21st Century Ship Lightweighting

1.0 OBJECTIVE.

1.1 The goal of naval architects has always been to build the lightest vessel possible that can survive service and mission requirements. Traditional drivers for lightweight construction have been speed and stability. In today’s environment, reduced fuel consumption and concomitant CO₂ emissions are becoming major ship design requirements. Shipbuilders have historically relied on material systems and structural arrangements that they are familiar with to meet weight objectives. Lightweight shipbuilding materials, such as high-strength steel, aluminum and composites, have presented unexpected challenges for the design community. The goal of this project is to document best practices in ship lightweighting and provide a strategy for addressing current shortcomings.

1.2 This research will take advantage of the Ship Structure Committee’s unique position as the industry’s think tank to influence the allocation of resources and government policy. Building lighter ships will make US and Canadian naval forces more agile and their fast ferries more cost effective. Moreover, lightweight ship structure has the potential to revitalize North America’s shipbuilding industry with high-skilled jobs.

2.0 BACKGROUND.

2.1 North American shipbuilding has a proud history producing maritime structures with lightweight shipbuilding materials. The established recreational yacht building industry has created a stable, highly skilled workforce and supply chain for composite and aluminum construction. The recent surge in demand for crew boats and the US Navy’s procurement of high-speed vessels has served to grow the capability to build aluminum vessels in North America. And larger naval vessels have supported breakthrough technologies in high-strength steel ship construction. The continent hosts the world’s premier research facilities and an established history of public/private partnerships to tackle engineering challenges facing 21st century shipbuilding.

1. However, Scandinavian shipyards have led the way with commercial and naval lightweight vessels. A recent collaborative Northern European design study concluded: “Typical weight reduction when using aluminum or FRP composites have been over 50% compared to a conventional steel design and cost analysis has demonstrated possible pay-back times of 5 years or less for the lightweight material investment.” [ref 8.1] This study focused primarily on commercial designs but both Sweden and Norway have recently produced all-composite warships with impressive weight savings over conventional steel designs. In the U.S., both Littoral Combat Ship (LCS) designs utilize aluminum construction, as does the multi-agency Joint High Speed Vessel (JHSV). Our next aircraft carrier will utilize high strength steel high in the structure to improve stability.

2. At a High-Speed Sealift Technology Workshop as far back as 1997 [ref 8.2] researchers estimated that potential ship structural weight savings on the order of 20% (near term) to 50% (far-term) were possible through the use of high-strength steel, aluminum and composite materials. However, our knowledge of design, manufacturing and fatigue performance with lightweight materials is not as advanced as with conventional steel ship construction. Specialized shipyards have mastered lightweight construction but their procedures are often considered proprietary and don’t percolate through the design community.

3. A prime motivation for lightweight ship construction in today’s environment is the uncertainty of the future price and availability of oil. The annual fuel operating cost for a DDG-51 destroyer jumped from $800K to $1.5M over the course of a year due to crude oil price fluctuations. Just as the Navy needs to reign in operating costs to support their mission, commercial fast ferry operators must increase the number of passenger-miles traveled on a gallon of fuel to remain economically viable.

2.2 The Ship Structure Committee has sponsored some excellent research that has led to more survivable ship structures. The goal of improving ship structural performance also includes the efficiency of those structures and the concept of lightweighting is at the heart of structural efficiency. The proposed research will compare design, material availability, qualification, fabrication, performance and life-cycle cost issues for high-strength steel,
aluminum and composite construction. Design tools and methodologies that can help accelerate the use of lightweight vessels will be addressed.

1. According to the International Energy Agency (IEA), “nearly 26% of the global energy production and nearly 58% of the global oil production have been consumed by transport in 2001.” [ref 8.3] The international community recognizes that the reduction of the weight of transport vehicles is one important method to reduce the energy consumption and the CO₂ emissions caused by the transport sector. However, research to date has focused on rail and road vehicles, leaving a gap in the maritime sector.

2. This project is needed to help waterborne transportation remain economically viable with other modes. Indeed, Boeing has made extensive use of lightweight composite construction for their new 777 aircraft in an effort to increase revenue for their customers. Car manufacturers understand that in order to raise their Corporate Average Fuel Efficiency (CAFE standard) they need to build lighter cars. High-speed rail trains make extensive use of aluminum and composite construction to meet their speed objectives. The maritime industry needs a blueprint to compete in the 21st century with other transportation modes that for competitive (air) or regulatory (automobiles) reasons have developed more advanced lightweighting strategies.

2.3 The adoption of lightweight shipbuilding materials has not been without some high profile failures that need to be addressed. In 2002, an all-composite, 55-meter Norwegian mine hunter completely burned after a fire started in the lift fan space [ref 8.4]. More recently, both variants of the US Navy’s Littoral Combat Ship have experienced structural issues related to lightweight construction; one (high strength steel hull) involving cracked welds [ref 8.5] and the other (aluminum hull) aggressive electrolysis in areas of dissimilar metals [ref 8.6]. While these examples represent vastly different failure mechanisms, they all affect the structural integrity of the ship and disproportionately retard the development of lightweight shipbuilding construction due to the high-profile visibility they attract.

2.4 The current state of lightweighting implementation in air, sea, and land vehicles and recommended ways to improve the use of lightweight materials and lightweighting solutions. For maritime vehicles, the report noted:

- High-strength steel presents challenges with product souring, welding, and distortion control;
- Aluminum construction requires attention to alloy selection, structural details, and joining procedures;
- Composite construction requires reliable, sufficient quantities of materials and a focus on material characterization, manufacturing quality assurance, and in-service non-destructive evaluation;
- By virtue of their size, large ships put a premium on material cost and joining technology.

3.0 **REQUIREMENTS.**

3.1 Scope.

1. The Contractor shall conduct an assessment of the aluminum, composites, and high-strength steel domestic and international shipbuilding industries. Design methods, material availability, manufacturing, durability, recent failures, life-cycle costs and recycling issues will be addressed.

2. The Contractor shall identify the “best practices” of the lightweight ship construction industry and the specific challenges that each material system confronts.

3. The Contractor shall address knowledge gaps required to design and build lighter ships.

3.2 Tasks.

1. The Contractor shall conduct an assessment of the domestic and international lightweight shipbuilding industry citing success stories and future opportunities. The contractor will also address high-profile structural failures of lightweight ship construction.
3.2.1.1 This task will address design issues as they relate to both our knowledge of particular material systems and our ability to predict structural response over the life of the ship.

2. The Contractor shall outline the challenges that various lightweight materials present to designers, shipbuilders and operators.

   3.2.2.1 Lightweight ship construction materials each have their own unique advantages and disadvantages, including cost. This task will attempt to quantify and compare parameters that need to be considered over the life of a ship to include: material property data confidence, material availability, fabrication issues (including joining), in-service performance, inspectability & repair, and end-of-life disposal issues.

3. The Contractor shall develop design strategies for systems level ship lightweighting.

   3.2.3.1 This task will cover ship lightweighting strategies that are not directly related to the choice of material systems. The effort will focus first on methodologies used to determine platform requirements, which accounts for a large percentage of weight growth, particularly with military ships. Multifunctional ship structures are another strategy for weight reduction. Panelization strategies that incorporate outfitting elements can also serve to reduce overall structural weight.

4. The Contractor shall develop metrics to evaluate various lightweighting approaches to ship design and construction based on specific platform requirements for a variety of ship types.

   3.2.4.1 Lightweight ship construction inevitably requires higher platform acquisition costs so the vessel operator needs to know at the preliminary design stage if these costs can be recouped over the life of the ship. Wartsila estimates that a 20% reduction in steel weight will give approximately 9% reduction in propulsion power requirements for large commercial ships. [ref 8.8] Similar metrics need to be developed for a variety of ships to facilitate return-on-investment decisions over a range of anticipated fuel prices.

5. The Contractor shall recommend future research needs and industrial policy required to build lighter ships domestically.

   3.2.5.1 Ship designers need higher levels of confidence with lightweight materials before more widespread use can be expected. The U.S. Navy was an early advocate of aluminum deckhouse construction only to backtrack after severe fatigue cracks developed. Ships are being required to remain in service far beyond their initial intended life, so it is imperative that we develop design tools able to predict response to repeated dynamic loads. This task will outline knowledge gaps that require future research to help us understand the long-term structural response of lightweight ship structures. We will also consider strategies required to reduce lightweight material acquisition and manufacturing costs.
3.3 Project Timeline

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<th>Task</th>
<th>Month 1</th>
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4.0 GOVERNMENT FURNISHED INFORMATION.

4.1 Standards for the Preparation and Publication of SSC Technical Reports.

5.0 DELIVERY REQUIREMENTS.

5.1 The Contractor shall provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 The Contractor shall prepare and host a project kick-off meeting and quarterly teleconferences to review project progress.

5.3 Upon project completion, the Contractor shall develop a project summary presentation in PowerPoint format suitable for professional conferences.

5.4 The Contractor shall provide a print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual.

6.0 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: date of award.

6.2 Project Completion Date: twelve (12) months from the date of award.

7.0 GOVERNMENT ESTIMATE. These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: twelve (12) months.

7.2 Total Estimate: $100,000
8.0 REFERENCES


