**Naval Construction and Engineering**

**Ship Design and Technology Symposium**

**Wednesday, May 4, 2016**

**MIT Samberg Conference Center, 50 Memorial Drive**

**Building E52-Sixth Floor, Dining Rooms 5 & 6**

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|---|---|
| 0800 - 0845 | Registration and Continental Breakfast |
| 0845 - 0920 | Welcome and Opening Remarks<br>- CAPT Joe Harbour, Director Naval Construction and Engineering<br>- Prof. John Leonard, Associate Head of the Department of Mechanical Engineering |
| 0920 - 0945 | Research Brief: Prof. Dick Yue<br>- Design of a Cooperative Oceanographic Collection Platform: LT Brandon Zoss |
| 0945 - 1010 | Research Brief: Prof. Chryssostomos Chryssostomidis<br>- Target Localization and Identification for Autonomous Marine Vehicles: LT Konstantinos Mentzelos |
| 1010 - 1030 | Break and Poster Sessions (featuring student theses and projects) |
| 1030 - 1055 | Research Brief: Prof. Alexandra H. Techet<br>- Experimental Study of the Human Interface with One Atmosphere Diving Suit Appendages: LT Chris Wilkins |
| 1055- 1120 | Student Design Project Brief<br>- Arsenal Ship (AFG): LCDR Christopher Wing, LCDR Johnathan Walker, LCDR(s) Roxane Powers, LT Christopher Wilkins |
| 1120 - 1145 | Student Design Project Brief<br>- Future Fast Frigate (3F): LCDR John Genta, LT Mike Rowles, LT Konstantinos Mentzelos |
| 1145 - 1200 | Break and Poster Sessions (featuring student theses and projects) |
| **1200 - 1300** | **Lunch Buffet and Keynote Address**<br>**The Honorable Dennis McGinn, ASN (EI&E)** |
| 1300 - 1320 | Break and Poster Sessions (featuring student theses and projects) |
| 1320 – 1345 | Student Design Project Brief<br>- MUUVership, An Exploration in Submarine-UUV Interfacing and Capability: LCDR Tom Finley, LCDR Timothy Dutton, LT Brandon Zoss, LT Joseph Leavitt |
| 1345 - 1425 | Research Brief: Prof. Alex Slocum<br>- Methods and devices for corrosion fatigue testing without acceleration: LCDR Douglas Jonart |
| 1425 - 1450 | Break and Poster Sessions (featuring student theses and projects) |
| 1450 – 1515 | Research Brief: Prof. Warren Seering and Prof. Dan Frey<br>- Integrating Model Based Engineering and Trade Space Exploration into Naval Acquisitions: LCDR(s) Justin Stepanchick |
| 1515 - 1545 | Student Design Project Brief<br>- Submerged Long Endurance Transport (SUBLET): CDR Nathan Mills, LCDR Jim Colgary, LCDR(s) Justin Stepanchick |
| 1545 – 1600 | Wrap-up and Concluding Remarks |
| **1600** | **Mission Complete** |

# History

In August 1897, the Chief Naval Constructor, Commodore Hichborn requested Massachusetts Institute of Technology to develop and offer a three-year course of study for the professional training of naval constructors. MIT cordially responded to this request and a course of study was agreed upon. The three years of work were designated as the Junior, Senior, and Graduate years. Successful completion of the course led to the Master of Science degree. In 1901, three graduates of the U.S. Naval Academy, Ensigns Ferguson, McEntee, and Spilman, began the course of study under the direction of Professor William Hovgaard.

A 1877 graduate of the Danish Naval Academy in Copenhagen, Hovgaard served in the Danish Royal Navy until 1883 when he was sent to the Royal Naval College in Greenwich, England, to study warship construction. He graduated from its three-year course in 1886 and the next year published his first naval book, "Submarine Boats." In 1901, as a Commander in the Danish Navy, he came to the United States to continue his study of the submarine and was induced by the Secretary of the Navy, John D. Long, to take charge of the new course for naval constructors at MIT. Professor Hovgaard resigned from the Danish Navy as a Captain in 1905. He was head of the new course, designated XIII-A, until 1933 when he retired as a Professor Emeritus. During his years as head of course XIII-A, Professor Hovgaard taught hundreds of naval officers and authored several widely used textbooks.

The Naval Academy graduates sent to MIT for the course officially were attached to the Navy Yard in Charlestown and were registered as regular MIT students. The faculty maintained close relations with the chief constructor in Washington and with the constructors and top civilian staff at the Navy Yard and Fore River Ship and Engine Company in Quincy. This served two purposes: the instruction at MIT was being adapted to the needs of the service, and the faculty could use the work under construction at both yards to illustrate the classroom instruction. The course schedule was arranged to permit the students to spend one afternoon a week at the Navy Yard.

The course for naval constructors differed from the regular course XIII studies in that it was more intensive, more advanced, and was focused on warship design. A feature of the course, presented from the beginning, was that it fully immersed students in the various subjects not only with lectures, but with projects and practical assignments designed to provide hands-on experience in drawing, machine tool work, and laboratories.

Since 1910, instructors in the XIII-A curriculum have also been commissioned U.S. Navy officers. The first, Professor Henry H. W. Keith, with course XIII-A from 1910-1945, was commissioned a Lieutenant Commander in the Corps of Naval Constructors during WWI. Instructor Harold Larner (1916-1917) also held a naval commission and retired as a Captain. From 1910-1945, Course XIII-A relied on long-term instructors such as Professors Hovgaard (Captain, Danish Navy, 1901-1933), Keith (Captain, USN, 1910-1945), and Rossell (Captain, USN, 1931-1946) to lead the naval construction program. In 1945, the Navy's Bureau of Ships inaugurated the practice of detailing two active duty officers as professors for relatively short terms (2-3 years). At any given time, one officer would be a trained and experienced naval architect and the other a naval engineer.

In January of 2005, the Department of Ocean Engineering merged with the Department of Mechanical Engineering. The Naval Construction and Engineering Program, formerly called XIII-A, is now Course 2N in the Center for Ocean Engineering, Department of Mechanical Engineering.

# MIT Naval Construction and Engineering Program Description

The graduate program in Naval Construction and Engineering is intended for active duty officers in the U.S. Navy, U.S. Coast Guard and foreign navies who have been designated for specialization in the design, construction, and repair of naval ships. The curriculum prepares Navy, Coast Guard and foreign officers for careers in ship design and construction and is sponsored by Commander, Naval Sea Systems Command. Besides providing the officers a comprehensive education in naval engineering, we emphasize their future roles as advocates for innovation in ship design and acquisition. All officers write a thesis and we endeavor to direct them toward research that supports the needs of the Navy or the Coast Guard. The course of study consists of either a two-year program, which leads to a Master of Science degree in Naval Architecture and Marine Engineering, or a three-year program, which leads to the degree of Naval Engineer.

The principal objective of both the two and three-year programs is to provide a broad, graduate level technical education for a career as a professional Naval Engineer with ship orientation. In addition to concentrating on hydrodynamics, structures, and design, the curricula of both programs provide an appreciation for total ship engineering in a manner not covered in mechanical, electrical, structural, nor nuclear engineering. This approach provides an academic background for individuals who will later occupy positions of influence and actively participate in the concept formulation, acquisition, construction/modernization, design, maintenance, or industrial support of large-scale ship system programs.

The curriculum emphasizes ship design through a sequence of five subjects. “Projects in New Construction Naval Ship Design” is the last in the sequence of subjects in naval ship design at MIT. This ship design project, along with the graduate thesis, represents the culmination of the three-year Naval Construction and Engineering Program. The ship design project provides each student with the opportunity to develop an original concept design of a naval ship. The project begins during their third summer, continues through the Fall semester and Independent Activities Period and completes in their final Spring semester. The major objectives of the project include: (a) application of their naval architecture and ship design education in a complete concept design process; (b) application of their MIT technical education to at least one area of detailed engineering in this project (e. g., structures, hydrodynamics, signatures); (c) contribution to existing MIT Center for Ocean Engineering design tools; (d) application of at least one new technology and assistance in answering design questions for sponsors. These objectives are the basis for specifying requirements and planning individual projects.

There are two active-duty Engineering Duty Officer faculty for the Naval Construction and Engineering program and officers from the U.S., Hellenic, Israeli, Turkish and Canadian navies and U.S. Coast Guard in the program. Officer students are admitted, and Navy faculty members are appointed, through normal MIT procedures. The program is a model of voluntary collaboration for the mutual benefit of MIT and the Navy.

## The Honorable Dennis McGinn

***Assistant Secretary of the Navy for Energy, Installations and Environment***

Mr. Dennis McGinn was appointed Assistant Secretary of the Navy (Energy, Installations & Environment) Sept. 3, 2013. In this position, McGinn develops Department-wide policies, procedures, advocacy and strategic plans. He also oversees all Department of the Navy functions and programs related to installations, safety, energy, and environment. This includes effective management of Navy and Marine Corps real property, housing, and other facilities; natural and cultural resource protection, planning, and compliance; safety and occupational health for military and civilian personnel; and timely completion of closures and realignments of installations under base closure laws.

McGinn is the former President of the American Council On Renewable Energy (ACORE), an organization dedicated to building a secure and prosperous America with clean, renewable energy. While at ACORE, he led efforts to communicate the significant economic, security and environmental benefits of renewable energy. Mr. McGinn is also a past co-chairman of the CNA Military Advisory Board and an international security senior fellow at the Rocky Mountain Institute.

In 2002, after 35 years of service, Mr. McGinn retired from the Navy after achieving the rank of Vice Admiral. While in the Navy, he served as a naval aviator, test pilot, aircraft carrier commanding officer, and national security strategist. His capstone assignment was as the Deputy Chief of Naval Operations for Warfare Requirements and Programs, where he oversaw the development of future Navy capabilities. In a previous operational leadership role, he commanded the U.S. Third Fleet.

Mr. McGinn is a past member of the Steering Committee of the Energy Future Coalition, the United States Energy Security Council, and the Bipartisan Policy Center Energy Board. He earned a B.S. degree in Naval Engineering from the U.S. Naval Academy; attended the national security program at the Kennedy School of Government, Harvard University; and was a Chief of Naval Operations strategic studies fellow at the U.S. Naval War College

## Gang Chen

***Carl Richard Soderberg Professor of Power Engineering,***
***Department Head, Mechanical Engineering,***
***Director, Pappalardo Micro and Nano Engineering Laboratories,***
***DOE EFRC: Solid-State Solar-Thermal Energy Conversion Center (S3TEC)***

Gang Chen is currently the Head of the Department of Mechanical Engineering and Carl Richard Soderberg Professor of Power Engineering at Massachusetts Institute of Technology (MIT), and is the director of the "Solid-State Solar-Thermal Energy Conversion Center ($S^3$TEC Center)" - an Energy Frontier Research Center funded by the US Department of Energy.

He obtained his bachelor and master degrees from Huazhong University of Science and Technology, and his PhD degree from the Mechanical Engineering Department, UC Berkeley, in 1993. He was an assistant professor at Duke University, a tenured associate professor at UC Los Angeles, before moving to MIT. He is a recipient of a K.C. Wong Education Foundation fellowship and a John Simon Guggenheim Foundation fellowship. He received an NSF Young Investigator Award, an R&D 100 award, and an ASME Heat Transfer Memorial Award. He is a fellow of AAAS, APS, and ASME. In 2010, he was elected a member of the US National Academy of Engineering.

# Dick K.P. Yue

***Philip J. Solondz Professor of Engineering,***
***Skolkovo Foundation Professor or Mechanical Engineering,***
***Professor of Mechanical and Ocean Engineering***

Dick K.P. Yue is the Philip J. Solondz Professor of Engineering, the Skolkovo Foundation Professor of Mechanical Engineering, and Professor of Mechanical and Ocean Engineering at MIT.

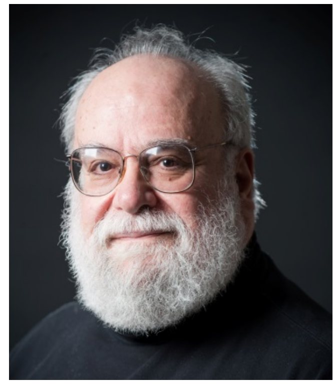
Professor Yue is a long-time MIT'er, having received all his degrees (S.B., S.M. and Sc.D.) in Civil Engineering from MIT. He has been a faculty member in the MIT School of Engineering since 1983. He is active in research and teaching in wave hydrodynamics, fluid mechanics and computational methods with applications to coastal and ocean engineering. Professor Yue is the Director of the Vortical Flow Research Laboratory and co-Director of the MIT Testing Tank facility, supervising an active research group of about 20 members. His main research focus is in theoretical and computational hydrodynamics, and he is internationally recognized for his expertise on ocean and coastal wave dynamics and for his extensive work in nonlinear wave mechanics, and large-amplitude motions and loads on offshore structures. Professor Yue has made seminal contributions in developing modern numerical methods for these problems, notably the development of the high-order spectral method for nonlinear wave-wave, wave-body, and wave-bottom interactions. Professor Yue has also made important contributions to the understanding of hydrodynamics of fish swimming, the complex mechanisms at the air-sea interface and their effects on interfacial processes. He has authored/co-authored more than two hundred papers and a two-volume textbook on theory and applications of ocean wave hydrodynamics.

Professor Yue served as Associate Dean of Engineering from 1999-2007 (as the number two person in the MIT's Office of the Dean of Engineering), and was actively engaged in the overall administration of the School and in its pioneering educational and research initiatives. During that time, he was the originator of the MIT OpenCourseWare (OCW) concept and its formulation and played a major role in its adoption by MIT and then in its successful implementation. Since its launch in 2001, MIT OCW has transformed the global higher education landscape. Under OCW, MIT has published all its teaching materials, over 2,200 courses plus substantial additional learning materials, including resources for high school students. To date, MIT OCW has been translated into many major languages and has been accessed by over 100 million educators and learners worldwide, and has inspired and launched an international consortium (of more than 200 institutions of higher learning from 47 countries) devoted to open educational resources. As well, the introduction of OCW laid the foundation for a potentially even greater educational impact through today's Massive Open Online Courses (MOOCs). Professor Yue is also the Founding Faculty Director of the MIT Engineering Undergraduate Practice Opportunities Program (UPOP), a program that is revolutionizing engineering education by giving undergraduates special training and industry-based work experiences. It addresses the core issue of the lack of career readiness, on-the-job skills and leadership training in traditional engineering education, and thus promotes the future success of MIT's engineering graduates. Currently, UPOP enrolls over half of all engineering majors, with an objective to benefit effectively all of MIT's graduates in the foreseeable future. Professor Yue additionally helped to create and served as the Founding Faculty Director of MIT Engineering Professional Educational Programs (PEP) office, consolidating many of MIT's existing activities in this area under one organization, and creating a focal point for developing new professional and custom educational programs and offerings. In 2008, in recognition of these and other wide-ranging activities benefiting MIT, Professor Yue received the prestigious Gordon Y. Billard Award for services of outstanding merit to the Institute.

Professor Yue is married to the former Miss Eva H. Wu. They have four children: Kevin Paul, Teresa Grace, Emily Joyce, and Brian John. The Yues reside in Weston, Massachusetts.

## Chryssostomos Chryssostomidis

***Henry L. Doherty Professor in Ocean Science and Engineering***
***Professor of Mechanical and Ocean Engineering***



Educated at MIT and at the University of Newcastle-upon-Tyne in naval architecture, Professor Chryssostomidis was appointed to the MIT faculty in 1970 and became a full professor in the Department of Ocean Engineering in 1982. That same year he was appointed director of the MIT Sea Grant College Program where in 1989 he established the MIT Sea Grant Autonomous Underwater Vehicles (AUV) Laboratory to develop technology and systems for advanced autonomous surface and underwater vehicles. Professor Chryssostomidis has also been director of the MIT Ocean Engineering Department Design Laboratory since its inception in the early 1970s. From 1994 to 2002, he served as Department Head of the department of Ocean Engineering where he established the Ocean Engineering Teaching Laboratory. In recognition of his dedication and excellence in teaching, he was awarded the Teaching Innovation Professorship for the MIT School of Engineering which he held from 1991 to 1993.

In 2003, with MIT Sea Grant staff, he created the Sea Perch Program, funded by the Office of Naval Research. The Sea Perch program trains educators across the United States and around the world to build a simple, remotely operated underwater vehicle, or ROV, made from PVC pipe and other inexpensive, easily available materials. Professor Chryssostomidis has supervised a number of undergraduates and graduate students at MIT who have held and continue to hold key positions in academia, industry and Government.

In 1994, he was elected as Fellow of the Society of Naval Architects and Marine Engineering. His over 100 publications display his wide range of interests including design methodology for ships, vortex-induced response of flexible cylinders, underwater vehicle design, design issues in advanced shipbuilding including the all-electric ship and T-Craft. He receives research support from the Office of Naval Research, the National Science Foundation, the Naval Sea Systems Command, and the National Oceanic and Atmospheric Administration, in addition to industry support. Professor Chryssostomidis also has an extensive consulting record. He has served on several National Research Council committees, most recently the National Academy of Engineering and the National Research Council committee for the Analysis of Causes of the Deepwater Horizon Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future. His most recent projects include the design of a new, all-electric, destroyer-class ship for the U.S. surface Navy; designing a system for wireless recharging of vessels and instruments in the open ocean; and numerical modeling and graphic depiction of coastal inundation events.

## Alexandra H. Techet

***Associate Professor of Mechanical and Ocean Engineering***

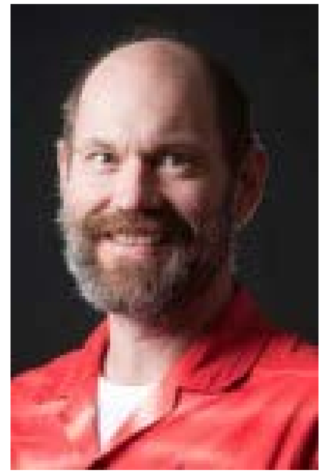

Prof. Alexandra (Alex) Techet is currently an Associate Professor of Mechanical and Ocean Engineering at MIT (with tenure). She first got the ocean bug as a kid growing up on the coast of North Carolina sailing and fixing boats. An avid sailor, SCUBA diver and water-polo player, Alex is drawn to water both in and out of the lab.

She received her B.S.E. in Mechanical and Aerospace Engineering in 1995 from Princeton University and then graduated from the MIT/WHOI Joint Program in Oceanographic Engineering with a M.S. in 1998 and a Ph.D. in 2001. In 2002, after a post-doc at Princeton University in the Mechanical and Aerospace Engineering Department, Prof. Techet returned to MIT as an Assistant Professor in the Dept. of Ocean Engineering. In 2005, Prof. Techet joined the Mechanical Engineering Dept. at MIT when the two departments merged. She also holds a guest appointment at the Woods Hole Oceanographic Institution and works with researchers there to develop oceangoing instrumentation. Professor Techet was a recipient of the 2004 ONR Young Investigators Award. Her imaging work has been recognized several times by the APS Gallery of Fluid Motion and has been featured on the cover of the Journal of Fluid Mechanics.

Professor Techet's research in experimental hydrodynamics has made important contributions to several key areas, including: 3D multi-phase flow imaging, spray hydrodynamics, water entry of spheres and projectiles, flow structure interactions, unsteady bio-inspired propulsion and maneuvering, and sensing at the air/sea interface. The goal of her research is to address long-standing hydrodynamics problems faced by the U. S. Navy and the ocean science and engineering communities through rigorous experimental investigation. Prof. Techet's work provides critical insights for the design and understanding of a wide range of systems that operate in the marine environment, including surface ships, submarines, undersea projectiles, offshore oil platforms, and ocean energy systems.

## Alex Slocum

***Pappalardo Professor of Mechanical Engineering***



Alexander H. Slocum is the Pappalardo Professor of Mechanical Engineering at MIT. Alex has written two books on machine design Precision Machine Design and FUNdaMENTALs of Design (free download on http://pergatory.mit.edu), published more than 150 papers, and has 116+ issued patents. Alex regularly works with companies on the development of new products and has been significantly involved with the invention and development of 11 products that have been awarded R&D 100 awards.

Alex is a Fellow of the ASME and the recipient of the Society of Manufacturing Engineer's Frederick W. Taylor Research Medal, ASME Leonardo daVinci Award, the ASME Machine Design Award, and the Association of Manufacturing Technology Charlie Carter Award.

Alex's areas of interest broadly include precision machine design as applied to machines and instruments for agriculture, healthcare, energy and water systems. He also seeks to help Fellows identify symbiotic opportunities where one system's problem can be another system's opportunity.

## Warren Seering

***Weber-Shaughness Professor of Mechanical Engineering and Engineering Systems***
***Co-Director, System Design and Management Program***

Warren Seering is Weber-Shaugness Professor of Mechanical Engineering and Professor of Engineering Systems. His prior positions at MIT have included Division Head of the Design and Systems Division of Mechanical Engineering, Co-Director of the Nissan Cambridge Basic Research Laboratory, and Co-Director of the MIT Center for Innovation in Product Development.

Professor Seering's research interests include machine dynamics, engineering system design, and product development. His teaching interests center on product development, design and dynamics.

Professor Seering has received numerous honors, among them the Ralph R. Teetor Educational Award from the Society of Automotive Engineers, the MIT Harold E. Edgerton Award, the Lincoln Arc Welding Foundation Design Commendation, a Best Paper Award from the ASME Design Theory and Methodology Conference, the Westinghouse Distinguished Lectureship at the University of Michigan, and the MIT Frank E. Perkins Award for excellence in Graduate Advising. He is a Fellow of the ASME.

Professor Seering is a member of the American Society of Mechanical Engineers and the Design Society. He holds a Ph.D. from Stanford University.

## Daniel D. Frey

***Professor of Mechanical Engineering and Engineering Systems***
***Co-director, Singapore-MIT International Design Center***

Frey's research concerns robust design of engineering systems. Robust design is a set of engineering practices whose aim is to ensure that engineering systems function despite variations due to manufacture, wear, deterioration, and environmental conditions. Frey is also actively involved in design of engineering devices for the developing world.

Professor Frey has worked intensively over the past two years with colleagues, administrators, and the Singapore Ministry of Education to establish a major new research center for engineering design. The Singapore-MIT International Design Center (IDC) is intended to be a source of new design theory, experimental evidence on effectiveness of design methods, improved teaching methods and equipment, and new technologically intensive designs. The IDC is also a nucleus for growth of the new Singapore University of Technology and Design (SUTD), which will begin teaching undergraduates in April 2012. The IDC will have active research and major facilities both at SUTD and at MIT.

Professor Frey has received numerous awards and honors. These include the Junior Bose Award for Excellence in Teaching in 2006, a best paper award from INCOSE in 2005, an NSF CAREER award in 2004; the MIT Department of Aeronautics and Astronautics Teaching Award in 2000; the Everett Moore Baker Memorial Award for Outstanding Undergraduate Teaching at MIT in 1999; and an R&D 100 Award in 1997 (for a virtual machining software he developed) and another R&D 100 Award in 2010 (for a new type of wheelchair he co-invented with a team led by Amos Winter).

Professor Frey is a member of the American Society of Mechanical Engineers (ASME), the American Statistical Association (ASA), the International Council on Systems Engineering (INCOSE), and the American Society of Engineering Education (ASEE). He holds a Ph.D. in Mechanical Engineering from MIT, an MS in Mechanical Engineering from the University of Colorado, and a BS in Aeronautical Engineering from Rensselaer Polytechnic Institute.

# CAPT Joe P. Harbour, USN

***Professor of the Practice of Naval Construction and Engineering***

Born in Ft. Collins, Colorado and raised in Wyoming, he received a Bachelor of Science in Electrical Engineering from the University of Wyoming and received his commission, through the Nuclear Propulsion Officer Candidate (NUPOC) program, at OCS on 01 MAY 1992.

He served as Sonar Officer, Reactor Controls Assistant, Main Propulsion Assistant, Strategic Missile Officer and Tactical Systems Officer on USS Nevada (SSBN 733 (GOLD)), completed seven deterrent patrols, completed his Submarine Warfare qualifications, qualified Engineer for Naval Nuclear Propulsion plants and completed his Strategic Weapons Officer (SD2) qualifications. He was then selected for lateral transfer to the Engineering Duty Officer Community and graduate studies at Massachusetts Institute of Technology (MIT) and was awarded two masters degrees, Naval Engineer and masters in EE, with emphasis on large propulsion electric motors and electric power systems in 2001.

His engineering duty officer tours include service as nuclear and non-nuclear Project Supervisor on submarine and CVN CNO availabilities, Shipyard Docking Officer, Deputy for Test Engineering & Planning and Business & Strategic Planning and as Operations Officer at Portsmouth and Norfolk Naval Shipyards (PNSY & NNSY). Between shipyard tours, he served at NAVSEA HQ WNY as the Ship Design Manager for the Submarine Rescue Diving and Recompression System (SRDRS), ensuring SRDRS met all applicable operation and technical requirements, and completed his tour at HQ as Executive Assistant for NAVSEA 05; Additionally he returned to MIT, as Academic Officer for course 2N, Naval Construction and Engineering Program, where he advised and instructed Naval Construction and Engineering curriculum to some 40 U.S. and foreign naval officers annually. CAPT Harbour also served TDY as an IA to Iraq - serving as the Director of Engineering and Fielding for JCCS-1 conducting counter RCIED Missions. In 2011 he was stationed on U.S. Fleet Forces staff as the Submarine Maintenance Branch Head where he managed Atlantic Fleet submarine maintenance. In 2012, after selection to captain, he transferred to NNSY as the Business and Strategic Planning Officer, where he lead forecasting and budgeting for $1.2B annual budget and 10,000 combined civilian and military workforce. He reported to MIT in July of 2014 as the Curriculum Officer for the Navy's 2N program.

His awards include the Meritorious Service Medal (three awards), Navy and Marine Corps Commendation medal (three awards), Army Commendation Medal and the Meritorious Unit Commendation, and various others. He is a member of the Acquisition Professional Community (APC), Society of Naval Architects and Marine Engineers (SNAME), the American Society of Naval Engineers (ASNE) and the academic society Tau Beta Pi.

## Commander Weston L. Gray, USN

***Associate Professor of the Practice of Naval Construction and Engineering***

Commander (CDR) Weston Gray is married to the former Melony Marie Benson. They have three sons: Frasher, Cason, and Evan.

Born and raised in rural Ohio, CDR Gray graduated from the University of Akron in 1999 with a degree in Electrical Engineering. After graduation, he was commissioned in the Navy and reported to Naval Nuclear Power Training Command (NNPTC) Charleston, South Carolina where he earned distinction as a Master Training Specialist.

CDR Gray lateral transferred to the Engineering Duty Officer (EDO) community in 2003. After the Submarine Officer Basic Course, he reported for duty aboard USS Maryland Gold to begin the EDO dolphin qualification. CDR Gray earned his EDO dolphins at Pearl Harbor Naval Shipyard while serving in various roles including Assistant Project Superintendent and Nuclear Project Engineer. In 2007, he deployed to Iraq in support of Operation Iraqi Freedom. To complete his Engineering Duty qualification, CDR Gray reported to the Massachusetts Institute of Technology (MIT) for graduate studies in 2008 where he took honors in his class and earned degrees in Naval and Electrical Engineering.

Following Graduate School, CDR Gray was assigned to NAVSEA 05 where he developed surface ship energy efficiency initiatives and led a PMS 320 project to create electric supply systems to support high power radars on future surface combatants. In 2012, CDR Gray was assigned as the Project Officer for Next Generation Submarine Electronic Warfare in PMS 435.

CDR Gray is currently serving as Academic Officer and Associate Professor of the Practice for Naval Construction and Engineering at MIT.

Commander Gray has been awarded the Defense Meritorious Service Medal, two Navy Commendation Medals, two Navy Achievement Medals, and various unit and campaign awards. He is a member of the Acquisition Professional Community (APC), the American Society of Naval Engineers (ASNE) and the academic society Tau Beta Pi.

**2016 2N Student Projects**

# 2016 2N Student Theses

# Surface Land Attack Gunner Platform Conversion (BB-AKE)

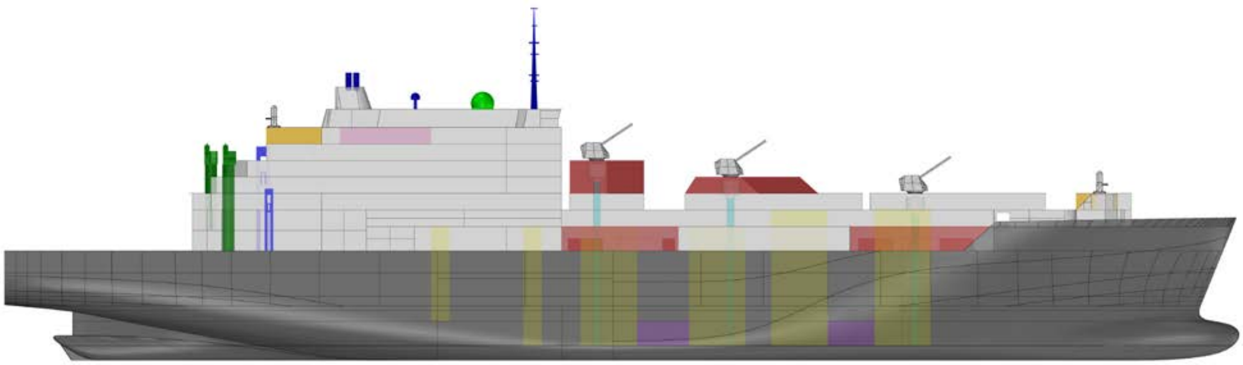
**LT Amber Mason, USN; LT Jessica Olena, USN; LT Justin Parker, USN**

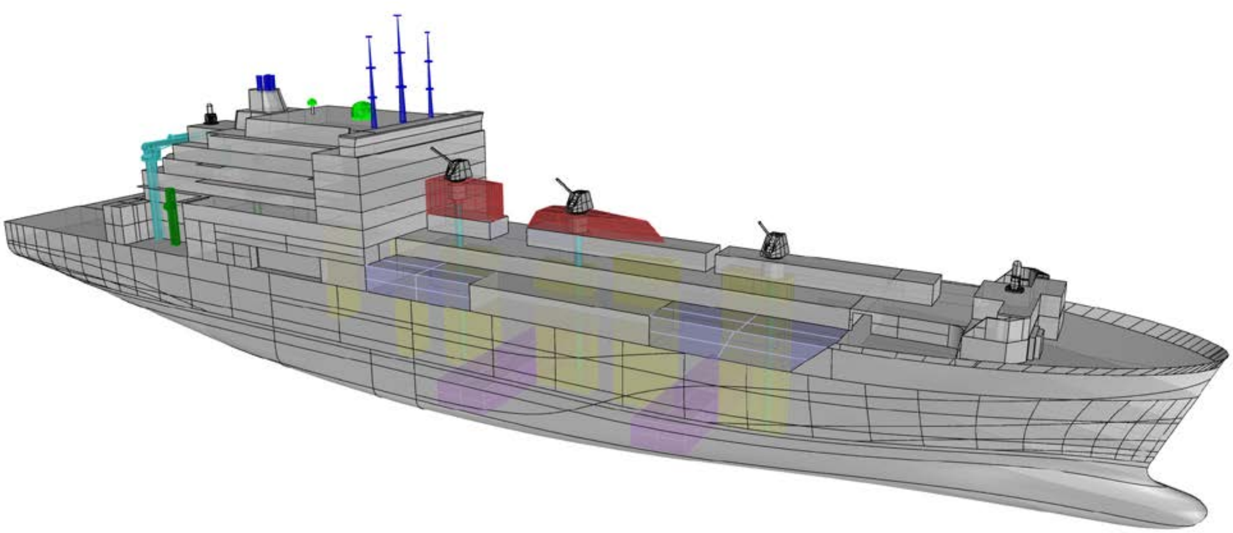
Since the retirement of the last Iowa-class battleship in 1992, the United States Navy has been without a true long-range Naval Surface Fire Support (NSFS) capability for the support of Marine Corps forces ashore. This study evaluated the T-AKE Lewis and Clark-class dry cargo and ammunition ships for conversion into effective, efficient, and economical modern-day battleships. Two specific hulls of this class were targeted for conversion: USNS Lewis and Clark (T-AKE 1) and USNS Sacagawea (T-AKE 2), both forward-deployed as part of the Maritime Prepositioning Force (MPF). More than the other explored options, these hulls provided for a strong secondary mission area by maintaining a portion of the ships' original MPF mission capabilities. Furthermore, as the focus of both missions is support of Marines ashore, the ships are able to retain their current forward-deployed homeports and seamlessly transition between roles.

The final design incorporated the installation of three MK 45 mod 4 5" gun systems arranged in a superfiring configuration forward of the main superstructure. The guns were armed with the forthcoming hypervelocity projectiles (HVP) in order to achieve the required NSFS gunnery range, and large magazines were added to provide a substantial ammunition stowage capacity. Overall, the design decreased total ship weight while maintaining original service life margins and a similar speed profile. The design retains the ability for integration of future weapons such as the railgun in further design iterations.

The table below summarizes the characteristics of the modified ship:

| T-AKE Characteristics | | |
|---|---|---|
| | **PRE-Conversion** | **POST-Conversion** |
| **GMT** | 2.78 m | 2.96 m |
| **Draft at Full Load** | 9.27 m | 9.14 m |
| **Maximum Speed** | 20.62 kts | 20.56 kts |
| **Design Endurance Range** | 16770 NM | 16797 NM |
| **Arrangeable Area** | 24626 $m^2$ | 24894 $m^2$ |
| **Storage Capacity** | 39,800 $m^3$ | 35,730 $m^3$ |
| **Ammunition Hold** | - | 1,800 Rounds HVP;<br>16,000 Rounds 20mm |





# MUUVership
# An Exploration in Submarine UUV Interfacing and Capability

**LCDR Thomas Finley, USN; LCDR Timothy Dutton, USN;
LT Joseph Leavitt, USN; LT Brandon Zoss, USN**

The objective of this study was to develop a concept design for converting an existing submarine design to a platform capable of launching, recovering, and maintaining unmanned underwater vehicles (UUV's). The target platform for the conversion was the Ohio Class Replacement (ORP) design, which was selected based on the available hull volume for hosting large UUV's and the ability for future design and production efforts to leverage ongoing ORP efforts.

Potential design solutions were developed from an array of possible design features, including UUV launch and recovery method, type of personnel-to-UUV interface, and level of available onboard UUV maintenance capability. These solutions were evaluated using an analytical hierarchy that assesses each variant for its potential operational effectiveness and overall risk, in terms of cost and technical concerns. One variant was selected for further refinement, based on a trade-off between performance and risk, along with consideration for likelihood of achieving the study objective.

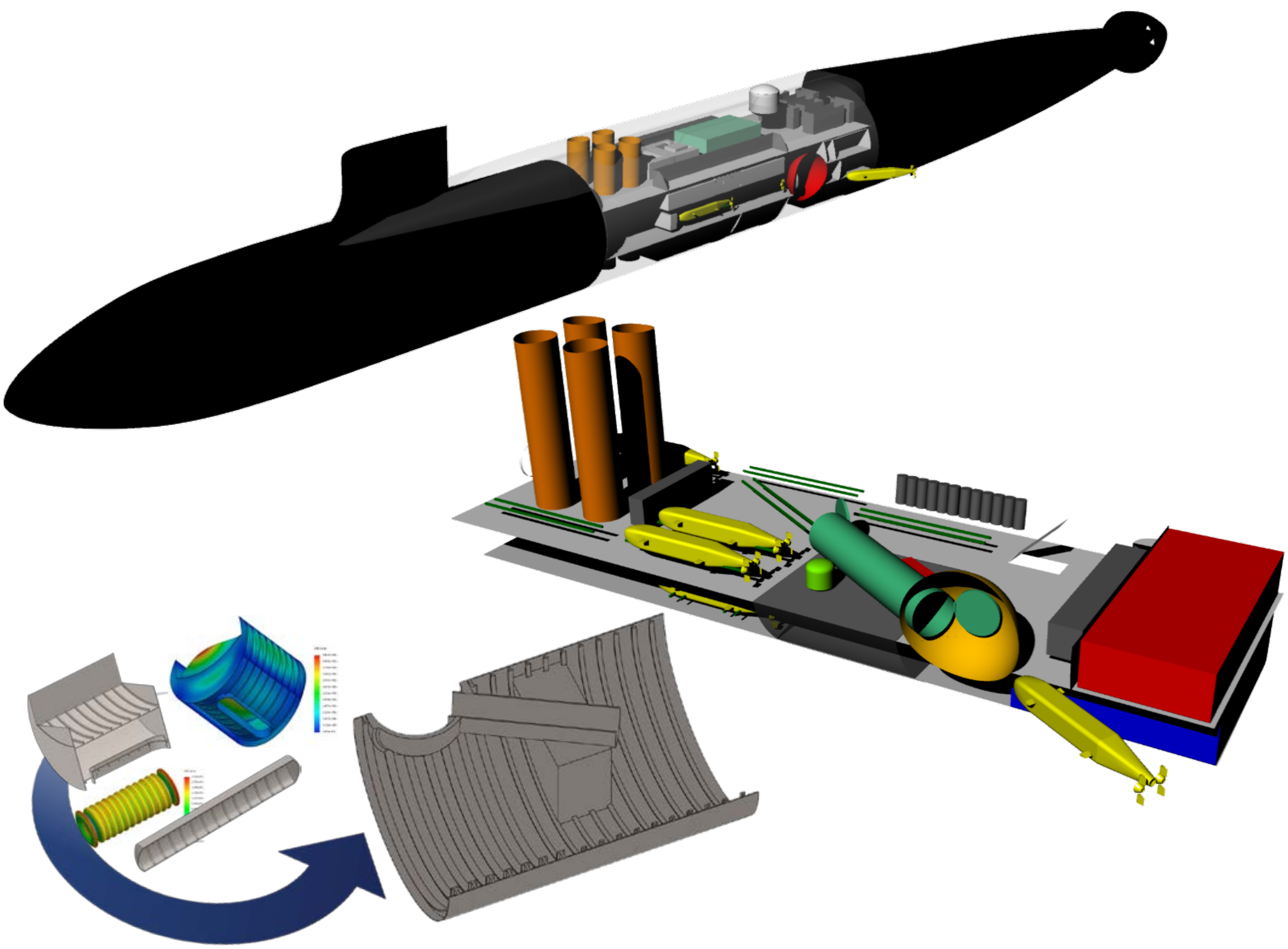
The selected variant consists of the baseline ORP hull with a modified Missile Compartment, in which the first missile quad-pack was retained and the missile tubes were converted to SSGN-type missile tubes while the remainder of the Missile Compartment, aft to the LET, was converted to a UUV launch, recovery, and maintenance module. The main operational component of the module is a torpedo-tube-based UUV launch and recovery interface connected to the hull via a bowl-shaped casting.

The selected concept was refined in terms of major system identification, removal of unnecessary ORP components, general arrangements, structural arrangements, and ship geometry. The refined concept was then analyzed to determine overall concept feasibility, including evaluation of weight and load conditions, lead and variable ballast requirements, general hydrostatic parameters, gross hydrodynamic characteristics, and structural integrity.

The concept analyses show that, overall, the design is feasible, but with major risks with respect to structural arrangements and unknown future UUV technologies, which must be considered in more detail in future design efforts. The final result of the study is a modified ORP-UUV host ship concept design consisting of updated system requirements and a general arrangement specification, along with recommendations for future studies and design developments.

Principle Dimensions with respect to the baseline hull are provided in the proceeding table.

| Parameter | ORP | MUUVership | Delta |
|---|---|---|---|
| LOA (ft) | 561 | 549 | -15 |
| Diameter (ft) | 43 | 43 | 0 |
| Displacement (Submerged) (LT) | 20,810 | 20,184 | -626.5 |
| Displacement (Surfaced) (LT) | | | -604.8 |
| GMT (ft) | | | +0.02 |
| BG (ft) | | | +0.06 |
| Trim (ft) | | | +0.28 |
| Reserve Buoyancy | | | +0.002% |
| LCG (ft aft FP) | | | -6.11 |
| VCG (ft abv BL) | | | -0.91 |



# Expeditionary Support Platform

**LT Michael Beautyman, USN; LT Randall Jagoe, USN; LT Matthew Swezey, USN**

This one-month long conversion design project evaluated a refitted LSD 41 as a carrier and operator of unmanned vehicles. The project explores the methods, requirements, and assumptions to convert a Whidbey Island-class Dock Landing Ship to an Expeditionary Support Platform (ESP). The report concludes with a design concept definition, feasibility analysis, conclusions, and recommendations for future iterations of this idea.

The project sponsor, NAVSEA 05D, requested the conversion of a well deck equipped amphibious ship to carry and tend to unmanned air, surface, and undersea vehicles.

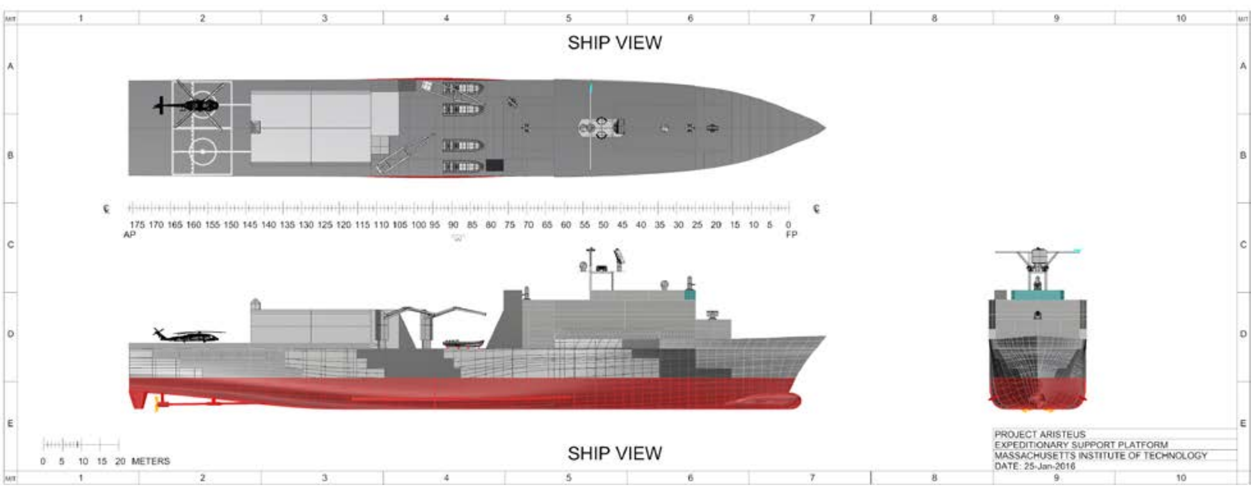
Key performance parameters were established based upon the current and projected capabilities of unmanned vehicles, USN standards, a projected concept of operations, and 2N course practices.

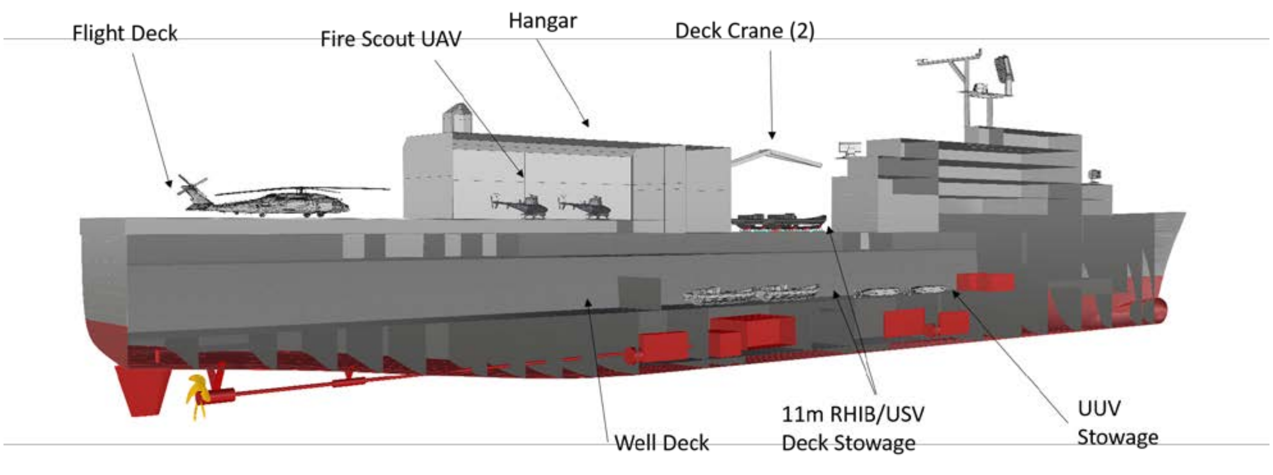
Available well deck equipped ships in the United States Navy vessel registry were reviewed, and LSD 41 was selected. This selection was based on several factors including the parent ship lifecycle, configuration, size, onboard equipment, and manning. Additionally, the requirements of existing and developing unmanned maritime systems were considered. The method of controlled convergence was used in combination with the classical design spiral to choose from several payload and structural variants without delaying the project by exploring too many paths.

The Advanced Ship and Submarine Evaluation Tool (ASSET) was utilized to modify the existing LSD model. The amphibious assault cargo and associated weights were removed, as well as the embarked Marines. Based on research with PMS 406 and the Office of Naval Research, unmanned vehicles, associated support systems (such as cradles and batteries), and upgraded command and control systems were given specific weights and locations on the ship. In addition, a hangar was added over the forward spot of the flight deck, and an additional aviation support space was added forward of the hangar. The well deck was modified with the use of the pre-existing water barrier to divide the deck into a wet launch and operations area and a dry reconfigurable mission area. The ESP is capable of carrying diverse combinations of unmanned systems across all three domains: underwater, surface, and air.

The ESP is a fiscally and structurally feasible concept that takes advantage of the versatility of the LSD 41 hull. The addition of the upgraded command and control suite allows the ship to manage its payload, while the well deck facilitates safe launch of recovery of vehicles in a variety of conditions and mission configurations.

| **Ship Characteristics** | |
|---|---|
| **Parameter** | **Value** |
| *LBP* | 176 meters |
| *Beam* | 25.57 meters |
| *Draft* | 5.92 meters |
| *Depth (Station 10)* | 16.15 meters |
| *Prismatic Coefficient* | 0.618 |
| *Lightship* | 12,563 metric tons |
| *Full Load* | 16,133 metric tons |
| *$GM_t/B$* | 0.143 |
| *Endurance (18 knots)* | 12,093 nm |
| *Maximum Speed* | 23.5 knots |
| *Sustained Speed* | 22.2 knots |
| *Accommodations* | 517 |
| *Conversion Cost* | $40.6 Million |



# Arsenal Ship (AFG)

**LCDR Chris Wing, USN; LCDR Johnathan Walker, USN;
LCDR(s) Roxane Powers, USN, LT Chris Wilkins, USN**

Evolving strategies for Air Warfare and Ballistic Missile Defense require changing our force structure as it pertains to the types of missiles carried onboard ships, specifically against threats using Anti-Access Area Denial (A2AD) tactics. The retiring Guided Missile Submarines (SSGN) and Guided Missile Cruisers (CG) present a capability gap in strike warfare. The AFG Class is designed to close this gap by providing a VLS cell inventory to independently launch Tomahawk Land Attack Missiles (TLAMs) and a remote launch magazine for escort surface combatants.

The AFG Concept of Operations (CONOPS) has 2 modes: independent and joint. In Independent Mode the AFG is fully manned and launches TLAMs to support strike operations. In Joint Mode the AFG becomes a Drone Ship and allows its escorting surface combatant to remote launch the missiles stored on the AFG. In Joint Mode, the AFG crew can be removed and the AFG remotely piloted by a surface combatant escort.

The AFG hull-form is a modified National Security Cutter hull that has traditional negative angles at the waterline but transitions to positive angles at a certain height above the waterline. Therefore, the AFG has a Battle Ballast System included which positions the knee of the hull to the water line, drastically reducing the negative angle cross sectional area and reducing the AFG’s susceptibility.

AFG has 184 VLS cells. It is capable of carrying a combination of TLAMs, Standard Missiles (SMs), and Evolved Sea Sparrow Missiles (ESSMs). The 184-cell total is comprised of two 64-cell Mk 41 VLS and fourteen 4-cell Mk 57 PVLS modules. ESSM, two 25mm deck guns, and countermeasure torpedo systems are included for self-defense.

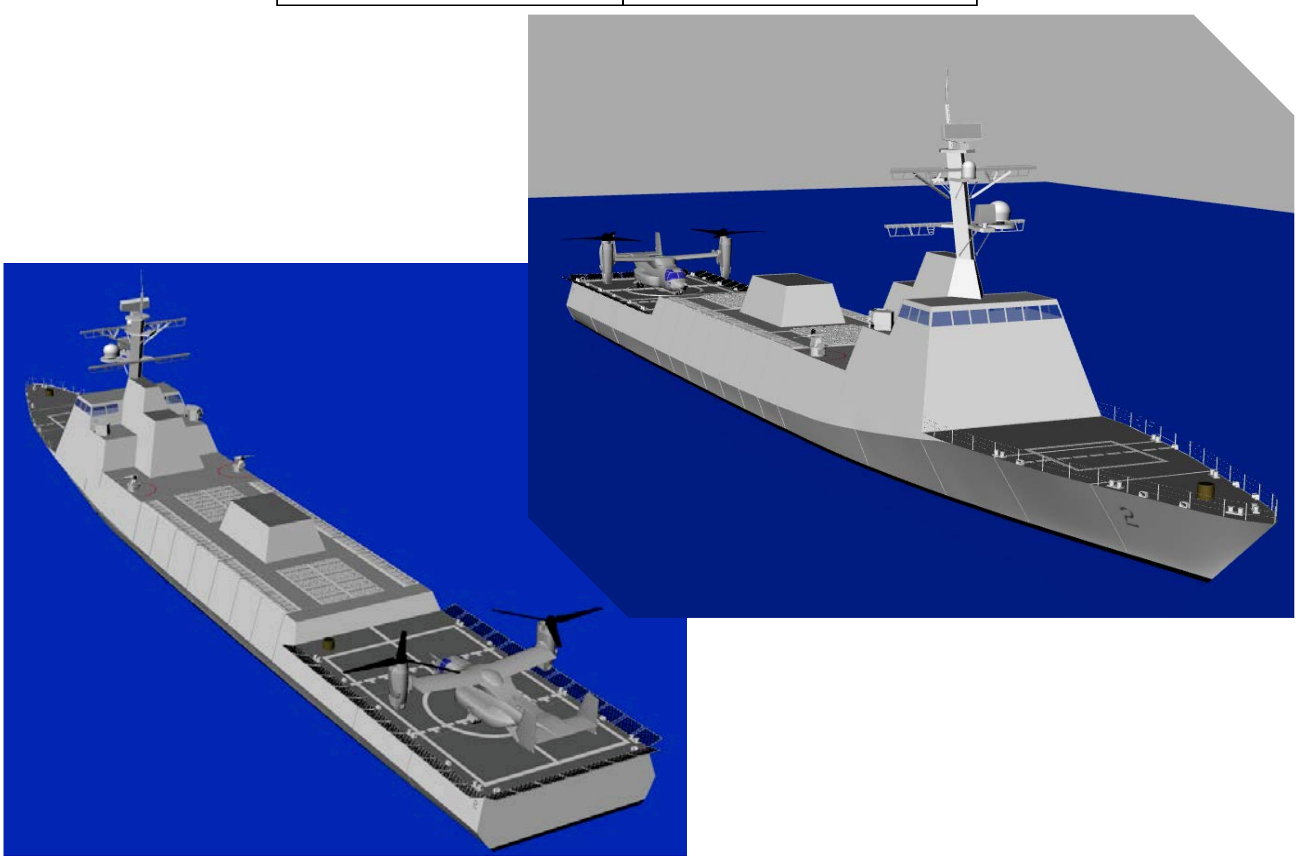
The AFG uses a Total Ship Computing Environment (TSCE) that includes a fully integrated combat system. The AFG also includes high levels of automation to aid in situational awareness, evolutions, coordination, damage detection and containment. This degree of automation allows for a small 48-person crew to operate the AFG and for drone operations when the crew is removed. The ship has the capability to land an MV-22 helicopter for crew transfer.

Power and propulsion is provided through an Integrated Propulsion System (IPS) with two Rolls Royce 6.4MW gas turbines, and one 26MW LM2500+ gas turbine. To allow for future missile growth without shaft interference, the AFG uses two 19MW podded propulsors and has a forward Auxiliary Propulsion Unit for casualty situations.

A minimum survivability baseline was determined in accordance with the Navy’s survivability instruction. The required capability after damage is to retain minimal propulsion in order to leave the battle space with no mission systems in operation. Based on this, the ship’s CONOPS, and the ability to operate the ship unmanned, key design specifications were reduced from the full combatant standard. Most notably, ship primary structure is designed to commercial standards, watertight compartmentation uses a two-compartment flooding standard instead of a 15% length standard, and only systems related to propulsion machinery, command & control, navigation, and ship and propulsion control systems are shock isolated. This set of tailored specifications results in a 22% cost reduction from full combatant standards.

The Initial Concept Design of the AFG illustrates that it is capable of maintaining the VLS missile cell capacity and increasing the precision strike capabilities of the US Navy.

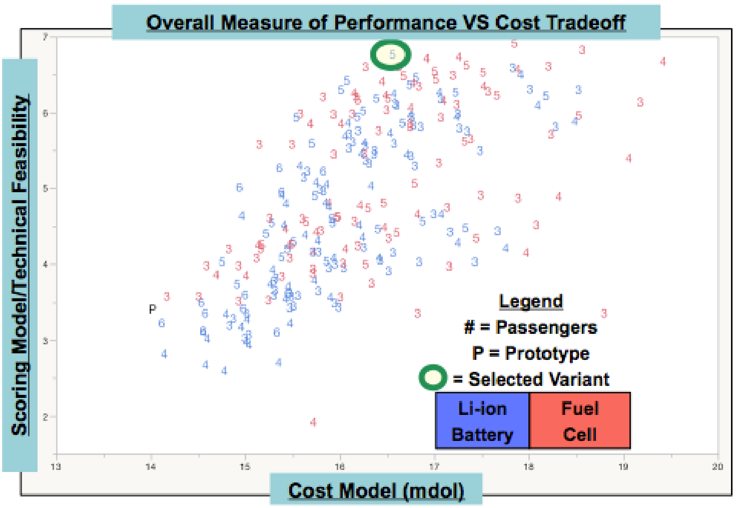
| Ship Characteristics | |
|---|---|
| **Parameter** | **Value** |
| LBP | 110.07 m |
| Beam | 14.88 m |
| Draft | 5.8 m |
| Depth (Station 10) | 10.16 m |
| Prismatic Coefficient | 0.685 |
| Lightship Displacement | 4,212 MT |
| Full Load Displacement | 5,800 MT |
| $GM_T$ | 1.29 m |
| Range | 4,000 nm |
| Maximum Speed | 25.2 knots |
| Sustained Speed | 23.7 knots |
| Lead Ship Cost | $1.14B |
| Follow Ship Cost | $885M |
| Crew | 48 |



# Submerged Long Endurance Transport (SUBLET)

**CDR Nate Mills, USN; LCDR Jim Colgary, USN; LCDR(s) Justin Stepanchick, USN**

This study developed a concept design for a Submerged Long Endurance Transport (SUBLET), a manned, lock in lock out (LIO) capable, dry submersible. (SUBLET) designed for launch and recovery from a modified Dry Deck Shelter (mod-DDS) hosted onboard a submarine. In support of the concept design, the study also sought to quantitatively evaluate the trade space defined by strict limits on volume and weight imposed by the mod-DDS.

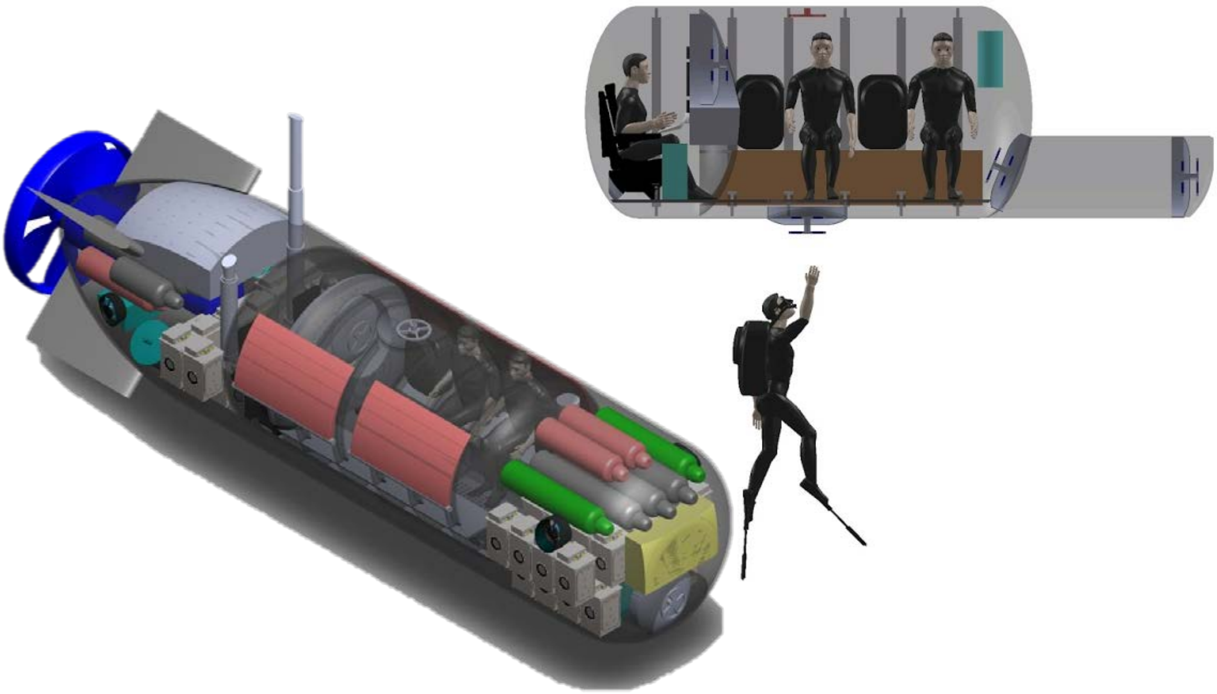



The trade space for the SUBLET was objectively evaluated using progressively layered, custom-built, Excel-based mathematical models. A full factorial Design of Experiments focused on critical design variables, with each variant's feasibility checked by the volume and weight models. The power model then estimated speed and range based on the feasibility model outputs and the variant power plant specifics. These three models supported the next layer of modeling, i.e., a weight-based parametric cost model and an operator-approved scoring model. Analysis of the full design space using the cost and scoring models allowed a cost-performance comparison and revealed Pareto optimal feasible designs. Linking these models provided a robust framework for trade space analysis, and the linked set was delivered to the project sponsor after completion. A dynamic design review using live-updating models and data visualization assisted the project sponsor in choosing the following design variables: a single propeller, 300 ft maximum depth, 120 ft mid-water column LIO depth, and 50 cubic ft of cargo volume. After further analysis of arrangements and balance, the final selection to a 5-person, battery-powered variant was made.

| Design Variable | Value |
|---|---|
| **Passengers** | 5 |
| **Propulsion** | Li-ion Battery 220 kW-hr |
| **Cargo Volume** | 50 cubic ft |
| **Propulsor** | Single Prop |
| **Max Operating Depth** | 300 ft |
| **Max LIO Depth** | 120 ft |
| **LIO Type** | Mid-water column |

Once the trade study was completed, Computer Aided Design illustrated and validated the SUBLET arrangement. The SUBLET passengers and payload enter through a Variable Ballast and Access Trunk (VBAT) and remain in the Command & Control (C&C) and LIO compartments while in transit. Combining the function of access and ballast control in the VBAT simplified SUBLET challenges in arrangement, volume allocation, and trim. When ready for LIO, the SUBLET deploys anchors forward and aft and partially floods the LIO compartment while equalizing pressure with the sea. LIO is primarily conducted through the bottom hatch and is controlled by one operator in the C&C space.

In satisfying the original goals, this project delivered detailed trade study feasibility and performance models, vetted scoring and cost models, and a review of decision criteria for selecting a battery or fuel cell for propulsion power. Overall, this technologically feasible SUBLET concept design provides a significant increase in operational utility over current submarine-launched assets at a reasonable cost.



# Future Fast Frigate (3F)

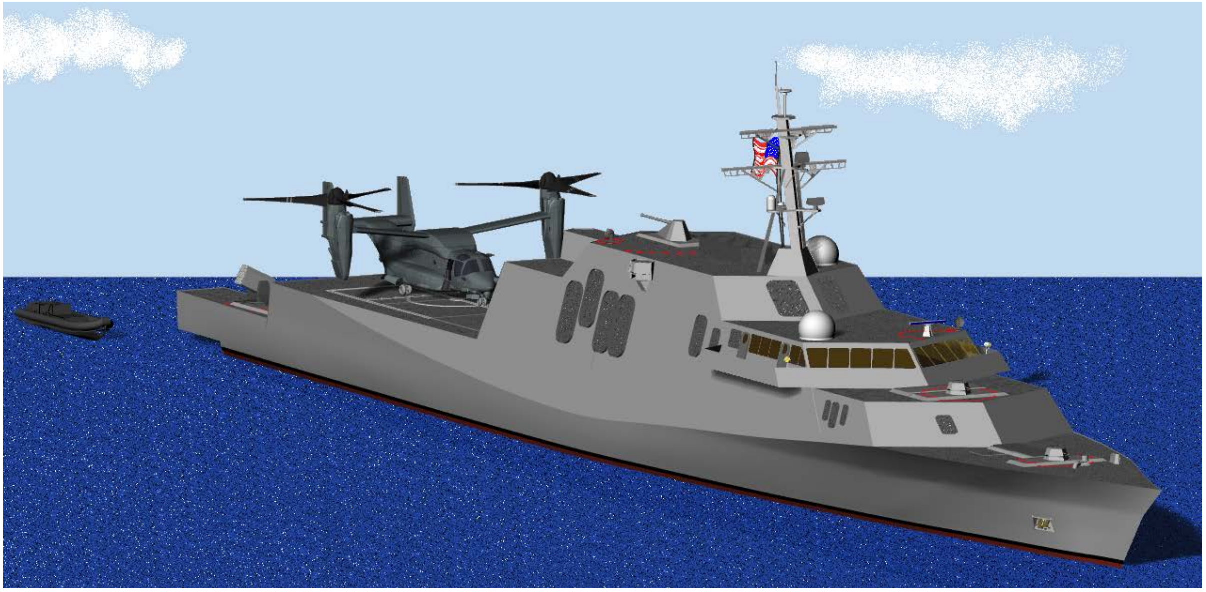
**LCDR John Genta, USN; LT Michael Rowles, USN; LT Konstantinos Mentzelos, HN**

The United States Navy's (USN's) Long-Range Naval Vessel Construction Plan calls for its current and under construction Small Surface Combatant (SSC) ships to be replaced starting in 2030. Program Executive Office LCS has undergone significant recent design and operational achievements that should be considered while designing a follow-on frigate. Concurrently with the procurement of LCS hulls are the three current LCS Mission Packages: SUW, MCM and ASW, along with a worldwide array of mission package maintenance and staging facilities to support the rapid exchange of mission packages on board an LCS or modified-LCS. To support an economical evolution of a technologically and tactically superior frigate design, now is the time to explore the follow-on SSC or Fast Future Frigate (3F).

The design process for 3F was fundamentally the same as for modern combatants; however, the design team accepted the challenge of setting speed and displacement requirements before determining missions for 3F. Thus, several different techniques were explored due to preserve weight and space budgets during early design. The process included selecting the hullform with the least residual resistance and a propulsion concept that incorporates both low fuel consumption and high maintainability/survivability. The selected hullform and propulsion plant were then integrated into a clean sheet ship design using several design tools and methods guided by traditional "spiral" design techniques. An Analytical Hierarchal Priority approach was used to inform mission system configuration design. During detailed arrangement design, survivability and modularity were prioritized where feasible. The design was put through a series of structural and stability analyses along with various sea keeping scenarios to determine the 3F's sea worthiness and mission effectiveness.

The outcomes from this study verify that using the 3F as a basis for future SSC is a feasible solution. The results also demonstrate that the 3F can achieve at least the same missions as a modified-LCS with displacement comparable to a USN frigate.

| **Ship Characteristics** | |
|---|---|
| **Parameter** | **Value** |
| ***LBP*** | 124.1 meters |
| ***Beam*** | 16.2 meters |
| ***Draft*** | 4.7 meters |
| ***Depth (Station 10)*** | 11.2 meters |
| ***Full Load Displacement (without margins)*** | 4,295 metric tons |
| ***Full Load Displacement*** | 4,985 metric tons |
| ***Trim*** | 0.15ºF |
| ***Range*** | 4,970 nm |
| ***Sustained Speed*** | 28 knots |
| ***Accommodations*** | 98 |



## Set-Based Design and US Navy Ship Design and Acquisition

**LCDR John Genta, USN**

| Prof. Warren Seering | Dr. Eric Rebentisch | Prof. Joe Harbour |
|---|---|---|
| Thesis Supervisor | Thesis Supervisor | Thesis Supervisor |

Recent efforts by the Department of Defense Acquisition Executive have focused the department's acquisition improvements with a series of memorandums known as Better Buying Power, driving US Navy ship design and acquisition professionals to better understand ship designs. Near and mid-term ship acquisition is being dominated by expensive, high priority new aircraft carrier and ballistic missile submarine replacement programs, forcing conventional surface ship design and acquisition sponsors to become more efficient. To mimic the results of Toyota Motor Corporation's ability to produce better cars faster in the late 20$^{th}$ century, the US Navy has explored using Toyota's set-based design philosophy for ship design. This project examines the amenability of set-based design across appropriate phases of the US Navy "Two Pass/Six Gate" ship design and acquisition process for conventional surface ships. Results revealed Gate Two and Gate Three are the most amenable to the principles of set-based design; as well as, decision logic for when not to utilize set-based ship design. Researched determined US Navy stakeholder's present ship design improvement priorities are the timeliness and performance of achieving Gate Four. Although set-based ship design has not yet been formally performed for preliminary design in support of developing a System Design Specification sheet for Gate Four, a recommended approach to set-based preliminary ship design is provided to inherently enable the principles of the set-based methodology by initially decomposing the ship along lines of form.

**Naval Engineer**
**Master of Science in System Design and Management**

# Target Localization and Identification for Autonomous Marine Vehicles

**LT K. Mentzelos, HN**

| **Prof. Chryssostomos Chryssostomidist** | **Principle Research Engineer Chathan Cooke** |
|---|---|
| Thesis Supervisor | Thesis Reader |

We present a paradigm for autonomous navigation of marine vehicles based on camera input. The camera video stream is utilized to perform target localization and object identification using state-of-the-art machine learning algorithms. In particular, deep convolutional neural networks are first trained offline using a collection of images of possible targets to be encountered (navy ships, sail boats, power boats, buoys, bridges, etc.). The trained network returns real-time classification predictions with up to 94% accuracy. This information, along with distance and heading relative to the targets taken from the calibrated camera, allows for the precise determination of vehicle position with respect to its surrounding environment and is used to compute safe maneuvering and path planning strategy that conforms to the established marine navigation rules. These algorithms can be used in association with existing tools, such as LiDAR and GPS, towards a completely autonomous marine vehicle. A pilot version of this system will be tested in realistic navigation scenarios in the Boston Harbor area.

**Naval Engineer**
**Master of Science in Mechanical Engineering**

## Design and Testing of a Low-Torque Pan-Tilt Mechanism

**CDR Nate Mills, USN**

| **Prof. David Trumper** | **Prof. Alex Slocum** | **Prof. Weston Gray** |
| --- | --- | --- |
| Thesis Advisor | Thesis Supervisor | Thesis Advisor |

U.S. Navy ships have non-rotating radar and electronic warfare devices installed, which are supported and trained by two-axis gimbals. In current shipboard solutions the payloads are often placed on a platform above the gimbal drive train, which results in high moment loads on drive components during a wave impact. As the payloads grow in size, the moment grows as well, and the current gimbal design is insufficient to support some payload geometries. This thesis presents a novel design of a low-mass two-axis machine that supports large payloads without large impact moments by locating the center of action along the axis of rotation. A functional prototype intended for shipboard installation was manufactured, assembled, and characterized in laboratory tests. The prototype was also subjected to environmental testing to military standards for temperature, vibration, and shock. Future improvements in machine function, promising areas for optimization, and an initial direction for taking the machine from prototype to product are presented.

**Naval Engineer**
**Master of Science in Mechanical Engineering**

# Automation as a Manpower Reduction Strategy in US Navy Ships

**LCDR(s) Roxane Powers, USN**

| **Dr. Bryan R. Moser** | **Prof. Joe Harbour** |
|---|---|
| Thesis Supervisor | Thesis Supervisor |

Over the last decade, the US Navy has pushed to increase the amount and complexity of automated technology employed on Navy ships. Although there are many reasons for this push, one of the main purposes is to reduce the number of personnel required to operate and maintain a ship -- at a dramatic reduction in personnel costs. This type of automation trend has caused ships to evolve from fully manually operated systems into socio-technical systems. The scope of this thesis is bound to a US Navy surface ship as the system. The study began by defining the current framework the US Navy uses to determine manpower requirements for a surface ships. Using a systems engineering approach, a simple diagram of the manpower model identifying all stakeholders, beneficiaries, inputs, and outputs was developed. This model was then used to identify system variables that affect the model throughout its lifecycle. Next, using key acquisition documents from DDG 51, LCS, and DDG 1000 programs, the selection, classification and implementation of automated technology on these platforms were explored. This data was then combined with the baseline manpower model to highlight key manpower/automation decisions versus mission growth over time for each platform. The results will allow key decision makers to better understand the tradeoffs between automation and manpower for ship modernization or new acquisitions.

**Naval Engineer**
**Master of Science in Engineering and Management**

# Integrating Model Based Engineering and Trade Space Exploration into Naval Acquisitions

**LCDR(s) Justin Stepanchick, USN**

| Prof. Warren Seering | Prof. Dan Frey | Prof. Joe Harbour | Bob Bacon |
|---|---|---|---|
| Thesis Supervisor | Thesis Supervisor | Thesis Reader | Draper Supervisor |

The Navy Acquisition force is faced with designing, procuring, and managing some of the most complex systems and technologies ever imagined. Balancing a shrinking and fickle budget environment with a program that has dynamic requirements and scheduling pressures only complicates this already difficult job. While developing these increasingly complex systems, the acquisition process is often faced with major program decisions without a sufficient analysis on a performance-versus-cost tradeoff. To surmount these challenges, the Navy must look at how industries excelled in similar environments.

The concept of Model Based Engineering (MBE) is introduced as a tool that could move Navy Acquisition from document-centric to model-centric, enabling efficiency and confidence in design, as demonstrated by some industries. Model Based Engineering is the practice of bridging models together from requirements to functions, for analysis, design, and verification of a system throughout the lifecycle. A tenet of MBE is model and design validation throughout development to ensure system requirements are met at delivery. Ultimately, the ability to understand and know the effects of changes in a subsystem on the overall performance can vastly improve a system's development. Through the practice of MBE, more confident design and acquisition decisions can be made earlier in the lifecycle. MBE's involves pushing coordination and integration of subsystems as early in development as possible. Applying MBE is demanding but, done successfully brings major benefits, such as reducing expensive rework late in the lifecycle.

Lastly, MBE must start with mathematical and physics-based trade study models. The importance of a thorough, quantitative, and objective trade study is often overlooked or minimized. A robust quantitative trade study allows management to make better performance-versus-cost acquisition decisions when they have the most control over design. Starting with trade space models further embeds MBE into an organization, allowing more model reuse and a greater return on investment.

**Naval Engineer**
**Master of Science in Mechanical Engineering**

# An Experimental Study of the One Atmosphere Diving Suit (ADS) and Data Analysis of Military Diving

**LCDR Jim Colgary, USN**

| **Prof. Alexandra Techet** | **Prof. Joe Harbour** |
| --- | --- |
| Thesis Supervisor | Thesis Reader |

The Atmospheric Diving Suit (ADS) is a one-man submarine with moveable, human-like appendages. As in a submarine, the suit's internal pressure is maintained at one atmosphere. This precludes the possibility of common diving related illnesses while giving the operator an increased depth of operation compared to traditional diving systems. The ADS provides additional capability for industries and militaries around the world, but is not without its own set of unique challenges and limitations. Current ADS maneuverability, specifically that associated with joint rotation, lacks natural movement and range of motion; rendering most normal underwater tasking more challenging and taxing on the operator. Concerns about the lack of maneuverability and usability of the current ADS, primarily raised by the U.S. Navy, and ADS operators, prompted the Office of Naval Research (ONR) to fund an investigation into the "next-generation" ADS. In partnership under a Small Business Technology Transfer (STTR) contract, Midé Technology and MIT teamed up to investigate new joint design. In an effort to better understand the existing ADS, an experimental test was completed with the commercial OceanWorks 1200 ft HARDSUIT™ ADS at Phoenix International in Bayou Vista, LA to characterize the kinematics of elbow and shoulder rotation. Using a suite of six Inertial Measurement Units (IMUs), equivalent ADS elbow and shoulder "flexion/extension" angles were extracted. A custom MATLAB® script was written to process data based on previous MIT IMU research associated with space suit design and other biomedical IMU research throughout medical and sports related fields. The ADS pilots' movement inside the suit characterized the current suit's maneuverability, baselining current capability. It is the intent of this study to inform future joint design by improving the understanding of the current ADS. In conjunction with the kinematic study, a numerical analysis of all military diving data was completed to better understand "how" the military dives. In addition to being presented in this paper, all military dive data is available to the public via www.militarydivingdata.com in an effort to keep the diving community best informed.

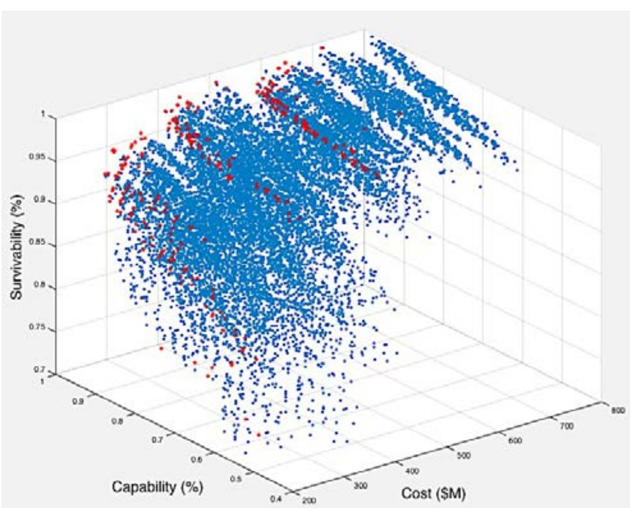
**Naval Engineer**
**Master of Science in Mechanical Engineer**

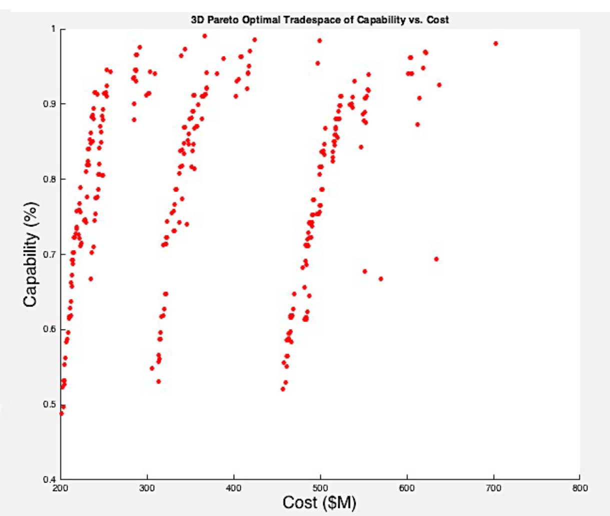
# Multi-Attribute Trade-Space Exploration for US Navy Surface Ship Survivability: A Framework for Balancing Capability, Survivability, and Affordability

**LCDR Johnathan Walker, USN**

| Dr. Eric Rebentisch | Prof. Olivier L. de Weck | Prof. Joe Harbour |
|---|---|---|
| Thesis Supervisor | Thesis Supervisor | Thesis Reader |

In a political environment of austerity it is important to understand the "ility" tradeoffs being made in new ship concept design, specifically between Capability, Survivability, and Affordability. Understanding these tradeoffs early in concept ship design gives Navy leadership real options for affordable ships. A combination of a tightened shipbuilding budget, large high priority procurement programs, and an emphasis on affordability will require high level tradeoffs to be made in future ship programs. Capability and affordability are typical "ility" tradeoffs in ship design. Survivability is an important third dimension that must be considered independently of capability and cost. A specific ship system can be costly and bring survivability to a design but not deliver a level of desired capability. This thesis proposes a framework to perform trade-space exploration by iteratively determining a concept naval ship design's capability, survivability, and cost across large trade-spaces incorporating thousands of concepts. An optimal set of designs is determined using 3-dimensional pareto-optimization methods. This thesis also demonstrates methods to navigate the space bound by the optimized set of designs so tradeoffs can be made while preserving the optimal balance of capability, survivability, and cost. Understanding these tradeoffs ultimately informs the designer the premium that has to be paid for increased survivability for a constant level of capability.




**Naval Engineers**
**Mechanical Engineering**

# Experimental Study of the Human Interface with One Atmosphere Diving Suit Appendages

**LT Christopher Wilkins, USN**

| **Prof. Alexandra Techet** | **Prof. Joe Harbour** |
|---|---|
| Thesis Supervisor | Thesis Reader |

This research provides the first quantitative look at how the human pilot interacts with a modern atmospheric diving suit (ADS) appendage. The ADS is a one person humanoid shaped submarine with articulated appendages manipulated through direct mechanical contact with the human pilot's appendages. The internal pressure of the ADS is maintained at the ambient pressure of the environment at which the pressure vessel is sealed, typically at sea level (approximately 101 kPa), which protects the pilot from exposure to the extreme pressures experienced in the water column.

The evolution of ADS designs have occurred over a period of three hundred years since the first recorded use of an ADS in England for salvaging treasure from sunken wrecks. The most commonly used modern ADS is the HARDSUIT™ designed by Dr. Phil Nuytten, and built by OceanWorks International. The HARDSUIT™ appendages utilizes a series of semi-spheres connected at angles with rotary joints to provide a range of motion similar to human appendages that can be maneuvered manually through direct contact even at depths beyond 2,000 feet of seawater (fsw). The HARDSUIT™ has been in use for decades in both commercial offshore use rated to 1,200 fsw and military submarine rescue capabilities rated at 2000 fsw, but until now there has never been a quantitative study of the interaction between pilot and suit and the forces used to manipulate the appendages.

For this study, an experiment was developed to collect data to analyze the contact forces experienced by the pilot during specific movements of the HARDSUIT™ appendages while submerged. The experiment was conducted using the commercial variant HARDSUIT™ owned and operated by Phoenix International, and the test subjects were volunteers from among their own experienced pilots. The subjects were outfitted with a pressure sensor on the wrist at the major point of contact with the arm appendage, and inertial measurement units were attached along both the pilot arm and the ADS arm to collect joint angle and acceleration measurements. The test subjects were submerged to 10 fsw in a training pool and performed a series of deliberate joint movements and functional tasks for data collection.

The data was analyzed to determine pressures, forces, and torques experienced by the pilots during appendage manipulation as well as determining the impulse (integration of force with respect to time) which was used to measure the level of effort expended throughout each motion. These force measurements were compared to the range of motion and acceleration measurements to normalize the exerted forces to the actual motion of the appendage. An approximation of added mass and drag forces acting on the appendage in motion was calculated to decouple the hydrodynamic resistance from the mechanical rotary joint resistance experienced by the pilots.

The results of this study are intended to inform the ongoing development of new ADS joint technology as well as provide a baseline of modern ADS performance for comparison with future designs.

**Naval Engineer**
**Master of Science in Ocean Engineering**

# Design and Analysis of Marine Sensing Systems: An Environmental Data Collection Swarm

**LT Brandon Zoss, USN**

| **Prof. Yue** | **Grgur Tokic** |
| --- | --- |
| Thesis Supervisor | Thesis Reader |

Recent advances in small-scale portable computing have lead to an explosion in swarming as a viable method to approach large-scale data problems in the commercial, scientific, and defense sectors. This increased attention to large-scale swarm robotics has lead to an increase in swarm intelligence concepts, giving more potential to address issues more effectively and timely than any single unit. Most impressive of the swarm concept is the ability to cover vast areas at a single time, without the need for costly and timely repositioning of expensive assets during the process. However, the majority of today's autonomous platforms are prohibitively costly and too complex for marketable research applications. This is particularly true when considering the demands required to persist in a marine environment.

This work presents a small, portable, and highly maneuverable platform as a method to collect, share, and process environmental data. Our platform is modular, allowing a variety of sensor combinations, and may yield a heterogeneous swarm. Kalman filters are utilized to provide integrated, real-time dynamic self-awareness. In addition to an environmentally savvy platform, we define computational framework and characteristics, which allow complex problems to be solved in a distributed and collective manner. This computational framework includes two methods for scalar field estimation, which rely on low order orthogonal Hermite basis functions. Low order fits provide a natural method for low-pass filtering, thus avoiding ambient noise recovery in the reconstruction process. Real-time environmental sampling and recovery allow for autonomous behaviors driven environmentally through globally measured parameters. Finally, we give evidence that large numbers can collectively tackle large-scale problems much more efficiently and timely than more capable and expensive units. This is particularly true when utilizing a unique methodology, presented herein, to best assemble in order to most affectively aggregate target parameters.

**Master of Science in Marine Engineering and Naval Architecture**
**Master of Science in Mechanical Engineering**

# Ocean Acoustic Uncertainty for Submarine Applications

**LT Matthew Swezey, USN**

| **Prof. Pierre Lermusiaux** | **Dr. Patrick Haley** |
|---|---|
| Thesis Supervisor | Thesis Reader |

The focus of this research is to determine the effects of uncertainties in dynamic ocean environments and quantify how those uncertainties affect the resulting acoustic pressure field. The quantified uncertainty can be used to provide enhanced sonar performance predictions for tactical decision aides.

High fidelity robust modeling of the oceans can resolve various scale processes from tidal shifts to mesoscale phenomena. These ocean models can be coupled with acoustic models that account for variations in the ocean environment and complex bathymetry to yield accurate acoustic field representations that are both range and time independent. Utilizing the MIT Multidisciplinary Environmental Assimilation System (MSEAS) primitive equation ocean model and Error Subspace Statistical Estimation scheme (ESSE), coupled with 3D parabolic equation acoustic models, we conduct a study to understand and determine the effects of ocean state uncertainty on the transmission loss.

The data utilized in this study was collected during the 2008 Quantifying, Predicting and Exploiting Uncertainty exercise. The region of study is focused on the ocean waters surrounding Taiwan in the East China Sea. This region contains complex ocean dynamics and topography along the critical shelf-break region where the ocean acoustic interaction is driven by several uncertainties. The 4D ocean models are used to simulate both 2D and 3D acoustic fields for analysis. The resulting ocean acoustic uncertainty is analyzed to quantify sonar performance and uncertainty characteristics with respect to submarine counter detection. Utilizing cluster based data analysis techniques the relationship between the resulting acoustic field and the uncertainty in the ocean model can be characterized. Furthermore, the dynamic transitioning be- tween the clustered acoustic states can be modeled as Markov process. This analysis can be used to enhance not only submarine counter detection aides, but it may also be used for applications in the study of acoustic communications and acoustic navigation systems to enhance understanding of the capabilities and behavior of uncertainties in these systems.

**Master of Science in Naval Architecture and Marine Engineering**
**Master of Science in Mechanical Engineering**

# Optical Orientation and Deformation Sensing

**LCDR Christopher Wing, USN**

| **Prof. Mathias Kolle** | **Prof. Joe Harbour** |
|---|---|
| Thesis Supervisor | Thesis Reader |

Mechanical systems throughout the marine industry are sensitive to large environmental forces that produce undesired deformations and changes in alignment. Passive systems that visually indicate these occurrences might be possible to fabricate based on naturally occurring micro-scale structural geometries that are optically sensitive to changes in relative orientations or dimensions. Specifically, production of a thin film whose surfaces feature appropriately customized mimics of the structures on some butterfly wings might provide a low-cost, easy-to-install system. Rigid optical mimics of micro-cavity arrays with a conformal Bragg reflector coating have been already been produced which generate iridescent reflections similar to their performance on the wings of the green swallowtail butterfly (*Papilio blumei*). The spherical geometry of these cavities results in the ability to easily define the necessary reflection paths within these cavities to affect the visual signature for a far-field observer. These paths always include only the points existing on certain discrete circular rings within the cavity and the position of these rings are defined by the relative angle of the incident light. Application of a carefully designed conformal Bragg reflector (which has a different incidence angle at each ring location) allows for control the of individual response of each of these reflection paths.

This project examined the potential for embedding customized versions of these structures within a thin film for use as a passive sensor for visual indication of excessive deformations and/or misalignments in sensitive mechanical equipment. A MATLAB-based simulation program was developed that estimated the optical characteristics of cavities within the full range of geometry options – cavity radius and closure extent - for any given Bragg mirror combination – materials, number, and thicknesses of layers. This allowed for quick definition of an entire reflection tradespace and subsequent selection of custom fabrication parameters that should provide an optimal visual response for any target application (chosen deflection limit in a particular lighting environment).

A simulation for a chosen system was used to predict the visual appearance of a coated sample as a function of relative angle. A rigid prototype with matching parameters was produced and its reflected spectra were measured for the same relative angles. The results of these two methods were then compared to validate the simulation/selection method.

**Naval Engineer**
**Master of Science in Mechanical Engineering**

## Examination of Doubly Fed Electric Machines in Naval Engineering Applications

**LT Michael Rowles, USN**

| **Prof. James L. Kirtley** |
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| Thesis Supervisor |


Early stage design effort is universally accepted as a primary force-multiplier towards minimizing life cycle costs in complex engineering. Naval power and propulsion development is among some of the earliest stage design effort made to control life cycle costs and accommodate production workflow. Selection of marine power and propulsion architectures for both new ship design and conversion involve performance modeling of potential systems under conditions developed through predictive analytics and established criteria. Component selection is made based on optimal matching of equipment performance to a developed operating profile. This three-dimensional “fuel map" is a two-degree of freedom performance relationship of power, speed, and fuel consumption. Upon selection and installation, however, plant operation devolves into a single degree of freedom “fuel curve” where power is required to achieve a specific shaft speed (propeller RPM to achieve thrust, fixed frequency electric power).

Off-design operation of the combustion power plants reduces operating efficiency and impacts maintenance requirements. Jointly this increases life cycle costs which impacts the overall utility of the platform. Ship design volume and weight budgets are also consumed by the need to have available power in reserve for maximum vice normal power demand further limiting the design utility. Integrated electric power plants have begun to address off-design operation through optimal prime mover loading and more versatile plant line-ups. Fundamentally, though, these inherent inefficiencies remains at some level due to the single degree of freedom of the prime mover output. Doubly-fed electric machines (DFEM) restore the second degree of freedom to that so greatly affects combustion prime mover output. DFEM power density is greater with reduced control and support footprint in comparison to traditional electric machines.

This project seeks to evaluate the incorporation doubly-fed electric machines into the naval power and propulsion architecture development. Results show more optimal plant operations are achieved for a given profile improving platform life cycle costs through reduced fuel consumption and maintenance demand. Research also indicates ship design managers can realize greater flexibility and improvement in their synthesis of solutions to address program requirements increasing the overall utility of fleet acquisitions.

**Naval Engineer**
**Master of Science in Mechanical Engineering**

# Methods and Devices for Corrosion Fatigue Testing without Acceleration

**LCDR Douglas Jonart, USN**

| Prof. Alex Slocum | Prof. Ronald Ballinger | Prof. Joe Harbour | Dr. David Johnson |
|---|---|---|---|
| Thesis Supervisor | Thesis Supervisor | Committee Member | Committee Member |

The US Navy is currently designing a class of submarines to replace the OHIO class vessels. If the new design can tolerate shaft removal and inspection every twelve years, vice the current 6, then fewer vessels are required to meet the operational requirements of the class, saving billions of dollars. The current limit on shaft design is corrosion fatigue, a complex process that is notoriously hard to model and therefore to predict. Corrosion fatigue lifetime depends on loading frequency and on temperature, complicating or eliminating approaches to accelerated testing that might otherwise help designers explore and verify the performance and reliability of designs and proposed designs. Existing test devices do not provide the right combination of frequency, multi-axial loading, exposure to environment, and test longevity to recreate the conditions experienced by operational submarine shafting. Two solutions are presented. First, a probabilistic model is developed that makes predictions on each of the stages of the corrosion fatigue process and integrates them to make life predictions of shafting. Testing is demonstrated on select component stages to validate and begin to calibrate the model. This model is an extension of earlier work, and this method would require a significant test program to complete the data set needed to turn the model into a robust tool for shaft designers. Second, two machines are developed that better recreate the experience of submarine propulsion shafting. Both machines combine bending, torsion, and seawater immersion. The first machine was created as a proof-of-concept prototype, but is being adopted by the Navy for baseline testing, and is therefore improved upon as part of the current project. The second machine provides for very long test durations, and provides a new capability for designers to evaluate and especially to verify submarine shafting system designs.

**Doctor of Philosophy in Mechanical Engineering**

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