EMBRACING CHANGE

Reducing cost and maximizing mission effectiveness with the flexible warship

BY SHAWNA GARVER AND JACK ABBOTT

United States Navy littoral combat ships (LCS) Independence (foreground) and Freedom. LCS is a flexible ship capable of supporting surface warfare, mine countermeasures, or anti-submarine warfare missions.
The first flexible warship design concepts were introduced more than 35 years ago. Since that time, they have increasingly become the design of choice for new naval combatants. A majority of NATO countries have implemented or are preparing to implement flexible warships into their fleets. Recent examples include the Italian/French FREMM, the United States LCS, and the German FLEXpatrol. Our purpose here will be to examine these flexible warships and learn about the advantages they provide that have caused navies to select them over more conventional designs.

In recent testimony to the Senate Appropriations Committee, United States Secretary of the Navy Ray Mabus stated, "Anything that you build, you’d have to be modular moving forward because to build these [weapons] systems in and not be able to change them as technology changes, no matter what kind of ship we build, we just can’t afford to do that. We take a look at these programs and change as requirements change, change as technology changes. And the great thing that a [flexible] ship like LCS brings is that as technology changes, as missions change, because it’s modular, you don’t have to change the whole ship, [or build a new class] you just change the weapons system."

Indeed, this testimony expresses the primary driver behind flexible warships—they provide the ability to keep pace with technology and mission changes without the expense of having to change the whole ship. In the current era of rapidly changing technologies, asymmetric threats, and reduced budgets, this is an attractive set of capabilities.

A major goal of the United States Navy in pursuing the development of flexible warships is to achieve greater levels of flexibility and cost efficiency over the lifecycle. In particular, this includes the following key objectives: achieve efficiencies in acquisition, sustainment, operations, and recapitalization; permit the use of common warfighting and HM&E systems; permit synchronized capability insertions across the force; and permit re-allocation of mission capability across ship types.

The defining characteristic of a flexible warship is the use of a modular open systems approach (MOSA) to standardize and modularize a portion of the combat and ship systems. The use of standard interfaces and pre-planned access routes enables system modules to be installed, changed out, and upgraded without significant modifications to the ship structure or supporting systems. This enables these flexible ships to be produced in parallel with their combat systems, rapidly updated, or perform multiple types of missions by swapping out combat system modules. MOSA is defined for navy use in the DOD Open Systems Architecture Contract Guidebook for Program Managers.

Motivations

In his argument supporting flexible warships, Secretary Mabus asserted that "we can’t afford" not to build them. Why is this so? What are the circumstances that have rendered conventional warship designs unaffordable?

Conventional warship designs are optimized to deliver a specific combat suite for the lowest acquisition cost. To accomplish this goal, the hull and HM&E systems are optimized along a design spiral. The result is a tightly-crafted, custom-designed ship that provides precisely the hull and systems required to support the specific combat suite. To optimize these designs, the combat system components must be well defined early in the design process. Optimistically, it takes approximately 10 years for a new naval ship design to start production; this means that, by the time the lead ship is delivered, its combat systems and concept-of-operations are at least 14 years old. Updates often are needed to bring obsolete systems up to the current mission requirements.

Unfortunately, because the ship was optimized for the original combat system, it is difficult and expensive to update. In fact, when efforts are made to update existing conventional warships, the modifications often do not prove cost effective, as they require extensive changes to the hull, superstructure, and mechanical and electrical subsystems. The results, in some cases, are ships with truncated service lives.

These limitations did not pose too big a problem during the well-funded World War One, World War Two, and Cold War eras, when navies faced unilateral, well-defined threats and experienced a measured pace of technological change. However, starting in the post-Cold War era, budgets have tightened and threats have become less well defined, more asymmetric, and subject to rapid change. In addition, combat system technology has been revolutionized with the integration of advanced computer systems, which require frequent updates. The inability to accommodate change, in many instances, rendered the conventional warship design unaffordable.

In the mid-1970s, it became apparent that a new, more flexible type of ship design was both desirable and feasible. Recent advances in ship production techniques and facilities to enable block construction had paved the way for increased application of modularization and standardization to both reduce production costs and enable a single ship design to accommodate a range of combat system suites. Measures-of-benefit studies showed significant increases in fleet effectiveness with lower production, maintenance, and conversion lifecycle costs.

History of modularity efforts

Modularity in the United States Navy started in 1975 under the SEAMOD (SEA systems MODification and MODernization by MODularity) program. Ideas that we may consider obvious today...
were addressed back then: parallel design and development; systems integration; standardized interfaces; modernization; new technology implementation; and adaptability to modern threats. An early conceptual drawing of a flexible warship is shown on page 25. This figure depicts a mid-sized combatant with standardized weapons stations that can accommodate a set of standardized combat modules.

There were positive results from the SEAMOD efforts, mainly the conclusion that modular payload ships could simplify the acquisition, construction, and modernization of ships and payloads. SEAMOD studies also revealed that combat system modularity would reduce lifecycle costs through reduced production costs and decreased effort to perform mid-life upgrades and conversions of weapons systems. Since the SEAMOD study, there have been several follow-on programs that continued the development of variable payload ships (VPS) concepts, including common and standardized hardware, standard interfaces and open architecture, and modular adaptable ships.

Modularity in the commercial manufacturing sector was adapted and implemented at a higher level and degree for many years. Modularity benefits in the development and manufacturing for automobiles and airplanes can easily be seen—the much larger quantities of aircraft and cars built for companies and individuals makes obvious the huge cost benefits of a modular approach. It is easy to understand the cost savings of providing one common platform for a line of vehicles that is applied for several specific products and over several hundred thousand units.

Modularity benefits in naval ships were harder to understand. Each ship class was designed and built for specific missions, not for flexibility. In addition, compared to automobiles and airplanes, the quantity of ships built per year was miniscule for the purpose of understanding cost savings spread over a class of ships. The main school of thought was that modular ships would weigh more and cost more. For the most part, modularity was discounted and managers didn’t want to risk production costs and ship performance to take on a new process.

A German shipyard took that risk first. Implementation of modularity started in the late 1970s with the Blohm & Voss shipyard, which created the MEKO (“Mehrzweck-Kombination” or “multi-purpose-combination”) warships for the German and other foreign navies. MEKO ships took advantage of the modularity benefits in acquisition. The modular production techniques that came out of this effort enabled Blohm & Voss to reduce their production schedule by up to 25% and reduce their production costs by up to 10%. This yielded market advantages and in 20 years, the yard sold more than 200 of their MEKO frigates.

A gun module installed on an LCS.
MEKO led the way for other navies and shipyards to implement the VPS concept. Notable examples are the Royal Danish Navy’s StanFlex (standard flex), France and Italy’s FREMM (frégate Européenne multi-missione or European multi-mission frigate), Germany’s MOPCO (modular platform concept), and Canada’s MCDV (maritime coastal defense vessels) and future SCSC (single class surface combatant). In 2002, the United States Navy embarked on the littoral combat ship (LCS) program, their first fully modular multi-mission ship.

**Principles of flexible warship design**

Flexible warship designs are often described as “plug-n-play” or “Legos.” Indeed, one of the easiest ways to conceptualize a flexible warship design is to draw a comparison with the familiar plug-n-play features of a desktop computer. A computer’s standard software and hardware interfaces enable various types of capabilities to be added and removed with minimal integration effort. The range of capabilities that can be added is dependent on the types of interfaces, number of ports, slots, and so forth. This standardization reduces costs through the efficiency of commonality and increased competition, as many suppliers can compete on price. It also spurs innovation, as more companies can provide new capabilities as long as they meet the interface standards. It’s not difficult to see the parallels in the design philosophy of a flexible warship design, which provides plug-n-play capability, embracing change to reduce total ownership costs and increase agility, capability, and innovation.

The challenge of a flexible warship design is how to take the simplistic concepts of Legos and plug-n-play and make them work for a real-world system as complex as a naval warship that is required to operate in mission critical, hostile environments. In a conventional design, the entire warship is optimized for one specific combat suite to perform one defined mission. The combat systems are integrated once and shipboard inter-system functions are developed and perfected. In a flexible warship, however, different parts of the ship and combat systems can be taken on and off the ship and upgraded multiple times. Developing a design that ensures that all the system permutations will function effectively together without major modifications is a significant engineering challenge.

To meet this challenge, naval ship engineers use the MOSA methodology in developing a total ship open systems architecture. The process for designing a flexible warship is to functionally partition the ship into functional element zones (FEZ). Each FEZ is a volume of the ship that provides space, structural support, and services for one major function (or collection of similar functions) located therein. Examples of functions that might be provided by a FEZ include: weapons; exterior communications; aviation; reconfigurable off-board vehicle support; habitability; or a collection of similar functions, such as the numerous battle management functions performed in a combat information center. It can be a single compartment or located in multiple adjacent compartments. The development of various FEZs on the ship as part of the ship general arrangements is key to achieving a flexible warship that can upgrade individual functions without disturbing other functions on the ship.

The next step is to determine the range or set of equipment systems each FEZ will support (including at-delivery and planned upgrades), and develop a modular, open system architecture with standard interfaces to support the most demanding requirements of the defined system set. The best practice is to use widely supported, consensus-based interface standards that are published and maintained by a recognized industry-navy-ship builder standards organization.

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The last step is to carefully plan the layout of the equipment and how this equipment will be moved in and out of place, both within the zone and through adjacent zones, if needed. This is especially important for any highly reconfigurable mission zones containing several stations, such as a waterborne mission zone. To determine the optimal zone arrangements, the designer performs trade-off studies to help determine loading and unloading patterns, given different zone volumes and constraints for specific mission module packages.

To facilitate the movement of modules and equipment through the ship, access routes are incorporated into the design. This total ship systems engineering effort enables the ship production schedule to be decoupled from the delivery and installation of the equipment. This results in a shorter production schedule and fewer production delays, which are often the result of delays in equipment delivery from third party suppliers. It also enables the equipment to be readily swapped out during upgrades or maintenance periods without the need to modify adjacent systems or structures.

The products of this total ship engineering approach are an interface control document; detailed zone arrangement drawings with defined station locations; module handling equipment specifications; and planned access routes. Together, these products provide the basis for the flexible plug-n-play design. Developers of future, yet-to-be-identified systems, are able to start with this set of design-to interfaces and zone architectures to ensure the successful integration of the new technology.

Benefits of flexible warship design
The primary benefit of a flexible warship design is improved mission effectiveness at a lower total ownership cost. Table 1 provides a summary of how various flexible warship design concepts contribute to benefits in the areas of production, maintenance, modernization, and mission effectiveness. These concepts, called flex enablers, are key technologies and design solutions developed by the naval shipbuilding community over the past 40 years to provide the needed flexible warship capability.

Total ownership cost benefits
Flexible warships use many design concepts that reduce total ownership costs. To maximize production cost savings, a flexible warship design includes access routes, defined cableways, module stations, and standard interfaces to decouple the production critical path schedule from the installation and integration of combat systems and other equipment. This reduces cost by enabling the ship and HM&E systems to be constructed at a faster pace, with the integration of the equipment occurring at the most optimal point in the process, rather than as dictated by the block sequence. Extensive analysis is also performed from the earliest stages of the flexible warship design to apply functional partitioning, standardization, modularization, and defined access routes to facilitate modernization to a range of combat systems. The result is a flexible warship that can be modernized without significant changes to the ship structure. This enables the navy to meet emerging threats.
### TABLE 1: SUMMARY OF FLEXIBILITY ENABLERS AND THEIR BENEFITS

<table>
<thead>
<tr>
<th>FLEXIBILITY ENABLERS</th>
<th>COST SAVING BENEFITS</th>
<th>SHIP EFFECTIVENESS BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acquisition/production</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Stations with standard interfaces and growth margins (SWaP)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Common computing, data, and comms infrastructure</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Decoupled payload–platform development</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Common source computer program library for multiple ships</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Flexible infrastructure</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Functional elements zones (FEZ)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pre-engineered elements (PrEE)</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Distributed system ways</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Module access routes</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hull commonality–parallel middle body</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Aperture stations with standardized interfaces</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**Functional element zone–module station interfaces.**

- **Set of modules**
- **Gun weapons module**
- **VLS weapons module**
- **Future planned weapons module**
- **Weapons station interfaces designed to meet most demanding requirements from set of modules**
by affordably and rapidly modernizing existing ship assets rather than building a new class of ships. The benefit of avoiding procurement of a new class of ships represents a savings of 10 years and more than a billion dollars.

Many of the flexibility enablers developed for production and modernization also contribute to reductions in maintenance costs due to the fact that the ship is more open and standardized. Less dense outfitting enables easier access to areas of the ship requiring maintenance. Standardization reduces the numbers of parts and facilitates replacement of systems.

Ship effectiveness benefits
Flexible warships enable improved operational effectiveness at delivery due to decoupling of combat system integration from the ship construction critical path schedule. Combat systems can be procured later in the acquisition cycle, resulting in a higher level of technological relevance at delivery.

Flexible designs enable ships to maintain higher levels of effectiveness over their lifecycles due to the ability to readily perform incremental upgrades and flex to the set of upgraded combat system capabilities. Through the use of standard interfaces, flexible ships enable new technologies to be deployed earlier than on a traditional design that would require retrofitting. Due to the design-for-modernization features, flexible warships can be modernized in significantly less time than a traditional ship. Benefit studies have estimated that, for the same modernization dollars (not including the cost of the combat systems) a flexible ship can be upgraded 3-4 times more often than a conventional ship. Of course, the actual number of upgrades performed on a flexible warship will vary according to need.

Due to the ease of upgrades, a flexible warship can be updated and modernized during regular overhaul periods. The need for extended one to two-year mid-life modernizations and conversions is reduced or eliminated. This results in increased ship availability levels over the lifecycle.

Changes and development
The flexible warship is an outgrowth of two coincidental developments. The first was the transition from well-funded navies battling large superpowers in World War Two and the Cold War to less well-funded navies battling smaller, changing threats. The second development was the transition from stick-built to modular block construction paving the way for increased use of standardization and system modularization. These changes led to the development of a wide range of flexible warship design and production techniques. The primary design objective of a flexible warship is to reduce total ownership cost and maximize mission effectiveness by enabling combat systems to be easily installed and upgraded over the ships lifecycle. This is a departure from traditional designs, which optimize at-delivery combat capability for the lowest possible acquisition cost. By embracing change, the flexible warship ship provides value to naval fleets by being more effective and less expensive over its lifecycle than a conventionally designed ship. Is the era of the conventional warship at an end? MT

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