaces more closely resemble cubicles than staterooms. To build crew or CPO berthing spaces in the same manner as current commercial modules requires breaking these larger spaces into smaller areas, similar to officer bunkrooms. In this respect, testing an officer stateroom offers lessons for all types of berthing spaces.

### **9.4 Test Restrictions**

Even if CVN-77 is redesigned from the hanger deck up, many systems will remain fixed in their present location. The magazines are located below the hanger deck, and will therefore remain in the same location. This in turn fixes the location of the weapons elevators. In addition, the carrier will still have to operate existing aircraft. Therefore, many of the aircraft launching and recovery systems will remain fixed in their present locations, as will the overall hanger size.

As shown in the CVN-75 arrangement drawings (Figures 3-3 to 3-8), the arresting gear and catapult machinery spaces are the primary systems on the gallery deck which conflict with habitability spaces. The weapons elevators run through habitability spaces on almost all decks. The ideal installation test spot must minimize the impact on the current arrangement, while avoiding potential interference problems with the previously mentioned systems. In addition, the test space must be located to facilitate the demonstration of the proposed installation method.



## **9.5 Potential Test Spaces**

Based on the arrangement of the CVN-75, there is a potential test space on the third deck, aft of the photography labs and reactor training spaces. This space is shown in Figure 9-

1. The space is currently divided into three compartments as follows:

### **Port Compartment**

**Overall Dimensions: 15 feet wide by 41 feet long**

**Contains:     1 Stateroom  
                  1 Bunkroom**

### **Middle Compartment**

**Overall Dimensions: 102 feet wide by 41 feet long**

**Contains:     22 Staterooms  
                  1 Community Sanitary Space  
                  2 Cleaning Gear Lockers  
                  2 Linen Lockers  
                  2 Conveyors  
                  2 Access Trunks**

### **Starboard Compartment**

**Overall Dimensions: 15 feet wide by 41 feet long**

**Contains:     1 Reactor Department File and Publications Room**

This space is a good test area for several reasons. There are very few non office or habitability systems located in the space. Only the two conveyors (numbers 8 and 9) and two access trunks in the middle compartment are fixed in position. Their impact is limited, however, by their location and size. The two conveyors and one access trunk are located next to each other and have a total restricted area of just 13.5 by 12 feet. The compartment is 41 feet long at that location, so there is still 27.5 feet of clear access past



this obstruction. The second access trunk is 6 feet wide by 11 feet long and located against the forward bulkhead, and has a minimum clearance of 15 feet on every side.

The middle compartment offers the best opportunity to test modular officer staterooms because it is large and has few obstructions. This helps both in the arrangement and installation of modular staterooms. And since this is a centerline compartment in the after end of the ship, there is very little hull curvature. This will increase arrangement efficiency.

Using this space as a test case has no impact on the overall ship arrangement since the compartment is already used for officer berthing. The test space is also in a good location to test the installation method. The port and starboard compartments do not have fixed systems that would prevent inserting modules through the sideshell. The modules are inserted on whichever side is against the outfitting pier. This provides the best access to material handling equipment and cranes. The longitudinal bulkheads make it necessary to cut openings in both the side shell and the longitudinal bulkhead on the installation side. While it is more expensive to cut two openings, if the modules can pass through one opening, they can pass through the second. The openings should be located to minimize rework without impeding module insertion.

In terms of risk management, the compartment is located low in the ship. This will minimize the effect of any weight penalties on stability. The compartment is small enough to limit the effect of any problems, but large enough to provide a good learning experience. Finally, the installation process will not directly impact any spaces with mission or critical path systems. This makes it possible to test the proposed installation method with minimal effect on the rest of the ship and the delivery schedule.

## **9.6 Test Program Participants**

The test program requires expertise in three major areas:

- **Familiarity with commercial module design and construction**
- **Familiarity with naval joiner work requirements and construction**
- **Familiarity with module installation and integration into the total ship.**

Experience with commercial module design and construction is critical. While NAVSEA's Affordability Through Commonality (ATC) group has examined officer stateroom modules, they have not built one. Kvaerner Masa's Piikkio cabin works factory has produced over 70,000 modular cabins over the last thirty years. Kvaerner is one of the few companies with this much experience. In addition to experience, the commercial sector brings a different perspective. The design approach should begin with commercial standards and work up, as opposed to starting with naval standards and working down. There are also U.S. joiner companies with some experience with modular cabins, although none has produced as many cabins for as wide a range of vessels. Ideally, a U.S. joiner company would team with a company with the same experience with modular cabins as Kvaerner to provide commercial input.

Teaming Kvaerner with a U.S. joiner company offers other advantages. Most of the major joiner companies in the U.S. are familiar with Navy requirements for construction of habitability spaces. This sort of teaming arrangement combines foreign experience with modules and domestic experience with Navy work. To minimize transportation costs, the modules should be built in the United States.

While these foreign manufacturers have experience producing modules, they are not responsible for installing the cabins. It is therefore a good idea to get help from a shipyard or subcontractor experienced with actually installing modular habitability

spaces. This group will work closely with Newport News. Installation should be done by Newport News or a U.S. joiner company, with guidance from the experienced shipyard or subcontractor. Finally, overall project management can come from NAVSEA's ATC program.

## **9.7 Test Program Schedule**

The test should install the modules as soon as possible after the ship is launched. This will minimize the interference in the port and starboard compartments from module installation. Later work in the middle compartment should avoid damaging the previously installed modules. In addition, if test program is not technically feasible, Newport News will have as much time as possible to reconstruct the space with a traditional joiner system, minimizing schedule risk.

This means the modules must be ready for installation about five years after contract award. The question is, "How much time will design development and production require?" A typical commercial module requires about 15 to 18 months from the beginning of design until the first production units are ready for installation.<sup>40</sup> The design work for this project is more extensive, since it will have to combine commercial technologies with Navy requirements, never an easy process. The project should therefore plan to have all team members on-line 24 months before planned module installation, or about three years after CVN-77 contract award. Before this point, the ATC program should be involved in any redesign efforts to ensure the test program is integrated into the total ship as smoothly as possible.

## **9.8 Distributive Systems**

Key to successfully integrating modules into a naval ship is reducing interferences with overhead distributive systems. This includes developing standard interfaces between

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<sup>40</sup> Interview with Kari Ruusunen, Naval Architect, Piikkio Cabin Works, by Gene Miller. At Kvaerner Masa-Yards Piikkio Cabin Works Factory, Turku, Finland, Feb. 24, 1998.

modules and distributive systems. In many ways, the success of a modular habitability test program depends on the use of zonal distributive systems. During installation this prevents previously installed modules from interfering with the installation of system runs, and vice versa. A zonal arrangement also makes it possible to keep overhead systems out of module overheads, reducing damage control problems. If possible, the modular habitability test program should coordinate with a zonal distributive system test program. The combination of these two programs offers the greatest potential cost savings.

## **9.9 Test Program Conclusions**

It is much more difficult to integrate modular habitability spaces into an existing design. However, it is necessary to demonstrate the technical feasibility of the modular concept before applying it in a new aircraft carrier design. The proposed testing program uses modular outfitting techniques in one small section of the current *Nimitz* design. This test program will develop and test a module design and installation plan to verify the technical feasibility of modular construction techniques. The small scope of the test limits risks to mission effectiveness, weight, and construction schedule.

## **9.10 Other Possible Applications for Habitability Modules**

This section explores the advantages and disadvantages of using modular habitability spaces in other types of naval ships.

### **9.10.1 Amphibious Assault Ships**

This category includes LHD, LHA, and LPH ships like the *Wasp*, *Tarawa*, and *Iwo Jima* class. These ships are very similar to aircraft carriers in many respects. They are large ships that incorporate a flight deck for AV-8B harrier aircraft and helicopters. Table 9-1 shows a comparison of the *Wasp* (LHD-1) and the *Nimitz*.<sup>41</sup>

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<sup>41</sup> Sharpe, Captain Richard, Editor, Jane's Fighting Ships 1997-1998, pp822, Butler and Tanner Limited,

|                  | <i>Wasp</i> Class (LHD-1)  | <i>Nimitz</i> Class (CVN-68) |
|------------------|----------------------------|------------------------------|
| Length           | 253.2 m                    | 332.9 m                      |
| Beam             | 31.8 m                     | 40.8 m                       |
| Displacement     | 41,000 MT                  | 98,500 MT                    |
| Propulsion Plant | Steam Turbine              | Nuclear                      |
| Speed            | 22+ kts                    | 30+ kts                      |
| Aircraft         | 42 H/C or 20 AV-8B & 6 H/C | 85+ Fixed Wing A/C           |
| Crew             | 1077 + 1870 Marines        | 6025                         |

Table 9-1 Comparison Between *Wasp* Class LHD and *Nimitz* Class CVN

Amphibious assault ships have on-board storage space for marine vehicles and large well decks for launching landing craft. In addition to a permanent crew of over a thousand men, they can accommodate almost two thousand marines. Amphibious assault ships and aircraft carriers are similar in overall size, capability, and crew size. This suggests modular habitability spaces have the same advantages and disadvantages for both ships. This is most likely if amphibious assault ships have the same launching weight restrictions as aircraft carriers. However, the cost advantage of modular construction techniques is decreased if greater preoutfitting is possible on these ships. Unlike aircraft carriers, the majority of the habitability spaces on amphibious assault ships is for embarked marines. Marines are stationed in their berthing compartments during general quarters, so these berthing areas must meet shock requirements. This limits the possibility to integrate commercial modular systems on these ships. There are no plans to build more of these ships in the near future.

#### 9.10.2 Other Amphibious Ships (LPD, LST, LSD)

These amphibious ships are smaller than the LHA and LHD classes. They are typically 500 to 700 feet long and displace 17,000 to 24,000 tons. They have 400-500 crew

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Great Britain, 1997.

members, and accommodations for 700 marines. Their smaller size and crew size reduce the utility of modular habitability spaces. The smaller size makes it more difficult to arrange the habitability spaces, and fewer cabins reduce the advantages of mass production. Most importantly, preoutfitting is used extensively in the construction of these ships, greatly reducing the potential cost benefits of modules.

### 9.10.3 Surface Combatants

The largest surface combatants in the U.S. Navy today are the *Ticonderoga* class cruisers. These ships are approximately 567 feet long and displace 9,600 tons, with a crew of 364 men. The DDG-51 class is the Navy's newest destroyer, with production scheduled to continue until 2005. At 8,300 tons and a crew of 323, the DDG-51 is slightly smaller than a *Ticonderoga* cruiser. Built in the late 1970s and early 1980s, the FFG-7 class frigates are the smallest surface combatants in the Navy, at only 4000 tons.<sup>42</sup>

The Navy is planning to begin construction of the next generation of surface combatants (designated the DD-21 class) by 2005. They are attempting to incorporate cost saving ideas into both the CVX and DD-21 design. However, it is unlikely modular habitability systems will have cost benefits for the DD-21. Like aircraft carriers, surface combatants are extremely weight, area, and stability sensitive. These constraints make area and weight penalties from modular habitability spaces difficult to accept. Unlike aircraft carriers, destroyers do not have the same launching weight restrictions which prevent preoutfitting. The current DDG-51 builders, Bath Iron Works and Ingalls Shipbuilding, both use extensive preoutfitting. At Ingalls, up to 70 percent of the outfitting work is done before launch.<sup>43</sup> Preoutfitting reduces or eliminates the cost advantages of modular systems. Without a cost advantage, weight and area penalties make modular habitability spaces undesirable on surface combatants.

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<sup>42</sup> Sharpe, Captain Richard, Editor, *Jane's Fighting Ships 1997-1998*, pp815, Butler and Tanner Limited, Great Britain, 1997.

<sup>43</sup> Ingalls Shipbuilding web page, [www.ingalls.com](http://www.ingalls.com), updated April 29, 1998.



#### 9.10.4 Hospital Ships

Hospital ships are very well suited to modular habitability spaces. The *Mercy* class hospital ships are 894 feet long and displace 69360 tons. In addition to a crew of over 1,200, they have beds for 1,000 patients.<sup>44</sup> They have large, full hull forms similar to cruise ships. Combined with the requirement for numerous, quiet habitability spaces, hospital ships are very similar to cruise ships. Modular habitability spaces should improve human engineering and reduce costs for a hospital ship. There are currently no plans to build additional hospital ships.

#### 9.11 Conclusions

Overall, aircraft carriers present the best opportunities to utilize modular habitability spaces. Some of the larger amphibious assault ships are similar to aircraft carriers, and might also benefit from modular construction techniques. Hospital ships are similar to cruise ships, and also candidates for modular habitability spaces. Their large size and the requirement for quiet habitability spaces make them ideal candidates for modular construction. However, most naval ships will not benefit from modular habitability spaces. While small crew sizes reduce the economies of scale, the bigger issue is preoutfitting. Most ships do not have the same preoutfitting restrictions as aircraft carriers. Outfitting habitability spaces on-unit or on-block, instead of on-ship, eliminates the cost benefit of using modules. Combined with weight and area penalties, this makes modular habitability spaces undesirable for most ships.

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<sup>44</sup> Sharpe, Captain Richard, Editor, Jane's Fighting Ships 1997-1998, pp844, Butler and Tanner Limited, Great Britain, 1997.

## **10.0 Conclusions**

**Aircraft Carriers are the most expensive ships in the world. Given recent reductions in defense spending, it is more important than ever to make these vessels affordable. With more than 6,000 crew members, one area for cost reduction is the construction and outfitting of habitability spaces.**

**The construction of these living spaces, which includes berthing and sanitary spaces, is governed by Navy requirements for materials, fixtures, and survivability. These specifications are contained in sections 621 and 644 of *the General Specifications for Ships of the U.S. Navy*. The requirements for the construction of living spaces in Navy ships are summarized below:**

**Materials – GRP/NOMEX honeycomb panels with fiberglass, HPPL, or CRES (stainless steel) faces. This is intended to reduce weight.**

**Coamings – Non watertight or semi-watertight depending on the adjacent compartment.  
Watertight for sanitary spaces.**

**Fixtures/Furniture – Bulkhead mounted furniture is permitted.**

**False Decks/Voids – False decks and inaccessible voids are prohibited.**

**Ceilings – Ceilings are generally prohibited for damage control reasons, with some exceptions.**

**Shock – All bulkheads must meet grade B shock requirements, as well as any furniture in marine berthing areas.**

**Habitability spaces do not have a high priority in the arrangement design of an aircraft carrier. The development of general arrangements follows a definite hierarchy. The**

carrier's primary mission is to operate combat aircraft, so this is the first design priority. Aircraft launching, recovery, arming, and maintenance systems are the most important systems, and drive the arrangements. The ship's propulsion and protection systems are on the next level of the hierarchy, dictating structural design and internal arrangements on lower levels. Habitability systems are at the bottom of the arrangement hierarchy. As a result of their low position in the design hierarchy, these systems are put in the remaining spaces after all the mission critical systems have been placed. This often results in the assignment of habitability spaces to oddly shaped, difficult to access, and widely separated locations.

Currently, all habitability spaces on aircraft carriers are built and outfitted after the ship is launched. First, coamings and curtain plate for each compartment boundary are measured, cut, fit, and welded on ship. This is time consuming because of restricted access to shop facilities and material handling equipment. Each joiner bulkhead panel is also specially cut for each installation location. Furniture is installed after the coamings, curtain plate, and joiner bulkheads are in place. Each piece of furniture has a unique foundation, and each foundation requires extensive on-ship cutting, fitting, and welding. Finally, the compartment is painted. All of this work requires careful coordination between many trades. Worse, on-ship hot work and painting interfere with work in surrounding spaces.

Although on-ship outfitting is expensive, it is done on carriers for several reasons. The primary reason for on-ship outfitting is the draft limitation of the graving dock where all new carriers are built. This prevents preoutfitting, which increases the vessel's weight at launch. In addition, the outfitting work is not on the critical path so there is no motivation to change the current schedule. Finally, waiting to do outfitting work until after launch gives Newport News Shipbuilding and the Navy the most flexibility to make design changes.

These facts indicate there is room for improvement in the construction of habitability spaces in aircraft carriers. Within the Navy, the Affordability Through Commonality

(ATC) program is trying to address many of these issues. The new integrated joiner bulkhead system (IJBS) attempts to reduce many of the problems associated with the on-ship construction of habitability spaces. The system is based on a standard dimension grid system with precut components. False ceilings are used to reduce curtain plate, and bulkhead mounted furniture eliminates heavy foundations. While this system reduces the labor required to build habitability spaces, most of the work is still done on-ship. In addition, the system components are more expensive than current materials. The ATC program has also developed a modular crew sanitary space (MCSS), which it plans to install on the new LPD-17 assault ships. However, the ATC program has not produced a modular berthing space.

Preoutfitting is the best opportunity to reduce construction costs of habitability spaces. Moving outfitting work off the ship improves access to shop facilities and material handling equipment. Since launching weight restrictions prevent on-block preoutfitting in aircraft carriers, the only alternative is to build habitability spaces as modules, on-unit, and insert the completed modules into the carrier after launch.

This is a common process in cruise ship construction. Modern cruise ships accommodate over 3,000 people, and have many habitability spaces. Outfitting habitability spaces on-ship has many of the same disadvantages in both carriers and cruise ships. However, the problem is worse in cruise ship because outfitting is the critical path. Any delays in outfitting lead directly to delivery delays. Preoutfitting habitability spaces is not really possible in cruise ships. Hull erection begins within six months of contract award, so there is not enough time to design the cabins, order materials, and build the cabins on-block before the blocks are erected in the graving dock.

To solve this problem, several cruise ship builders use prefabricated modular cabins. Special factories build the cabin modules in parallel with the ship. The modules are completed by the time the ship is launched, and transported from the factory to the shipyard by truck, rail, or sea. At the shipyard, the modules are inserted into the ship

through openings in the hull, and moved into position with special dollies. The cabins are glued, nailed, or welded into position.

These commercial habitability modules offer cruise ship builders several advantages. The modules are floorless and use bulkhead mounted furniture to reduce weight. Because the modules are built in a special factory, their construction process is carefully monitored. This manufacturing control reduces weight and improves quality. Since working conditions are better in a factory than on a ship, labor hours are reduced, lowering costs. Finally, modular cabins reduce the required on-ship outfitting that has caused schedule and quality problems in past construction programs.

While modules initially appear to be a good solution for aircraft carriers, there are several problems. Like many decisions naval architects must make, using modular construction techniques for habitability spaces involves many trade-offs. Every ship is different, so different considerations inevitably result in different production decisions. It is not surprising that modular construction techniques, which have many advantages for cruise ships, do not have as many advantages for aircraft carriers.

The MIT Naval Ship Construction and Engineering program year-long design project helps address these issues. By integrating modular habitability spaces into a new aircraft carrier design, it is possible to analyze and quantify the advantages and disadvantages of modules. From an arrangement design perspective, concurrent engineering helps incorporate features that facilitate the use of modular habitability spaces. Where possible, designers should position habitability spaces together, and avoid locating mission and habitability system in the same compartment.

The biggest advantage of using modular habitability spaces in aircraft carriers is cost. Modular habitability spaces shift outfitting work off the ship into a factory. Even with higher material costs, the reduction in labor costs can reduce habitability space outfitting costs up to 15 percent. However, because outfitting work is not on the critical path there are no potential savings for reducing construction time, as in the cruise ship industry.

The biggest disadvantages are area and weight penalties. Because modules are a fixed size, designers can not use all the available area in high curvature or unusually shaped spaces. With traditional joiner systems, designers can use stepped bulkheads to utilize this area. The unused area that results from incorporating modules is an “arrangement efficiency penalty.” The area penalty for using modules ranges from 7 to 15 percent, depending on the geometry of the compartment.

Modular habitability spaces are also heavier than “stick built” joiner systems. Stiffening bars are required during module transportation. While these bars add weight during shipping, they are removed upon installation, and are not a real problem. The largest problem is redundant bulkheads. Each module includes four sides, so module placed side by side or against bulkheads have redundant walls. These extra panels increase the weight by 8 to 13 percent over stick built systems.

These advantages and disadvantages assume the module is built to meet Navy survivability standards. Using commercial modules can eliminate weight penalties. Commercial modules use lighter furniture mounting and coaming systems to lower weight. This results in a 30 percent weight savings versus a comparable Navy modular system. While these commercial modules have very good fire resistance characteristics, they are not built to withstand shock.

It is not possible to accurately judge the merits of a system without considering its effects on the total ship. Based on the assumptions made in this research, the final decision will trade off the 15 percent increase in berthing area and 13 percent increase in berthing weight with a 15 percent cost reduction. If the ship is area sensitive, the increased area requirement will force an increase in ship size. This increase in size might cost more than the savings from using modules. By the same token, if the ship is stability or draft restricted, an increase in weight might force an increase in beam. This also adds to construction costs and can hurt mission effectiveness. However, if the ship design is neither draft nor area restricted, incorporating modules will offer cost, maintenance, and

human engineering benefits. Although the benefits of modular construction vary with design, they offer potentially significant cost savings that justify further investigation.

However, neither the Navy nor U.S. shipbuilders have used modules in past ship construction programs. Therefore, the Navy should conduct a test program with the new CVN-77 to: a) validate the technical feasibility of modular construction techniques in Navy ships, b) quantify and confirm weight and area penalties, and cost savings, and c) gain experience in module design, installation, and total ship integration for future programs. This test program should only outfit a small section of CVN-77 to minimize risk. The Navy can apply the results of this test program to future aircraft carriers.

Other types of naval ships are not as well suited to modular habitability spaces. Large amphibious assault ships are similar to small aircraft carriers, and might benefit from modular construction techniques. However, surface combatants and smaller amphibious ships do not have the preoutfitting restrictions of aircraft carriers. Outfitting habitability spaces on-unit or on-block instead of on-ship eliminates the cost benefits of using modules.

Modular construction techniques are not a solution to all outfitting problems. Although modules are well suited for cruise ship construction, they do not offer as many advantages to aircraft carriers. Cabin modules reduce outfitting costs and construction delays in cruise ships without significant area and weight penalties. However, because outfitting is not on an aircraft carrier's critical path, there are no potential construction time savings. While there are potential cost savings, designers must balance these savings with possible weight and area penalties. To minimize area and weight penalties, naval architects must design the ship from the beginning to incorporate modular construction techniques. The final decision must consider the effects of integrating modular habitability spaces on the total ship design.

**APPENDIX A: SECTION 621, LPD-17 SHIP SPECIFICATION**



**SECTION 621**  
**NONSTRUCTURAL BULKHEADS AND PARTITIONS**

**621a. Definitions**

5 **Nonstructural bulkheads.**- Bulkheads which do not contribute to the strength of the hull and do not support decks.

**621b. Nonstructural bulkheads**

10 **General.**- Nonstructural bulkheads are of three general types: joiner bulkheads, expanded metal bulkheads, and nonload bearing lightweight plate.

Except where structural bulkheads are required for strength or tightness, nonstructural bulkheads shall be installed.

15 Bulkheads for bounding and subdividing such spaces as offices, passages, quarters, foodservice spaces, pantries, and medical and dental spaces shall be joiner type.

20 Nonstructural bulkheads attached to portions of decks subject to helicopter landings or vehicle and forklift motion and all joiner bulkheads, shall have a rattle proof deflection joint along the top edge to permit a deck vertical deflection of plus or minus 50 mm without damage to the bulkhead. Deflection clips securing the top of the joiner bulkhead panels shall provide a positive clamping force to minimize rattles.

25 In addition to the regular stiffening, nonstructural bulkheads shall be stiffened locally in way of furniture, lavatories, waterclosets, door hooks, door stops, clothes hooks, and other articles supported from or attached to bulkheads as required.

30 Where equipment is mounted on nonstructural bulkheads, the analysis of design loads shall consider the ship motion factors specified in Sect. 070.

Wherever exposed threads may subject personnel to injury, "hex acorn" or "cap" nuts shall be installed. Finish caps shall also be provided for "tee" nuts.

35 Bulkheads enclosing the Carpenter Shop and Damage Control Shop shall be solid for the full deck height.

40 **Joiner bulkheads.**- Joiner bulkheads shall be of GRP/NOMEX, non-filled, sandwich constructed panels. The GRP/NOMEX honeycomb panel consists of a paintable phenolic resin impregnated fiberglass face sheet over an aramid fiber honeycomb core. The face sheets shall be of modified phenolic pre/preg with 4 ply of 7781 or 7642 weave cloth with an average resin content of 50 percent by weight and a nominal thickness of 1 mm. The honeycomb core dimension shall be 6 mm (1/4 inch) hexagonal shaped cell size with a nominal core density of 50 kg/m<sup>3</sup> (3.1 lb/ft<sup>3</sup>) in accordance with SAE AMS 3711D.

45 The overall panel thickness shall be 15.88 mm, +0.00 mm -0.38 mm (0.625 inch, +0.00 -0.015 inches) thick including the decorative face sheets. Where decorative sheathing is required by Sect. 637, face sheets shall be 0.68 to 0.94 mm (0.027 to 0.037 inches) thick of either High Pressure Plastic Laminate (HPPL) or CRES 304, ASTM A240, No. 4 finish.

50 HPPL material shall be factory bonded directly to the fiberglass face sheet and meet the fire performance standards of CRD-104.

For CRES faced joiner panels, the fiberglass face sheets shall be omitted on both sides of the panel and the CRES sheets shall be factory bonded directly to the aramid fiber honeycomb core material. Where CRES faced joiner panels are required, the opposite face sheet, which is also CRES, shall be covered with the proper finish material as specified for the adjoining space.

Where CRES faced joiner panels are used for boundaries, CRES 316L material shall be used for coamings and CRES 304 material shall be used for curtain plates and associated bulkhead erection and reinforcement members.

Unless otherwise specified, drawing, NAVSEA No. 803-5959189 illustrates acceptable design features, details of construction, and construction material requirements for a GRP/NOMEX joiner bulkhead system. Except for the material requirements for the GRP/NOMEX panel, the remaining GRP material requirements identified on the drawing shall not be used. Bottom edge joints in dry spaces shall be sealed with a commercial quality, all-purpose, paintable adhesive/caulking compound. Bottom and vertical edge joints in wet spaces shall be sealed with silicone sealant AMS 3362. The vertical edges of the plastic laminate shall be clamped under the H-post cover and post reinforcement members to prevent the plastic laminate from separating from the joiner panel.

In spaces containing both bulkhead sheathing and joiner bulkheads, the joiner bulkhead finish material shall be the same class as the finish material of the bulkhead sheathing, and the color of the bulkhead sheathing and the joiner bulkheads shall be coordinated with each other. Spaces with bulkhead sheathing are listed in Sect. 637. Joiner bulkheads in spaces other than those listed in Sect. 637 shall be painted in accordance with Sect. 631.

Where acoustic or thermal insulation is required on joiner bulkheads, the insulation shall be attached to the bulkhead and the HPPL finished material shall be omitted. Joiner bulkheads in mess areas which receive acoustic or thermal insulation shall be covered in accordance with sheathing requirements specified in Sect. 637.

Bulkheads around spaces which have mechanical exhaust and natural supply ventilation, shall be of a completely closed joiner type with openings located as required for ventilation purposes. If openings for natural ventilation are required, they shall be cut in the upper portion of the joiner bulkheads, with metal hoods installed wherever light tightness is required. Penetrations, such as for piping and wiring, need not be fitted with collars provided that clearances are less than 13 mm.

If practicable, joiner bulkheads shall be located in line with stanchions.

Construction of bulkheads which separate air conditioned from non-air conditioned areas shall be of fumetight construction.

Bulkheads of darkrooms, staterooms, the Quiet Room and similar spaces shall be constructed so as to exclude light.

**Expanded metal bulkheads.**- Wherever an enclosure is necessary for a space which does not require a solid bulkhead, expanded metal may be used.

Drawings, NAVSHIPS No. 805-1649742 and 805-1649743 illustrate acceptable design features and construction details for expanded metal bulkheads. Expanded metal bulkhead panels shall be in

accordance with ASTM F1071, and expanded metal doors in accordance with ASTM F1072. Doors to spaces with expanded metal bulkheads shall also be expanded metal.

5 Expanded metal bulkhead coamings shall be provided as specified in this section. Where coamings are not provided, deck or bottom clips, welded to the deck and panel, shall be furnished to support expanded metal bulkheads. Clear openings between panel bottom and finish deck shall not be greater than 80 mm.

10 A curtain plate shall be provided at the top of expanded metal bulkheads. Brackets or vertical stiffeners, welded to the curtain plate and deck above, shall be installed at a spacing of 610 mm for reinforcement of the curtain plate. Collar plates shall be installed in way of overhead deck stiffeners.

15 Material used in the manufacturing of clips, brackets, or collar plates, shall be 3 mm (11 gauge) thick steel, ASTM A36.

Expanded metal bulkheads, with locked doors, shall be installed around auxiliary machinery located in passageways and living spaces. Bulkheads around fire fighting and damage control equipment shall be fitted with doors without locks.

20 Bulkheads or enclosures within storerooms protected by inert gas flooding systems, shall be constructed of expanded metal.

An expanded metal insert, 250 mm by 525 mm, shall be provided in the upper section in each non-air conditioned storeroom where lightweight plate bulkheads are installed. The insert shall be  
25 located as remotely as practicable from the door.

Clear openings around edges of expanded metal bulkheads shall not be greater than 10 mm. Bolts shall be peened over or tack welded to the nut when used as connecting hardware between individual panels.

30 **Nonload bearing lightweight plate bulkheads.-** Nonload bearing lightweight plate bulkheads constructed similar to drawing, NAVSHIPS No. 804-1649526, may be used for nonstructural bulkhead boundaries of storerooms and shops, and for miscellaneous built-in lockers.

Bulkheads around the Registered Publications Office and the Strong Room shall be of sturdy construction with plating thicknesses not  
35 less than 3 mm steel. Bulkheads around the Medical X-Ray Exposure Room and Dental Operating Room No. 1 shall be of steel construction with plating thicknesses not less than 6 mm. Bulkheads shall have no openings other than the access door and any necessary piping, wiring conduits, and ventilation ducts. The bulkheads shall be closely  
40 fitted around the pipes, conduits, and ducts.

Nonload bearing lightweight plate bulkheads shall be coated in accordance with Sect. 631.

#### 621c. Partitions

45 **Partitions for showers and waterclosets.-** See Sect. 644.

**Light traps.-** Light traps shall be installed in locations shown on the drawings to permit access from the weather to lighted spaces without violating darken ship security. A clear headroom of 2 m shall be maintained in way of panel swing. The light trap shall have  
50 a minimum passageway width of 600 mm.

Designated light trap areas shall have a dull black finish on all interior surfaces. Bulkhead, deck, and overhead surfaces of lighted spaces within the boundaries of the light trap, and adjacent to the

interior ship side entrance to the light trap, shall be painted black where practical. The area to be painted black adjacent to the interior ship side entrance to the light trap shall be the lighted space surfaces contained within a vertical cylindrical wedge. The vertical axis of the cylindrical wedge shall correspond to the bulkhead vertical edge of the light trap entrance doorway, shall have a 1.3 m radius, shall be bounded top and bottom by the overhead and deck of the lighted space, and shall be bounded on its sides by the lighted space bulkhead and the light trap panel creating the doorway.

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15
- Panel body material shall be of a waterproof fabric with a dull black finish. Panels shall have sufficient drag stripping to effect light proof connections, but shall not create a tripping hazard in the light trap passageway. When in the fully rigged position, the ends of adjacent light trap panels shall overlap a minimum of 150 mm when the light trap is formed by two panels parallel to the weather accessway, and overlap 25 mm when the light trap is formed by three or more panels parallel to the weather accessway.

- 20
- No access closures, closure plates, or other possible sources of light leakage, such as openings around piping, electrical cable, and crevices, shall breach the black painted area of light traps.

- 25
- Drawings, NAVSHIPS Nos. 805-1630833 and 805-1630834 illustrate the acceptable design features for the types and construction details of light traps. The method of installation shall be designed to permit light trap assemblies to be readily removed and reinstalled repetitively without special tools and without deterioration of panel assembly or attachment fittings.

- 30
- Materials used in the manufacture of panel frame, shields, angles, valance stiffeners and such shall be ASTM B209, 6061-T6 aluminum alloy. Fabricated pieces, such as valances and brackets, which are permanently affixed within light trap areas by welding or by mounting hardware, shall be ASTM B209, 5052-H32 aluminum alloy. Mounting hardware shall be corrosion-resistant steel.

#### 621d. Coamings

- 35
- Tightness classifications and welding requirements are as follows:

- 40
- Non-watertight coaming.**- Where a coaming serves as a boundary between adjoining dry spaces, the coaming shall be intermittently welded on both sides when making connections to the deck and to the vertical structure at the end of the coaming.

- 45
- Semi-watertight coaming.**- Where a coaming serves as a boundary between a wet space and a dry space, the coaming shall be continuously welded on the wet side boundary and intermittently welded on the dry side when making connections to the deck and to the vertical structure at the ends of the coaming.

- 50
- Watertight coaming.**- Where a coaming serves as a boundary between adjoining wet spaces, the coaming shall be continuously welded on both sides when making connections to the deck and to the vertical structure at the end of the coaming.

**Intermittent welding.**- As a minimum, intermittent welding shall consist of a bead of weld 25 mm long, with adjacent beads spaced not greater than 150 mm apart.

Coamings for nonstructural bulkheads.- Unless otherwise specified, joiner, expanded metal, and lightweight plate bulkhead coamings shall be 150 mm high, 5 mm (7 gauge) thick steel, ASTM A36, painted, and of non-watertight construction. Watertight coamings shall be installed between adjoining wet spaces. Semi-watertight coamings shall be installed in the following spaces provided they are not adjacent to another wet space:

- 10 Fwd and Aft Battle Dressing Stations
- 10 Wardroom Galley
- 10 Galley
- 10 Bakery
- 10 Wardroom Scullery
- 10 Crew Scullery
- 15 Commanding Officer Pantry
- 15 Laundry
- 15 Blood Bank and Laboratory
- 15 Medical Waste Processing and Holding Room
- 15 Medical Central Supply and Sterilizing Room
- 20 Scrub Room
- 20 Solid Waste Processing Room
- 20 Plastic Waste Equipment Room

Watertight and semi-watertight coamings shall be 150 mm high, 5 mm (7 gauge) CRES 316L material with a 2B finish in accordance with ASTM A480.

Coamings for nonstructural bulkheads shall also be of semi-watertight construction in the following applications:

- 30 a. When bounding a space likely to have water or oil upon the deck.
- b. When used to protect stores or deck equipment against mop water or leakage from adjoining spaces where liquids are stowed for operating mechanical systems.
- 35 c. When provided for ratproofing.

For coaming requirements for nonstructural bulkheads in sanitary spaces, see Sect. 644.

Free-standing coamings.- Coamings shall be of watertight construction. Coamings shall be fabricated of 5 mm (7 gauge) CRES 316L material with a 2B finish in accordance with ASTM A480, and provided with a 13 mm diameter CRES 316L rod with a 2B finish, continuously welded to the top edge of the coaming.

Free-standing coamings shall not interfere with equipment operation or maintenance, nor obstruct access to equipment foundations, mounts, or installing hardware.

In areas where structural or nonstructural bulkhead coamings provide equivalent liquid containment, free-standing coamings shall be omitted.

50 A 150 mm high coaming shall be installed in way of steam-jacketed kettles.

A 75 mm high coaming, as measured above the deck covering, shall be installed in way of laundry washer-extractors.

Coaming for bulk stowage areas within the Bakery shall be the same height as the bulk stowage gratings.

5 Coamings 100 mm high shall be installed around AFFF stations and around all installed portable AFFF proportioners. The coamings shall extend in way of the wye gate fitted on the discharge side of the proportioners.

Coamings 150 mm high shall be installed around gasoline pumps in gasoline pump rooms and around gasoline pumps and hose reels in open and enclosed gasoline replenishment and service stations.

10 Coamings 75 mm high shall be installed on the deck below ballast/deballast manifolds and in other locations to prevent hydraulic oil leaks/spillage from causing a slip hazard on the deck.

Allowable tolerance for finish height of free-standing coamings is minus zero plus 13 mm.

15

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**APPENDIX B: SECTION 644, LPD-17 SHIP SPECIFICATION**

**SECTION 644**  
**SANITARY SPACES AND PLUMBING FIXTURES AND FITTINGS**

**644a. General**

5 This section contains the requirements for emergency wash facilities, drinking water coolers, service sinks, and sanitary facilities.

Open work plumbing shall be provided unless otherwise specified.

10 Hot and cold potable water and drain connections shall be installed for equipment requiring these connections.

Fastenings of plumbing fixtures to watertight and oiltight structure shall not impair the tightness of the structure.

Penetration of CRES deck covering under steam jacketed kettles shall be avoided except for drainage of the area within the coaming.

15 Seawater shall not be supplied to any food preparation or scullery spaces except to garbage pulpers.

**644b. Sanitary spaces, construction and details**

20 Sketch, NAVSEA No. LPD 17-644-001 illustrates acceptable arrangements, design features, construction details, and material requirements for sanitary spaces.

Sanitary space boundaries and quantities of fixtures shall be as shown on the drawings and as specified in this section. Sanitary space construction details shall be consistent throughout the ship to  
25 the maximum extent practicable.

CRES, specified herein, shall be CRES 316, except for coamings which shall be CRES 316L.

30 Sanitary space bulkhead panels and partitions shall be constructed of CRES formed flush panels, 1.27 mm (18 gauge) thick. The bulkhead panels shall be supported by a CRES framework. The individual panels and partitions shall be removable in a non-progressive manner from the inside of the sanitary space.

The outside of sanitary spaces, when exposed to view, shall be provided with flush finished panels. Where distributive systems of  
35 the sanitary space are exposed to view, a joiner bulkhead shall be installed to enclose the distributive systems. The material and finish of the exterior panels and joiner bulkhead shall be in accordance with the requirements of the adjacent space. Flush exterior panels or joiner bulkheads are not required when the  
40 sanitary space boundary abuts ship structure or another sanitary space.

Sanitary space erection and attachment of components and accessories shall be by Huck bolts, CRES machine screws or bolts with nuts or press nuts as applicable. Components and accessories shall  
45 be mounted and fully supported by bulkhead panels, framework or partitions. Panels shall be reinforced or doubled in way of mountings. Panel joints shall be sealed by neoprene gaskets. The exposed surfaces of the interior CRES panels, partitions and trim shall be No. 4 finish in accordance with ASTM A480.

50 Ceilings shall be provided. Ceiling panels shall be CRES or aluminum factory applied white epoxy finish, progressively interlocking and rattle free. The first and last ceiling panel shall be fixed into position by the use of machine threaded captive



- fasteners. Ceiling panels shall be removable from the inside of the sanitary space. The ceiling panels shall be supported by a framework which shall be of CRES or galvanized steel. Galvanized steel frameworks shall have a factory applied epoxy or powder polyester coated finish. The faying surfaces of galvanically dissimilar metals shall be specially treated and insulated in accordance with Sect. 631. The CRES or galvanized steel clips on the underside of the ceiling framework shall be coated with silicone grease. The under side of the ceiling shall be not less than 2.0 m from the steel deck.
- 5  
10  
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20
- Ceilings in way of toilet and shower spaces, showers in baths and combined shower and drying areas shall be CRES. Curtain plates or fascia plates shall be provided separately or in combination as needed, to separate the volume above the sanitary space from adjacent spaces.
- Ventilation and electrical systems serving the sanitary space shall be installed behind the bulkhead panels and above the ceiling panels. Within sanitary spaces, piping systems for potable water, vacuum waste collection, and lavatory plumbing drains and vents shall be grouped to minimize the number of connections to the ship's systems and concealed behind removable bulkhead and ceiling panels. Portions of piping systems which directly connect to sanitary fixtures may be exposed between the bulkhead panel and the fixture mounted thereon.

25

Access panels shall be provided for access to systems serving the sanitary space for inspection, maintenance and repair. Quick-acting hinged access panels shall be provided for access to damage control fittings which are concealed by the bulkhead panels or ceiling. The quick-acting hinged access panels shall be labeled in accordance with Sect. 602.

30

Hardware shall be CRES, chrome plated brass or chrome plated bronze. Sanitary space welds exposed to view shall be profiled and ground smooth to blend into the surrounding metal. Burrs and sharp edges shall be ground smooth.

35  
40

Sanitary spaces, showers, and combined shower and drying areas shall be provided with a CRES watertight welded coaming, not less than 125 mm high, except that the coaming between adjacent combined shower and drying areas shall be 75 mm high capped with a 13 mm diameter CRES rod. An intermittent weld may be used for the non-sanitary space side of the coaming when this boundary is not required to be watertight. Sanitary space fixtures shall be installed on 750 mm center to center spacing and like fixtures shall be grouped together into functional areas. Access to washing facilities shall avoid the need to pass through the watercloset area.

45

Water heaters shall not be located within the sanitary spaces.

Combined shower and drying areas.- Individual combined shower and drying areas shall be provided in crew and troop sanitary spaces.

50

Partitions and doors shall be provided as needed to enclose the combined shower and drying areas and the enclosure shall be not less than 725 mm by 1475 mm inside dimensions. The combined shower and drying area door shall be polycarbonate with CRES frame, provided with a latch and hold back hook and bumper. The door shall swing into the enclosure, be 534 mm wide, and be undercut 180 mm above the sill. A ventilation exhaust terminal and light shall be provided in the shower drying area ceiling.

**Showers.-** Showers shall be provided in baths and in toilet and shower spaces. Partitions and doors shall be provided as needed to enclose the showers serving baths. Showers shall be not less than 725 mm by 725 mm inside dimensions. The shower doors shall be  
5 polycarbonate with CRES frame, provided with a latch and hold back hook and bumper. The door shall swing out of the enclosure, be 534 mm wide, be close fitted to the sill with a splash guard and have a ventilation opening above the shower door.

**Waterclosets.-** Partitions and doors shall be provided as needed to  
10 form individual watercloset enclosures. Toilet and shower spaces serving one single person stateroom and Deck WR/WC spaces do not require watercloset partitions and doors.

Watercloset partitions shall be supported from the ceiling framework and the bulkhead panels and framework. The inside width of  
15 the watercloset enclosure shall be not less than 725 mm. The watercloset door shall be reinforced double wall CRES, 534 mm wide provided with latch, hold back hook and bumper, spring loaded hinges to hold the door in the open position when not in use, and swing into the enclosure. The watercloset door shall be installed not less than  
20 665 mm from the front of the watercloset bowl. The watercloset shall be installed so that the upper edge of the bowl is 430 mm above the steel deck. Toilet paper holders shall be installed on the panel or partition which is on the hinge side of the watercloset enclosure door. Each watercloset enclosure shall be provided with a  
25 ventilation exhaust terminal.

**Lavatories.-** The top surface of the lavatory bowl shall be 850 mm above the steel deck. The center of the mirror over the lavatory shall be 1575 mm above the steel deck.

30 **644c. Emergency wash facilities**

Emergency wash facilities include eye/face wash units and combination deluge shower eye/face wash units. Services to these units shall be taken from cold potable water supply at a minimum pressure of 207 kPa and a maximum pressure of 620 kPa. The supply  
35 root valve to each unit shall be locked open and classified "W".

Local and remote alarms shall be provided for each unit (Circuit AE). Each local alarm shall consist of a visual alarm, audible alarm and cutout switch and shall be located in the passageway outside the space so protected. The cutout switch shall allow the audible alarm  
40 to be silenced by attending personnel. The remote alarm signals shall be provided to the Damage Control System, see Sect. 202.

**Combination deluge shower eye/face wash units.-** Combination deluge shower eye/face wash units shall be provided in the Forklift Truck Battery Charging Station and Storage Battery Shop.

45 Combination deluge shower eye/face wash units shall be Haws Drinking Faucet Co., Model 8330, fitted with drains and stay-open valves.

An information label shall be provided at each unit inscribed as follows:

**ATTENTION**

**THIS EMERGENCY SHOWER EYE/FACE WASH UNIT WILL NOT  
BE USABLE WHEN MATERIAL CONDITION ZEBRA IS SET AND  
WHEN POTABLE WATER IS SECURED.**

5 **USE EXTREME CAUTION DURING THESE TIMES.**

**WEAR PROTECTIVE CLOTHING AND A FULL FACE SHIELD.**

An information label shall be provided at eye level in the  
immediate vicinity of each visual and audible alarm inscribed as  
10 follows:

**ATTENTION**

**THE EMERGENCY SHOWER EYE/FACE WASH UNIT IN  
(SPACE LOCATION)**

15 **HAS BEEN ACTIVATED.**

**PROVIDE IMMEDIATE PERSONNEL ASSISTANCE  
AND NOTIFY SICK BAY.**

**Eye/face wash units.-** Eye/face wash units shall be provided in the  
20 following spaces:

Auxiliary Machinery Rooms  
Aviation Fuel Quality Control Laboratory  
Blood Bank and Laboratory  
25 Boat Gear Storeroom and Workshop  
Dental Operating Room No. 2  
Electric Shop  
Filter Cleaning Shop  
Hangar  
30 HAZMAT Equipment Room and Storeroom (Used/Excess HM)  
Helicopter Workshop  
Hull Repair Shop  
Hydraulic Shop  
IC and Gyro Rooms No. 1 and No. 2  
35 Internal Combustion Engine (ICE) Shop  
Laundry  
Machine Shop  
Main Machinery Rooms  
Medical X-Ray Darkroom  
40 Medical Waste Processing and Holding Room  
Oil and Water Test Laboratory  
Paint Issue Room  
S.D. Issue Room (HAZMINCEN)  
S.D. Storeroom (Flammable Liquids)  
45 Valve Repair and Test Shop  
VCHT Rooms

Where a service sink exists, eye/face wash unit, Haws Drinking  
Faucet Co., Model 7612, shall be installed over this sink.  
50 Elsewhere, eye/face wash unit, Haws Drinking Faucet Co., Model 7777,  
7778B, 7650, or 7612, shall be installed.



A swing spout type faucet, T & S Brass and Bronze Fixtures, Model B-297, shall be installed for steam jacketed kettles, and deck mounted mixing machines in foodservice spaces. The faucets shall be located so that they are at a suitable height for filling steam jacketed kettles and mixing bowls. Faucets for steam jacketed kettles shall be located to serve more than one kettle.

A bucket fill faucet, Speakman, Model No. SC 5821 VB, shall be provided in Cleaning Gear Lockers.

A bucket fill faucet, Speakman, Model No. SC5821 VB, shall be provided in the Forward and After Battle Dressing Stations, Medical Operating Room No. 2, Surgical Dressing Room/Main Battle Dressing Station and Medical Operating Room No. 1, and in Triage. The faucet shall be located 610 mm above the finished deck.

Laundry spray gun.- A laundry spray gun assembly, Cissell, Model AKA14, shall be provided for each group of presses. A cold potable water connection shall be provided above each group of presses for attaching the laundry spray gun, located so that the operator can spray items on all presses in the group.

644f. Miscellaneous requirements

In Main Machinery Rooms and Auxiliary Machinery Rooms, a service sink shall be provided. One mirror and one light fixture shall be provided and installed over the service sink. One waste receptacle and six coat and hat hooks, see Sect. 640, shall be provided and installed adjacent to the service sink.

In Drying Room (Navy Embarkation), a service sink shall be provided. One mirror and one light fixture shall be provided and installed over the service sink.

An enclosed Deck WR & WC shall be provided in each Main Machinery Room and in each Auxiliary Machinery Room.

644g. Shock

Joiner bulkheads and panels surrounding troop, troop officer and SNCO sanitary spaces shall meet grade B shock requirements.

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TABLE I.- SANITARY SPACE FIXTURES AND ACCESSORIES

| ITEM   | COMMERCIAL MODEL NO.                           | QUANTITY              |  |         |           |            |                              |                                 |  |
|--|--|-----------------------|--|---------|-----------|------------|------------------------------|---------------------------------|--|
|  |  | STATEROOM<br>(Note 1) | BUNKROOM<br>AND SNCO<br>RECREATION<br>ROOM | BATH    | TOILET/SH | WR, WC, SH | DECK WR &<br>WC<br>(Note 12) | VISITOR<br>WR & WC<br>(Note 12) | MEDICAL<br>SANITARY<br>SPACES (See<br>Sect. 652) |
| Case, toilet article                             | Turnbull Ent., 485-000                         | -                     | -  | 1       | -         | -          | -                            | -                               | -  |
| Dispenser, toilet tissue<br>(double)             | Bradley Corp., 5241                            | -                     | -  | -       | 1         | Note 2     | 1                            | 1                               | Note 2   |
| Dispenser, toilet tissue<br>(single)             | Bradley Corp., 5071                            | -                     | -  | 1       | -         | -          | -                            | -                               | -  |
| Dispenser, paper towel                           | Bradley Corp., 252                             | -                     | 1  | -       | -         | 2          | 1                            | 1                               | 1 per space                                      |
| Dispenser and shelf, soap                        | Bobrick, B-2014 (Note 13)                      | -                     | -  | -       | -         | Note 3     | 1                            | 1                               | Note 3   |
| Faucet, lavatory                                 | Speakman, SG-4136-LD, with<br>strainer, S-3440 | -                     | -  | 1       | -         | Note 4     | -                            | -                               | Note 4   |
| Grab bar, shower                                 | Bradley Corp., 857-2                           | -                     | -  | 1       | 1         | Note 5     | -                            | -                               | Note 5   |
| Grab bar, watercloset                            | Bradley Corp., 857-2                           | -                     | -  | -       | -         | Note 6     | -                            | -                               | Note 6   |
| Holder, tumbler and toothbrush                   | Bradley Corp., 9044                            | Note 7                | Note 7                                     | 1       | -         | -          | -                            | -                               | -  |
| Hook, robe, double                               | Bradley Corp., 912                             | -                     | -  | 1       | 1         | Note 14    | -                            | -                               | Note 5   |
| Lavatory   | Elkay, ELV-2219-CS                             | -                     | -  | 1       | -         | Note 8     | -                            | -                               | See Sect.<br>652                                 |
| Lavatory unit                                    | TMP 484E                                       | 1                     | 1  | -       | -         | -          | -                            | -                               | -  |
| Light, mirror                                    | LC DOANE Navy Symbol 351                       | -                     | -  | 1       | -         | Note 4     | 1                            | 1                               | Note 4   |
| Mirror, laminated                                | Bradley Corp., 780-2424-3                      | -                     | -  | -       | -         | Note 4     | 1                            | 1                               | Note 4   |
| Receptacle, waste, with liner                    | Bradley Corp., 357                             | -                     | 1  | 1       | -         | 2          | 1                            | 1                               | Note 9   |
| Sanitary napkin disposal<br>receptacle, portable | Bradley Corp., 4781-15                         | -                     | -  | Note 10 | Note 10   | Note 10    | Note 10                      | Note 10                         | Note 10  |
| Seat, watercloset                                | Envirovac, 2502985-001                         | -                     | -  | Note 11 | 1         | Note 2     | 1                            | Note 11                         | Note 2   |
| Shelf, mirror                                    | Bradley Corp., 9094                            | 1                     | 1  | 1       | -         | -          | -                            | 1                               | -  |
| Shower curtain                                   | Bradley Corp., 9533                            | -                     | -  | -       | 1         | Note 5     | -                            | -                               | Note 5   |
| Shower curtain hooks                             | Bradley Corp., 9536                            | -                     | -  | -       | As Req    | As Req     | -                            | -                               | As Req   |
| Shower curtain rod                               | Bradley Corp., 953                             | -                     | -  | -       | 1         | Note 5     | -                            | -                               | Note 5   |
| Shower mixing valve assembly                     | Symmons Hydapipe<br>64 Model 1-807S-285        | -                     | -  | 1       | 1         | Note 8     | -                            | -                               | Note 5   |
| Sink, hand wash                                  | Elkay, ELV-1817-C                              | -                     | -  | -       | -         | -          | 1                            | 1                               | -  |
| Soap, dish                                       | Bradley Corp., 9014                            | Note 7                | -  | 1       | -         | -          | -                            | -                               | -  |
| Towel bar  | Bradley Corp., 907                             | Note 7                | Note 7                                     | Note 4  | -         | Note 4     | -                            | -                               | Note 4   |

TABLE I.- SANITARY SPACE FIXTURES AND ACCESSORIES (Continued)

| ITEM                 | COMMERCIAL MODEL NO.                              | QUANTITY              |  |      |           |                   |                              |                                 |  |
|----------------------|---|-----------------------|--|------|-----------|-------------------|------------------------------|---------------------------------|--|
|                      |   | STATEROOM<br>(Note 1) | BUNKROOM<br>AND SNCO<br>RECREATION<br>ROOM | BATH | TOILET/SH | WR,WC,SH          | DECK WR &<br>WC<br>(Note 12) | VISITOR<br>WR & WC<br>(Note 12) | MEDICAL<br>SANITARY<br>SPACES (See<br>Sect. 652) |
| Tray, shampoo        | Hopeman Bros., Inc.,<br>SHR-01-90                 | -                     | -  | 1    | 1         | Notes 5<br>and 14 | -                            | -                               | Note 5   |
| Watercloset assembly | Envirovac Part No. 5800147-<br>001. See Sect. 593 | -                     | -  | 1    | 1         | Note 8            | 1                            | 1                               | See Sect.<br>652                                 |

NOTES:

1. For Staterooms not provided with a Bath.
2. One fitting or accessory shall be provided per watercloset.
3. One fitting per lavatory.
- 5 4. One fitting or accessory shall be provided per lavatory.
5. One fitting or accessory shall be provided per shower.
6. One shall be provided in each watercloset stall in medical and casualty overflow sanitary spaces.
7. One each shall be provided for each occupant.
- 10 8. The quantity of fixtures in each washroom, watercloset, and shower space shall be as indicated on the drawings.
9. One shall be provided in Ward WR, WC & SH.
10. Twenty-five sanitary napkin disposal receptacles shall be provided and shall be delivered to the Supervisor. One bulkhead clip  
15 shall be installed in each watercloset stall for mounting receptacle.
11. In Private Bath and Visitor WR & WC, provide watercloset seat, with cover, Envirovac, Part No. 2503752.
12. Provide a throw latch and keeper, HMS Marine Hardware, Inc., HMS-30-107, on the interior side of the access door.
- 20 13. Soap dispenser shelf shall be provided with a 20 mm lip on the front and two sides.
14. One fitting or accessory shall be provided per drying area.

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**APPENDIX C: WEIGHT ESTIMATE OF NAVY MODULE, IJBS,  
AND COMMERCIAL MODULE**

**Modular Stateroom Weight Estimate, Based on LJBS System**

|                |        |            |
|----------------|--------|------------|
| Height (Total) | 2 m    |            |
| Coaming Height | 0.15 m | (6 inches) |
| Panel Height   | 1.85 m |            |
| Panel Width    | 0.75 m |            |

**Component Weights**

|                      |               |            |             |         |           |
|----------------------|---------------|------------|-------------|---------|-----------|
| Side Extrusion       |               |            | Total Area  | Opening |           |
| Density              | 2770 kg/m3    | (Aluminum) | mm2         | mm2     |           |
| Height               | 1.85 m        |            | Side Piece  | 1274    | 385       |
| Cross Sectional Area | 0.000889 m2   |            | Bottom      | 1428    | 612       |
| Total Volume         | 0.00164465 m3 |            | Perimeter   |         | Thickness |
| Weight               | 4.56 kg       |            | Corner Post | 129.3   | 3.1       |
|                      |               |            | Top Piece   | 88      | 3.1       |

**Bottom Piece**

|                      |                |
|----------------------|----------------|
| Density              | 2770 kg/m3     |
| Width                | 0.644 m        |
| Cross Sectional Area | 0.000816 m2    |
| Total Volume         | 0.000525504 m3 |
| Weight               | 1.46 kg        |

**Top Piece**

|                      |                |
|----------------------|----------------|
| Density              | 2770 kg/m3     |
| Width                | 0.644 m        |
| Cross Sectional Area | 0.0002728 m2   |
| Total Volume         | 0.000175683 m3 |
| Weight               | 0.49 kg        |

**Panel Faces**

|              |             |
|--------------|-------------|
| Density      | 2770 kg/m3  |
| Depth        | 0.001 m     |
| Area         | 2.775 m2    |
| Total Volume | 0.002775 m3 |
| Weight       | 7.69 kg     |

**Core**

|         |              |
|---------|--------------|
| Density | 50 kg/m3     |
| Depth   | 0.028 m      |
| Area    | 1.1914 m2    |
| Volume  | 0.0333592 m3 |
| Weight  | 1.67 kg      |

**Total Panel Weight**

|                     |     |
|---------------------|-----|
| 2 * Side extrusions | 9.1 |
| Bottom              | 1.5 |
| Top                 | 0.5 |
| Faces               | 7.7 |
| Core                | 1.7 |
| Glue                | 0.1 |

20.5 kg

**Coaming Weight**

|                        |            |         |                              |           |      |
|------------------------|------------|---------|------------------------------|-----------|------|
| Density                | 7870 kg/m3 | (Steel) | Coaming Cross Sectional Area |           |      |
| Width                  | 0.75 m     |         | Perimeter                    | Thickness | Area |
| Cross Sectional Area   | 0.00108 m2 |         | 360                          | 3         | 1080 |
| Total Volume           | 0.00081 m3 |         |                              |           |      |
| Structural Weight      | 6.37 kg    |         |                              |           |      |
| Chock Material, Etc    | 1 kg       |         |                              |           |      |
| Total Weight/Per Panel | 7.37 kg    |         |                              |           |      |

**Deflection Joint Weight**

|                        |             |         |                                       |           |      |
|------------------------|-------------|---------|---------------------------------------|-----------|------|
| Density                | 7870 kg/m3  | (Steel) | Deflection Joint Cross Sectional Area |           |      |
| Width                  | 0.75 m      |         | Perimeter                             | Thickness | Area |
| Cross Sectional Area   | 0.000828 m2 |         | 276                                   | 3         | 828  |
| Total Volume           | 0.000621 m3 |         |                                       |           |      |
| Total Weight/Per Panel | 4.89 kg     |         |                                       |           |      |

|                            |          |  |  |  |  |
|----------------------------|----------|--|--|--|--|
| Total Weight Per Panel     | 32.77 kg |  |  |  |  |
| Number of Panels (w/o T/S) | 17       |  |  |  |  |
| Total Panel Weight         | 557.1 kg | (Includes Coaming and Deflection Joint, but not fasten |  |  |  |

**Ceiling Panel Weight**

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|                          |          |
|--------------------------|----------|
| Total Ceiling Area       | 13.5 m2  |
| Panel Weight             | 20.5 kg  |
| Panel Area               | 1.39 m2  |
| Equivalent Num Panels    | 9.73     |
| Estimated Ceiling weight | 199.5 kg |

Corner Post Weight x 4                      8.9 kg

|                              |               |
|------------------------------|---------------|
| Subtotal Material Weight     | 765.5 kg      |
| 10% Margin For Fasteners     | 76.6 kg       |
| <b>Total Material Weight</b> | <b>842 kg</b> |

**Estimate Toilet/Shower Weight**

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|                          |          |
|--------------------------|----------|
| Based on MCSS Weights    |          |
| Panel (Both Sides Faced) | 28.30 kg |
| Panel (Single Face)      | 14.15 kg |
| Post                     | 20.75 kg |
| Corner Post              | 20.05 kg |

|                             |                 |
|-----------------------------|-----------------|
| 6 Panels (Both Sides Faced) | 169.8 kg        |
| 4 Panels (Single Face)      | 56.6 kg         |
| 4 Corners                   | 80.2 kg         |
| 6 Posts                     | 124.5 kg        |
| Total, Materials            | 431.1 kg        |
| 30% Margin for Fixtures     | 129.3 kg        |
| <b>Total T/S Weight</b>     | <b>560.5 kg</b> |

|                            |         |
|----------------------------|---------|
| Estimate Furniture Weight  |         |
| Commercial Furniture Suite | 500 kg  |
| 50% Margin For "Sturdier"  | 250 kg  |
| Total                      | 750 kg  |
| <hr/>                      |         |
| TOTAL WEIGHT               | 2153 kg |