Naval Construction and Engineering

Ship Design and Technology Symposium

Thursday, May 4, 2017

MIT Samberg Conference Center, 50 Memorial Drive

Building E52-Seventh Floor, Dining Rooms M & I

0800 - 0845	Registration and Continental Breakfast
0845 - 0900	Welcome and Opening Remarks - CAPT Joe Harbour, USN; Director, Naval Construction and Engineering - Prof. Dick Yue; Head, Ocean Science and Engineering Area
0900 - 0925	Student Conversion Project Brief Structural Feasibility Assessment of a D0 Ice-Classed LCS: LCDR Sjaak de Vlaming, LT Jordan Fouquette
0925 - 0950	Research Brief: Prof. Themis Sapsis - Design, Evaluation, and Validation of a Naval Ship Structural Health Monitoring Tool: LT Jessica Olena
0950 - 1010	Break and Poster Sessions (featuring student theses and projects)
1010 - 1035	Student Design Project Brief - SOC-R(X) Next Generation Riverine Craft: LCDR Timothy Dutton, LT Justin Parker
1035- 1100	Research Brief: Prof. Henrik Schmidt - Analysis of Dynamic Acoustic Source Positioning: An Autonomous Swarm Approach: LT Matt DiVittore
1100 - 1125	Student Conversion Project Brief - Conventional Submarine Converted to Carry Unmanned Undersea Vehicles: LCDR J. Ben Thomson, LT Matthew DiVittore, LT Benjamin Parker
1125 - 1200	Break and Poster Sessions (featuring student theses and projects)
1200 - 1300	**Lunch Buffet and Keynote Address** **RADM Brian Antonio, USN – Program Executive Officer, Aircraft Carriers**
1300 - 1320	Break and Poster Sessions (featuring student theses and projects)
1320 – 1345	Student Design Project Brief - Submersible Support Vessel: LCDR Randall Jagoe, LT Michael Beautyman, LT Jessica Olena
1345 - 1410	Research Brief: Prof. John Leonard - Intent Aware Collision Avoidance for Autonomous Marine Vehicles: LT Joseph Leavitt
1410 - 1430	Break and Poster Sessions (featuring student theses and projects)
1430 – 1455	Student Conversion Project Brief - DDG 51 Flight III with ADC Capability: LCDR Nathaniel Byrd, LT Adam Campbell, LT David Ingraham
1455 - 1520	Student Design Project Brief - Medium Displacement Unmanned Surveillance Asset (MDUSA): LCDR Thomas Finley, LCDR Amber Mason, LT Joseph Leavitt
1520 – 1530	Wrap-up and Concluding Remarks
1530	**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.

An 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.

Rear Admiral Brian Antonio, USN

Program Executive Officer, Aircraft Carriers

Rear Adm. Brian Antonio graduated from the U.S. Naval Academy in 1983 with a Bachelor of Science in Naval Architecture. He also earned a Master of Science in Mechanical Engineering as well as a naval engineer's degree in 1990 from the Massachusetts Institute of Technology.

Upon commissioning, he served aboard USS Peterson (DD 969) as an anti-submarine warfare officer and damage control assistant. He subsequently was approved for lateral transfer to the engineering duty officer community.

As an engineering duty officer, Antonio's tours include ship superintendent, Norfolk Naval Shipyard; budget officer; Atlantic Fleet Maintenance Officer's Staff; acquisition manager, USS San Antonio (LPD 17) Class New Construction Program (PMS 317); operations cycle director, Surface Combatant Modernization Program Office (PMS 400F); ship design manager, Future Aircraft Carriers (SEA 05); and chief of staff, deputy assistant secretary of the Navy for Ship Programs. From 2007 to 2011, Antonio served as the major program manager for Future Aircraft Carriers (PMS 378).

While serving as executive assistant and naval aide to the assistant secretary of the Navy for Research, Development and Acquisition, Antonio was selected for promotion to flag rank and was assigned as fleet maintenance officer on the staff of the U.S. Pacific Fleet. In September 2013, he returned to Washington, D.C., and served as program executive officer for littoral combat ships. He assumed duties as program executive officer for aircraft carriers in June 2016.

Antonio is a qualified surface warfare officer. His personal awards include the Distinguished Service Medal, Legion of Merit (four awards) and Meritorious Service Medal (five awards).

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^3TEC 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, Sc.D

Philip J. Solondz Professor of Engineering
Professor of Mechanical and Ocean Engineering

Dick K.P. Yue is the Philip J. Solondz Professor of 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 some three 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. Professor Yue was the Engineering School Director of International Programs 2007-2013, and the MIT Director of the Singapore-MIT Alliance (SMA). 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.

Michael S. Triantafyllou

William I. Koch Professor of Marine Technology,
Director of the Center for Ocean Engineering

Undergraduate studies (1969-1974) in Naval Architecture & Marine Engineering at the National Technical University of Athens, graduate studies in Ocean Engineering at MIT (SM Ocean Engineering, SM Mechanical Engineering 1977, ScD 1979).

Assistant Professor (1979-83), Associate Professor (1983-90), Professor (1990-2004), Department of Ocean Engineering, MIT; Professor of Mechanical and Ocean Engineering (since 2004). He has published in the areas of dynamics and control of marine systems, experimental fluid mechanics, and biomimetics: M.S. Triantafyllou & G.S. Triantafyllou, 1995, "An Efficient Swimming Machine", *Scientific American*, 272, 64-70. M.S. Triantafyllou, G.S. Triantafyllou, D.K.P. Yue, 2000, "Hydrodynamics of Fish Swimming", *Annual Review of Fluid Mechanics*, 32, 33-53. J.C. Liao, D.N. Beal, G.V. Lauder, & M.S. Triantafyllou, 2003, "Fish exploiting vortices use less muscle", *Science*, 302 (5650), 1461-1608, November 28, 2003.

Prof. Triantafyllou is a member of the Society of Naval Architects & Marine Engineers, the American Physical Society, the American Society of Mechanical Engineers, and the Intern. Society for Offshore & Polar Engineers. Honors and Awards include: William I Koch Professorhip in Marine Technology (since 2008), Cover of *Science* (2003), RoboTuna on permanent exhibit at the Museum of Science, London (since 1998); prototype *RoboTuna* in national traveling exhibit on robots, Science Museum of Minnesota (2003-2004). Visiting Professor, ETH Zurich (1999), NTU Athens (1994, 2000), NTH Norway (1993), Kyushu U. (1986). *Discover Magazine* Awards for Technological Innovation (1998). ABS/Linnard Prize for best paper in the *Transactions of SNAME* (1997). Highlight Paper of 1995 *Scientific American*. H. L. Doherty Professorship in Ocean Utilization (1983-1985).

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.

Henrik Schmidt

Professor of Mechanical and Ocean Engineering

Henrik Schmidt is Professor of Mechanical & Ocean Engineering at the Massachusetts Institute of Technology. He received his MS degree from The Technical University of Denmark in 1974, and his PhD. from the same institution in 1978. From 1978 to 1982 he worked as a Research Fellow at Risoe National Laboratory in Denmark. From 1982 to 1987 he worked as Scientist and Senior Scientist at the NATO SACLANT ASW Research Centre in Italy. He has been on the MIT faculty since 1987. He has served as Associate Director of Research at the MIT Sea Grant College Program from 1989-2002, and as Associate Department Head 1994-2002. He served as Acting Department Head of Ocean Engineering from 2002 - 2004. Professor Schmidt's research has focused on underwater acoustic propagation and signal processing, in particular on the interaction of sound in the ocean with seismic waves in the ocean bottom and the Arctic ice cover. His work has been of theoretical, numerical and experimental nature. He has been Principal Investigator in two Arctic ice station experiments, and Chief Scientist for several recent, major experiments in coastal environments. He has developed numerically efficient numerical algorithms for propagation of acoustic and seismic waves in the ocean and solid earth environment, including the SAFARI and OASES codes which are used as a reference propagation models in more than 100 institutions around the world, including all US Navy laboratories and most major universities involved in underwater acoustics and seismic research. In recent years Professor Schmidt has been pioneering the development of new underwater acoustic sensing concepts for networks of small Autonomous Underwater Vehicles (AUV) for distributed MCM and ASW. Prof. Schmidt was lead-PI for the multi-institutional PLUSNet team developing a distributed, autonomous acoustic sensing concept, under the ONR Undersea Persistent Surveillance Program. In addition to a long string of papers in the archival literature, Professor Schmidt has co-authored a textbook on computational ocean acoustics. He is a Fellow of the Acoustical Society of America (ASA), and he was the 2005 recipient of the ASA "Pioneer of Underwater Acoustics" medal.

John Leonard

Professor of Mechanical and Ocean Engineering
Samuel C. Collins Professor

John J. Leonard is a Professor of Mechanical and Ocean Engineering. He is also a member of the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL). His research addresses the problems of navigation and mapping for autonomous mobile robots. He holds the degrees of B.S.E.E. in Electrical Engineering and Science from the University of Pennsylvania (1987) and D.Phil. in Engineering Science from the University of Oxford (1994). He studied at Oxford under a Thouron Fellowship and Research Assistantship funded by the ESPRIT program of the European Community. Prof. Leonard joined the MIT faculty in 1996, after five years as a Post-Doctoral Fellow and Research Scientist in the MIT Sea Grant Autonomous Underwater Vehicle (AUV) Laboratory. He has served an associate editor of the IEEE Journal of Oceanic Engineering and of the IEEE Transactions on Robotics and Automation, and is an IEEE Fellow. He was team leader for MIT's DARPA Urban Challenge team, which was one of eleven teams to qualify for the Urban Challenge final event and one of six teams to complete the race. He is the recipient of an NSF Career Award (1998), an E.T.S. Walton Visitor Award from Science Foundation Ireland (2004), the King-Sun Fu Memorial Best Transactions on Robotics Paper Award (2006).

Jacopo Buongiorno

TEPCO Professor and Associate Department Head, Nuclear Science and Engineering
Director, Center for Advanced Nuclear Energy Systems (CANES)

Jacopo Buongiorno is the TEPCO Professor and Associate Department Head of Nuclear Science and Engineering at the Massachusetts Institute of Technology (MIT), where he teaches a variety of undergraduate and graduate courses in thermo-fluids engineering and nuclear reactor engineering.

Jacopo has published over 70 journal articles in the areas of reactor safety and design, two-phase flow and heat transfer, and nanofluid technology. For his research work and his teaching at MIT he won several awards, including, recently, the Ruth and Joel Spira Award (MIT, 2015), and the Landis Young Member Engineering Achievement Award (American Nuclear Society, 2011).

He is the Director of the Center for Advanced Energy Systems (CANES), which is one of eight Low-Carbon-Energy Centers (LCEC) of the MIT Energy initiative (MITEI), as well as the Director of the MIT study on the Future of Nuclear Energy in a Carbon-Constrained World. Jacopo is a consultant for the nuclear industry in the area of reactor thermal-hydraulics, and a member of the Accrediting Board of the National Academy of Nuclear Training. He is also a member of the Naval Studies Board (National Academies of Sciences, Engineering, and Medicine), the American Nuclear Society (including service on its Special Committee on Fukushima in 2011-2012), the American Society of Mechanical Engineers, and a participant in the Defense Science Study Group (2014-2015).

Tomasz Wierzbicki

Professor of Applied Mechanics

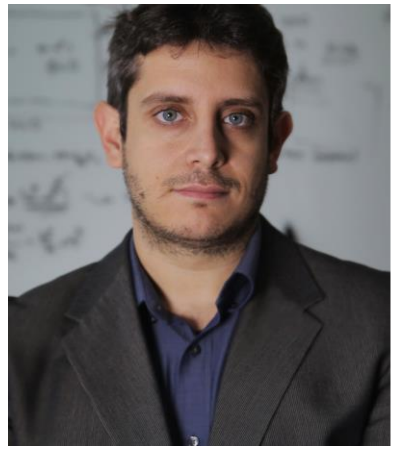
Director, Impact and Crashworthiness Laboratory

Professor Tomasz Wierzbicki received his MS degree from the Department of Mechanical Engineering of the Warsaw Technical University. He earned his PhD degree in 1965 from the Institute of Fundamental Technological Research under the supervision of Professor Piotr Perzena of the Polish Academy of Sciences. Soon after that, he went for a one year postdoctoral study at Stanford University and collaborated with Professor E. H. Lee. In 1981, he was promoted to a full professor at the Polish Academy of Sciences and in the same year, he left for the United States, which has become his home.

In 1983, he was appointed as a full professor at MIT, where he is currently directing the Impact and Crashworthiness Lab. He is the author of over 150 papers published in major international journals. In 1986, he received the Alexander von Humboldt senior US scientist award. Professor Wierzbicki spent over three years working in the BMW R&D Department in Munich. He directed a number of large industry oriented programs at MIT with the support of over 50 major automotive, aluminum and shipbuilding companies. Professor Wierzbicki's research and consulting interests are in the area of dynamic plasticity, structural failure, crashworthiness, ultralight material, and more recently ductile fracture. As of August 2007, he became an Associate Editor of the *International Journal of Impact Engineering*.

Themis Sapsis

Associate Professor of Ocean Engineering



Dr. Sapsis is an Associate Professor of Mechanical and Ocean Engineering at MIT, where he has been a faculty since 2013. He received a diploma in Ocean Engineering from Technical University of Athens, Greece and a Ph.D. in Mechanical Engineering from MIT. Before becoming a faculty at MIT, he was appointed Research Scientist at the Courant Institute of Mathematical Sciences at New York University. His research interests focus on the development of order-reduction and stochastic methods for the analysis of dynamical systems characterized by complex processes, uncertainty and extreme events. He is the recipient of three Young Investigator Awards (Naval-, Army- and Air-Force- research office), as well as the Alfred P. Sloan Foundation Award.

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 led 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.

Lieutenant Commander Jonathan E. Page, USN

Associate Professor of the Practice of Naval Construction and Engineering

Lieutenant Commander (LCDR) Jon Page is a native of Canton, Michigan. He graduated from the United States Naval Academy in 2002, earning his commission and a Bachelor of Science in Systems Engineering. He also holds a Master of Science in Engineering Management and a Naval Engineer's Degree from the Massachusetts Institute of Technology.

His operational tours include the Communications Officer aboard USS Stethem (DDG 63) during the operational test and evaluation (OPEVAL) of the Block IV Tactical Tomahawk. Ashore, he served in several positions at Southwest Regional Maintenance Center, including Project Officer, Project Manager, Class Team Business Officer, and Waterfront Business officer, all within the Waterfront Operations Department. He also served as the Ship Design Officer for DDG 1000 within PMS 500 from 2011 until 2014, managing the technical baseline and changes during construction of the lead ship through its float off. Subsequently, he served as the Officer-In-Charge of Supervisor of Shipbuilding Bath's San Diego Detachment.

Currently, LCDR Page serves as the Academic Officer and Associate Professor of the Practice for Naval Construction and Engineering at MIT.

Lieutenant Commander Page earned the Meritorious Service Medal, three Navy Commendation Medals, two Navy Achievement Medals, various unit and campaign awards, and is expert qualified in both rifle and pistol. He is a member of the Acquisition Professional Community (APC), the American Society of Naval Engineers (ASNE), the Society of Naval Architects and Marine Engineers (SNAME) and the International Council of Systems Engineering (INCOSE).

2017 Student Conversion Projects

2017 Student Design Projects

2017 Student Theses

Aegis Ashore Afloat (AAA)

LCDR Daniel Huynh, USN; LT David Ferris, USN; LT Nicholas Dadds, USN

The U.S. Navy currently has two active Ballistic Missile Defense (BMD) platforms, the Aegis Destroyer (DDG-51) and Aegis Cruiser (CG-47). The upcoming Destroyer variant, DDG-51 Flight III, will be the first ship to incorporate a new 14-foot Air and Missile Defense Radar (AMDR), which is approximately 30 times more sensitive than the SPY-1D radar found onboard DDG-51 Flight IIA. While a significant improvement, the 14-foot AMDR does not solely achieve the Navy's objective performance characteristics due to limitations with the DDG-51 design. A 22-foot AMDR array, planned for the now-canceled CG(X) class, was originally sought to improve BMD capability and address the evolving ballistic missile environment. Therefore, a potential capability gap exists in BMD radar coverage. This study sought to provide a timely, cost-effective solution to enhance the radar capability of our current platforms by exploring the feasibility of installing the existing Aegis Ashore system, excluding interceptors, onboard a commercial containership.

The mission profile for Aegis Ashore Afloat (AAA), as the concept is called, involves AAA working in close partnership with other Aegis platforms to provide additional look capability in support of BMD. AAA would pass targeting data to missile platforms, extending their coverage range. AAA could also provide final illumination when necessary, effectively increasing the number of missiles a platform is able to launch.

All systems needed to support both Aegis Ashore and the additional crew are supplied independently from the host-ship via standard containerized modules. These modules include everything from electrical power generation, damage control gear, and reverse osmosis units to recreation rooms, barber facilities, and garbage processing stations. The modular concept comes, in part, from DARPA's Tactical Expandable Maritime Platform (TEMP) program. The design ensures that all containers are structurally stable and accessible underway while meeting or exceeding all Navy crew habitability requirements.

The baseline ship for the feasibility study was a 1,040 twenty-foot equivalent unit (TEU) size containership. Designed to ensure the host-ship would continue to satisfy commercial strength, stability, and watertight integrity requirements, the only containerized systems installed below-deck were fuel tanks, "dirty water" tanks, and watertight TEUs provided for additional reserve buoyancy. After modeling and analysis, this study concludes that installing an Aegis radar system on a relatively small containership is feasible. The use of larger containerships would only improve the AAA concept through the addition of capability.

The preferred configuration for AAA has the Aegis Ashore deckhouse located at the bow of the containership, with only the pilot house limiting radar coverage in the aft sector. The additional support systems, including crew habitability, are located between the Aegis Ashore deckhouse and the flight deck, with some select systems located on the container bays just forward of the containership pilothouse. By design, the installation package is modular and nearly independent of all host-ship systems, which allows AAA to be installed on a range of commercially available containerships.

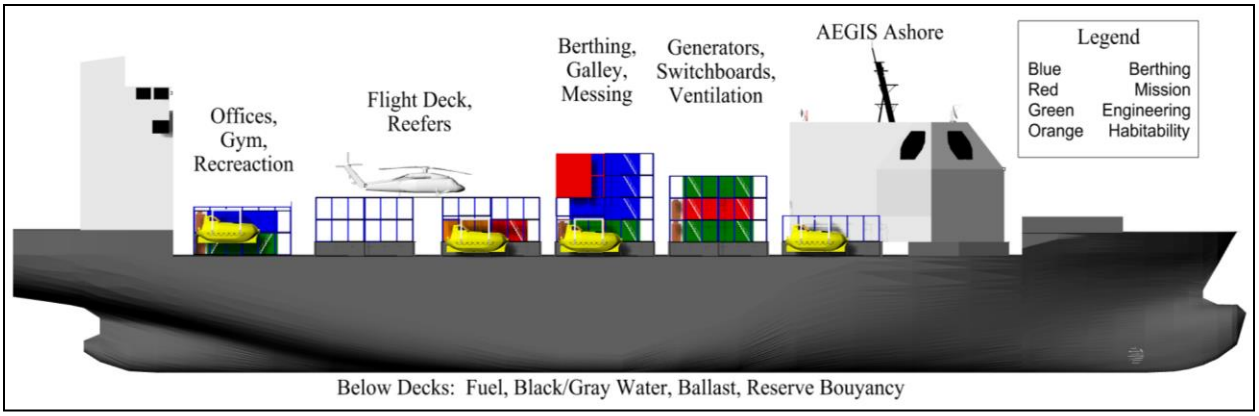


Figure 1: Final AAA Arrangement

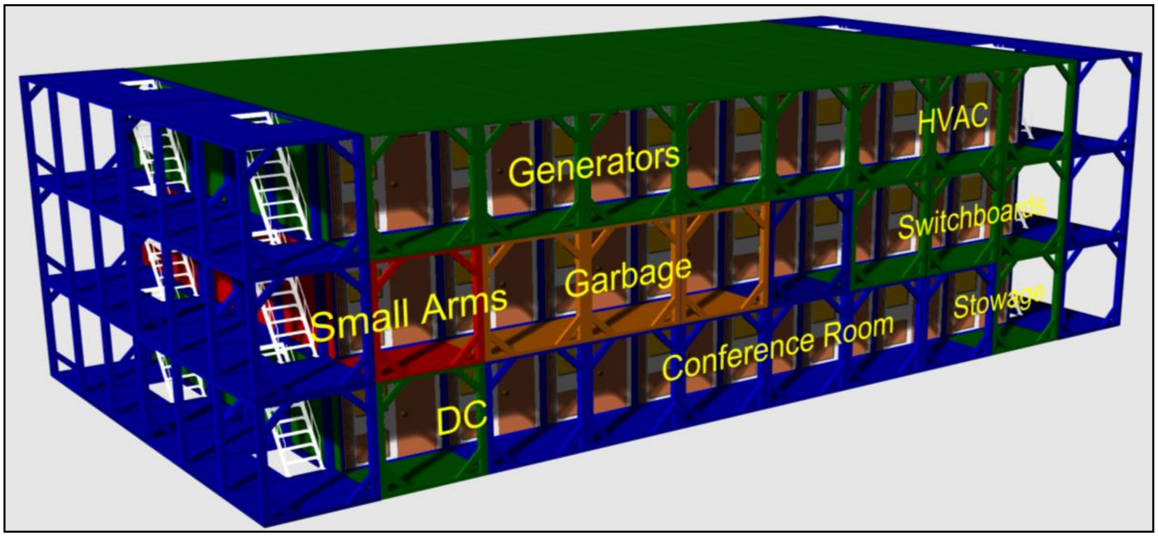


Figure 2: Example of one 40-foot modular support section

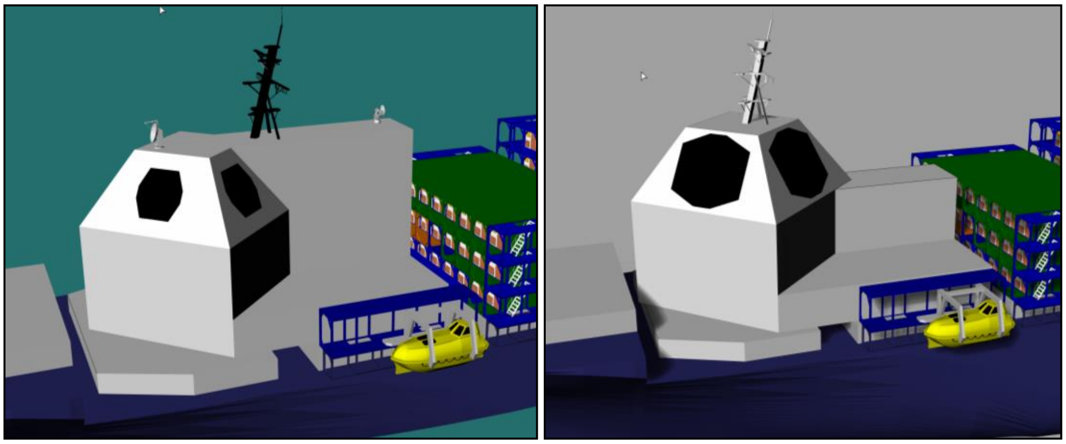


Figure 3: A concept comparison of the 9-foot (current Aegis Ashore) and 22-foot (CG-X) arrays

DDG-51 FLT IIIA ADC VARIANT

What will assume ADC responsibility when CGs decommission?

LCDR Nate Byrd, USN; LT David Ingraham, USN; LT Adam Campbell, USN

The Ticonderoga Class Cruiser fulfills the Air Defense Commander mission for the Carrier Strike Group. In the 2030s the CG and first of the Arleigh Burke-Class destroyers will be decommissioned resulting in the loss of a dedicated ADC platform along with a reduction in surface Vertical Launch System capacity. The Navy originally planned on a CG(X) ship to assume ADC responsibility but the program was cancelled in 2011. With no active program to provide this capability, this study explored converting a DDG-51 FLT III into a dedicated ADC platform.

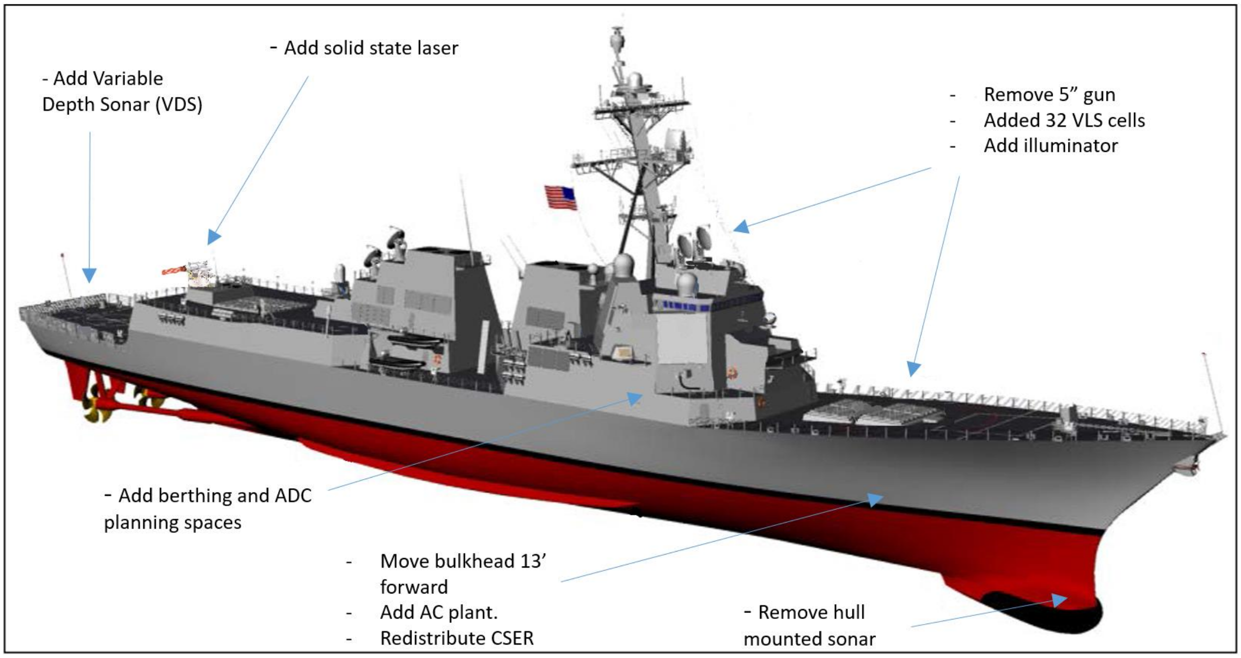
DDG-51 class ships can assume the ADC role for short periods of time. DDG-51 requires specifically trained personnel, an O-6 CO for Command and Control, and dedicated planning/debriefing spaces in Combat Information Center.

NAVSEA 05D conducted the Destroyer Payload Module study in 2016 to evaluate the feasibility of adding ADC, VLS cells, and Space Weight Power and Cooling (SWaP-C) margin for future systems. The DPM study provided thorough and robust options for adding capabilities with a 53' plug. Adding the plug impacts survivability in a negative way, specifically the floodable length.

This study differs from the DPM report in configurations explored. We analyzed feasibility of adding ADC capability with either zero modifications to the hull or a 13' plug, resulting in decreased Non-Recurring Engineering and construction costs. To accomplish adding ADC capability, two systems and spaces were examined to be repurposed, the MK45 5" gun and the AN/SQS-53C hull mounted sonar. The loss of these capabilities could be offset with a low cost medium range strike missile, which was called out as a required future asset in the 'Distributed Lethality' article, along with a towed Variable Depth Sonar.

Our "Preferred Variant" consisted of the DDG-51 FLT III hullform with 5" gun and hull mounted sonar removed. A manning analysis was performed to determine the impact to configuration on manning, resulting in an overall increase of five personnel. Extensive modifications occurred in the forward ⅓ part of the ship to accommodate ADC planning spaces, berthing, and an additional AC plant. The only structural change required was moving a bulkhead forward 13' to allow for a 64 cell VLS module instead of the installed 32 cell module.

Our "Preferred Variant" provided ADC capability, 128 VLS cells, 20% > service life allowance margin for electric and cooling, 10% > service life allowance for displacement, and 0.55' KG margin. This study assumed a 14' AMDR array. It is feasible to convert a DDG-51 to handle ADC capability, however, an analysis of whether a larger AMDR array is required and what impacts are made to NSFS and ASW missions is recommended.



Modified from: GAO (analysis); Navy (image and data). | GAO-16-613

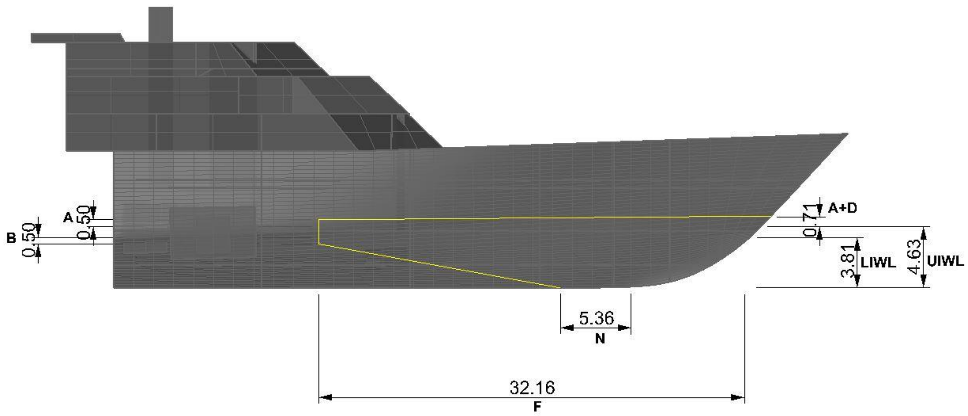
Structural Feasibility Assessment of a D0 Ice-Classed LCS

LCDR Sjaak de Vlaming, USN; LT Jordan Fouquette, USN

This study assessed the feasibility of modifying future builds of the Littoral Combat Ship (LCS, Freedom variant) to meet structural requirements for Arctic operation. Specifically, this project modified the LCS 1 hull form such that it adhered to the D0 ice class requirements as defined by the American Bureau of Shipping (ABS) Steel Vessel Rules (SVR), 2017. The mission, concept of operations, and operational profile of the LCS remained fixed, but gained an enhanced geographical range to support Arctic missions as set forth in the "U.S. Navy Arctic Roadmap 2014-2030" issued by the Chief of Naval Operations in 2014. At present, no U.S. Navy surface ship has the capability to maintain an Arctic presence, so a modified LCS Freedom class enables the protection of U.S. interests in the Arctic as well as the accretion of institutional knowledge necessary for the design of future Arctic ship classes.

The final design of our D0 ice-classed LCS met all of the requirements of the ABS SVR Part 6, Chapter 1 (Strengthening for Navigation in Ice), Section 5 (Requirements for Vessels Intended for Navigation in First-year Ice), synthesized with satisfactory stability characteristics in ASSET, and satisfied the weight/KG limits of LCS 17, which represents the state of the class to which these modifications would be applied. A primary consideration is that our model appropriates most of the ship's Service Life Allowance (SLA) for structural enhancements, thus precluding weight additions for other reasons as the ship ages (weight chart below). While it may be possible to reduce the total weight gain via optimization, a substantial loss of SLA is unavoidable and would need to be accepted as a tradeoff for the LCS gaining access to the Arctic.

A final and critical caveat to acknowledge in this design is that although the structural enhancement is feasible, it does not enable a ship that can cleave through ice at 30+ knots. The design of a ship which could navigate D0 ice at high speed would require a re-visitation of first principles; the ABS rules used for our analysis are governed by a Commanding Officer's "due caution and concern" and imply a speed of approximately 4 knots while in D0-classed waters.



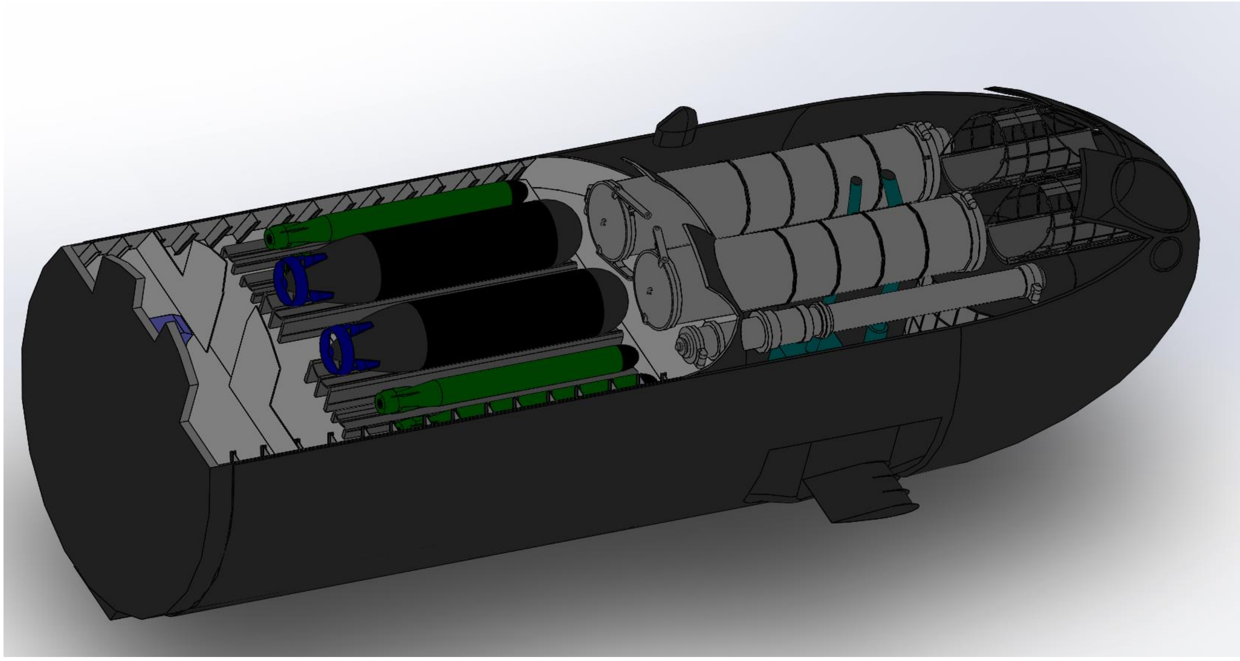
	Pre-Modification Weights	Post-Modification Weights	Weight Increase
	Weight [MT]	Weight [MT]	Weight [MT]
Shell Plating & Internals	202.88	210.29	7.41
Frames	12.67	52.40	39.73
Total	215.55	262.69	**47.14**
Total + 10% Margin	237.11	288.96	**51.85**

Conventional Submarine Converted to Carry Unmanned Undersea Vehicles (SSKU)

LCdr J. Ben Thomson, RCN; LT Matthew DiVittore, USN; LT Benjamin Parker, USN

Given recent improvements in submarine technology, such as air-independent propulsion, improved energy storage technologies, and Unmanned Undersea Vehicle (UUV) capabilities, it is worth considering augmenting the current fleet of nuclear-powered submarines with modified conventional attack submarines (SSK) which can act as specialty ships for intelligence, surveillance, and reconnaissance, covert deploying and retrieval of UUVs, and special operations forces support.

This study shows that modifying a modern European-built SSK to incorporate UUV deployment and recovery is feasible and provides considerable advantages. Additionally, that the modifications can be achieved with little change to trim and overall stability of the submarine. These findings are expected to apply to other SSKs if the weight ratio of torpedoes displaced to Large UUVs (LUUV) embarked is equivalent. We have shown the feasibility through the modification of a VICTORIA Class submarine currently in use by the Royal Canadian Navy (RCN). The VICTORIA Class was selected as it has already been adapted for USN weapons and sensors, and technical data is readily available. It must be understood that this project is meant to show the feasibility, through engineering analysis, of converting a modern European-built submarine such as the platforms considered for the recent COLLINS Class Replacement Project and to be implemented as a design change prior to construction. Implementation specifically on the VICTORIA Class was used only to validate the design.



Medium Displacement Unmanned Surface Asset (MDUSA)

LCDR Thomas Finley, USN; LCDR Amber Mason, USN; LT Joseph Leavitt, USN

The Chief of Naval Operations (CNO) in his Sailing Directions describes the vision for the future Navy to employ unmanned systems with advanced autonomy, and to fully integrate these systems with their manned counterparts to extend the reach and effectiveness of ships and maintain a preeminent maritime force. Capitalizing on recent advancements in autonomous applications for Unmanned Surface Vessels (USVs), notably the Office of Naval Research (ONR) Autonomous Continuous Trail Unmanned Vessel (ACTUV) program, the MDUSA project explores the USV design trade space in keeping with these directions, applying the concept to a larger, unmanned, pier-launched platform. Serving as a patrol vessel, MDUSA conducts autonomous search, detection, tracking, and identification of Air, Surface, and Sub-surface threats, and through satellite communication links, provides early warning and queuing to larger, standoff fleet assets. The Surface Action or Battle Group with which it is interacting retains remote supervisory control and oversight, as well as batteries release authority for installed kinetic weapons capabilities. Due to its unmanned nature, MDUSA can expand the battlespace into more hostile and less navigable waters, allowing it to act as a force multiplier and assist in establishment of battlespace dominance. To expand current USV mission capabilities, a kinetic weapons payload and self-defense systems were incorporated into the design. Traditional mast and deckhouse features were retained in the design for optimal sensor placement, necessary manning requirements during platform testing scenarios and emergency RTHP operations, and to accommodate future growth improvements.

With the Concept of Operations for naval USV's still in development, rapidly developing and changing unmanned vehicle technology, and the open nature of the design requirements, the design effort was approached using a Set Based Design methodology. Design variables were explored and varied within multiple function based trade spaces, including the hull, power and propulsion, and mission capabilities. Changes in the design variables yielded response variables that exposed infeasible and dominated solutions within the individual trade spaces. The response variables also served as links across the trade spaces such that infeasibility and dominance could be examined at the whole ship level. An Analytic Hierarchy Process (AHP) was finally employed to yield a group of highly preferred solutions from which a single variant was selected for further development.

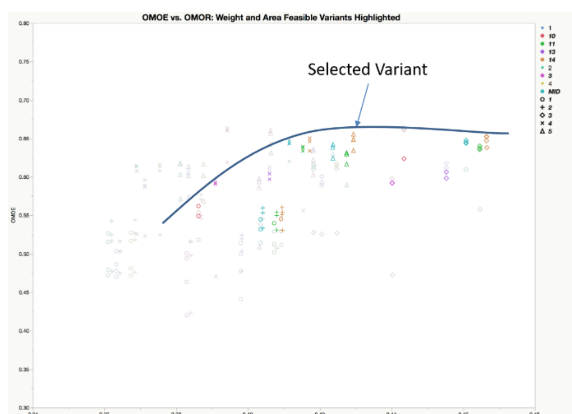


Figure 1 – OMOE vs. OMOR used to select variant for point design.

Dimension/Attribute	Value
Displacement	308 mt
Length Overall	52 m
Maximum Speed	28 kts
Endurance Speed	12 kts
Endurance Range	10,000 nm
Operation Length	60 days
Point Defense	Mk 36 SRBOC Mk 53 NULKA
Kinetic Weapons	Mk 56 ESSM

Table 1 – MDUSA Principle Dimensions and Attributes

Preliminary performance analyses as well as space and weight allocations were conducted while assessing individual trade spaces, ensuring that the point design would remain feasible in the later stages of the project. The traditional point design spiral was executed for the selected variant, yielding higher fidelity performance information and detailed arrangements. MDUSA provides a feasible conceptual design solution to further the expansion of USV capability, thus providing the Fleet Commander with risk mission sets.

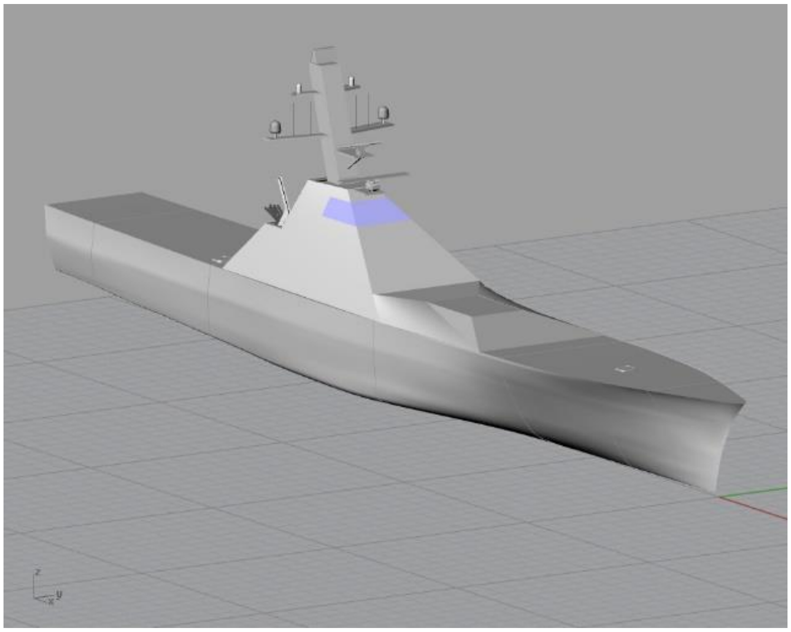


Figure 2 – Isometric View of MDUSA Conceptual Design

Submersible Support Vessel (SSV)

LCDR Randall Jagoe, USN; LT Michael Beautyman, USN; LT Jessica Olena, USN

The Submersible Support Vessel (SSV) is a vessel designed to support the expansion of special mission capabilities through support of the Dry Combat Submersible (DCS). The DCS is a small underwater vehicle that can transport operators to the site of a mission inaccessible by larger underwater assets, at a higher speed than an open diver system, in a protected, dry environment that increases operator mission endurance. The current DCS is too large to be carried by a submarine and requires a surface vessel to support operations. Presently, the United States Navy uses contracted vessels to support testing and training of undersea vehicles, however these vessels are adapted from commercial offshore supply vessels and lack dedicated support capabilities for the DCS and other underwater vehicles.

The SSV is based on a commercial offshore supply vessel design that meets American Bureau of Shipping (ABS) classification requirements. The key feature of the SSV is a 16-meter long, 8-meter wide moon pool at the center of the ship that allows for launch and recovery of the DCS, SEAL Delivery Vehicles, or unmanned vehicles. The moon pool has two doors at the bottom that are closed during transit and open during launch operations. A secondary means of launch and recovery is provided by the ship's topside deck crane. While many mission and life support systems are organic to the ship, the SSV also provides a substantial upgrade in user-configured area to customize storage of containerized mission specific cargo while maintaining ample personnel living and support space. A commercial diesel-electric power plant powers the ship. Two azimuthal thrusters at the rear of the ship provide propulsion, assisted by one drop-down azimuthal bow thruster that also provides dynamic positioning during launch and recovery operations.

The Submersible Support Vessel is a feasible design. It provides a modern, capable platform to support the sponsor needs. This platform provides the Navy with an organic option to meet special mission capabilities without the need for outside contracts.

SSV Characteristics	
Parameter	*Value*
LOA	108.3 m
LBP	107.3 m
Beam	22.0 m
Draft (Full Load)	6.1 m
Depth	14.3 m
Lightship Displacement	5,737.3 mton
Full Load Displacement	9,716.3 mton
Endurance Range	12,000 NM
Maximum Speed	18 kts
Launch and Recovery	60 ton capability deck crane; 16-meter long, 8-meter wide moon pool with overhead crane

Special Operations Craft – Riverine (Next Generation)

LCDR Timothy Dutton, USN; LT Justin Parker, USN

Asymmetric warfare continues to be the predominant form of combat in the 21st century. Small-scale, high-intensity conflicts demand the application of special operations forces (SOF), who in turn require specialized equipment to accomplish their elite mission. For naval special operations missions, the Special Operations Craft - Riverine (SOC-R) has been a mainstay of actions in contested riverine and littoral waterways. However, the craft is aging and will soon exceed its lifespan and utility. Special Operations Command (SOCOM) therefore requested concept exploration for a replacement to sustain the vital SOC-R mission. Beyond simply reiterating the features of the SOC-R, the new vessel was to incorporate enhanced capabilities and innovative features in order to amplify the original craft's already-considerable prowess.

This report explores the design for such an advanced craft to succeed the SOC-R. The concept vessel meets or exceeds the detailed performance requirements tailored specifically for the insertion and extraction of SOF personnel in hostile areas. Concurrently, it maintains its predecessor's strict limitations on displacement, draft, and dimensions, driven largely by operational and transportability considerations. Most significantly, the new craft improves upon the original SOC-R in three key areas: speed, lethality, and maintainability. These improvements are realized through leveraging state-of-the-art technologies that have been developed in the time since the original SOC-R's inception. The resultant design, termed SOC-R(X), is a fast, maneuverable, lethal, survivable platform ready for the naval special warfare mission.

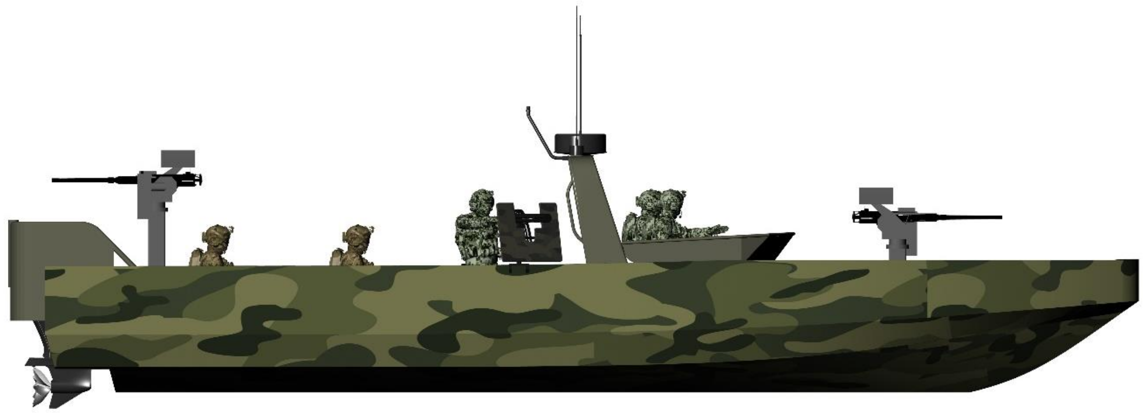
The design team conducted its primary analysis using the MAXSURF suite of naval architecture tools, following a design spiral specific to planing craft. Further analysis for arrangements used Rhino computer-aided design software, and a structural analysis was conducted in MAESTRO Marine. The team consulted numerous subject-matter experts for operational and technical insight, including: SOCOM, NSWC Carderock Combatant Craft Division, NSWG-4 Special Boat Team 22, USNA Naval Architecture and Ocean Engineering, and various MIT departments. Overall, this study resulted in a feasible design concept for a SOC-R replacement that balances proven characteristics with advanced features in an effort to maximize the efficacy of this high-performance vessel.

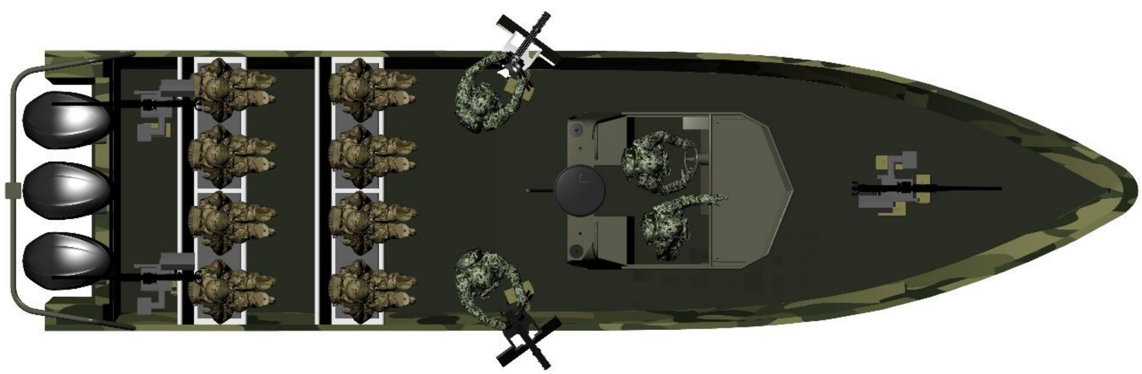
Notable design specifics include:

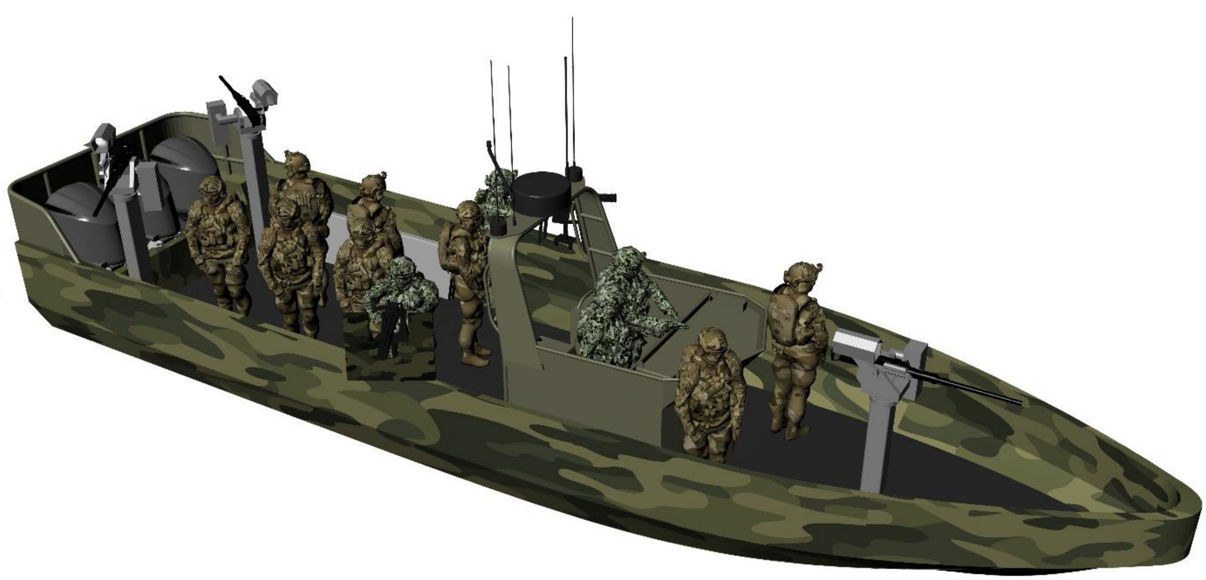
- Hullform: **deep-vee-cutoff** improves seakeeping with high speed and maneuverability
- Propulsion: **diesel outboards** provide substantial weight savings over waterjets as well as improved maintainability in-theater through ability to swap engines; **surface-piercing propellers** provide efficient high-speed propulsive force while maintaining draft limitation
- Armament: **three stabilized mounts** significantly increase accuracy of fire and may be locally or remotely controlled, providing greater flexibility in operation (Rafael Mini-Typhoon mount or similar, armed with up to .50-caliber guns); **two standard mounts** with miniguns provide high volume-of-fire; overlapping fields of fire achieved in all directions

Principal characteristics:

- Length: 38 feet
- Beam: 9.5 feet
- Draft: < 2 feet
- Speed: > 40 knots
- Acceleration: 25 knots in 14 sec
- Displacement: 17700 lbs
- Transportable via C-130
- Strengthened for airdrop, beaching
- Seating for 8 SOF passengers + gear
- Seating is removable and stowable for maximum space when necessary







Load Bearing Interface Design for a Pan-Tilt Mechanism for Severe Marine Environments

LT Michael Beautyman, USN

Prof. Alex Slocum
Thesis Supervisor

The Naval Research Laboratory (NRL) requested the design of a two-axis gimbal device for the shipboard support of a sensor payload. Previous design efforts (Mills, 2016) presented a low-mass two-axis (pan and tilt) machine with future work recommended for the interface connecting the payloads to the tilt shaft. Vibration and shock testing induced failure in that sensor payload to tilt shaft interface, which was bolted, taking the system out of service and creating a potentially hazardous situation for Sailors. This thesis proposes a tapered, hollowed shaft and flange interface connected by an interference fit that is fastened and preloaded by a single custom bolt for ease of maintenance at sea.

This simplified design is a departure from existing rotary tapered interfaces, such as seen in machine tooling, and focuses on connecting massive payloads to their actuators when subjected to severe loading. This design is uniquely suited to withstand large bending moments and loading as demanded by military standards for shock. A custom machine was designed and constructed to subject scaled designs to military standard environmental testing for shock in the laboratory. A reduced and a full-scale prototype were modeled and manufactured. Future work addressed includes adapting tapered interfaces to different design requirements and expanding their use in large mass actuator systems.

Naval Engineer

Master of Science in Mechanical Engineering

Analysis of Dynamic Acoustic Source Positioning: An Autonomous Swarm Approach

LT Matthew DiVittore, USN

Prof. Henrik Schmidt
Thesis Supervisor

As underwater autonomous vehicles become more prevalent, and their missions more complex, a novel means of underwater acoustic communication with respect to source positioning must be developed which takes advantage of the unique nature of sound propagation through the underwater environment while minimizing the number and energy use of the source agents. Through the use of objective functions, a dynamic positioning algorithm was developed to reduce transmission loss from the source agent to a given target as it changes position over time. Objective functions were also developed which govern the behavior of a swarm of interacting source agents as a function of user selected operating profile. Simulations in several operating environments show a single dynamic source agent results in overall reduced transmission loss when compared to a static source at a fixed depth over many credible operating scenarios with a target is at slow speeds and moderate initial depth separation. The use of a source agent swarm in a depth zone operating profile yields better results for targets at higher velocity or operating in areas of deeper water.

Master of Science in Naval Architecture and Marine Engineering

Master of Science in Mechanical Engineering

An Investigation into the Effects of Cavitation Number on Surface Piercing Hydrofoil Hydrodynamic Properties

LCDR Timothy Dutton, USN

Prof. Michael Triantafyllou
Thesis Supervisor

The fluid-dynamic design of hydrofoils to support marine crafts at high speeds has received growing interest in recent years. Theoretical, physical, and numerical methods for the design of high speed hydrofoils belong to disciplines at the intersection between naval architecture and aeronautical engineering. Physics involved in the design of high-speed surface-piercing hydrofoils is complex involving three different fluid phases (air, water and vapor) and complex fluid dynamic mechanisms like unsteady cavitation and ventilation and their interaction.

For speeds considerably higher than the incipient cavitation speed, the hydrofoil sections need to be adapted and design to exploit cavitation instead of avoiding it. This is particularly true for surface piercing hydrofoils that in addition to cavitation are affected by ventilation from the free surface.

The paper presents main results of an investigation into the relative formation of ventilation and cavitation regions of surface piercing super-cavitating hydrofoils (SPSCHs), with special attention to the effects of cavitation number. The relative size and location of the ventilation and cavitation regions have significant contributions to the hydrodynamic properties of the SPSCHs, in particular lift and drag forces.

A series of 3D multi-phase Reynolds Averaged Navier-Stokes Equation (RANSE) simulations of varying cavitation number reveal the dependence of the ventilation and cavitation regions on the cavitation number, angle of attack, and distance from the free surface. The RANSE simulations are validated against an analytical estimate based on an appropriate lifting line method at near zero cavitation numbers, and against empirical results obtained through tow tank testing at higher cavitation numbers. The analytical and empirical validation bound the range of cavitation numbers considered in this study from $\sigma = 0.05$ to $\sigma = 2.47$.

Previous studies attempting to predict the performance of SPSCHs using a viscous lifting line (VLL) method have not taken the effects the free surface into account. As such, they sufficiently far away from the free surface such that ventilation will not occur. A modified version of these VLL methods, informed by the effects of cavitation number presented here, would allow for the more general application of the VLL to SPSCHs.

Naval Engineer

Master of Science in Mechanical Engineering

Slip Clutch Design for Position Sensitive Systems in Marine Environments

LCDR Thomas P. Finley, USN

Prof. Alex Slocum	**Prof. Joe Harbour**
Thesis Supervisor	Thesis Reader

The Naval Research Laboratory (NRL) requested a two-axis pan tilt mechanism be designed, built and tested for shipboard deployment of a sensor payload. Of paramount consideration in this design was the robustness of the system in the face of wave impact loading from "green water" taken over the superstructure of naval vessels. Central to addressing this consideration is the prevention of drive train failures given wave or other forms of impact loading. Through the course of work completed for his Master's thesis, CDR Nathan M. Mills brought the design effort through initial bench testing. Several failures were experienced due to mechanical component performance. One component selection that required improvement was the torque limiting slip clutch used in both the pan and tilt drive sections. The component selected induced positioning errors in the system which were inherent to the method through which it provided the torque overload protection. The goal of the present work was to complete the design of a slip clutch that minimizes positioning errors to allow for its shipboard use in the NRL sponsored pan tilt system. The design has been completed in a manner that supports the use of the slip clutch in other systems that require accurate positioning and torque overload protection in both marine and non-marine environments.

The slip clutch design uses a physical principal similar to that used in spring loaded, ball and detent devices (SLDs). SLDs are used commercially in applications that require accurate and repeatable forces for positioning or indexing of components. The major difference between the existing component and the present design is the use of a curved beam and ball bearing rather than a spring and ball combination. This eliminates sliding friction encountered at the ball and detent interface and in the spring housing. Using the curved beam as the method of engaging the ball bearing on the detent associates the position error of the slip clutch to the stiffness of the beam. As the beam begins to displace vertically, the stiffness of the curved beam provides increased engagement force, but the angle at which the resultant force is imparted to the beam through the ball bearing decreases. Through the balance of these two competing effects in relation to beam, ball bearing and detent sizing, an optimum that minimizes angular positioning error can be found.

Naval Engineer

Master of Science in Mechanical Engineering

Uranium Extraction from Seawater: Investigating the Hydrodynamic Behavior and Performance of Porous Shells

LT Amanda M. Hamlet, USCG

Prof. Alex Slocum
Thesis Supervisor

As global temperatures rise, scientists work to further develop alternative energy sources. More communities may turn to nuclear power to meet their energy needs leading to an increased demand for uranium. There are 5.7 million tonnes of known land-based uranium reserves, and approximately 4.3 billion tonnes available in the ocean at a concentration of 0.0033 ppm. While terrestrial sources of uranium exist in limited quantities, the oceans contain much larger quantities, which can be extracted and used to fuel nuclear power plants. The challenge becomes developing a method of extracting the uranium from seawater that is cost competitive with terrestrial mining. Coupling a system that extracts uranium with an existing offshore structure, such as a wind turbine, reduces the costs of mooring and maintenance, making the price of uranium from the ocean more comparable to the price of terrestrial sources. In ocean-based systems, valuable metals are selectively removed via fibrous polymeric adsorbent materials. These materials are not inherently strong or durable, however. One solution is to contain them in a shell structure that bears the environmental loads. This work aims to characterize the flow of water in and around porous shells containing uranium adsorbent in order to inform extraction system design. Shells with different hole patterns were fabricated and tested. The corresponding flow in and around the shells was examined qualitatively using computational fluid dynamics and dye flow studies. The form drag of the different shells were determined experimentally and verified through CFD. This information was used to model a net of uranium adsorbent shells submerged in the ocean and subject to various currents. The dynamic forces due to wave motion and vortex induced vibration were studied and added to the model. Findings from the model will be used to inform uranium extraction system design in an offshore environment.

Master of Science in Naval Architecture and Marine Engineering

Master of Science in Mechanical Engineering

Examination of Hull Forms for an Offshore Nuclear Plant

LCDR Randall Jagoe, USN

Prof. Jacopo Buongiorno	Prof. Michael Golay
Thesis Supervisor	Thesis Reader

The Nuclear Science and Engineering Department at MIT has an ongoing research project to develop the concept of an Offshore Nuclear Plant (ONP). This project highlights the advantages of the offshore location by reducing the risk of natural disasters and cost of terrestrial nuclear power facilities. The original ONP conceptual design consists of a large cylindrical floating platform similar to existing platforms in the offshore oil and natural gas industries.

This research investigates the advantages and disadvantages of different hull forms that the ONP may use. Multiple platform designs were modeled to compare the differences in seakeeping and stability. These variants explored the characteristics and combinations of flat hull plating to replace the original cylinder shape, lengthening the platform to minimize overall depth and draft. The different hulls were modeled and then analyzed using a three-dimensional radiation-diffraction panel method to simulate each platform's response in a given sea state. The variants were compared utilizing the JONSWAP spectrum for a 100-year storm in North Sea and evaluating the response in six degrees of freedom.

While seakeeping performance is the primary characteristic evaluated, other effects of the design changes such as mooring complexity, ease of construction, usable area, operations, and security were also compared.

Naval Engineer

Master of Science in Mechanical Engineering

Intent Aware Collision Avoidance for Autonomous Marine Vehicles

LT Joseph W. Leavitt, USN

Prof. John Leonard
Thesis Supervisor

Proposed applications of autonomous marine vehicles in dynamic and uncertain environments continuously grow as research unveils new enabling technology and academic, commercial, and government entities pursue new marine autonomy concepts. The safe operation of these vehicles in the marine domain, which is dominated by the presence of human-operated vehicles, demands compliance with collision avoidance protocol, namely the International Regulations for Preventing Collisions at Sea (COLREGS). Strict application of this protocol can lead to an over-constrained motion planning problem, in which it is difficult for a vehicle to identify a safe and efficient motion plan.

This thesis proposes a framework for COLREGS-compliant autonomous marine vehicle collision avoidance in which vehicles use intent information to reduce certain COLREGS-specified constraints, thereby improving the ability of vehicles to resolve and implement safe and efficient motion plans. The thesis explores the concept of intent, including appropriate intent abstractions for the marine domain, communication of intent, and the application of intent to the COLREGS-compliant motion planning problem. The proposed intent-aware framework incorporates intent formulations and communications relevant to the marine domain to allow vehicles to release one another from strict compliance with a particular COLREGS rule based on inferred risk of collision. Simulations and on-water experiments demonstrate the feasibility of the framework, as well as improved performance over current COLREGS-compliant implementations in terms of both vehicle safety and mission efficiency.

Naval Engineer

Master of Science in Electrical Engineering and Computer Science

Material Characterization and Axial Loading Response of Pouch Lithium Ion Battery Cells for Crash Safety

LCDR Amber Mason, USN

Prof. Tomasz Wierzbicki	**Prof. Elham Sahraei**	**Prof. Joe Harbour**
Thesis Supervisor	Thesis Supervisor	Thesis Reader

Throughout the years, consumer demand and advanced applications have continued to mandate longer and longer battery runtimes, and battery manufacturers have responded accordingly with the introduction of and subsequent improvement upon lithium ion batteries. Due to its high-energy density and lack of memory effect, this battery chemistry has proven very successful in a variety of applications such as cell phones, laptops, and vehicles, and continues to be exploited as technological industry demands are ever-rising. However, one of the primary concerns inhibiting expansion of use of this product, particularly in Naval applications, is the potential safety risks associated with this type of battery.

Current cell and battery pack design practice focuses first on optimization of energy and power output, the result of which is then mechanically safety tested. Unfortunately, this post-manufacture safety testing offers no visibility on the causes and mechanisms of inner structural failure for feedback of mechanical strength characteristics into the design. The aim of this study was to provide characterization of the pouch material used in the manufacture of certain high energy pouch lithium ion battery cells, the moment of onset of internal electric short circuit relative to mechanical deformation of the same high energy cells under varying deformation scenarios, and mechanical deformation response to axial loading of small pouch lithium ion battery cells for use in comprehensive mechanical deformation simulation modeling. To this end, uniaxial tensile stress, biaxial punch, and full cell compression tests were performed on a particular make and model of high energy pouch lithium ion battery cells and its pouch material. The study also included the design and construction of a device for in-plane axial compression testing of small pouch lithium ion battery cells in order to investigate buckling response under varying degrees of confinement. All testing results were subsequently used to inform the development of an accurate and practical computational model intended to predict mechanical deformation and related short circuit behavior of Li-ion battery cells and stacks in real world impact scenarios. The intent is such that this detailed computational modeling of the interior of a lithium ion battery cell will offer valuable information in helping to close the design feedback loop, allowing for a much more robust design overall.

Naval Engineer

Master of Science in Mechanical Engineering

Design, Evaluation, and Validation of a Naval Ship Structural Health Monitoring Tool

LT Jessica Olena, USN

Prof. Themis Sapsis
Thesis Supervisor

The US Navy implements structural preventative maintenance procedures onboard its vessels using ship's personnel inspection. These procedures have been largely successful in identifying major problem areas before any interference with mission execution has occurred. However, changes in the Navy's manning philosophy to minimal manning and new ship designs focused on automation encourage a re-evaluation of these structural preventative maintenance procedures. Automation of structural inspection and damage detection may reduce associated manpower costs as well as inform better preventative maintenance schedules for US Navy vessels.

This study outlines a modeling tool for structural health monitoring using non-linear Kalman Filter methodologies such as the Extended Kalman Filter and the Ensemble Kalman Filter to identify damage within a structural model. Through the observation of structural responses and the formulation of a Kalman Filter, it is possible to produce estimates of structural parameters related to damage, specifically changes to elastic modulus and changes in material density. The results of this modeling tool were evaluated to quantify the time and length scales required for damage detection and were validated against a structural model generated in the MAESTRO Global Structural Analysis software suite.

Naval Engineer

Master of Science in Mechanical Engineering

Design and Numerical Analysis of an Unconventional Surface-Piercing Propeller for Improved Performance at Low and High Speeds

LT Justin Parker, USN

Prof. Michael Triantafyllou	Prof. Joe Harbour
Thesis Supervisor	Thesis Reader

Traditional propellers operate fully submerged, with cavitation limited as much as possible in order to minimize its disruptive and damaging consequences. Conversely, super-cavitating propellers operate in an encompassing vapor cavity, thereby averting these negative effects while substantially reducing drag on the blades. Surface-piercing propellers, operating under a similar concept as super-cavitation, often achieve even greater efficiency by drawing in an air cavity from the free surface. Existing small craft have demonstrated the ability of such propellers to yield extremely high speeds (110+ knots); nevertheless, the full potential of these propellers has yet to be explored. In particular, designs often neglect low-speed performance, focusing solely on high-speed operation. This research therefore developed a new surface-piercing propeller concept designed instead to maximize performance across the spectrum of operating speeds.

Applying established theory for super-cavitating hydrofoils, the new blades were shaped based on theoretical maximally-efficient two-dimensional profile sections. Furthermore, in order to affect the low-speed performance enhancement, the trailing edge of each profile was appended with a unique "tail" form that allows the blade to resemble a traditional propeller when operating at sub-cavitating speeds without sacrificing super-cavitating performance. The design used an existing racing propeller as a baseline for comparison, matching certain characteristics (rotational speed, advance speed, number of blades, hub size) in order to ensure equivalent operating conditions. Computational fluid dynamics (CFD) of the 2D profiles informed changes to the profile shapes until lift-to-drag (L/D) was maximized while ensuring a fully-encompassing vapor cavity. The complete propeller was drafted from these optimized radial sections for full 3D CFD analysis.

Results from both the 2D and 3D CFD simulations revealed promising benefits to propulsive efficiency. High-speed performance met or exceeded that of the baseline propeller, and low-speed performance showed significant improvement. This surface-piercing propeller concept offers an unconventional design with convincing results for balanced low- and high-speed operation.

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