## Naval Construction and Engineering
## Ship Design and Technology Symposium

### Thursday, April 27, 2023

### 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<br>- CAPT Jeremy Leghorn, Director Naval Construction and Engineering<br>- Prof Pierre Lermusiaux, Interim Co-Department Head |
| 0900 – 0925 | Student Design Project Brief<br>- Gray Zone Combatant: LT Kelsey Cathcart, LT Jack Cathcart |
| 0925 – 0945 | Student Conversion Project Brief<br>- DDG FLT IIA LASER Retrofit: LT Jon Daus, LT Thinh Hoang, LT Mikala Molina |
| 0945 – 1010 | Research Brief: Prof Steven Leeb<br>- Combat Power Monitor: LT Isabelle Patnode, LT Michael Bishop |
| 1010 – 1030 | Poster Session |
| 1030 – 1050 | Student Conversion Project Brief<br>- Cruise Ship to Affordable Housing: LT Avi Chatterjee, LT Jason Webb, LT Heather Willis |
| 1050 – 1110 | Student Conversion Project Brief<br>- T-ATF Conversion for Ocean Plastics Retrieval: LT Asia Allison, LT Matt Kruse, LT Katie Spaeth |
| 1110 – 1135 | Student Design Project Brief<br>- Next Generation Attack Submarine: LCDR Lucas Stone, LCDR Alex Wunderlich, LT Jarod Kramer |
| 1135 – 1205 | Break, lunch served |
| **1205 - 1255** | **Lunch Buffet and Keynote Address:**<br>**Rear Admiral David Goggins: PM, AUKUS Integration and Acquisition Program Office** |
| 1255 – 1310 | Break, transition |
| 1310 – 1350 | Research Brief: Prof Themis Sapsis<br>- LT Brady Hammond: Real-time Autonomy and Maneuvering Simulation of an Unmanned Underwater Vehicle near a Moving Submarine using Actively Sampled Gaussian Process Surrogates of Hydrodynamic Interactions<br>- LT Jarod Kramer: Inductive Transfer Learning to Quantify Extreme Event Statistics of Ship Motions using RNN |
| 1350 – 1410 | Poster Session |
| 1410 – 1430 | Student Conversion Project Brief<br>- LSD-41 to Diving and Salvage Conversion: LT Christopher "CJ" Sarao Jr., LCDR Christos Gkiokas |
| 1430 – 1455 | Student Design Project Brief<br>- Project Black-Foot: LT Jillian Uzoma, LT Eric Young, LT Camilo Duque |
| 1455 – 1500 | Wrap-Up and Concluding Remarks |
| **1500** | **Mission Complete** |

**Design Projects** **Conversion Projects** **Thesis Topics**

**Rear Admiral David Goggins**
**Direct Reporting Program Office, AUKUS Integration and Acquisition**

Rear Adm. David (Dave) Goggins was born in Los Angeles, California. He attended the University of California, Berkeley, and graduated in 1989 with a Bachelor's of Science in Nuclear Engineering and Material Science Engineering. His graduate education includes a Master's of Science in Operations Research from the Naval Postgraduate School, and two Masters of Science from the Massachusetts Institute of Technology in Mechanical Engineering and in Naval Architecture and Marine Engineering.

Goggins' Navy career began as a submariner aboard USS TECUMSEH (SSBN 628) where he served as an electrical officer, reactor controls assistant, and assistant operations officer. He was then selected for lateral transfer to the Engineering Duty Officer Community and reported to the Supervisor of Shipbuilding, Conversion and Repair (SUPSHIP) in Groton, Connecticut. At this command, he served as the lead ship coordinator for PCU CONNECTICUT (SSN 22) from initial hull erect to the initial stages of Post-Shakedown Availability planning.

Subsequent shore duty tours included serving as the Assistant Repair Officer at Naval Submarine Support Facility in New London, Connecticut; SEAWOLF Class Project Officer and Program Manager's Representative at SUPSHIP Groton; SSGN Conversion Project Officer and Program Manager's Representative at SUPSHIP Groton; VIRGINIA Class Assistant Program Manager for New Construction within PEO Submarines; and a staff assignment within the Office of Chief of Naval Operations, Undersea Warfare Division (N97).

As an Individual Augmentee, Goggins participated in Operation Iraqi Freedom. While in Iraq, he supported the military's counter-IED effort and was responsible for fielding over 3,000 mission critical systems to counter the rapidly evolving IED threat.

Goggins served as major program manager for two shipbuilding construction programs – the VIRGINIA Class attack submarine and COLUMBIA Class ballistic missile submarine. Under his leadership and guidance, the VIRGINIA Program delivered three submarines to the fleet, started the initial design work on the VIRGINIA Payload Module and Acoustic Superiority, and won the DoD Value Engineering Award and the David A. Packard Award for Acquisition Excellence. As the COLUMBIA Program Manager, the program completed Milestone B, awarded the Detail Design and Construction Readiness Contract, and started prototyping efforts.

His Flag Officer assignments include Program Executive Officer, Attack Submarines from October, 2021 to June 2022; and Program Executive Officer, Submarines from August 2018 to September 2021.

In 2022, Goggins was named as the Special Assistant to the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RD&A)) for the Australian-United Kingdom-United States (AUKUS) Partnership. Upon the completion of the 18-month consultation period, he became the first commander of the Navy's Direct Reporting Program Office for the AUKUS I&A office that is dedicated to supporting the Royal Australian Navy's ability to operate, maintain, and build conventionally-armed, nuclear-powered attack submarines.

**DDG FLT IIA Laser Retrofit**

LT Jonathan Daus, USN; LT Thinh Hoang, USN; LT Mikala Molina, USN

The US Navy been investing great resources into modernizing the fleet with advanced technologies that can keep maintain maritime superiority over its peer and near-peer competitors. Specific interest has evolved within the electromagnetic spectrum and the development of laser weapons systems. The first solid-state laser (SSL) weapon installed on a ship was the 30 kW beam power Laser Weapon System (LaWS) onboard the USS Ponce from 2014 to 2017. Other SSL weapons have been implemented but have focused their ability on small boats and UAVs.

As laser technology has improved, their ability to combat different threats has come to fruition. Specifically, the US Navy is looking to integrate a 300 kW Laser Weapons System (LWS) onboard a FLT IIA DDG to combat Anti-Ship Cruise Missiles (ASCMs). This conversion project explored the feasibility of integrating a 300 kW LWS, to include its power requirements and auxiliary support systems. The focus of the conversion was identifying the Space, Weight, Power, and Cooling (SWAP-C) in order to validate if the LWS could fit into the existing structure and be supported by currently installed power and cooling capabilities. Both structural integrity and ship stability were verified once the identified sizes and weights were known.

A300 kW LWS carries a relatively low efficiency of 25-30%. For this study, efficiency was assumed to be 25% to account for "worst-case" scenario. Other assumptions that played a role in this conversion were that the LWS would replace the aft Close-In Weapons System (CIWS) and its associated spaces, 01 level aft habitability spaces were consumable for the LWS, and a laser pulse (lase) would last six seconds. The 300 kW LWS was treated as a "black box" with global requirements provided by the project's sponsors. The three major subsystems marked for study were the power management system, thermal management system, and dry air supply system.

The interaction between those subsystems and the LWS are shown in Figure 1.

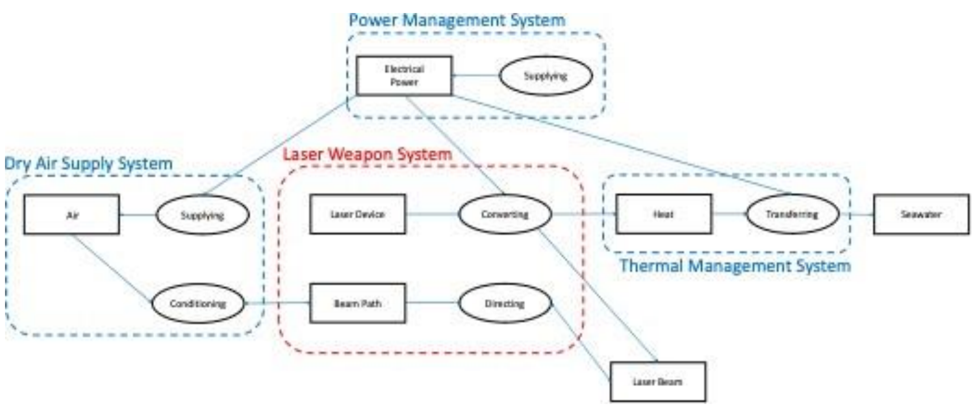



*Figure 1. LWS System Decomposition*

To support 300 kW of "lase" power, it was determined that a battery-based power supply of 200 kWh of energy and 222 Ah of capacity was needed. These values include a 35% margin to account for uncertainty and inefficiencies. The next factor to consider was battery chemistry.
Lithium-ion, (*Li-ion*) Lithium-Iron Phosphate (*LiFePO4*), and Nickel-Zinc (*NiZn*). Although Li- ion presented the most efficient energy storage system, its fire safety risks would create a great damage control related challenge onboard a warship. This study would ultimately recommend NiZn for risk reduction, given that there is adequate space and weight allowance within the DDG.

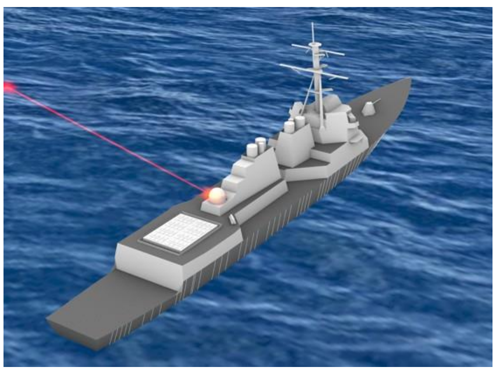
To meet the meet the challenge of cooling the LWS, three different systems were analyzed: Chill Water with Thermal Storage Module (CW with TSM), Pumped Refrigerant, and High Temp LWS (HTLWS). In each case the cooling system would have to reject 900 kW of heat flow (256 RT) rapidly to maintain temperature in the LWS. Although further ship impact analysis focused on the weight/space impacts of the CW with TSM system, this study would recommend the HTLWS based on having the least amount of additional equipment needed and would also provide for future combat systems install due minimal demand from the CW system.

In order to maintain controlled flow within the beam path, the LWS required a dedicated, oil-free Dry Air Supply system. The Dry Air Supply system was design to be within Collective Protection System (CPS) boundaries to minimize contamination and control air quality. The system was size and weight estimates were drawn from commercial sourced equipment to be accounted for in revised ship structural and stability calculations.

Shipboard impacts were also investigated during this study. Spatial arrangements were estimated based on equipment sizing and ships drawings. Weight estimates were conducted and used in determining ship stability impacts. With the additional loading, a structural analysis was conducted utilizing beam theory to determine new stresses. U.S. Navy shipboard electrical plant sizing requirements were then verified based on LWS power demands. Finally, shipboard auxiliary systems were discussed to account for second and third order effects of a LWS conversion. Relevant parameters are presented in Table 1.

*Table 1. Summary of Relevant Ship Characteristics*

| | Baseline | Conversion (LWS) | Change (%) |
|---|---|---|---|
| Displacement (LT) | 9256 | 9299 | 0.46% |
| KG (ft) | 24.85 | 25.02 | 0.68% |
| GM (ft) | 3.46 | 3.34 | -3.47% |
| $Stress_{keel}$ (ksi) | 16.27 | 16.72 | 2.80% |
| $Stress_{deck}$ (ksi) | 16.43 | 16.89 | 2.81% |



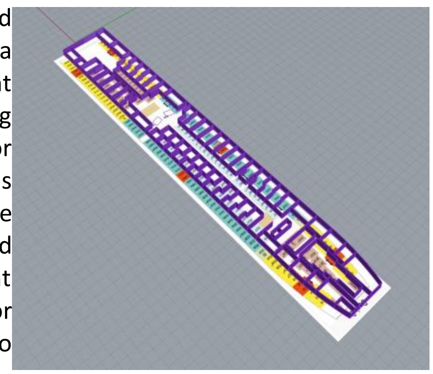
This study validated the feasibility of installing a 300 kW LWS onboard a FLT IIA DDG and would recommend the U.S. Navy pursue this system. It is also recommended that the Navy choose proven or near- proven systems to support a short turnaround for a DDG conversion, testing, and fleet integration. Future studies should look to investigate the impact of scaling a LWS based on power to determine feasibility as a conversion opportunity or identify the need for larger LWS integration into new construction.

**Team CASH (Converted Affordable Ship Housing)**

LT Avi Chatterjee, USN; LT Jason Webb, USN; LT Heather Willis, USN

This study evaluated the feasibility of converting a cruise ship into an affordable housing community. The idea is motivated by a confluence of factors: the affordable housing crisis besetting many cities and regions across the United States, the windfall of cruise ships available for purchase at reasonable prices in a post-pandemic world, and the apparent suitability of cruise ships to be repurposed for housing. This project aimed to address whether that last assumption was actually valid and whether this sort of proposal could prove feasible and cost-competitive against a traditional, land-based housing approach.

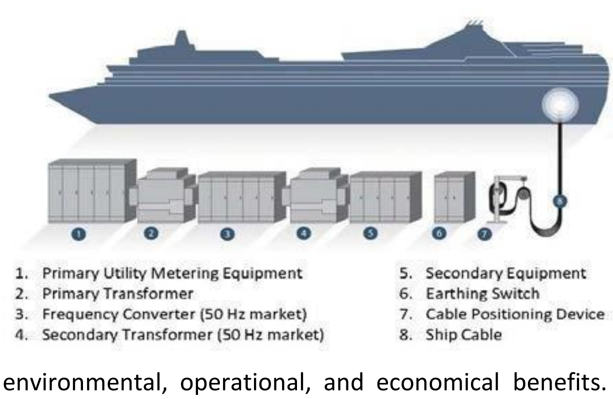
Early in the design process, the team contacted and interviewed various subject matter experts who had previously explored this idea in order to better develop our design parameters and associated requirements. The two main design parameters were affordability and desirability, as we strove to maintain the proper balance between these two central, and at times competing, qualities. They drove the design process as we attempted to not just convert cabins into housing units but to create a space where people would actually want to live, and could afford to do so.



To assess this idea's feasibility, we selected a baseline cruise ship variant based on vessel size, potential housing capacity, price, and availability of a representative model. Our 3D model was used primarily for weight estimations, intact and damaged stability analysis, and baseline remodeling to render a final proposed ship design. In order to properly account for conversion-related weight changes, a pre-conversion weight estimate was calculated on a per-deck basis using the Ship Work Breakdown Structure (SWBS) group weight allocations for a similar-sized U.S. naval warship, and modified with applicability factors to better reflect the cruise ship's weight contributors. Publicly available 2D deck plans were used as the basis for arrangement modifications. Each deck was evaluated and redesigned to provide some aspect of the affordable housing community.

The five current cabin decks were repurposed for the actual housing units. The most common unit merged four existing small-sized cabins in order to provide a desirable unit size and permit the installation of an in-unit kitchen. This "base unit" was priced such that the median Boston income earner could reasonably afford it, *i.e.* spend no more than 30% of their gross income on rent. A spectrum of smaller and larger housing units was established to cover a wider range of income earners. In total, our design proposed 246 housing units of varying sizes and prices that were able to accommodate approximately 350 people.

The remaining decks were modified to provide all the additional amenities, facilities, and furnishings deemed necessary in order to provide a desirable living space. These included: an enhanced fitness center, indoor pool, business center, grocery store, movie theater, multiple green spaces, daycare center, and three decks of parking. Weight removal and addition estimates were calculated on a per-deck basis in order to determine a post-conversion weight estimate and facilitate post-conversion stability analysis, which demonstrated improved stability performance compared to the pre-conversion model.




To provide the major utilities required for onboard living–electricity, water, sewage–we proposed concurrent investments in pierside and shipboard infrastructure and equipment upgrades to allow the cruise ship to connect to the city's power, water, and waste distribution systems on a permanent basis. The continued use of installed onboard systems to account for these needs proved either infeasible or unwise, whereas investments in ship-to-shore power technology and interoperability with the city's distribution systems were shown to have long-term environmental, operational, and economical benefits. Despite this approach rendering much of the installed onboard equipment no longer necessary, we were unable to identify compelling reasons to pursue large-scale engine room equipment removal. The final design maintained the engine room largely in the as-is configuration but with systems and equipment no longer necessary being retired in place in order to avoid undue maintenance and upkeep costs. To ensure the vessel's relocatability, our design maintained two of the four main diesel engines in an operational status to provide redundant sources of organic power generation.

Cost estimates for all aspects of the conversion process–acquisition, refurbishment, retrofit, operations, maintenance, and staffing–were estimated using comparable historical data and SME input to determine the overall feasibility of the proposal. The key cost consideration was whether the annual rent revenue could cover the annual operational costs. We determined that the expected revenue would not fully cover all of these expenses, but that this shortfall could be accounted for with a small amount of additional public funding or more favorable utility discount rates. A comparative cost analysis between the proposed design and a similarly-sized land-based apartment complex was also conducted, which concluded that by avoiding new construction costs, the cruise ship conversion would be significantly less expensive overall.

This project determined that the conversion of a cruise ship into affordable housing is both technically and financially feasible, and offers crucial advantages over comparable
land-based approaches.

| | **Fixed Costs ($M)** | | **Operational Costs ($M)** |
|---|---|---|---|
| Purchase: | 45.0 | Utilities: | 2.6 |
| Refurbishment: | 53.3 | Staffing: | 1.1 |
| Infrastructure: | 23.3 | Lease: | 0.2 |
| **Total:** | **121.6** | | **3.9** |

**Converted T-ATF Class Ship for Ocean Plastics Retrieval**

LT Asia Allison; LT Matt Kruse; LT Katie Spaeth

## Project Motivation

Plastics are durable, high-strength, corrosion-resistant materials that are relatively energy-efficient to manufacture. Unfortunately, plastics are generally not economical to recycle and lose strength when reprocessed. Most plastics are dumped in landfills or incinerated but some of this waste ultimately ends up in the world's waterways. This is a major issue because plastics pose numerous threats to marine wildlife and humans. Additionally, floating plastic "patches" can present entanglement problems to seagoing vessels.

There are few processes in nature which can remove plastics from the ocean at a sustainable rate. Human-driven efforts have been initiated to either manually or autonomously remove the waste. The most well-known and successful company to tackle this problem is *The Ocean Cleanup*, a Netherlands based non-profit primarily targeting the removal of floating ocean plastics in the Great Pacific Garbage Patch. To help augment their efforts, it was proposed that a recently decommissioned U.S. Navy or Military Sealift Command (MSC) ship be converted for the purposes of ocean plastics retrieval.

## Existing Ocean Plastics Retrieval Technology and Ship Selection

*The Ocean Cleanup* currently employs two Maersk Trader class ships that utilize shipboard winches to control the dragging of two "wing" sections separated by a long, rectangular retention zone (*Figure 1, Left*). The towing vessels travel at approximately 1.5 knots and floating plastic waste accumulates along the wings, slowly migrating toward the central retention zone area. Approximately once per week, the retention zone is brought onboard one of the ships. A crane is then utilized to hold the zone vertical while releasing the plastics collected onto the ship's aft deck (*Figure 1, Right*). Onboard, the plastics are manually sorted by the ship's crew and ultimately stored in conex boxes (also located on the ship's aft deck).

*Figure 1: The Ocean Cleanup's Jenny 002 System (Left) and Retention Zone on Aft Deck (Right)*

Based on the equipment required to handle the netting system and the general scheme of operations used by *The Ocean Cleanup*, a Naval ship platform was selected that possessed similar towing and lifting equipment, adequate empty space for plastics storage, and excellent maneuvering abilities at slow speeds. The optimal ship class that had these characteristics was the MSC's decommissioning Fleet Ocean Tug (USNS Powhatan T-ATF-166) Class (shown in *Figure 2*, *Left*). The final proposed design for the converted.

T-ATF included two new cranes with increased lifting capacity and the addition of a plastics sorting and compacting machine within an interior main deck space (*Figure 2, Right*).

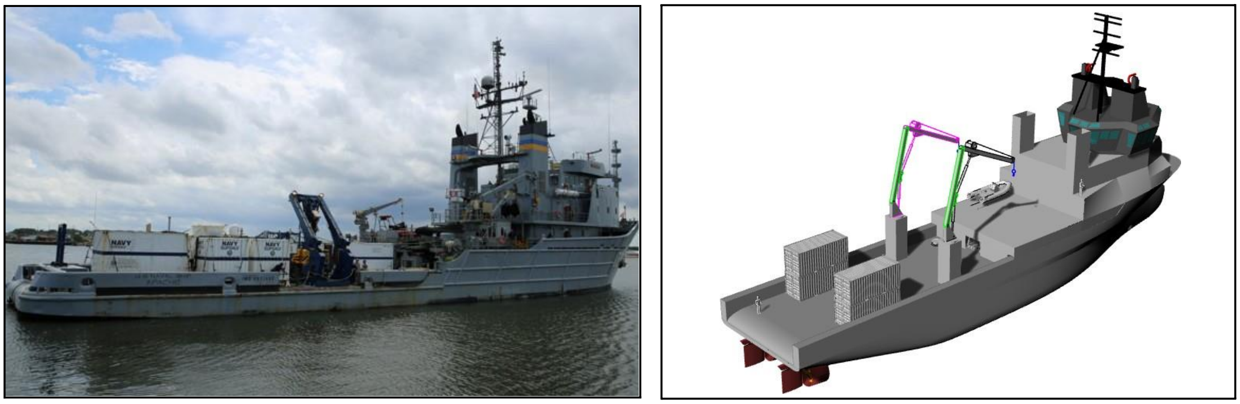



*Figure 2: USNS Apache (T-ATF-172)(Left) and Converted Platform (Right)*

**Design Philosophy and Assumptions**

The purpose of this conversion project was to provide the fleet with a "Green Graveyard" ship, still owned and operated by MSC, whose primary purpose was to perform plastics cleanup efforts. The following design philosophy was adopted to perform this conversion project: (1) Plastics retrieval is the primary mission, (2) Feasibility and Scalability, and (3) Operations should minimally impact the environment.

The final design did not alter the original ship hullform, or propulsion and electrical plants. The only changes made were to support the plastics capturing equipment utilized by *The Ocean Cleanup*. These converted ships were proposed to operate only out of Naval continental U.S. ports. Installed sorting and compacting equipment was assumed to be suitable for marine environment operation and could be scaled to fit inside proposed ship spaces.

**Feasibility and Performance Analyses**

The feasibility study performed in this project was limited by the lack of an available T-ATF 3D model. Instead, a standard offshore supply vessel was utilized for all Rhino modeling as well as MAXSURF stability and seakeeping analyses. The off-shore supply vessel had similar structural arrangements but some adjustments were made to more accurately represent the T-ATF class ship.

The feasibility analysis assumed hull strength, propulsion and electrical power requirements were satisfied. The intact stability analysis satisfactorily passed for hydrostatic conditions. Seakeeping analysis reflected favorable conditions for tow operations and working personnel limitations. Additionally, an operational profile was created in order to predict fuel consumption which was required for conversion and operational cost analysis. The total estimated cost was $43 million.

**Conclusion**

Based on this initial conversion study, a comprehensive analysis was warranted to determine the full technical feasibility of this project. In future studies, further structural analysis due to the additional weights of cranes, sorter and compactor was recommended. An electrical analysis needs to be performed to verify installed electrical capacity meets the electrical demand of added equipment. Finally, intact and damaged stability analysis should be completed for all loading conditions.

**Ship Conversion: Addition of a 150MT Active Heave Compensated Crane and Dynamic Positioning System Thrusters on a Decommissioned LSD-41**

LCDR Christos Gkiokas, Hellenic Navy; LT Christopher Sarao, USN

## Study Selection

The call for diving and salvage maritime capability is growing. Due to great power competition in the U.S. Pacific Fleet, the demand for maritime salvage and Ship Wartime Repair and Maintenance (SWaRM) has increased. The SWaRM concept identifies the processes required to provide in-theater ship and submarine repair. Most salvage platforms are outsourced through commercial contracts, offering only a temporary solution. When the United States goes to war it will be all about time; how much time does it take to get the right equipment on location?
Recapitalizing a decommissioned LSD-41 hullform for a command diving and salvage ship could alleviate these issues if the converted ship is capable of fleet salvage and diving multi-mission operations. This conversion project conducted a feasibility study on the addition of a 150MT active heave-compensated (AHC) crane and dynamic positioning system (DPS) to a decommissioned LSD-41 amphibious warship.

The motivation for the 150MT AHC crane was commercial best practices and the anticipated need during SWaRM. The motivation for the DPS was the dive manual, as divers must either have DP2 capability or a 2 (or more) point moor. The moor takes time, skill, and space to set, and is only good in shallow water. The LSD-41 offered the capability of fleet salvage and diving operations by providing communications, offices, space, and accommodations, as well as a large unobstructed flight and well deck that allowed for the embarkation of a variety of stand-alone and interchangeable vehicles/systems. The converted command diving and salvage ship can support missions in humanitarian assistance, oil spill response, rescue, salvage, towing, and wide area search and surveillance (UUV and UAV).

## Technology Selection

MacGregor's 150MT AHC knuckle jib crane was selected because it was commercially accepted and offered a similar foundation footprint size as the 60t starboard crane already in place that could either be welded or bolted to the deck. Additional upgrades support 3D motion compensation and ship to ship transfer.

Thrustmaster's Portable Dynamic Positioning System (PDPS) was selected because it is DP-2 ABS class certified and saved time and money. The modularly designed hydraulic power units were completely independent and did not require vessel utilities, eliminating intrusive engineering work. The thrusters can be quickly and easily installed and rem oved pierside without requiring drydocking.

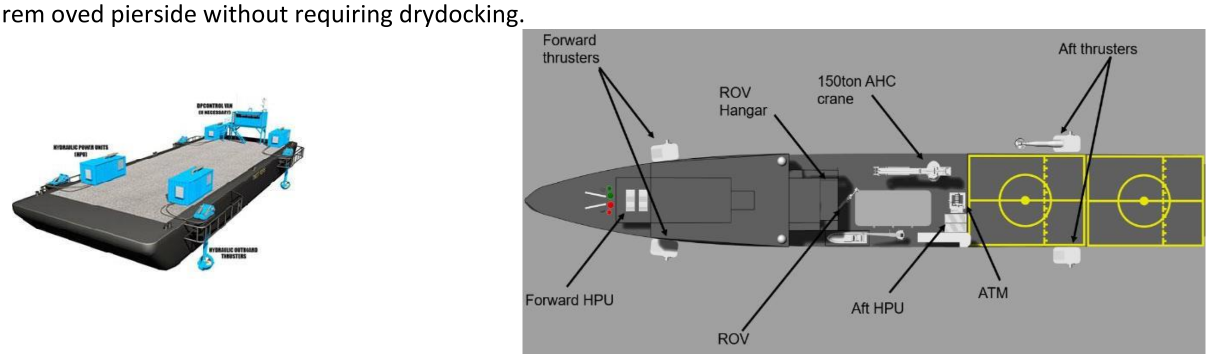



*Figure 1: Thrustmaster Portable Dynamic Positioning System Installed on a Vessel (left) and Conversion (Right)*

## Ship Selection

The Dock Landing Ship (LSD) is a Naval warship designed to support the Navy's amphibious assault operations by transporting and launching amphibious craft and vehicles near shore. The *Whidbey Island* class (LSD- 41) is comprised of eight ships and was designed specifically to permit Landing Craft Air Cushion (LCAC) operations. The LSD-41 hullform offers a 134m well deck which is flooded to launch and recover landing craft for amphibious assault, as well as a flight deck to land and launch up to two CH-53E helicopters. The LSD-41 was selected because of the limitless conversion opportunities due to the flight deck, well deck, and accommodations.

Table 1 summarizes the converted operational profiles and design characteristics based on the new missions.

*Table 1: Diving and Salvage Command Ship Operational Profiles and Design Characteristics*

| | Lightship | Full Load | Minimum Operating Condition | Units |
|---|---|---|---|---|
| LOA | 186 | 186 | 186 | m |
| Lpp | 177 | 177 | 177 | m |
| Max Beam | 35 | 35 | 35 | m |
| Speed | 20+ | 20+ | 20+ | kts |
| Displacement | 13004 | 16735 | 15136 | MT |
| Trim | 0.73A | 0.62A | 0.71A | m |
| Heel Angle | 0 | 0 | 0 | degrees |
| GMt | 3.17 | 3.86 | 3.57 | m |
| Draft MS | 5.02 | 6.06 | 5.62 | m |

**Design Philosophy and Assumptions**

All calculations were based on the standard LSD-41 hullform values. The major assumption of this project was that the original hullform and propulsion system would remain unchanged in the converted ship design. The controllable pitch propellers (CPP) served as the primary transit propulsion and were integrated with the thrusters for towing, debeaching, and station keeping evolutions. The focus of this study was on the naval architecture feasibility on the installation of a 150MT AHC crane and DP-2 system.

**Feasibility and Performance**

The focus of this study was to determine the feasibility of installing a 150MT AHC crane and DP-2 thruster system on a decommissioned LSD-41. A naval architecture analysis of the arrangements, weights, stability, structural integrity, and seakeeping determined that the conversion to a diving and salvage command ship is feasible. Stability and structural integrity results were verified with ABS and U.S. Navy standards and regulations. The seakeeping results identified the ships operational areas up to and including sea state five for various tasks and locations. The bollard pull of the diving and salvage ship was calculated with the use of both the CPP and thrusters to validate the towing of an aircraft carrier. The selling point of this conversion would focus on the financial and multi-mission benefit of recapitalizing a decommissioned amphibious warship to a diving and salvage command ship versus the new construction rescue and salvage ships.

**Conclusion**

This team found that the LSD-41 hullform is a viable conversion for a diving and salvage command ship. To determine if this conversion provides a payback to the U.S. Navy a further cost analysis should be completed and compared with the new construction cost of the T-ATS *Navajo* class rescue and salvage ships. Additionally, further detailed studies should be included in the added benefits of the well deck and flight deck have to offer for a multi- mission diving and salvage command ship in support of battle-damage repair.

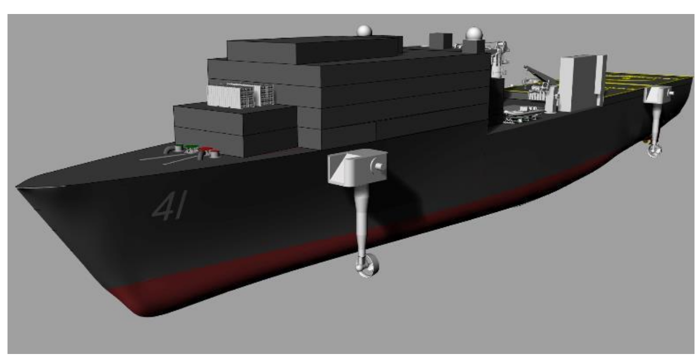


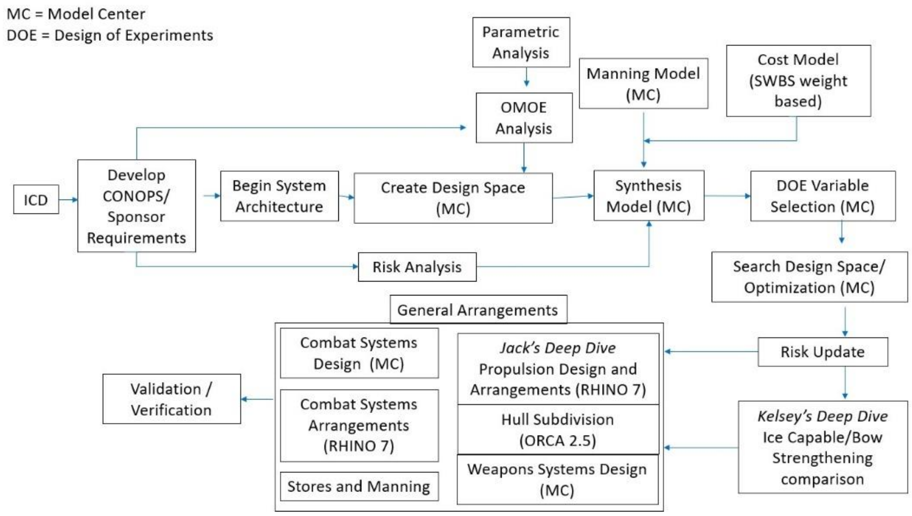

*Figure 2: Current LSD-41 (Left) and Modified (Right)*

**Gray Zone Combatant Executive Summary**

LT John Cathcart, USN & LT Kelsey Cathcart, USN

The Gray Zone Combatant (GZC) was designed to provide long-term presence and intelligence gathering capabilities to the US fleet as an independent operator in “gray zones”. A gray zone is defined as a maritime region that is remote, separated from traditional logistical pathways, and subject to extreme or unpredictable weather conditions to include first year ice. This vessel class will contribute to the US Navy’s strong defensive posture in all global waters while simultaneously providing surveillance and support to the US Navy and all allies.

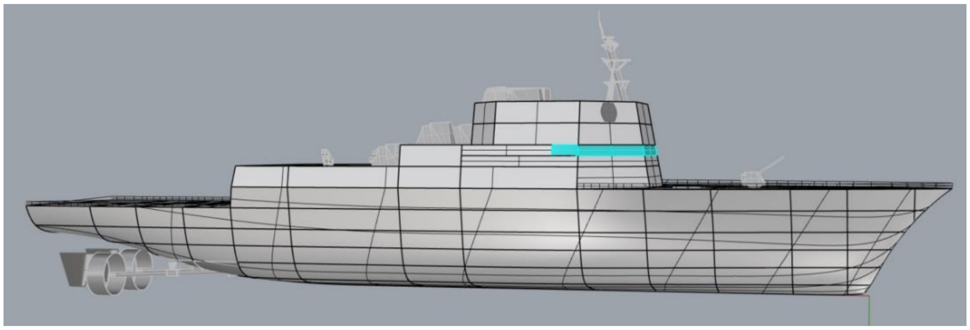
The GZC was designed with a total ship synthesis approach utilizing design tools intended to replace ASSET in the 2N program fostered by collaborative research between 2N and Virginia Tech under the mentorship of Dr. Alan Brown. The Naval Concept and Requirements Exploration Tools (C&RE) allowed the team to execute the design of the GZC in stages which ensured that the final design was able to meet all operational requirements stated in the initial capabilities document (ICD). To ensure all important parameters of warship design were considered a work flow was created to allow the design team to work on separate portions of the design simultaneously. This work flow also provides a clear breakdown of how the CR&E tool functions throughout an entire design phase.




A design of experiments was completed in order to create response surface operators representing all hull design parameters. A multi objective optimization utilizing the total ship synthesis model embedded in the C&RE tool was then completed, which yielded the final hull design of the GZC and included all installed combat systems. These include an embarked LAMPS helicopter, UXV (small and medium size), and many offensive and defensive weapon capabilities such as a 32 VLS cell, RAM, 57mm, and the Naval Strike Missile. The GZC is powered by a hybrid electric plant similar to FFG-62 which includes one LM2500 G4+ prime mover on the ship’s centerline for achieving sustained speed, and one electric motor installed on each shaft for normal operations up to cruise speed. Two Fairbanks Morse secondary power generation modules, and two ship service generators provide all required electrical power to support all propulsion, hotel, and combat systems loads. The endurance speed for the GZC is 16 knots and maximum speed is 25 knots. Due to the GZC large fuel capacity the endurance range is estimated to be just over 3 times the range of DDG-51 and 2 times greater than FFG-62.

The Gray Zone Combatant is designed to provide the Navy with a surface ship with an increased endurance range capable of operating for extended periods of time without the typical logistics support found in a CSG. This goal caused the hull to be optimized for maximum endurance range rather than high speeds needed to operate within a CSG. To utilize these combatants in these regions the GZC was designed with a reinforced bow to withstand first year ice common in arctic regions. As an Arctic nation it is important the US has the capability to operate combatants in areas of the world that are becoming increasingly more accessible to both civilian and military traffic. The GZC was designed to provide early ISR capabilities and be able to both defend itself and provide offensive posturing if need be while awaiting backup from larger surface combatants if conflict arises.

Upon completion of this project the design team recommends pursuing the next stages of design for the Gray Zone Combatant. This ship met all sponsor requirements, is within reasonable monetary standards for a new surface combatant and would provide the US the resources needed to build and maintain a presence in regions that US naval surface combatants don't typically operate.



| Design Variables | Value | | Design Variables | Value |
|---|---|---|---|---|
| Length overall (ft) | 401.9 | | Endurance Speed (kts) | 16 |
| Beam (ft) | 71.5 | | Sustained Speed (kts) | 23.75 |
| Draft (ft) | 22.3 | | Max Speed (kts) | 25 |
| L to B ratio | 5.62 | | Displacement (MT) | 8389 |
| B to T ratio | 3.21 | | Endurance Range (NM) | 13999 |
| Design Waterline (ft) | 370.4 | | | |

**SSN XIPHIAS**

LCDR Lucas Stone, LCDR Alex Wonderlich, LT Jarod Kramer

The Navy is always searching for tomorrow's weapons and platforms that will give its sailors an edge over adversaries across a range of mission areas. The next generation of nuclear-powered attack submarines, classified as SSNs, is no exception. It is critical that the new generation of SSNs replacing the Virginia Class Submarine embraces technologies that can deliver platform performance that rivals growing threats posed by present and future adversaries in the undersea warfare domain. A range of SSN attributes are required to create the most capable undersea warfighting platform, from speed and acoustic superiority to weapons payload. This design project aims to achieve these attributes, by embracing unique design features not traditional to the U.S. submarine fleet.

Dubbed SSN XIPHIAS, this project explores the concept design of a double hull, sailless submarine to improve performance while maintaining all other attributes and requirements. The design must also compensate for changes to operational practices driven by these unique features. The team also considered present and future mission areas by incorporating tried-and- true technology where beneficial and by adopting emerging technologies where necessary to improve the platform's longevity. To accomplish this, knowledge and resources outside the normal U.S. Navy practices were leveraged to alter and improve traditional tools and practices for submarine concept development.

*Figure 1: Final XIPHIAS concept design.*

The concept design requirements were collectively determined with the project sponsor. These requirements aim to achieve the most capable platform possible, while wholly committing to the unique design features. Therefore, the team embraced the double hull, sailless design and performed hydrodynamic, hull optimization, arrangements, structural, concept of operations, and maintenance studies. Through the formulation of a concept design and the studies performed, the team found that a double hull design complements a sailless submarine by providing additional freeboard for surfaced operations while retaining a smooth body of revolution outer hull.

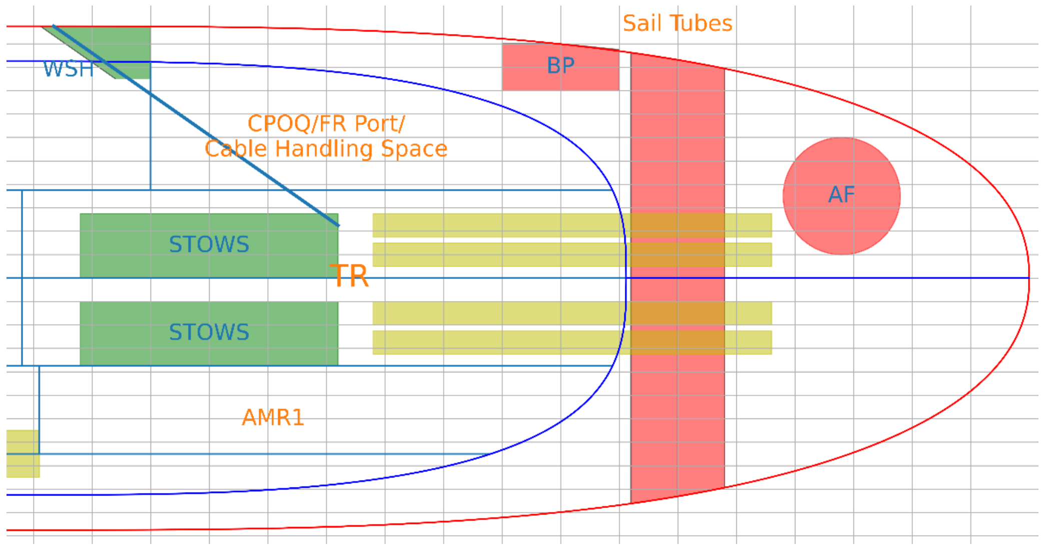



*Figure 2: Side view of torpedo room and sail tubes.*

The sail removal and double hull construction created distinctive challenges for the team across all aspects of the concept design process. Chiefly among them is determining arrangements and operational considerations for a large payload and the placement of components usually placed within a sail (e.g., communication masts and periscopes). Thus, these two platform qualities drove most of the design. The team designed for no topside manning during normal surfaced operations and opted to use eight individual telescoping masts placed in the forward main ballast tank, immediately forward of the pressure hull forward closure head. This placement minimizes the impact of the scopes and antennas on internal arrangements, at-sea and in-port maintenance operations, and reduces the number of complex pressure hull penetrations.

The team was able to develop a double hull, sailless submarine that exceeds threshold requirements for speed, vertical launch capability, and small horizontal payload, while meeting objective requirements for torpedoes and cost. Final design characteristics seen in Table 1.

| XIPHIAS Final Specifications | | | |
|---|---|---|---|
| **Hull Length** | 344 ft | **Cost (5th ship in class)** | $4.7 B |
| **Hull External Diameter (LOD)** | 43 ft (8.0) | **Electric Plant** | 8000 kW |
| **Maximum Speed** | 33.3 kts | **Surfaced Draft** | 31.7 ft |
| **Shaft Hp** | 45,000 Hp | **Freeboard** | 11.3 ft |
| **VLS** | 14 | **GM** | 1.26 ft |
| **Torpedo Tubes/Stows** | 8/48 | **Margin Lead** | 10.9% |
| **Small Torpedo/Stows** | 4/28 | **Volume Error** | 4.9% |
| **Submerged Displacement** | 10,986 lton | **Reserve Buoyancy** | 25.0% |

*Table 1: Final XIPHIAS concept design specifications.*

**Project Blackfoot**

LT Camilo Duque, LT Jillian Uzoma, LT Eric Young

The United States (US) Navy's fleet of surface ships is comprised of large, highly-capable, yet costly warships that take years to build and maintain. At their current capacity, US shipyards struggle to build new complex ships like the Ford class aircraft carrier or Zumwalt class destroyer. This new construction backlog also inhibits each shipyard's ability to maintain the Navy's existing fleet. As high end at-parity adversaries build weapons capable of causing major battle damage and ship attrition, the Navy must create ships capable of delivering major combat capabilities using less shipyard resources. Emerging autonomous capabilities allow us to create unmanned and rapidly producible swarm ships capable of delivering lethal combat power at a low cost. Inspired by the WWII era Patrol Torpedo (PT) boats, we propose an autonomous swarm of planing surface combatants that can be built in commercial pleasure craft shipyards and delivered to battle without stressing existing naval assets.

The design team spent a significant time clearly defining the ship's Concept of Operations (CONOPS) and outlining the requirements as this project is unique and this framework needed to be established in order to start to design our vessel. The CONOPS involves not only the mission of the PT boat once in the Operational Area (OPAREA), but also the method of transport from the manufacturing site to the OPAREA. After the problem was clearly defined and with the design philosophy established, we moved into design space exploration. We utilized both qualitative and quantitative means to make design decisions. We created a Python script to automate the generation of over 50,000 variants of hulls so that we could select the best five to analyze further. We considered 19 combinations of payloads and then narrowed it down to three options. Using the selected five hulls and three payloads, we conducted an Overall Measure of Effectiveness (OMOE) analysis to select a final variant. The parameters of this selected hull are listed in the two tables below in table 1.

| **Parameter** | **Value** |
|---|---|
| Length on Deck | 40 ft |
| Beam | 8 ft |
| Chine Height | 4 ft |
| Chine Width | 5 in |
| Chine Beam | 6.4 ft |
| Bow Fullness | 0.3 |
| Bow Rake Angle | 40 degrees |
| Mid Deadrise | 20 degrees |
| Aft Deadrise | 15 degrees |
| Material | Fiberglass |

| **Parameter** | **Payload Option C** |
|---|---|
| Weapons | 2x Saab Torp, 4x Spike NLOS |
| Length (in) | 178 |
| Weight (lbs) | 2,900 |
| Max Eff Range (NM) | 13.5 |

***Table 1:*** *Final Variant characteristics*

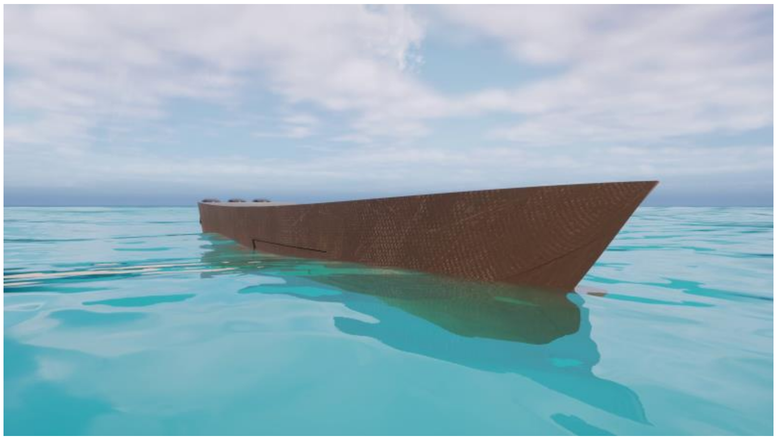


***Figure 1:*** *Final PT Boat Design*

Next the design team moved into detailed design. With our vessel dimensions determined, we made careful decisions about arrangements, considering weight distribution with each iteration of the design. Additionally, we designed weapon launchers for our unique mission and also designed stern launch equipment to launch the swarm of PT boats from the stern ramp of the Roll-On/Roll-Off (Ro-Ro) vessel, ARC Endurance. Electrical and auxiliary equipment was selected and loitering times were verified based on equipment power needs. Our final arrangements are shown below in figure 2.

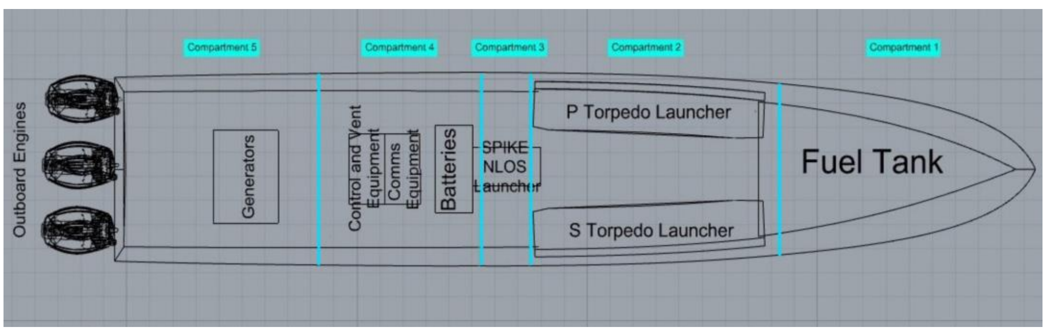



***Figure 2:*** *2D Arrangements of Final Design*

Finally, we completed feasibility and performance analyses on the final variant. We analyzed inact and damaged stability, powering and resistance, trim, and seakeeping through a variety of hand calculations and computational methods. The PT boat successfully met all requirements, passed our stability checks, and met all other applicable standards.

**FRC Corrosion Prevention**

LT Isabelle Patnode, USN

| Prof. Steven Leeb |
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| Thesis Supervisor |


The USCG FRC fleet is experiencing corrosion at an unacceptable rate in the FRC propulsion shaft tunnels. An investigation into this problem was conducted from the perspectives of "root cause" and "prevention." Root causes for the corrosion stem from an unfortunate interaction in a complex, two-stage galvanic protection system on-board the ship that uses both passive zinc protection and impressed current cathodic protection (ICCP) from an active, feedback-controlled power supply. By using custom measuring instruments and applying them on an in service FRC in order to better understand the complications with galvanic protection on the FRC, crucial insights were discovered. The ICCP power supply unit is intended to prevent corrosion by actively injecting current through the starboard anode in order to raise the magnitude of the voltage measured between the reference electrode and the hull. The FRC design expects the combination of ICCP and passive zinc installation to provide dual approach to ensuring corrosion protection. However, additional passive protection provided by zinc installation in the starboard bow thruster near the reference electrode raises the measured protection level causing the automatic controller in the ICCP power supply unit of the FRC to "think" that the ship is adequately protected, thus turning off the active current protection. The ship puts intense wear on the passive zinc protection and receives no benefit from the ICCP, which has effectively turned itself "off." The difficult-to-protect shaft tunnel rusts when the local zincs in the tunnel expend before the scheduled maintenance cycle. This presentation will include a full summary of analysis and results, along with a review of laboratory experiments, computer numeric simulations, and field experiments with several FRCs in the USCG fleet concluding with specific, actionable suggestions for mitigating corrosion in the FRC stern tube.

**UUV Autonomy and Control Near Submarines Using Actively Sampled Surrogates of Hydrodynamic Interactions**

LT Brady Hammond, USN

| **Prof. Themis Sapsis** |
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| Thesis Supervisor |


Many tools have been developed to simulate Unmanned Underwater Vehicle (UUV) motion and autonomous behaviors to evaluate UUV capabilities. However, there is no simulator that performs real-time modeling of the complex hydrodynamic interaction force and moments that a UUV experiences when operating near a moving submarine. These hydrodynamic interactions must be determined in real time to simulate the launch and recovery of UUVs from submarines. Potential flow models may be fast enough to solve the hydrodynamic interactions in real time, but by oversimplifying the physics and neglecting viscosity, they introduce inaccuracies into the simulations. Computational Fluid Dynamics (CFD) is capable of accurately modeling these hydrodynamic interactions, but simulations take hours or days to solve. To overcome this obstacle, a machine learning method known as Gaussian Process (GP) regression is used to create a surrogate reduced-order-model that predicts the hydrodynamic interactions in real time. The GP regression model is trained by actively sampling CFD simulations in order to accurately model complex hydrodynamic interactions. This new approach allows the GP regression model to be incorporated into a UUV motion simulator and evaluate how the UUV is affected by the hydrodynamic interactions. Operating envelopes are developed that outline regions where the UUV safely overcomes the hydrodynamic interactions and where the UUV is overpowered and collides with the submarine. By incorporating this surrogate model into the autonomy architecture, new autonomous behaviors are created that compensate for the hydrodynamic interactions by adjusting the desired UUV heading and speed which allows it to better stay on course.

**Investigating the Use of Inductive Transfer Learning and RNN to Quantify Extreme Event Statistics of Ship Motions**

LT Jarod Kramer, USN

| **Prof. Themis Sapsis** |
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| Thesis Supervisor |


Ship motion software has been a critical tool for designers to study the extreme responses of ships in irregular waves. These studies and simulations often take thousands of hours to predict and analyze the ship's motion. Simulation results are often imperative to ensure the development of accurate operational guidance, typically in the form of plots, advising the crew on safe course and speed combinations to avoid dangerous roll and pitch motions. Two programs in use by the Navy to fill this need are the fast, lower-fidelity SimpleCode program and the slower, higher-fidelity Large Amplitude Motion Program (LAMP). Previous efforts have developed a framework to leverage machine learning through a Long Short-Term Memory (LSTM) network architecture to augment the SimpleCode program by mapping its ship motion output to the more accurate LAMP output without adding significant computational overhead. This process of using an LSTM neural network to improve the SimpleCode output provides the opportunity to supply predictions and guidance to the crew in real-time. However, the limits of this mapping across various sea domains still need to be discovered. By investigating these limits, a more generalized LSTM can be realized through inductive transfer learning and a model agnostic meta-learning approach, one that leverages the training of previous networks to augment SimpleCode across a broader range of seas or produce more accurate results on a narrow set of sea conditions after very few training samples.