



Naval Construction and Engineering Ship Design and Technology Symposium

Thursday, April 28, 2022

MIT Samberg Conference Center, 50 Memorial Drive
Building E52-Seventh Floor, Dining Rooms I & T

- 0800 – 0850 Registration and Continental Breakfast
- 0850 – 0900 Welcome and Opening Remarks
- CAPT Jeremy Leghorn, Director, Naval Construction and Engineering
 - Prof Nicholas Makris, Director of the Center for Ocean Engineering
- 0900 – 0925 **Student Design Project Brief**
- Missile Corvette: LT Elliot Collins, LT Chris Hein, LT Scott Oberst
- 0925 – 0945 **Student Conversion Project Brief**
- DDG FLT IIA Endurance Range Conversion Project: LCDR Lucas Stone, LT Jack Cathcart, LT Jillian Uzoma
- 0945 – 1005 Poster Session
- 1005 – 1025 **Student Conversion Project Brief**
- Fireship Conversion: LT Kelsey Cathcart, LT Jarod Kramer, LT Eric Young
- 1025 – 1045 **Student Conversion Project Brief**
- Flettner Rotors on a T-AKE: LCDR Alex Wunderlich, LT Camilo Duque, LT Chris Tomlinson
- 1045 – 1110 **Student Design Project Brief**
- Littoral Transport Vessel: LT Megan Hagen, LT Christopher Reynolds, LT Matthew Valcourt
- 1110 – 1130 Poster Session
- 1130 – 1150 **Research Brief: Prof Steven Leeb**
- Combat Power Monitor: LT Devin Quinn, LT Andrew Moeller
- 1150 – 1210 Break, lunch served
- 1210 – 1300 **Lunch Buffet and Keynote Address**
Vice Admiral William J. Galinis, Commander, Naval Sea Systems Command (NAVSEA)
- 1300 – 1310 Break, transition
- 1310 – 1350 **Research Brief: Prof Themis Sapsis**
- Hydrodynamic Interactions of an Unmanned Underwater Vehicle operating in proximity to a Submarine: LT Brady Hammond
 - Predicting Extreme Event Statistics for Ship Motions and Loads: LT Dayne Howard
- 1350 – 1410 Poster Session
- 1410 – 1435 **Student Design Project Brief**
- Mine Sweeper Replacement Platform (MSRP): LT Dayne Howard, LT Joshua Malone, LT Kelli Waterman
- 1435 – 1455 **Student Conversion Project Brief**
- Arctic Region Combatant Trials of Ice Capabilities (ARCTIC): LT Andrew Moeller, LT Natasha Patterson, LT Ivan Reyes
- 1455 – 1500 Wrap-Up and Concluding Remarks
- 1500 **Mission Complete**

Design Projects

Conversion Projects

Thesis Topics

Vice Admiral William Galinis
Commander, Naval Sea Systems Command



Vice Adm. William (Bill) Galinis is a native of Delray Beach, Florida. He is a 1983 graduate of the U.S. Naval Academy where he received a Bachelor of Science in Electrical Engineering. He holds a Master of Science in Electrical Engineering from the Naval Post Graduate School.

Galinis' sea duty assignments included engineer officer on board USS Roark (FF 1053) and damage control assistant on board USS Vreeland (FF 1068).

His engineering duty officer tours include supervisor of Shipbuilding, Conversion and Repair, New Orleans, where he worked on both new construction and repair projects including assignment as the Amphibious Warfare Program Office (PMS 377) program manager's representative for the Dock Landing Ship (LSD) Cargo Variant (CV) Shipbuilding Program; Board of Inspection and Survey, Surface Trials Board as damage control inspector; and a number of program office and staff positions

including the Destroyer (DD 21) and Landing Platform Dock (LPD 17) Program Offices, Office of the Chief of Naval Operations in the Requirements and Assessments Directorate, and in the Office of the Deputy Assistant Secretary of the Navy for Shipbuilding as the chief of staff.

Galinis' command assignments include LPD 17 program manager; Supervisor of Shipbuilding, Gulf Coast; and as the commanding officer of the Norfolk Ship Support Activity (NSSA).

Galinis' flag assignments include commander, Navy Regional Maintenance Center during which time he also assumed the duties of deputy commander for Surface Warfare, Naval Sea Systems Command; and most recently Program Executive Officer, Ships.

Galinis became the 45th commander of the Naval Sea Systems Command (NAVSEA) June 19, 2020. As NAVSEA commander, he oversees a global team responsible for the development, construction, delivery and maintenance of the Navy's ships, submarines and systems.

He has received various personal, unit, and service awards including three Navy Battle "E" awards.

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DDG FLT IIA Endurance Range Conversion Project

LCDR Lucas Stone, USN; LT Jack Cathcart, USN; LT Jillian Uzoma, USN

DDG FLT IIA class ships have been completing essential missions for the US Navy since 2000. This class of ship has a current endurance range of about 4500 NM. The objective for this conversion project was to determine the feasibility of extending this range by approximately 60 percent, while keeping the maximum speed above 26 knots, and maintaining all other mission capabilities. With the DDG as the limiting factor in a strike group's endurance range, this improvement will greatly enhance the strike group's mission capability. Additionally, DDGs that are independent deployers will be able to remain in essential operational areas while also traveling greater distances prior to refueling.

The baseline ship used in this project is the U.S. Navy's DDG FLT IIA hull design. We were able to obtain the ASSET match model that has been previously validated by Naval Surface Warfare Center, Carderock Division (NSWCCD) and used this model as a reliable starting point for the conversion project. Throughout the conversion project the design team briefly explored the concepts of adding additional fuel tanks, propeller modification, engine conversion and reducing endurance speed to increase the endurance range. We considered the feasibility of each and ultimately decided that an engine conversion in addition to reducing the endurance speed to 16 knots was the best way to achieve this objective.

Various engine configurations and specific engines were considered in an in-depth evaluation of the tradespace. Rather than solely looking at the endurance range calculations, the design team concurrently analyzed the mission profile range, by referring to a studied time-speed profile of DDG FLT IIA class ships. The ship operates at speeds less than 10 knots for the majority of its underway time, so a Combined Diesel and Gas Turbine (CODOG) engine configuration consisting of a high-speed diesel engine (HSDE) and gas turbine engine allowed for more fuel-efficient loading conditions at these lower speeds, while still being able to reach the required maximum speed. The baseline ship consisted of four LM2500-30 gas turbine engines, so we decided to keep two of the baseline engines and replace the two inboard GTM modules with HSDEs. We researched many HSDEs to find the right combination of power, weight, and size. The selected CODOG arrangement features an LM2500-30 gas turbine and a Rolls Royce MTU 20V4000M93 HSDE for each shaft.

An extensive analysis of this configuration was completed; to include arrangements, weight changes, fuel efficiency and range calculations at both endurance speed and across the time-speed profile, and risks associated with the conversion. The MTU engines are smaller in all dimensions, and therefore there were no potential problems with equipment spacing. Together, they result in a net increase of 40 tons. The weight was added roughly centerline and low on the ship, which reduced KG by 0.03 meters, increased draft by .02 meters, and increased GM by .03 meters, which is all within an allowable range. Additional propulsion plant foundations and new resilient mounts are needed for the heavier and louder diesel engines. The main reduction gear (MRG) increased in size by approximately 5%. Backed by the advice of our project sponsors, it was determined that both the intake/exhaust systems, and necessary lube oil systems could be re-purposed from the original GTM to support the new HSDE. Below are the detailed drawings of one of the modified engine rooms.

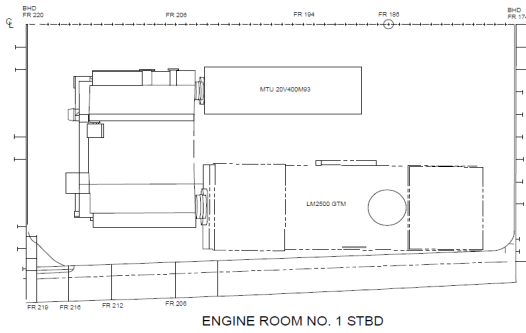


Figure 1. Engine Room #1 STBD

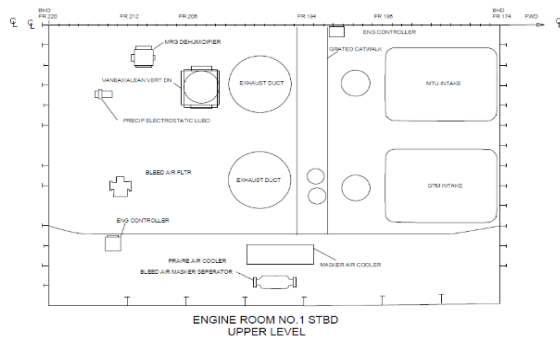


Figure 2. Engine Room #1 STBD Upper

The DDG's total resistance, required brake horsepower, and specific fuel consumption were used to calculate the endurance range at each speed. We recorded this endurance range at 16 knots and observed an increase of 3,500 NM compared to baseline. Endurance ranges were calculated for both split plant and trail shaft operations, with a 15% added resistance included when in trail shaft. To also provide mission profile range, the time at each speed was weighted based on the DDG time-speed profile. With the CODOG conversion, the endurance range of the DDG FLTIIA at 16 kts is 8000 NM, an increase of 75%, and the mission range increased by 2100 NM. The maximum speed dropped from greater than 30 knots to 28 knots, but still exceeds the resource sponsors requirement of 26 knots.

	Baseline	CODOG	Change
Endurance Range (NM)	4500 @ 20 kts (7000 @ 16 kts)	8000 @ 16 kts	+3500 (+1000)
Mission Range (NM)	5900	8000	+2100
Max Speed (kts)	>30	28	-2
Displacement (MT)	9400	9440	+40
Propulsion Weight (MT)	840	870	+30
KG (M)	7.57	7.54	-.03
GM (M)	1.28	1.31	+.03
Draft (M)	6.66	6.68	+.02

Table 1. Comparison of baseline to modified configuration characteristics

After an in-depth analysis, the design team concluded that a conversion of the ship's propulsion plant is an effective and feasible solution to the objective of increasing the range of the DDG FLT IIA. The team recommends a CODOG engine arrangement featuring one LM2500-30 GTM and one MTU 20V4000M93 HSDE per shaft. Risks associated with this conversion include CODOG reduction gear installation and operation, enhanced structural support and sound mounts for the diesels, and compatibility issues with existing auxiliary equipment.

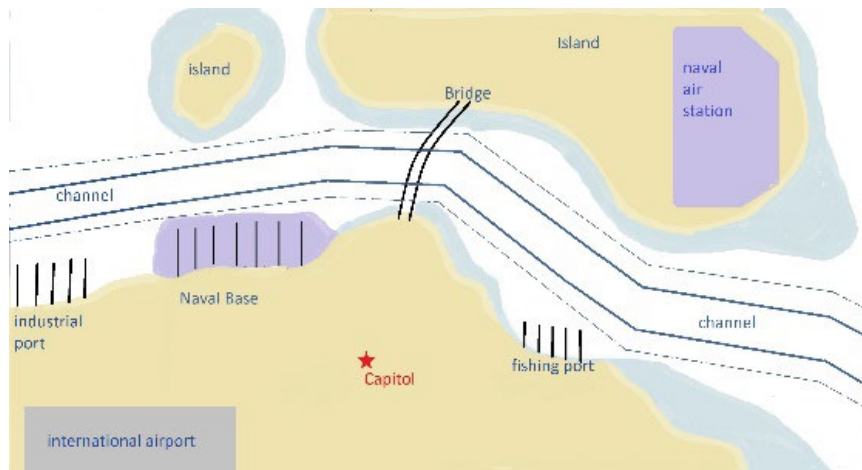
Creating HAVOC: A Modern-Day Fireship Conversion

LT Kelsey Cathcart, USN; LT Jarod Kramer, USN; LT Eric Young, USN

Historically a fireship was a ship filled with combustibles or explosives, deliberately set on fire, and steered or drifted into an enemy fleet to destroy ships, break naval formations, or induce panic. These vessels were used due to the large tactical benefit the fireship could offer at a low cost against a much larger fleet but the rise of steam propulsion and iron hulls led to a gradual decline in the use of traditional fireships.

The objective of this conversion was *to reduce enemy coastal capabilities by disabling critical enemy infrastructure using a converted disposable maritime platform*. This was accomplished by understanding the sponsor's requirements and creating our own derived requirements. The sponsor required the team to create a fireship that can cause maritime port denial/disruption without risking US lives, the project cost no more than the US equivalent missile that would be utilized to execute a similar task and that is was manufacturable at speed/scale of expendable weapon systems and can be applied to a variety of hulls.

A scenario for the fireship was created to bound the conversion by fabricating a nautical chart of the



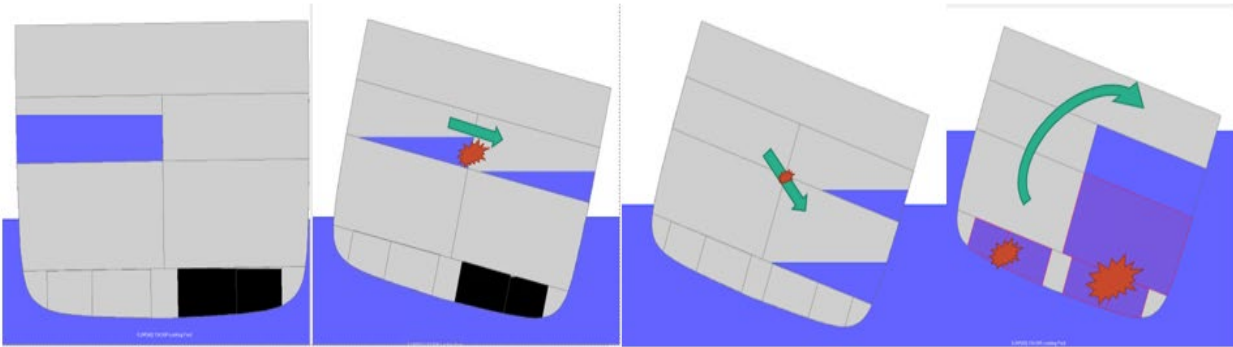
enemy nation seen to the left. The fireship will conduct its mission by entering the narrow channel and ultimately sinking through a series of controlled flooding and explosions under the bridge. This location was chosen to block the narrow channel to any deep draft vessel that needs to get to the Naval Base or industrial pier. This led the team to decide what vessel to convert in

order to ensure the vessel could hide in plain sight and accomplish all of the requirements.

To accomplish this mission the team researched autonomous systems that could be retrofitted to fit pre-existing ship systems, allowing for smooth execution of the mission at minimal costs. To select a final hull a port analysis was performed, and the team opted to convert a fishing trawler by adding longitudinal bulkheads to the lower decks. The addition of these bulkheads allowed for simulations of controlled flooding and the eventual capsize of the vessel. The trawler hull was entered into POSSE where the team needed to essentially reverse engineer the software to see how a vessel would sink rather than how to salvage a vessel that was already damaged. This was done by assessing how to properly distribute weight throughout the vessel to



maintain stability and proper seakeeping while getting to the target site but ensure the vessel capsizes in the desired manner (on its port side) under the bridge. The figures below represent the four stages the vessel will execute enroute to its target location. Finally, the team provides recommendations for further alterations or additions that can be made to a hull to hinder salvage efforts; thereby prolonging denial of access to the port or ocean by the opposing nations navy.



This fireship concept is a novel approach to a historic concept and the team recognized there are endless possibilities in the conceptual approach to this project. Team HAVOC utilized the tools and software for designing ships in a way they have not yet been utilized and the outcome was promising in that it showed these tools could be manipulated for alternate purposes. A fireship's success is entirely dependent on the scenario it is used but for the purposes of this conversion the goal was successfully met and executed.

Ship Conversion: Addition of Flettner Rotors on a T-AKE

LCDR Alex Wunderlich, USN; LT Chris Tomlinson, USN; LT Camilo Duque, USN

Study Selection

The maritime industry faces increased pressure to reduce emissions and reliance on fossil fuels. In 2011, the International Maritime Organization (IMO) adopted a strategy to reduce the greenhouse gas emissions from ships. It was the first international body to mandate energy efficiency measures. The initial goal was to make the ships built in 2025 30% more efficient than those built in 2014. The new goal of the IMO is more stringent, aiming to reduce total emissions by 40% by 2030 and 50% by 2050 compared to emissions in 2008. In 2016, the Paris Climate Accords sought to limit the global temperature rise to 2 °C above pre-industrial levels and pursue limiting the rise to 1.5 °C. These accords accounted for climate change mitigation, adaptation, and financing to ascertain this goal. The 2021 United Nations Climate Change Conference (COP26) laid the foundation for a global push to global net-zero carbon emissions. With the IMO at the forefront of the trend to reduce emissions, ship builders are looking at new and old technologies to reduce emissions while still meeting global demands.

The military may face similar pressure as the economy changes and technology advances. Unlike military ships classed by the Naval Sea Systems Command (NAVSEA), military supply ships are classed by the American Bureau of Shipping (ABS). As a result, these ships are subject to ABS regulations, which are influenced by the regulations of the IMO. Since improvements in diesel technology alone are not expected to meet these standards, this conversion project investigates an alternate method to achieve this goal.

Technology Selection: Flettner Rotors and their Operation

Power sources with zero emissions include solar, fuel cells, and wind. Before steam engines, wind power was the preferred power source on the high seas and allowed access to all ports. Furthermore, after taking a deeper look into the improvements in wind propulsion methods, one of the more promising methods is Flettner Rotors. Flettner Rotors are spinning, vertical columns that employ the Magnus Effect to induce a horizontal “lift” force for propulsion. A picture of the Flettner rotors installed on a vessel and a diagram explaining the Magnus Effect are shown below.



Figure 1: Flettner Rotor Installed on a Vessel (Left) and Description of Magnus Effect (Right)

Previous studies of Flettner rotors on bulk carriers revealed significant cost savings due to reduced fuel use, along with commensurate reductions in NO_x (nitrogen oxides) and CO₂ (carbon dioxide) emissions.

Ship selection: T-AKE: purpose and image

Since these regulations would impact ships operated by vessels classed by ABS sooner than military ships, this conversion project conducted a feasibility study on adding Flettner rotors to a T-AKE dry cargo ship. The figure below shows the original T-AKE on the left and the modified T-AKE with Flettner Rotors on the right.

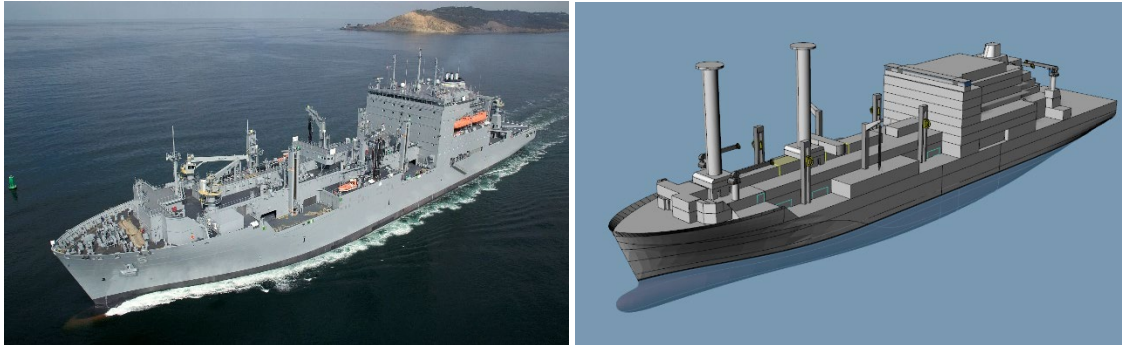


Figure 2: Current T-AKE (Left) and Modified (Right)

The T-AKE is not the ideal ship for this project. It has essential topside equipment that interferes with placing the maximum number of rotors onboard. More and larger rotors are desired for best results with the Flettner Rotor. The idea behind selecting arguably the most limiting candidate for this project was to demonstrate feasibility even in this limiting scenario.

Design Philosophy and Assumptions

All calculations will be based on standard T-AKE hull form at design length, beam, and displacement for this study. Only minor changes will be made to the machinery onboard to accommodate the implementation of Flettner Rotors. The focus of this study was on (1) the change in overall fuel consumption and seakeeping, and (2) the feasibility of installation on the vessel while meeting current ABS radar and visibility standards.

Feasibility, Performance, and Cost-Savings

The focus of our study was on the effect of Flettner Rotors. Thus, the project team opted not to create costly, custom rotors but instead used rotors already commercially available for comparison. Norsepower is a Finnish company that specializes in the installation, operation, and maintenance of Flettner Rotors. They have five standard Rotor sizes ranging from 18 to 35m tall with a lifespan of 25 years. The cost and saving potential were evaluated from both the emission and financial point of view. Reduction of fuel emissions was expected, so the selling point would focus on the financial benefit from adding these rotors.

Conclusion

Analysis of these rotors along with installation guidance from the manufacturer found the installation of two 28m tall Flettner rotors on a T-AKE is a viable option that produces an estimated \$5.6 million in savings over the Rotor's lifecycle, 3.2% reduction in emissions, and a monetary payback period of 4.9 years. The project team found that current regulations stood in the way of better performance for these Rotors. For example, placing two 35 m tall Flettner Rotors onboard would save \$9.46 million. However, this is not possible with current ABS visibility restrictions. Changing the current regulation to adding visibility assistance from live video would allow more significant emission reduction for this technology.

Conversion of a FLT I DDG into an Ice Capable Ship

LT Andrew Moeller (USCG), LT Natasha Patterson (USN), LT Ivan Reyes (USN)

Increases of global temperatures in recent years have brought about receding levels of ice in the Arctic, opening up previously inaccessible and unnavigable areas, resulting in a significant increase in maritime activity. The sea ice has been declining at a rate of 13% per decade in the summer and 3% per decade in the winter. The U.S. Navy's Arctic strategy identified the need for ready forces in maintaining maritime defense and power projection within the Arctic region, and in the coming years the Navy will seek to increase its presence, operational experience, and infrastructure in this region to preserve U.S. national interests. One method to achieve these goals is to modify the existing Arleigh Burke Class Guided Missile Destroyer (DDG 51) to operate in an arctic environment.

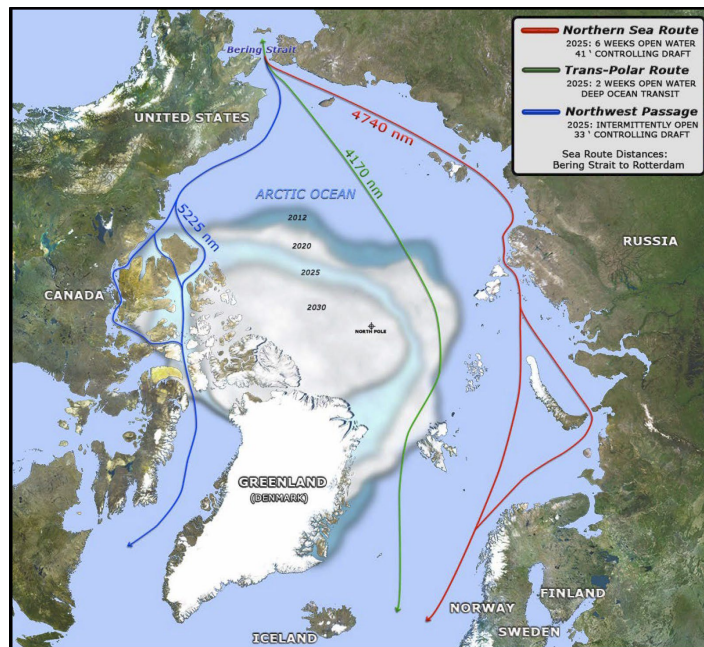


Figure 1: 2025 Projection of Open Water Conditions

Our investigation documents the process of converting and modernizing a Flight I Guided Missile Destroyer DDG 51 (FLT I DDG) to support the Navy's strategic outlook in the Arctic region. The project defines what arctic capabilities can be added to the ship for the cost of \$100 million, and further examines what capabilities can be added for a total cost of \$200 million.

This design concept was conducted using a tradespace evaluation based on the U.S. Navy's strategic requirements for Arctic operations chosen through literature reviews, analysis of previous arctic conversion and design projects, and discussions with subject matter experts (SMEs). The Analytic Hierarchy Process (AHP) was used to explore the design tradespace and determine the optimal solution for enhancing arctic capabilities while minimizing costs. From a budgetary standpoint, the project focuses on ship conversion funding allocation. Variant costs include estimates based on tax-exempt material and man-hour labor, but exclude facilities costs such as shipyard services and daily expenses. The decided concept is a feasible design, adding the necessary capability for sustainable operation in the Arctic region with appropriate mitigations to minimize overall risk while meeting the sponsor's cost threshold requirements.

Littoral Transport Vessel

LT Megan Hagen, LT Christopher Reynolds, LT Matthew Valcourt

The Littoral Transport Vessel (LTV) is a high-speed troop transportation craft designed to increase individual Marine combat effectiveness upon arrival to shore by reducing the ship-to-shore transit's time duration and improving the overall ride quality. While the Assault Amphibious Vehicles (AAV) play a main role in these operations by providing ship-to-shore transportation, significant passenger fatigue is incurred during these transits. AAVs also lack shore-to-shore transit capability which significantly reduces their overall utility. Plans are underway to replace the AAV with the Amphibious Combat Vehicle (ACV) throughout the next decade, but this upgrade will only provide marginal improvements. There are also other ships capable of transporting troops within this same operational space (such as the LCU 1700 and LCAC), but these vessels are mainly used for transporting heavy equipment due to their large size and robust structure. Therefore, a faster ship focused on safe personnel transportation and increased range which could be used during initial insertions would fill an operational gap in the USMC's littoral combat capabilities.

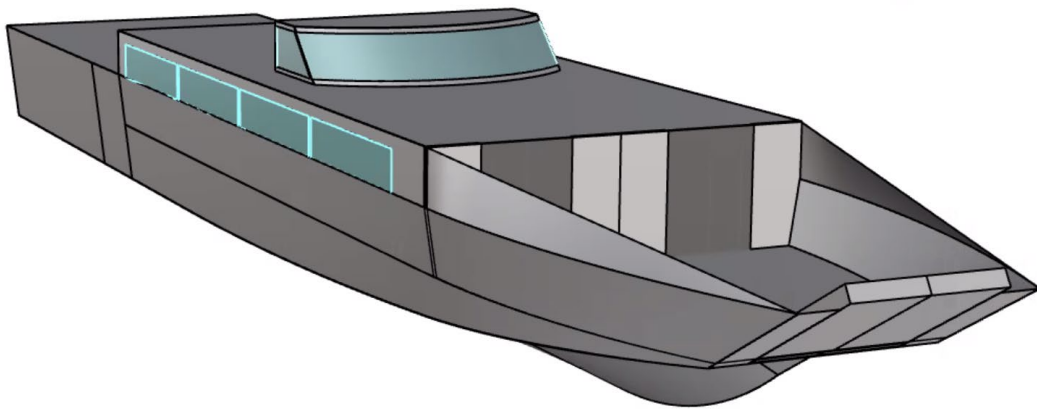
To allow for maximum design exploration freedom, the only sponsor requirement was that the LTV must safely transport Marines from ship-to-shore while maintaining individual Marine's combat effectiveness. As a result, the design team began by conducting stakeholder interviews and researching into both existing technology and the overall operational space. From this investigation, the project's CONOPs, customer requirements, derived requirements and assumptions were all defined to scope the project. Equipped with this scope, a system-level concept exploration was performed using a set-based design approach for each aspect of the LTV's design to determine the best overall solution. From this process, LTV was designed as a high-speed, hard-chine planing monohull.

Tools available within MIT's ship design repository were not well-fit for the resultant vessel's size and hull-structure. Consequently, the design tradespace was created using a MATLAB[®] script developed within this project and based on an established industry design methodology for planing vessels. This script generated different hull geometries and powering configurations, and from this tradespace, a single hull variant was selected and further constructed using CAD modeling software. Using this model, final arrangements were established, and hydrostatics, seakeeping, and stability analyses were performed. Lastly, a cost model was developed using open-source tools from the University of Michigan, and this model was further validated by planing hull industry partners.

In conclusion, the LTV is a feasible, cost-effective solution which would fill a current operational gap within the USMC's amphibious community and introduce shore-to-shore transit capability. A 12 nm transit would be reduced to approximately 30 minutes, and the LTV could support a variety of configurations including up to 86 passengers and/or 67,400 lbs of cargo through the use of removable seats. The LTV also met all seakeeping and stability requirements necessary to ensure optimal combat effectiveness for troops upon reaching shore. LTV provides an excellent combination of cost and capability, and this vessel would enable the USMC to successfully meet future challenges in the littoral operational space. For these reasons, LTV is recommended for further study and consideration.

LTV Specifications			
Parameter	Quantity	Parameter	Quantity
Length Overall (ft)	106.5	Shaft Horsepower (HP)	6,459
Length Between Perpendiculars (ft)	96.83	Brake Horsepower (HP)	6,693
Beam Overall (ft)	21.21	Installed Electrical Power (ekW)	198
Length/Beam Ratio	5.02	Prime Mover	2 x MTU 12V 4000 M93L

Lightship Displacement (lbs)	179,601	Propulsor	2 x Hamilton HM721
Full Load Displacement (lbs)	260,517	Transmission Gearbox	2 x ZF 7600, light duty
Full Load Draft (ft)	4.4	Electric Generator	2 x Caterpillar C4.4
Depth (ft)	9.54	Fuel Capacity (lbs)	11,237
Total Height (ft)	16.12	Water Capacity (gal)	1500
Projected Chine Length (ft)	95.85	Passenger Capacity	86
Chine Beam (ft)	19.52	Cargo Capacity (lbs)	67,400
Deadrise (deg)	17.5	Vertical Acceleration (at Sustained Speed)	0.6g's at LCG
Trim (deg)	2	Sea State	4
Hull Material	Aluminum, 5000 Series	SWH (ft)	8.2
Sustained Speed (kts)	35	Armament (# mounts for crew-served weapons)	2
Max Speed (kts)	40	Crew Size	2-3
Endurance Range (nm)	245	Project Cost (2021 FY\$)	11-17 Million



Missile Corvette

LT Elliot Collins, USN; LT Chris Hein, USN; LT Scott Oberst, USN



As older platforms that employ the Vertical Launch System (VLS) are decommissioned, the Navy will lose 20% of its total available VLS cells. This study investigated the design and feasibility of a missile corvette (DDC) that would replace these cells in an affordable and distributed manner while preparing for a future conversion to full autonomy. It will serve as a steppingstone toward a Large Unmanned Surface Vessel (LUSV) which is currently being developed by PMS 406, The Navy's Unmanned Maritime Systems program office. The LUSV concept is centered around deployment as an additional "adjunct" floating magazine to supplement a separate target data ship (TDS). The DDC is meant to bridge the gap between the unmanned vessel challenges of the present and the LUSV of the future. Flexible architecture and a design philosophy prioritizing future autonomy will deliver a vessel that is both initially capable and able to fill the future role of the LUSV.

The initial requirements for the DDC consisted of 24 sponsor-defined requirements with an additional seven derived requirements generated by the design team. Through these requirements and cooperation with PMS 406, the team produced a design philosophy that consisted of the following ordered priorities: lethality, affordability, reliability, maneuverability/endurance, and flexibility. Due to the sponsor-furnished primary missions of Strike Warfare (STW) and Anti-Surface Warfare (ASUW), lethality was nearly synonymous with the number of VLS cells. Flexibility addressed readiness for future autonomy and maneuverability/endurance ensured that the DDC could maneuver with existing battlegroups.

Initial exploration examined a number of combinations of hull forms, VLS configurations, and other systems and characteristics. Through a technically rigorous system-level analysis and evaluation process, the team generated a valid possible solution set within the Rapid Ship Design Environment (RSDE) which weighed cost versus a requirement-based Overall Metric of Effectiveness (OMOE). From this solution set, a preferred variant was selected which utilized the monohull National Security Cutter (NSC) as a base and included 48 VLS cells and an Integrated Power System (IPS).

Further analysis focused on feasibility and optimization of specific capabilities of the DDC. One of the most difficult aspects of this design was the relatively small size of a corvette-sized vessel. While there is no accepted definition of what a corvette class actually entails, parametric analysis of corvettes from navies around the world indicate no more than 4,500 LT or 400 ft length overall. Because of this, the DDC endeavored to be as small as possible while still delivering the desired VLS cells to support STW and ASUW missions. One of the key aspects of the DDC that supported this was the inclusion of an IPS instead of a traditional mechanical propulsion train. IPS offered a number of benefits. First, it enabled

flexible engineering plant configuration which allowed the team to include all of the desired engineering systems in a space-limited hull. The team opted to install seven diesel generators to supply power and propulsion to the DDC. IPS enabled the distribution of these generators around the ship, thereby enhancing survivability. Finally, IPS and the team's decision to include multiple medium-sized generators enabled efficient generator loading, reducing lifecycle costs through fuel savings.

Analysis was conducted to ensure the operability of VLS on a relatively small vessel. Because VLS has kinematic constraints, detailed in STANAG 4154, the sponsor requirement of operability in sea state five proved a pervasive problem. Detailed technical analysis was conducted to reduce the motions experienced by VLS to include geometric placement and motion-reducing systems. Ultimately, the DDC was able to launch in a restricted sea state five window.

The team performed detailed technical analysis in three areas of ship design. The first investigated engine room ventilation to effectively manage the heat generated by IPS engineering spaces. Through CFD analysis, intake and exhaust ducting was reduced in size by an average of 17.5% while still meeting ISO standards for diesel ventilation air flow requirements. The second study investigated the inclusion of passive anti-rolling fins to expand the VLS launch window in the most extreme case. While moderately effective, these fins did not appreciably lower the motions to enable VLS launch in the worst case of sea state five. The final analysis explored the replacement of traditional propellers with podded propulsors to further increase fuel efficiency. Podded propulsors would require significant hull modification that would increase resistance, effectively eliminating the increased efficiency from the podded propulsors. Moreover, they would require significant rearrangement of transverse bulkheads, leading to the DDC failing floodable length criteria. For these reasons, they were not included in the final design.

Pursuant to the affordability tenet of the design philosophy, the team conducted a detailed cost analysis which utilized the MIT cost model and an unofficial evaluation by Naval Sea Systems O5C, both of which utilize SWBS-based Cost Estimation Ratios (CERs). The O5C results without inclusion of GFE indicated a lead ship cost of \$521.5 in TY23 dollars with follow-on hulls costing an average of \$382.0M in CY22 dollars, well within the \$500M goal. The MIT cost model assessed the costs to be higher, by including a fixed ratio estimate for GFE costs. The lack of a GFE estimate in the O5C analysis accounts for some of the difference between the two estimates.

The final DDC design offered a modern material solution to the loss of VLS cells brought on by the decommissioning of Ticonderoga class cruisers and SSGNs. Built to be lethal, cost effective, and quickly deliverable, the DDC offered a minimally manned vessel that could be deployed alongside a target data ship to bolster the amount of missile cells available in a SAG, CSG, or ARG. The DDC supports STW, ASUW engagements, and own ship self-defense at an affordable cost.

Mine Sweeper Replacement Platform (MSRP)

LT Dayne Howard, USN; LT Joshua Malone, USN; LT Kelli Waterman, USN

Sea mines have long played an important role in naval warfare. The threat of mines can come from any adversary, from non-nation state actors to near-peer competitors. The U.S. Navy's dedicated MCM ships, Avenger class vessels, are aging and will soon require replacement (Cancian, 2020). Current solutions to fill this strategic gap, including Littoral Combat Ships (LCS) with MCM modules, fail to provide a dedicated platform which addresses the inherently dangerous nature of minesweeping operations. This study is motivated by the need to replace the Avenger-Class with a dedicated MCM platform, combined with the rising technological opportunities associated with autonomous vehicles to reduce the MCM mission risk to personnel.

This project focused on Concept of Operations determination, design space exploration, concept definition, and feasibility and performance analyses of our chosen design. The Minesweeper Replacement Platform (MSRP) ship designed is a Small Waterplane Area Twin Hull (SWATH) vessel made out of composites. It operates independently but can support strike group operations and is designed to be fully manned for transits while conducting minesweeping operations autonomously to reduce risk to personnel. The SWATH hullform, modeled after the TAGOS-19, was chosen as the base hullform for this vessel for a number of reasons. The stability and seakeeping characteristics of SWATH hulls make them well suited for autonomous navigation, minesweeping equipment requirements, and reduction of underwater signatures. Additionally, SWATH hulls house major equipment above the waterline which reduces underwater signatures and thus the risk of mine detonation. The composite hullform further reduces underwater signatures over that of steel or aluminum counterparts. The MSRP is equipped with two small boats to transport the crew off the ship prior to executing minesweeping operations and recover them once the ship has cleared the minefield. Figure 1 shows the final concept design of the MSRP.

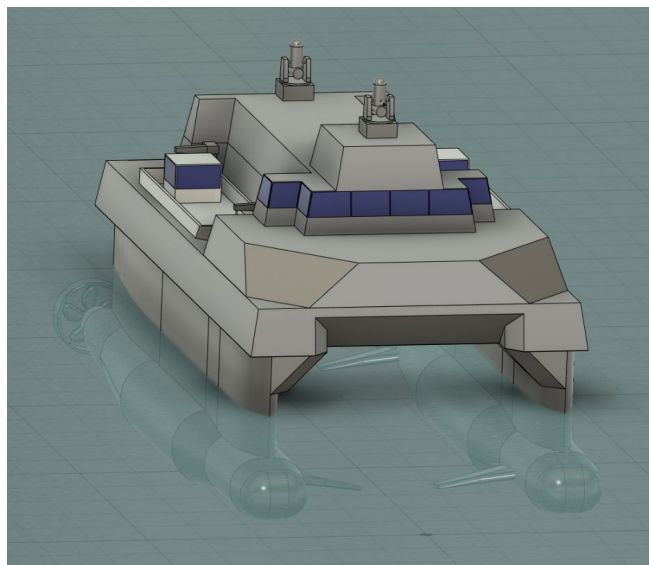


Figure 1: Final MSRP Concept Design

Seakeeping, powering and endurance and hull structural analyses were conducted with the MSRP meeting all applicable standards as well as meeting all customer requirements. Final vessel

characteristics for the MSRP are shown in Table 1. The MCM systems are shown in Table 2. These systems combine to satisfy each part of the Mine Warfare Hunt-Kill Chain: Detect, ID, Control, Engage, Assess.

Metric	Value
Endurance	30 days
Range	5035 nm at 15 kts
Maximum Speed	16.7 kts
Crew Size	75
Physical Security	AT/FP, SUW/AW self-defense
Draft	7.27 m
Maximum Beam	26 m
LOA	50 m

Table 1: Final MSRP Characteristics

MCM Equipment	Use
SQQ-32 towed variable depth sonar	Detect & ID
Barracuda Launcher	Neutralize
SLQ-37	Minesweep
MPCS and MEDAL	Command & Control
MFTA	Detect
Klein Side Scan Sonar	Detect

Table 2: MSRP MCM Equipment

Significant arrangements for the MSRP are shown in Figure 2.

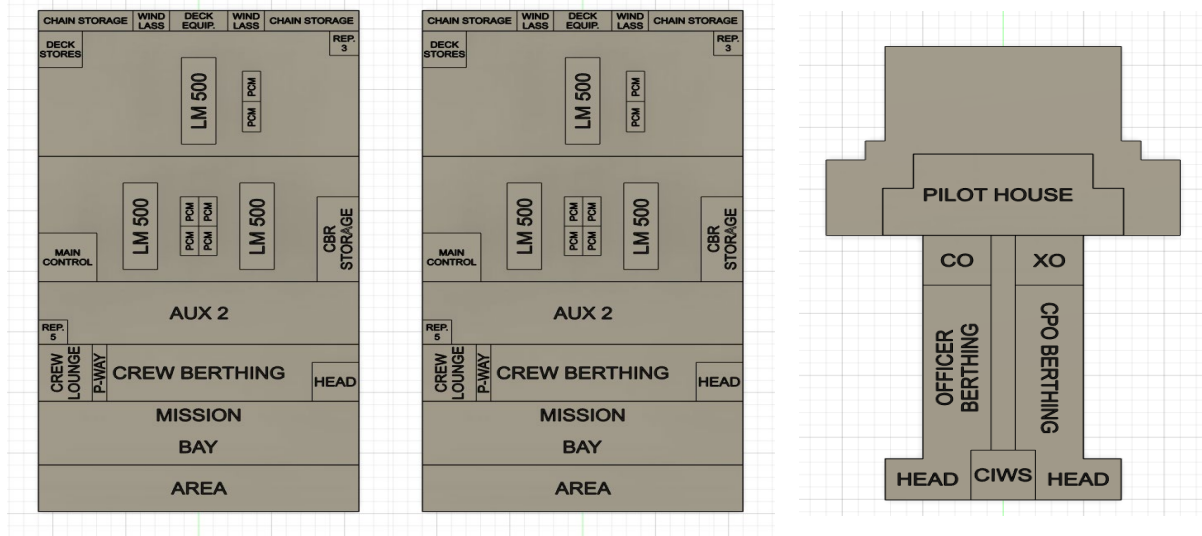


Figure 2: MSRP First Deck, 01 Level, and 02 Level

Reference

Cancian, M. F. (2020, November). U.S. Military Forces in FY2021, Navy. Center for Strategic and International Studies. https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/201109_Cancian_FY2021_Navy.pdf, Accessed July 12, 2021.

Good Vibes: Shipboard Fault Detection Methods for Condition Based Monitoring

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Vibration analysis has long been used as a measure for machine health. Condition-based maintenance strategies have used vibration analysis of time and frequency domains as maintenance action triggers with various levels of success. These traditional analysis methods are greatly affected by operating conditions and mounting, which can make fault identification nearly impossible. Computational advances in signal processing have provided more targeted approaches for vibration analysis. These approaches leverage spectral coherence to identify subtle shifts in cyclo-stationary behavior. Demonstration of these techniques to classify operation of capacity-controlled reciprocating compressor is presented, along with measures to aid in the proper setting of capacity control devices for more efficient system operation. These techniques along with more traditional methods are used to identify various reciprocating machine faults and support root-cause analysis of failed immersion heaters.

Master of Science in Mechanical Engineering

Extracting Electromechanical Signals for Icebreaker Insights

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Nonintrusive load monitoring has a proven track record of providing benefits for equipment operation logging, fault detection and diagnostics, condition-based maintenance, and energy scorekeeping. A nonintrusive load monitor (NILM) can measure the aggregate of electromechanical signals at a central utility point and extract individual loads from this power stream. Segregating and identifying these unique electrical signatures from various shipboard machinery components allow a NILM to assess the health of equipment and predict potential failures before they are evident through traditional monitoring methods. NILMs have been installed on multiple US Coast Guard and US Navy vessels over the past several years, collecting vital data that has rapidly accelerated the monitoring capabilities of this technology. This work specifically expands upon the previous successes and applies the same concepts of fault detection and equipment diagnostics to a 140 ft US Coast Guard icebreaking tug, USCGC THUNDER BAY. The NILMs installed on THUNDER BAY are capable of directly monitoring the electric propulsion drive, which coupled with its unique icebreaking mission allow the NILM to gain crucial insights into ship operation that have not been previously available. Additional improvements were developed for the NILM's software and hardware components to incorporate an added wireless capability, allowing the NILM to act as a central processor for a physically securable network of wireless sensing nodes. Testing was conducted in four separate shipboard environments to confirm the feasibility of this network architecture. Specific methods for implementing this sensor network are discussed, and techniques for combining both power and vibration measurements are presented to identify insights that were previously unattainable through power monitoring alone.

Master of Science in Naval Architecture and Marine Engineering

Master of Science in Mechanical Engineering

Modeling Hydrodynamic Interactions between a Submarine and UUV using Non-Myopic Multi-Fidelity Active Learning Gaussian Process Regression

LT Brady Hammond

Abstract

The United States Navy has developed many custom tools capable of predicting the hydrodynamic forces and moments of different Unmanned Underwater Vehicles (UUVs). However, they do not have a tool that enables them to accurately simulate the hydrodynamic interaction forces and moments that a UUV experiences when operating in close proximity to a moving submarine. Real-time modeling of these hydrodynamic interactions is essential to simulate the motion required to launch and recover UUVs from submarines. Potential flow models are fast enough to be solved in real time, but lack the accuracy of Computational Fluid Dynamics (CFD) simulations which often take hours or days to solve. A machine learning algorithm called Non-Myopic Multi-Fidelity Active Learning was developed for Gaussian Process (GP) regression to create a surrogate model capable of predicting the UUV and submarine hydrodynamic interactions in real-time. By utilizing the low cost of the low fidelity simulations to explore the domain and the high-fidelity simulations to improve the model accuracy, this method was able to outperform other active learning multi-fidelity GP regression modeling techniques. This surrogate model can be integrated into UUV control and autonomy systems and motion simulators to further enable UUV launch and recovery from submarines. Additionally, this new active learning method may also be used to create higher accuracy and lower cost surrogate models in other real world applications.

Keywords: Hydrodynamic Interaction; Unmanned Underwater Vehicle; Non-Myopic Active Learning; Multi-Fidelity Gaussian Process Regression, Machine Learning

Predicting Extreme Event Statistics for Ship Motions and Loads

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Ship operators and designers alike use ship motion simulation software to predict ship responses in irregular ocean waves including the statistics of extreme events. Ship operators rely on precalculated polar plots during heavy seas to select speeds and headings that will protect the ship and crew from dangerously extreme pitch and roll motion. Ship designers use simulations over thousands of operational hours to predict the effects of vertical bending moment on the structural integrity of the ship. This thesis considers two simulation methods that fulfill these needs, Large Amplitude Motion Program (LAMP) and SimpleCode. LAMP is higher-fidelity but computationally expensive, while SimpleCode uses a reduced order model but is orders of magnitude faster. This thesis investigates the use of machine learning, specifically a Long Short-Term Memory (LSTM) artificial neural network, to augment SimpleCode, such that the combined results are high fidelity, akin to LAMP, without significant computational overhead. The LSTM proves effective in creating a map directly from the output of SimpleCode to the output of LAMP. The LSTM's performance over large sea state domains, including unimodal and bimodal seas, is studied. The distribution of motion peaks predicted by the LSTM over thousands of operational hours in a given sea state is shown to closely resemble that of LAMP. The time savings of using the LSTM approach are quantified and found to be significant.