



# Naval Construction and Engineering Ship Design and Technology Symposium

Thursday, May 3, 2018

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, Director Naval Construction and Engineering
- 0900 – 0925 Student Conversion Project Brief  
- New Self-Defense Test Ship: LCDR William Taft, LT Travis Rapp, LT Kevin Stevens
- 0925 – 0950 Research Brief: Prof Themistoklis Sapsis  
- Adaptive Sequential Sampling for Extreme Event Statistics in Ship Motions: LT Kevin Stevens
- 0950 – 1010 Poster Session
- 1010 – 1035 Student Design Project Brief  
- Large Surface Combatant (LSC): LT Adam Campbell, LT Jordan Fouquette, LT Benjamin Parker
- 1035 – 1100 Research Brief: Prof Henrik Schmidt and Dr. Michael Benjamin  
- Enabling Tactical Autonomy for Unmanned Surface Vehicles in Defensive Engagements: LT Adam Campbell
- 1100 – 1120 Poster Session
- 1120 – 1145 Student Conversion Project Brief  
- Forward-Deployed VLS Reload: LT Robert Carelli, LT William Hentschel, LT Udit Rathore
- 1145 – 1200 Break, lunch served
- 1200 - 1250 Lunch Buffet and Keynote Address**  
**RADM William Galinis, Program Executive Officer, Ships**
- 1250 – 1300 Break, transition
- 1300 – 1325 Student Design Project Brief  
- NexT-AGS, Oceanographic Research Vessel: LCDR Daniel Huynh, LCDR Nathaniel Byrd, LT David Ingraham
- 1325 – 1350 Research Brief: Prof Themistoklis Sapsis  
- Analysis of Submarine Availability Cost Data, 2006-Present: LCDR Sjaak de Vlaming
- 1350 – 1410 Poster Session
- 1410 – 1435 Student Design Project Brief  
- JAWFISH: SEAL Transport Submersible: LCDR Sjaak de Vlaming, LT Nicholas Dadds, LT David Ferris
- 1435 – 1500 Research Brief: Prof Pierre Lermusiaux  
- Time Optimal Multi-Waypoint Mission Planning in Dynamic Flow Fields: LT David Ferris
- 1500 – 1520 Poster Session
- 1520 – 1545 Research Brief: Prof A. John Hart  
- Build Environment Pressure Effects on Selective Laser Melting (SLM) Processing of Select Engineering Alloys: CDR Jonathan Gibbs
- 1545 – 1550 Wrap-Up and Concluding Remarks
- 1550 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 William Galinis, USN** *Program Executive Officer, Ships*

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

Galinis' tours as a surface warfare officer included damage control assistant aboard USS Vreeland (FF 1068) and engineer officer aboard USS Roark (FF 1053). He was selected for transfer to the engineering duty officer community in September 1991.

Galinis' initial engineering duty tour was with the supervisor of shipbuilding, conversion and repair, New Orleans, where he worked on both new construction and repair projects including assignment as the Amphibious Warfare Program Office (PMS 377) program manager's representative for the LSD (CV) Shipbuilding Program. He subsequently served as the senior damage control inspector for the Board of Inspection and Survey, Surface Trials Board as well as in a number of program office and staff positions including the DD 21 and LPD 17 Program Offices, Office of the Chief of Naval Operations in the Requirements and Assessments Directorate and in the Office of the Deputy Assistant Secretary of the Navy for Shipbuilding as the chief of staff.



Galinis' command assignments included LPD 17 Program manager — leading the commissioning of the first four ships of the LPD 17 San Antonio Class, delivering the fifth ship and starting construction on four additional ships; Supervisor of Shipbuilding, Gulf Coast overseeing Navy ship construction projects and Foreign Military Sales work in shipyards along the Gulf Coast and Wisconsin; and as the commanding officer of the Norfolk Ship Support Activity (NSSA) where he led ship maintenance and repair efforts.

Galinis' first flag assignment was commander, Navy Regional Maintenance Center during which time he also assumed the duties of deputy commander for surface warfare, Naval Sea Systems Command. He was responsible for managing critical ship modernization and maintenance, training, foreign military support contracts and inactivation programs.

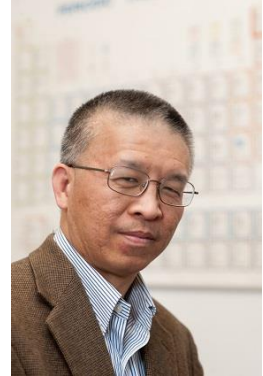
Currently, Galinis is serving as program executive officer, ships, where he is responsible for Navy shipbuilding for surface combatants, amphibious ships, logistics support ships, support craft and related foreign military sales.

Galinis has received various personal, unit and service awards including the Navy Battle "E" Award (three 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<sup>3</sup>TEC Center)" - an Energy Frontier Research Center funded by the US Department of Energy. He obtained his PhD degree from the Mechanical Engineering Department, UC Berkeley. He was a faculty member at Duke University and UCLA, before joining MIT in 2001. He received an NSF Young Investigator Award, an R&D 100 award, an ASME Heat Transfer Memorial Award, a Nukiyama Memorial Award by the Japan Heat Transfer Society, a World Technology Network Award in Energy, an Eringen Medal from the Society of Engineering Science, and the Capers and Marion McDonald Award for Excellences in Mentoring and Advising from MIT. He is a fellow of American Association for Advancement of Science, APS, ASME, and Guggenheim Foundation. He is an academician of Academia Sinica and 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.

## **Nicholas Makris**

***Director of the Center for Ocean Engineering,  
Professor of Mechanical and Ocean Engineering,  
William I. Koch Professor of Marine Technology,  
Director of the Laboratory for Undersea Remote Sensing  
Secretary of the Navy/Chief of Naval Operations Scholar of Oceanographic Sciences***

Professor Makris is an international leader in ocean science and engineering. After graduating from MIT with a SB in Physics and PhD in Ocean Engineering, he served at the Naval Research Laboratory in Washington DC where he conducted research with many of the US Navy's advanced undersea sensing tools, vessels, aircraft and facilities around the world at the end of the Cold War (1991-1997) before returning to MIT as a faculty member. He has published extensively on the physics of sensing and perception; wave propagation and scattering in random dispersive media; noise, scintillation and statistical estimation; undersea exploration; marine ecology; efficient and economical hurricane power quantification from underwater sound; and polar and icy satellite exploration. He served as Chief Scientist on numerous large international oceanographic expeditions around the world from the Nordic Seas to the Revillagigedo Islands of Central America. He has pioneered the use of ocean acoustic waveguide remote sensing to instantaneously image and continuously monitor oceanic fish and marine mammal populations over continental shelf scales. Professor Makris has presented his sensing methods on Capitol Hill at the US House of Representatives in the context of fisheries and at the House of Lords of the UK Parliament in the context of nuclear nonproliferation. He has worked with Senator John Kerry and the Massachusetts State Government to help resolve the New England Fisheries Crisis. He served on NASA's Science Definition Team for the Jupiter Icy Moons Orbiter, and is a Secretary of the Navy/Chief of Naval Operations Scholar of Oceanographic Sciences, Fellow of the Acoustical Society of America and recipient of the A B Wood Medal in Underwater Acoustics. He is a Bose Research Fellow.



His work has been featured by most major news organizations, including the BBC, New York Times, NPR, The Economist, Washington Post, Los Angeles Times, United Press International, and Telegraph.

Some examples of his publications include:

- N.C. Makris, P. Ratilal, D. Symonds, S. Jagannathan, S. Lee, R. Nero, "Fish population and behavior revealed by instantaneous continental-shelf-scale imaging," *Science*, Volume 311, 660-663 (February 3, 2006);
- Nicholas C. Makris, Purnima Ratilal, Srinivasan Jagannathan, Zheng Gong, Mark Andrews, Ioannis Bertatos, Olav Rune Godoe, Redwood W. Nero, J. Michael Jech, "Critical Population Density Triggers Rapid Formation of Vast Oceanic Fish Shoals", *Science*, Vol. 323, No. 5922, 1734-1737 (March 27, 2009);
- D. Wang, H.Garcia, W. Huang, D.D. Tran, A.D. Jain, D. H. Yi, Z. Gong, J. M. Jech, O. R. Godø, N. C. Makris, & P. Ratilal, "Vast assembly of vocal marine mammals from diverse species on fish spawning ground", *Nature*, doi:10.1038/nature16960, 02 March 2016;
- P. Ratilal and N.C. Makris, "Mean and covariance of the forward field propagated through a stratified ocean waveguide with three-dimensional inhomogeneities," *J. Acoust. Soc. Am.* 118, 3532-3559 (2005);
- S. Lee, M. Zanolin, A. Thode, R. Pappalardo, N.C. Makris, "Probing Europa's Interior with Natural Sound Sources," *Icarus* 165, 144-167 (2003);

**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.



**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.



**Ron G. Ballinger**  
*Professor (Emeritus) of Nuclear Science and Engineering and Materials Science and Engineering*

Ronald G. Ballinger is a Professor of Nuclear Science and Engineering and Materials Science and Engineering. Professor Ballinger was also Head of the H.H. Uhlig Corrosion Laboratory in the Department of Materials Science and Engineering at MIT. Professor Ballinger was active in the teaching of graduate and undergraduate subjects in reactor design, corrosion engineering, chemistry, mechanical behavior and physical metallurgy.



Professor Ballinger served for 8 years in the nuclear submarine navy before attending college. After receiving his B.S. in Mechanical Engineering from Worcester Polytechnic Institute in 1975 he did his graduate work at MIT. He received his S.M. in Nuclear Engineering in 1977 and in Materials Science in 1978. He received his Sc.D. in Nuclear Materials Engineering in 1982 with a thesis entitled "Corrosion Fatigue of Nickel Base Alloys for Nuclear Applications." After receiving his Sc.D. he joined the faculty with a joint appointment in the Nuclear Engineering and Materials Science and Engineering Departments.

Professor Ballinger has taught the MIT Nuclear Science and Engineering Department's courses related to fuel development and performance and corrosion engineering since his joining the faculty. He has taught these courses as well as corrosion and chemistry courses in the Department of Materials Science and Engineering. He has developed and taught in several industrial courses with EPRI and/or the Materials Aging Institute in the area of environmental degradation.

Professor Ballinger has authored or co-authored more than 100 scientific publications and is a member of several professional societies including the National Association of Corrosion Engineers, The American Society for Metals, The Electrochemical Society, The American Nuclear Society, and the American Society for Testing and Materials. Professor has served as Chair of the Materials Science and Technology Division of the American Nuclear Society.

Professor Ballinger is a member of the International Cooperative Group on Environmentally Assisted Cracking of Light Water Reactor Materials (ICG-EAC). The ICG-EAC is charged with the development of methodology for understanding of Light Water Reactor (LWR) materials.

Professor Ballinger has served or is serving on several DOE committees dealing with the stabilization, processing and disposition of metallic uranium fuel from the production reactors as well as from research reactors including teams to evaluate options for the Hanford, Savannah River, and INEL sites. He also is, or has been, a member of several DOE committees to evaluate advanced reactor options and materials for these options. These committees include: (1) the DOE Independent Technical Review Group (ITRG): Design Features and Technology Uncertainties for the Next Generation Nuclear Plant. The ITRG was tasked with evaluating options for the Next Generation Nuclear Plant (NGNP), (2) The DOE Power Conversion Unit Study Committee tasked with evaluation options for the NGNP power conversion unit, and (3) the Idaho National Laboratory Materials Review Board. Professor Ballinger was a member of the Independent Performance Assessment Review Panel (IPAR) that evaluated the suitability of the license submittal for the Yucca Mountain waste repository.

Professor Ballinger is a member of the NRC Advisory Committee on Reactor Safeguards.

## **A. John Hart**

*Associate Professor of Mechanical and Ocean Engineering  
Director of the Laboratory for Manufacturing and Productivity*

Prof. John Hart serves as an Associate Professor of Mechanical Engineering at MIT. He received his Bachelor of Science in Engineering from the University of Michigan, and S.M. and PhD from MIT in Mechanical Engineering. Following graduating, he returned to U of M as an Assistant Professor of Mechanical Engineering, Chemical Engineering, and Art/Design from 2007-2013. He returned to MIT in 2013 to take his current position in the faculty and received tenure in 2017.

John leads the large and diverse Mechanosynthesis research group which aims to accelerate the science and technology of advanced manufacturing in areas including additive manufacturing, nanostructured materials, and the integration of computation and automation in process discovery. He also teaches undergraduate and graduate courses in manufacturing processes, advanced materials, and research methods. John has published >125 papers in peer-reviewed journals, and is co-inventor on >50 patents, many of which have been licensed commercially. He has also co-founded three advanced manufacturing startup companies, including Desktop Metal. John has been recognized by prestigious awards from NSF, ONR, AFOSR, DARPA, ASME, and SME, by two R&D 100 awards, by several best paper awards, and most recently by a 2017 MIT Ruth and Joel Spira Award for Distinguished Teaching.



**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.



**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 the Doherty 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 where he worked on stochastic methods for turbulence.



Prof. Sapsis work lies on the interface of nonlinear dynamical systems, probabilistic modeling and data-driven methods. He has numerous contributions on the development of robust and efficient statistical prediction algorithms that take into account the challenges and constraints imposed by real world problems, primarily motivated by ocean engineering applications. He has published in the areas of uncertainty quantification for turbulent fluid flows in engineering and geophysical systems and his methods and algorithms have been extensively adopted and applied by others in fields such as data assimilation and filtering, CFD and optimization, probabilistic dynamical systems and others. A particular emphasis of his work is the formulation of mathematical methods for the prediction and statistical quantification of extreme events in complex engineering and physical systems such as extreme ship motions, extreme mechanical vibrations, rogue waves in the ocean, and hot-spots in turbulence.

His work has been featured by major news organizations, including the BBC and The Economist. 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 for Ocean Sciences.

Some examples of his publications include:

M. Farazmand, T. Sapsis, A variational approach to probing extreme events in turbulent dynamical systems, *Science Advances*, 3:e1701533 (2017)

W. Cousins, T. Sapsis, Reduced order precursors of rare events in unidirectional nonlinear water waves, *Journal of Fluid Mechanics*, 790 (2016) 368-388

T. Sapsis, A. Majda, Statistically accurate low order models for uncertainty quantification in turbulent dynamical systems, *Proceedings of the National Academy of Sciences*, 110 (2013) 13705-13710

T. Sapsis, Attractor local dimensionality, nonlinear energy transfers, and finite-time instabilities in stochastic dynamical systems with applications to 2D fluid flows, *Proceedings of the Royal Society A*, 469 (2013) 20120550

**Pierre Lermusiaux**  
*Doherty Associate Professor in Ocean Utilization*

Dr. Lermusiaux is Professor of Mechanical Engineering and Ocean Science and Engineering at MIT. He received a Fulbright Foundation Fellowship (1992), the Wallace Prize at Harvard (1993), the Ogilvie Young Investigator Lecture in Ocean Eng. at MIT (1998), and the MIT Doherty Chair in Ocean Utilization (2009-2011). In 2010, the School of Eng. at MIT awarded him with the Ruth and Joel Spira Award for Distinguished Teaching. He has made outstanding contributions in data assimilation, as well as in ocean modeling and uncertainty predictions. His research thrusts include understanding and modeling complex physical and interdisciplinary oceanic dynamics and processes. With his group, he creates, develops and utilizes new mathematical models and computational methods for ocean predictions and dynamical diagnostics, for optimization and control of autonomous ocean systems, for uncertainty quantification and prediction, and for data assimilation and data-model comparisons. He has participated in many national and international sea exercises. He has served on numerous committees and organized large meetings and workshops. He is associate editor in three journals. He has more than hundred refereed publications.



## 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.



## Michael S. Triantafyllou

*Director, MIT Sea Grant*

*The Henry L. and Grace Doherty Professor in Ocean Science and 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 Professorship 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).



**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.

**Commander Jonathan E. Page, USN**  
*Associate Professor of the Practice of Naval Construction and Engineering*

Commander (CDR) 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. While there, he delivered the first-in-class USS Lewis B Puller (ESB 3) and started construction on the USNS Hershel "Woody" Williams (T-ESB 4).



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

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).

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# **Multi-purpose Unmanned Vehicle Assault (MUVA) Ship**

**LCDR Andrew Freeman, USN; LT Aaron Sponseller, USN; LT Casey Strouse, USN**

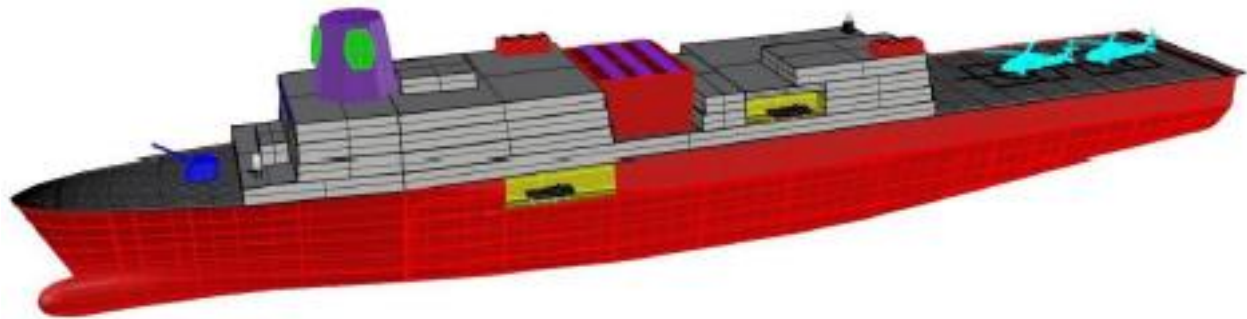
Over the past two decades, unmanned systems have become increasingly relevant in meeting the Navy's operational demands. Despite the strides that have been made in UxV technology, no ship class has been designed explicitly to host these systems. We examined the conversion of an existing ship to meet this purpose. The San Antonio Class Amphibious Transport Dock (LPD) is a ship class currently in production designed to provide the Navy and Marine Corps with a modern, sea-based platform for transporting and deploying marines via well deck operations, flight operations, and small boat operations. We used the LPD-17 hull as our baseline for an unmanned host and added DDG-51 Flight IIA combat capabilities while eliminating the amphibious mission requirements. With the complete change in mission profile, the new vessel was redesignated as a Multi-purpose Unmanned Vehicle Assault (MUVA) ship.

We designed the MUVA platform to operate in a similar environment as current DDGs, but employing the additional UxV platforms to extend its reach. This gives it additional in-situ capability beyond a DDG, improving operational availability and influence for commanders. The MUVA ship may lack speed compared to a DDG, but is able to dwell for long periods of time while still covering a large area due to the capability and maneuverability of unmanned payloads.

Due to the uncertain nature of UxV operations, we focused extensively on our design philosophy criteria of flexibility, interoperability, and reliability. This focus led us to find ways to deploy UxVs rapidly, increase margins, incorporate redundant systems, and reduce interface requirements for payloads. Effort was made to minimize structural changes, though some were necessary to accommodate operation and stowage of some UxVs as well as to incorporate the combat requirements.

The preferred MUVA ship design included the following key modifications to meet both the combat capability and UxV host requirements:

- Addition of Mk-45 5" on forecastle
- Replaced forward/aft RAM with CIWS
- Addition of 48 VLS Cells amidships
- Extended hangar
- Removal of aft AEM/S
- Addition of SPY-1 to forward AEM/S
- Expanded CIC for greater UxV command and control
- Extensive storage and maintenance space for the full range of UxVs
- Three additional boat davits for rapid USV/UUV launch and recovery



*Figure 1: Preferred MUVA Design*

# **Podded Propulsion Test and Demonstration Ship (PPTDS)**

Conversion of an *Oliver Hazard Perry* Class Frigate

**LCDR David Johnsen, USN; Lcdr Matthew Washko, USN; LT Ioannis Dages, HN**

Several international navies, including those of the Australians, French, and Spanish, use podded propulsion systems, due to their increased efficiency and control as well as several other observed benefits. However, the U.S. Navy has made only small, initial steps towards pursuing their implementation and has yet to fully investigate the employment of these underwater devices on its naval vessels, for which a significant number of unknowns and uncodified risks remain. To fully understand the feasibility considerations associated with podded propulsion, this project analyzed the conversion of an Oliver Hazard Perry (FFG-7) class frigate to a Podded Propulsion Test and Demonstration Ship (PPTDS). The baseline decommissioned FFG-7 hull was chosen due to the remaining U.S. inventory and its proven seaworthiness, which would result in a cheaper (and, hence, more feasible) demonstration ship than a new vessel built solely for testing.

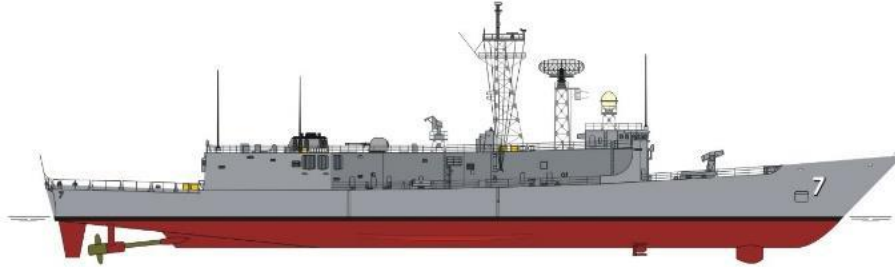
Utilizing modeling and simulation tools with a traditional FFG-7 model, the team conducted an in-depth analysis of the podded propulsion asset, including ship arrangements, electrical power requirements, weight and space requirements, hydrostatics, stability, seakeeping, speed, and maneuvering. While the sponsor requested these specific analyses to assist with the conversion's feasibility determination, allowance for significant latitude in decision-making and design space exploration was provided, with conversion cost minimization as a driving constraint. The resultant analysis led to two feasible variants: (i) removal of the rudder and replacement with one contra-rotating pod (CRP variant) and (ii) full replacement of the current propeller and rudder with two pods, placed transversely symmetric under the hull (twin-pod variant). For each of these final variants, the team evaluated two powering methods: (i) conversion of the ship's electrical system to power both the vessel and the pods and (ii) powering the pods with one temporary generator in each hangar, while powering the ship with existing in-hull generators.

A review of all available pod and powering options led to the team's determination that the CRP variant (ABB's 4.8-MW, 62-ton Azipod® DO 1250) with two temporary electric diesel generators (MTU's V3200M, 26.5 tons each – or similar modules) that can be loaded into FFG-7's hangar bay is the most cost-effective option for initial testing. With the PPTDS designed for one purpose, subsequent design refinements would be limited to specific models of Azipod® and temporary diesel generators that are available on the market at the time of construction. The team's PPTDS design has a significant margin in all major naval architectural areas, facilitating future design alteration efforts to minimize cost and increase feasibility of execution.

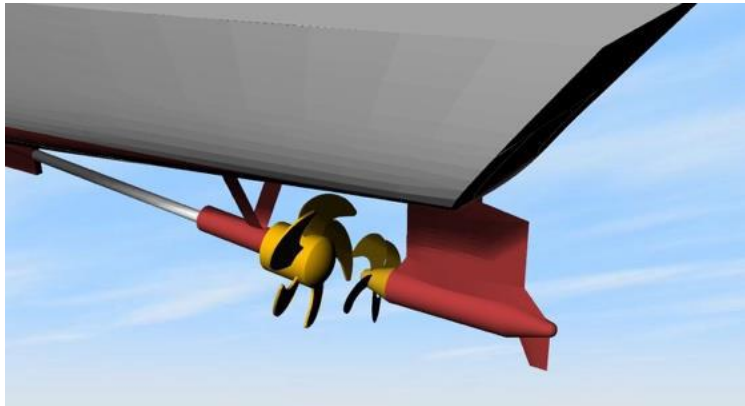
Using FFG-7 weight reports, Azipod® specifications, and open-source generator specifications, the weight analysis revealed that the conversion's required modifications are well within the trim system's compensation capabilities (102 tons removed + 115 tons added = +13 tons added total). The selected CRP variant is capable of 25-knot sustained speed and within the STANAG 4154 limits up to sea-state 7, considerably above a test and demonstration ship's projected needs. This proposed single-pod design is a cost-affordable option (\$80M-\$120M, based on ABB's previous conversion work and nominal man-day rates at public shipyards), with a large dependence on FFG-7's current condition and the work required to restore the vessel to a sea-going status.



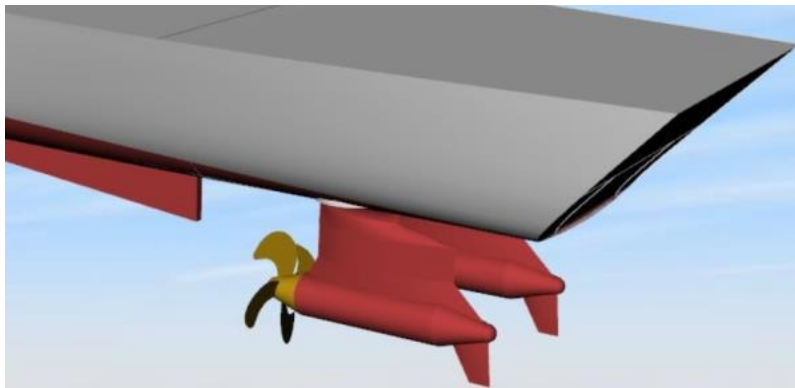
With benefits of enhanced maneuverability and minimal acoustic and magnetic signatures, the CRP variant is a feasible option for the U.S. Navy, who could refine the team's cost and weight estimates and conduct a more extensive evaluation of FFG-7's conversion for PPTDS service.



*Figure 2: Oliver Hazard Perry Class Frigate*



*Figure 3: Contra-rotating Pod Variant*



*Figure 4: Twin-Pod Variant*

## Forward Deployed VLS Reloading

**LT Robert Carelli, USN; LT William Hentschel, USN; LT Udit Rathore, USN**

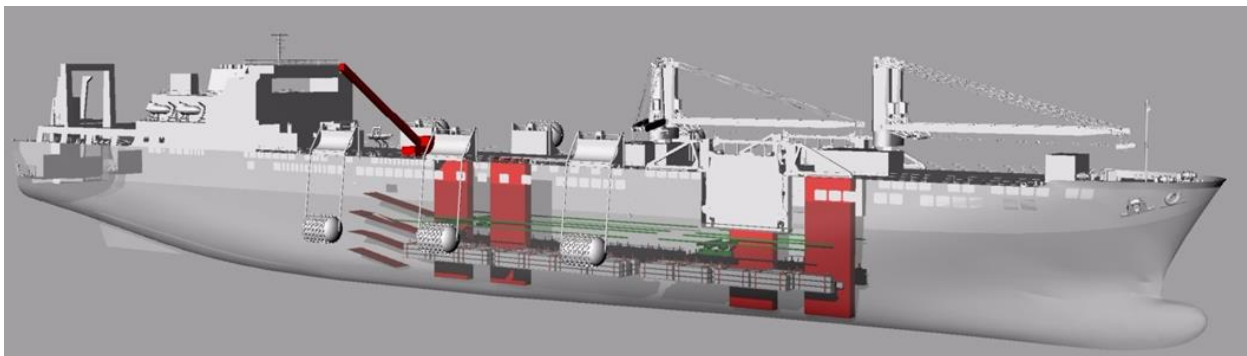
The US Navy has over 109 surface ships and submarines that employ vertical launch systems (VLS). The ability to reload VLS cells rapidly is vital to sustaining continuous forward deployed operations in a contested environment. The extensive infrastructure required to conduct safe and secure weapons transfer operations limits the number of ports around the world that can rearm combatants. This study evaluated the feasibility to fill the capability gap by refitting the 62,069 ton Bob Hope Class T-AKR with magazines and weapon transfer systems for mobile VLS reloading capability.

The T-AKR is a class of vehicle transport cargo ships capable of Roll-On-Roll-Off (RO/RO) and primarily used for prepositioning of Army vehicles. Its vast cargo capacity made it an ideal platform to carry a large payload of VLS supplies into theater. Additionally, its dual pedestal cranes offer a transfer capacity to load the missiles without external support.

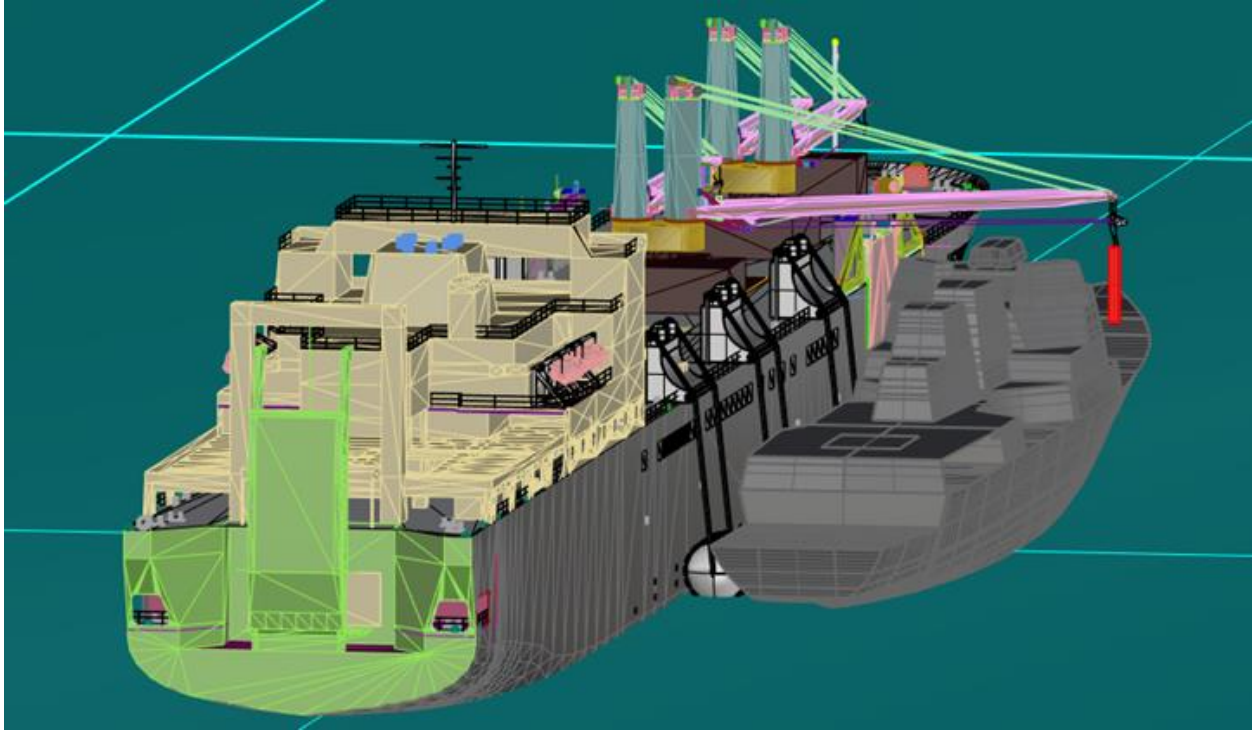
Our design philosophy focused on a delivering a long-term flexible and survivable solution for VLS transport and rearmament of the Surface Fleet. Due to the urgent need for this capability, the project team aimed to minimize the cost and complexity by leveraging existing cargo handling technology, minimizing the impact on the parent hull, and avoiding any modification of the current missile canisters.

Using the Pugh method we reduced the design space from 96 possible designs to three feasible variants and selected a final concept design that offered greatest magazine capacity and canister throughput for the lowest technical risk. Our design removed 328ft of deck from the T-AKR to convert 4 cargo compartments to 2 magazines with subsystems necessary to comply with US Navy explosive safety standards. The new weapons transfer system included overhead cranes and elevators to service both magazines and a rapidly deployable ship-to-ship (STS) fendering system necessary to conduct transfer operations in protected anchorages.

After modeling and analysis, this study concluded that the T-AKR had sufficient space, stability, seakeeping, and structural margin necessary for forward deployed VLS rearming. The preferred configuration achieved a maximum capacity of 428 canisters and is capable of simultaneously reloading 2 combatant VLS modules at a rate greater than 8 canisters per hour.



*Figure 5: T-AKR Elevator and Hold Concept*



*Figure 6: Reloading CONOPS Perspective*

## A New Self-Defense Test Ship

**LCDR William Taft, USN; LT Travis Rapp, USN; LT Kevin Stevens, USCG**

Since 1981, the U.S. Navy has employed a series of unmanned ships to conduct self-defense weapons system testing. The current Self-Defense Test Ship (SDTS) is not equipped with a SPY-6 Air and Missile Defense Radar (AMDR), Aegis Combat System, or Block-2 Evolved Sea-Sparrow Missile (ESSM) and is therefore unsuitable to conduct testing for the Flight III series of *Arleigh Burke*-class destroyers which are expected to enter service in 2023. As part of MIT's four-week course 2.704: Projects in Naval Ship Conversion, three graduate students sponsored by NAVSEA 05 investigated the academic feasibility of converting an existing naval vessel to fill this capability need without jeopardizing the crucial testing for non-Aegis combat systems conducted onboard the existing SDTS.

The group selected a *Ticonderoga*-class cruiser as the most suitable starting point for this conversion after a brief analysis of alternatives, and quickly narrowed the focus to the ex-*Ticonderoga* which is currently moored in Philadelphia awaiting disposal. Using this stricken ship bypassed the opportunity cost of taking an operational cruiser away from the Fleet. Equipped with a general impression of *Ticonderoga*'s current status gleaned through a brief tour of this vessel, and technical data from a match-model in the Navy's Advanced Ship & Submarine Evaluation Tool (ASSET) software package, the group set about analyzing the feasibility of system-level modification options capable of satisfying the project requirements. Distilling 34,992 permutations of feasible propulsion systems, electrical systems, weapon systems, and combat system architectures yielded a configuration which balanced cost, capability, and future flexibility.

In this final variant, propulsion would be provided exclusively by the starboard propeller shaft powered by a single marine gas turbine engine, which, along with the steering system, would be converted for remote operation. The as-designed electric plant would be returned to operation and supplemented by an additional gas turbine generator. A 4160 VAC electric distribution system would be installed in the space vacated by the removal of the port propeller shaft. The aft twin-arm missile launcher would be replaced by an eight-cell vertical launch system to accommodate the ESSM, and large portions of the forward and aft superstructures would be removed entirely to accommodate a combat system modularized into a shipping-container-like architecture. To operate in a manned condition during transit, the pilothouse would similarly be modularized and would tie in to the remote-control infrastructure; berthing and messing for the reduced crew would be accommodated in the areas formerly designated for Chief Petty Officers.

The weight and stability changes associated with these modifications were analyzed using the Navy's Program of Ship Salvage Engineering (POSSE) software package, which demonstrated that in this configuration the vessel could safely accommodate up to 214 tons of combat system payload, centered 20 meters above the keel, in addition to 128 tons of modularized containers. With the addition of approximately 1,000 tons of solid ballast, this vessel would be capable of carrying an additional 300 tons of combat systems payload at the same height, making SDTS capable of accommodating Aegis and non-Aegis combat systems.

A cost analysis using a combination of data from the Navy's Regional Maintenance Centers, the MIT 2N cost model, and ship repair estimation techniques established a total estimated conversion

cost of approximately \$75 million, excluding the cost of the combat systems payload. While unconventional in design, the cost and future flexibility provided by this conversion represent a reasonable option to satisfy the Navy's SDTS capability gap.

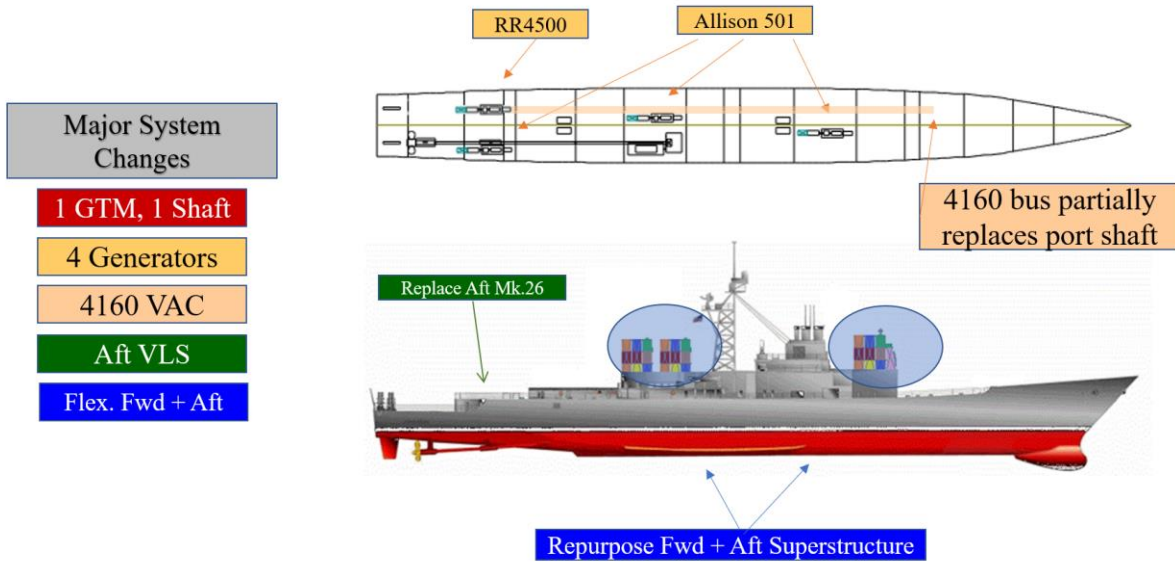


Figure 7: New Self-Defense Test Ship Concept

## Jawfish: Submarine-Launched Manned Submersible

LCDR Sjaak de Vlaming, USN; LT Nicholas Dadds, USN; LT David Ferris, USN

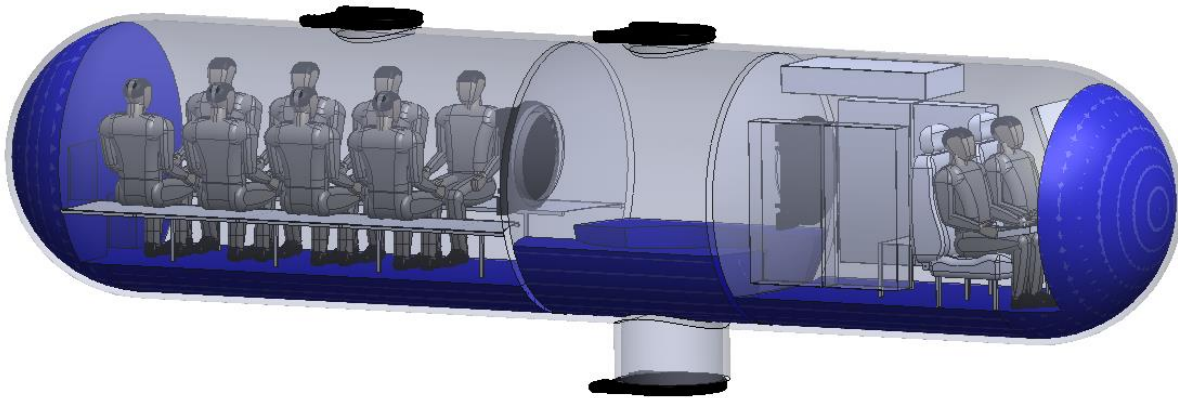
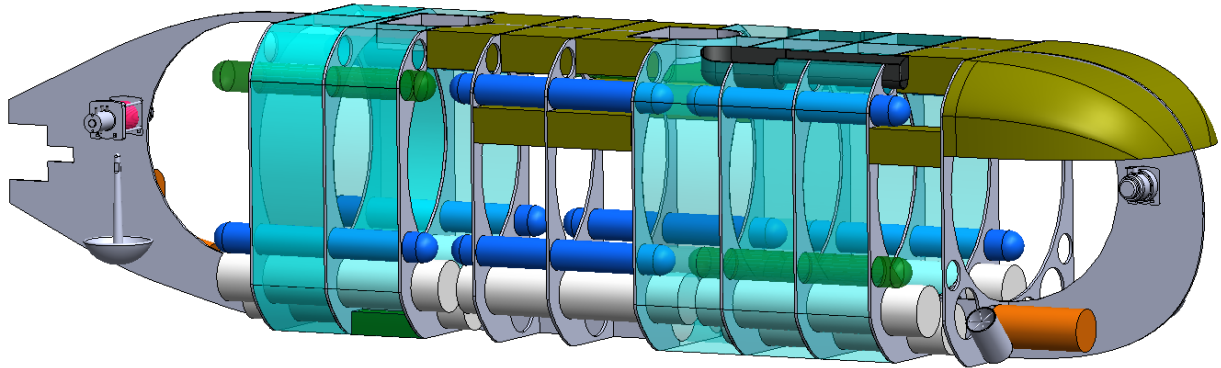
JAWFISH is an original naval vessel sponsored by U.S. Special Operations Command (USSOCOM); this year-long design project addresses the demand for a clandestine, dry-atmosphere, manned submersible which mates to a submarine host. Although the Advanced SEAL Delivery System once filled that role, critical setbacks to that program in 2008 resulted in an acute capability gap. As a smaller and lighter platform, JAWFISH constitutes a re-imagining of that design space.

The high-level technical requirements for JAWFISH constrained its design within the weight and space envelope of the Modernized Dry Deck Shelter (not to exceed 218,600 lbs and 506” in length). Using an Analytical Hierarchy Process with a scratch-built model to assess technical utility and cost, this design effort analyzed a total of 37,800 unique configurations in order to identify a Pareto frontier of optimal JAWFISH variants. This process evaluated the primary design variables of Crew Size, Cargo Space, Maximum Range, Loiter Time, Lock-in/Lock-Out Cycles, and Station-Keeping Ability, whose relative values were provided by manned submersible operators in the SEAL community. The primary technology tradeoff analyzed in this study was the means of station-keeping, expressed as an anchoring capability, a hovering capability using thrusters, or a combination of both.

From a pool of seven final JAWFISH variants, USSOCOM chose a vehicle with both anchoring and hovering with capacity for 10 crewmembers. This enabled final validation of the model by assessing JAWFISH trim and stability characteristics by means of an equilibrium polygon. Feedback from the sponsor indicates that this project was highly successful as a reference point for future manned submersible acquisition.

### Principal Characteristics:

Length x Beam x Height	42' 2" x 8' x 9'	Max Op Depth	400 ft
Crew	8 divers/2 pilots	Max LIO Depth	190 ft
Cargo	40 ft <sup>3</sup>	Max Speed	10 knots
Range	120 nm	Endurance Speed	5 knots
LIO Capability	Anchoring/Hovering	Energy Source	Li-ion, 621 kWh
Divers per LIO	5	Life-cycle Cost	\$120.6 Million



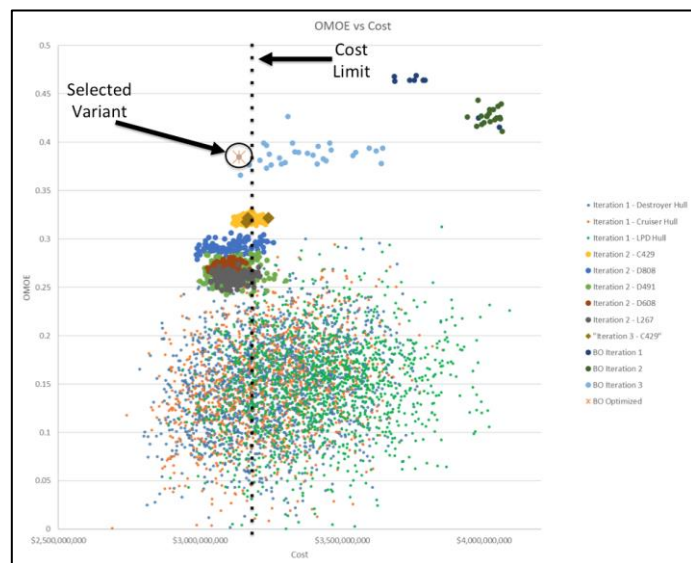
# Large Surface Combatant (LSC)

**LT Adam Campbell, USN; LT Jordan Fouquette, USN; LT Benjamin Parker, USN**

Due to the evolving capabilities of our foreign adversaries and our aging inventories of Cruisers and Destroyers, the time has come for the United States Navy to determine effective and viable replacements for the future fleet. This led to the creation of the Future Surface Combatant Force comprised of large, small, and unmanned surface combatant ships. Specifically, the Large Surface Combatant (LSC) will serve as the replacement for Cruisers and Destroyers by encompassing the multi-mission capabilities of each platform, respectively.

The goal for this project was to conduct an in-depth evaluation of a concept design for the Large Surface Combatant. The LSC is a multi-mission capable platform with the capability and flexibility to take advantage of both current and future technologies. This study includes in-depth analyses on requirements for adaptable design, the integration of advanced weapon systems including the electromagnetic railgun and high-energy laser, and incorporation of various UxV platforms.

The hull-form and allocated support for installed mission systems of the preferred variant were selected by taking a set-based design approach coupled with machine learning. Specifically, the machine learning techniques applied were Gaussian process regression and Bayesian optimization. The set-based design was conducted using the Rapid Ship Design Environment (RSDE) and ASSET programs to produce thousands of unique variants within the design space. Gaussian process regression was trained using these variants to build surrogate models for Overall Measure of Effectiveness (OMOE) and Bayesian optimization was implemented to search these models for the optimal solution.



The LSC features a flexible architectural arrangement for inclusion of both existing and future technologies. This was accomplished by taking a zonal approach for ship systems and equipment configurations. These zones are predetermined spaces with maximum allowances for space (area and volume), weight, power, and cooling (SWAPC). The zones are categorized into four overall system groups:



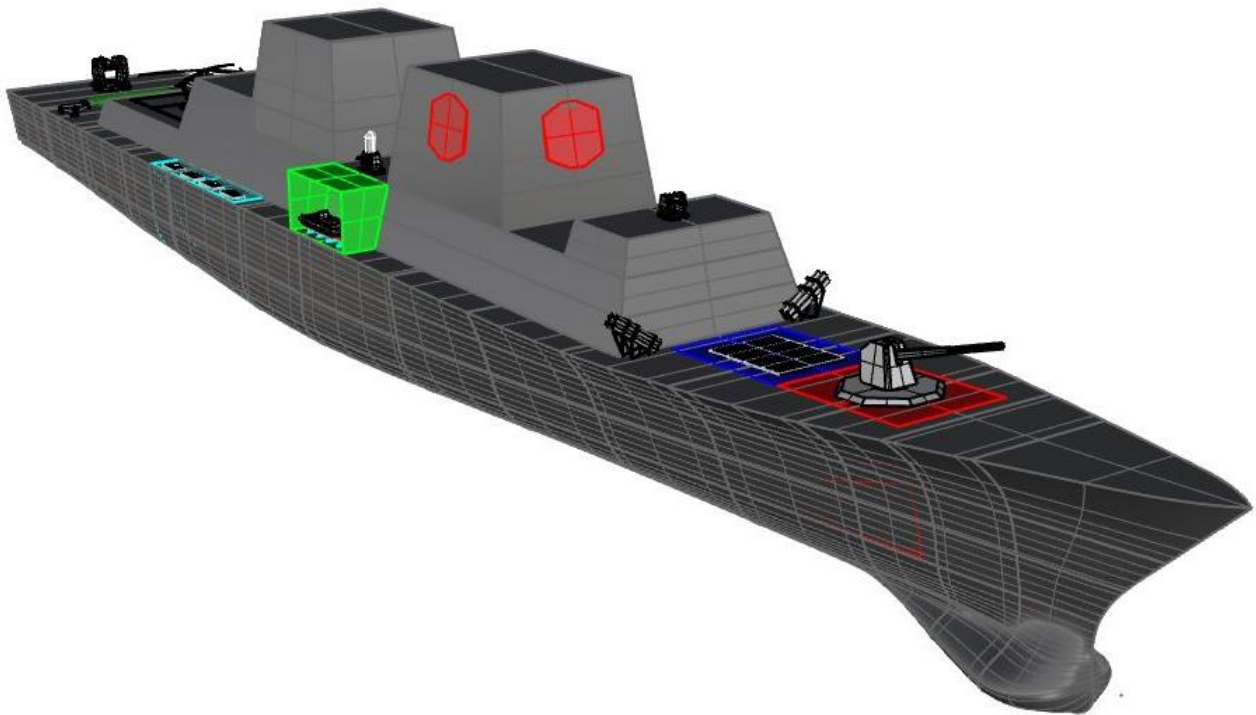
SYSTEMS	ZONES
Weapon Systems	Main Battery
	Secondary Armament Large
	Secondary Armament Medium
	Secondary Armament Small
	High Energy Defensive Weapon Defensive Weapon
Sensors	Air Search Radar
	Surface Search Radar
	Fire Control
	Electronic Countermeasure
	Communications
Aviation	Aviation Zone
Waterborne Vehicles	Waterborne Vehicle Zone

- 1) Weapon Systems
- 2) Sensors
- 3) Aviation
- 4) Waterborne Vehicles

Each system is comprised of zones based on their specific functionality.

The Large Surface Combatant developed by the project is a feasible and highly mission-capable design. The capabilities and concepts introduced in this project will provide the Navy with the most technologically advanced, multi-mission surface combatant in the world which will not only surpass our existing Cruisers and Destroyers, but will far exceed the capabilities of any of our foreign adversaries at the tip of the spear.

Large Surface Combatant Characteristics	
Parameter	Value
LOA (m)	175.56
LBP (m)	167.02
Beam (m)	25.25
Draft (m)	7.51
Full Load Displacement (mton)	17571.8
Endurance Range (nm)	5796.35
Maximum Speed (kt)	29.09



## NexT-AGS: Next-Generation Oceanographic Survey Ship

**LCDR Nathaniel Byrd, USN; Lcdr Daniel Huynh, USN; LT David Ingraham, USN**

Military Sealift Command's (MSC) T-AGS ships perform oceanographic, acoustic, biological, bathymetric, and geophysical surveys to gather and provide data in support of undersea warfare and bottom mapping. However, the current lineup of ships are quickly approaching the end of their service life and do not adhere to new build requirements or take advantage of advancing technologies. There is additionally a two year backlog of surveys requested by combatant commanders, indicating a strong demand signal requiring continued presence.

The Next Generation T-AGS (NexT-AGS) project is sponsored by the Oceanography Capabilities and Requirements division of OPNAV (Office of the Chief of Naval Operations) in order to investigate a new design. This design is faster, more fuel-efficient, quieter, and augmented with organic unmanned capabilities while incorporating the following regulatory mandates: double-hulling in way of all oil and fuel tanks, tier-3 main engine exhaust gas treatment, sewage / garbage treatment, and ballast water treatment. To facilitate the launch/operation/retrieval of Autonomous Underwater Vehicles (AUVs), the NexT-AGS is fitted with a large moonpool which can take advantage of the benefits to surveys and scientific exploration while accommodating potential rapid advancements in autonomous vehicle capabilities.

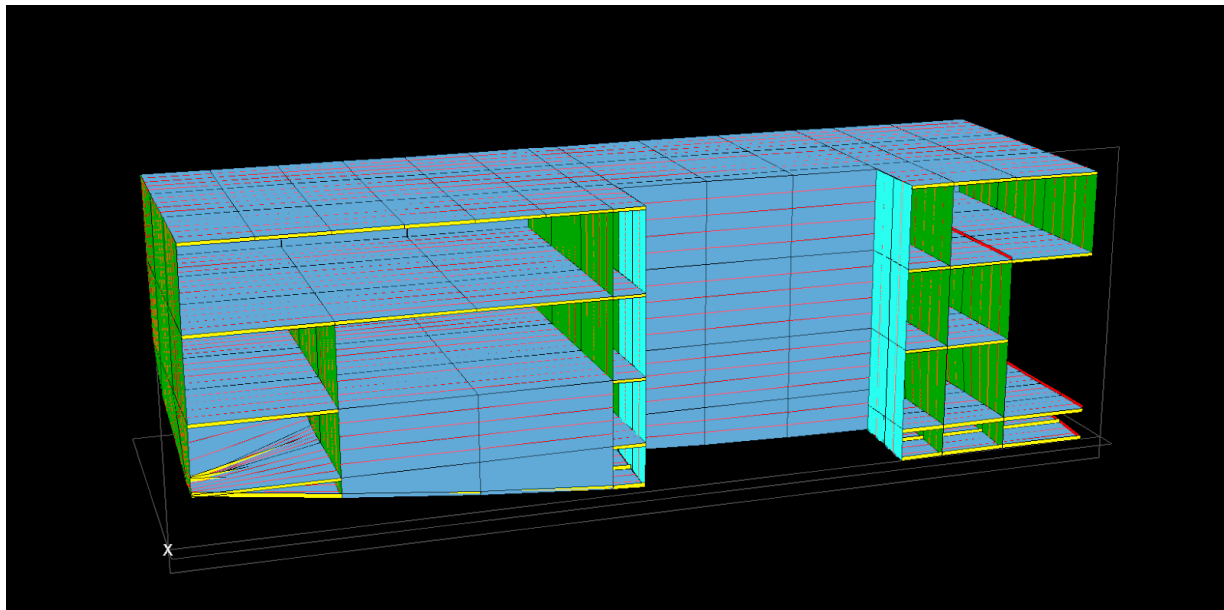
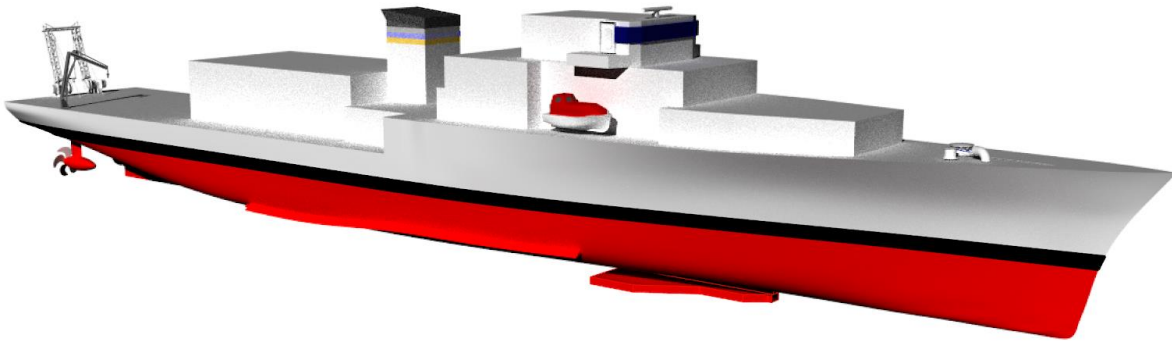
The current T-AGS 60 class required many changes since her contract was initially awarded in 1991, from the sonar gondola that was backfitted to reduce the sonar degradation from bubble sweepdown to the enlarged skeg that was backfitted to improve the poor directional stability due to the sonar gondola. These backfits were costly and added a significant resistance penalty to the T-AGS class. The challenge for the NexT-AGS was to develop a design that met all requirements and regulations and provided superior survey quality while also minimizing resistance.

The NexT-AGS design originated with the T-AGS hullform which was subsequently heavily modified and redesigned to meet regulatory mandates and American Bureau of Shipping (ABS) classification requirements. Key changes to the propulsion system include the use of more efficient electric drive azimuth pods with an optimized engine size and operating configuration for both transit and survey speeds. These changes provide an increase in survey coverage area by 17-47% over the baseline T-AGS at no additional fuel cost. A larger moonpool accommodates the largest variants of AUVs without the complex launch and recovery system currently in place and provides margin for future growth in AUV usage. The longer hullform allows moving the gondola towards midships which increases directional stability, allowing for the use of a smaller skeg.

Preliminary performance analyses on the NexT-AGS conclude that our initial design provides a feasible solution to meet the current sponsor demands. It improves survey coverage area without sacrificing quality and provides adequate margin for both power and AUV carrying capacity.

NexT-AGS Key Characteristics:

- LBP: 117 m
- Beam: 17.5 m
- Draft: 5.5 m
- Transit Speed: 15 knots
- Endurance Range: 13000 nm
- Displacement: 5994 mton
- Moonpool Size: 12' x 24'
- Dynamic Position: Level 1
- ABB Azipod CO 1250 Electric Podded Propulsors



Structural Analysis of the Moonpool section within Maestro Marine

# Combined Tensile-Compressive Biaxial Loading of Li-ion Battery Components

**LCDR Nathaniel Byrd, USN**

<b>Prof. Tomasz Wierzbicki</b>	<b>Prof. Joe Harbour</b>
Thesis Supervisor	Thesis Reader

Lithium-ion batteries under a mechanical load can develop failures in the internal multi-layer structure. Due to the flammable materials required for construction the safety of the battery has been in question since it was first developed. Internal failures can create a short circuit which may lead to thermal runaway, resulting in fire and sometimes the explosion of the battery. Due to the increasing use of lithium-ion batteries in military and consumer products the number of incidents involving batteries has risen and with it a growing concern for safety. Larger batteries required for unmanned and electric vehicles increase the risk associated with storing batteries onboard naval ships and severity of damage from a collision involving an electric vehicle.

This thesis investigates the failure mechanism of internal lithium-ion battery components when subjected to a constant out-of-plane compression while increasing in-plane tension to the point of failure. The constant compression models the internal pressure a battery may be subject to due to certain designs, operating environments, such as the ocean, or damage to the external protective casing. This thesis will also demonstrate the methods used to optimize a mechanical system designed to apply constant compression while increasing tension. The results will be used to characterize and anticipate the effect of lateral compression on the failure load of lithium-ion battery cells. The existing micro model can then be modified to the experimental conditions in this thesis in order to compare the experimental and modeled results. This comparison will be used to refine and validate the micro model and ultimately bring us closer to improving the design of lithium-ion batteries.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

# **Enabling Tactical Autonomy for Unmanned Surface Vehicles in Defensive Swarm Engagements**

**LT Adam Campbell, USN**

<b>Prof. Henrik Schmidt</b>
Thesis Supervisor

This research incorporates practical applications of marine vehicles with robotics control theory to reduce the vulnerability of allied assets to asymmetric warfare.

This work utilizes the Mission Oriented Operating Suite with Interval Programming (MOOS-IvP) to enable a number of simulated unmanned surface vehicles (USV) to provide defense for a high value unit (HVV) against fast attack craft (FAC) aggressors.

The primary objective is to enable a swarm of defending vehicles to protect the HVV and successfully counter a swarm of aggressors with the ability to adapt to changing situations. This research makes it possible for autonomous defenders to react according to variables such as number of defenders, number of aggressors, known kinematic capabilities of defenders, perceived kinematic capabilities of aggressors, and positional distribution of aggressors. I first describe a theoretical framework for analyzing the engagements based on game theory by constructing the defense scenario as a three-party differential game. I utilize MATLAB to demonstrate optimal solutions to this scenario as an application of game theoretical guidance, which was developed for use in missile guidance systems. I then present algorithms and behaviors to demonstrate that the multi-objective optimization in MOOS-IvP approaches the optimal solutions in the vehicles' autonomous response during engagements consistent with the three-party differential game. I finally present MOOS-IvP simulation data to prove autonomous tactical decision-making in more realistic engagement scenarios.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

**Risk-Based Treatment of Uncertainty in Trade Space Exploration: Application via Monte Carlo Simulation on a Manned, Mini-Submersible Model**

**LT Nicholas Dadds, USN**

<b>Prof. Dan Frey</b>
Thesis Supervisor

In design, modeling and simulation are commonly used to answer questions of interest as it is both inefficient and expensive to physically build and evaluate numerous possibilities. Any modeling effort aims to build the simplest model while capturing the real-world trends appropriately. When modeling highly complex systems or pushing technological bounds, it can be expected for variables in the model to possess elements of uncertainty. In a trade space approach, different design combinations may exhibit different uncertainty profiles. Omitting these uncertainties in the modeling effort can misrepresent design combinations in the overall trade space in terms of capability and cost. Therefore, if the uncertainties are not represented the decision maker is accepting an unknown level of risk when selecting a design.

This thesis proposes that uncertainty in early stage design is not well represented, despite its playing a major role in a system’s ultimate success. This research explicitly accounts for uncertainty in model inputs via probability distributions instead of simply applying “best estimate” deterministic values. These distributions are sampled via Monte Carlo simulation to generate an uncertainty profile for different design combinations, thereby increasing the validity of the model outputs. This approach for capturing the implications of uncertainty in early stage design allows for a more accurate representation of the system level design risk. Ultimately, the deterministic design points in the trade space are quantitatively and qualitatively evaluated against the design points incorporating uncertainty. Understanding that model outputs can only ever be as good as model inputs, the exploration of the effect of uncertainty on the design trade space is important.

An example of Trade Space Exploration for the conceptual design of a manned, mini-submersible is used to demonstrate an approach for quantifying and visualizing uncertainty to inform decision making. This case study suggests that visualizing risk at the system level in a typical performance versus cost context is valuable.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

## **Analysis of U.S. Navy Submarine Availability Cost Data**

**LCDR Sjaak de Vlaming, USN**

<b>Prof. Themis Sapsis</b>	<b>Prof. Joe Harbour</b>
Thesis Supervisor	Thesis Reader

The maintenance of a warship requires an involved combination of scheduling, funding, and execution. For one finite maintenance period, known as an "availability," a small setback in one of these areas can have a significant deleterious effect on the availability as a whole. Compounded and obscured by complexity, the root causes of such setbacks may remain unresolved and recur within the same availability or in one that follows, resulting in cumulative cost increases and schedule delays.

The United States Navy has a strong incentive to better understand availability execution. In support of that objective, this thesis investigates man-hour cost data from 57 submarine availabilities across all four public naval shipyards, spanning 315 ship systems, from December 2006 to December 2017.

The results of this thesis are best understood in two parts: the first is an observation of system population characteristics, and the second is a multiple linear regression analysis. The first part identifies nine specific submarine systems for which work is systematically over- or underestimated in a majority of availabilities, and also partitions the data to gain insights about the performance of categorical subsets, such as a particular shipyard, availability type, or period in time, compared to the aggregate. These results include a "tier ranking" of the systems whose improvement would yield the greatest benefit for cost. The second part yields two different multiple regression models of the data to create revised estimates for what is known as "New Work." Both models result in significantly higher error than that which exists without them, invalidating multiple linear regression analysis as a path to gaining insights about availability performance.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

# **Time Optimal Multi-Waypoint Mission Planning in Dynamic Flow Fields**

**LT David Ferris, USN**

<b>Prof. Pierre Lermusiaux</b>
Thesis Supervisor

As the US Navy places more emphasis on unmanned marine vehicles, they will be expected to perform at greater range and provide more capability. Mission planning for autonomous marine vehicles must consider the operating environments and currents to maximize mission effectiveness. This thesis demonstrates the use of exact equations to predict time-optimal mission plans for a marine vehicle that visits a number of locations in a given dynamic ocean current field. The missions demonstrated begin and end in the same location and visit a finite number of locations or waypoints in the minimal time; this problem bears close resemblance to that of the classic “traveling salesman,” albeit with the added complexity of a continuously changing three-dimensional flow field.

The paths, or “legs,” between all goal waypoints are generated by numerically solving exact time-optimal path planning level-set differential equations. The equations grow a reachability front from the starting location in all directions. When the front reaches a remaining waypoint, a new reachability front is immediately started from that location. This process continues until one set of reachability fronts has reached all goal waypoints and has returned to the original location. The time-optimal path for the entire mission is then obtained by trajectory backtracking, going through the optimal set of reachability fields in reverse order. Due to the spatial and temporal dynamics, a varying start time results in different paths and durations for each leg and requires all permutations of travel to be calculated.

Even though the method is efficient and the optimal path can be computed serially in real-time for common naval operations, for additional computational speed, a high-performance computing cluster was used to solve the level set calculations in parallel. This method is first applied to several hypothetical missions. The method and distributed computational solver are then validated for naval applications using an operational multi-resolution ocean modeling system of real-world current fields for the complex Philippines Archipelago region. Because the method calculates the global optimum, it serves two purposes. It can be used in its present form to plan multi-waypoint missions offline in conjunction with a predictive ocean current modeling system, or it can be used as a litmus test for future solutions to the traveling salesman problem in dynamic flow fields.

**Naval Engineer**

**Master of Science in Mechanical Engineering**



# **Multipath Arrival Tracking for Marine Vehicles Utilizing Pattern Recognition**

**LT Jordan Fouquette, USN**

<b>Prof. Henrik Schmidt</b>
Thesis Supervisor

In recent years, interest in the Arctic Region has been steadily growing as it has become more accessible due to continued ice recession. This increased accessibility opens up the possibility for nations to take advantage of the region's abundant resources and trade routes thereby increasing military, political, and commercial interest. The extreme temperatures and significant ice cover in this region have created a unique and challenging acoustic environment. At increased distances, individual acoustic ray path data becomes inconsistent due to improper ray path identification and fading. Marine vehicles have the ability to overcome these challenges and increase contact tracking capabilities by taking advantage of the patterns associated with these multipath arrivals.

Through the use of pattern recognition, a multipath arrival tracking algorithm was developed to utilize the unique characteristics associated with each individual ray path for long range tracking purposes. This tracking algorithm analyzes the amplitude and arrival time patterns amongst all individual ray paths in order to accurately identify each ray path as scattering and fading occurs, thereby increasing range-tracking capabilities. This becomes especially useful in the Arctic Region as contacts of interest can be tracked regardless of their position above, below, or within the Beaufort Lens- a newly discovered sound duct from 100 to 200 meters depth. Simulations covering the numerous depth combinations of sources and receivers with respect to the Beaufort Lens illustrate the difficulty in contact tracking within this harsh environment and highlight the effectiveness that is presented by utilizing multipath arrival data. The developed algorithm takes advantage of these unique patterns in order to provide a unique tracking capability for marine vehicles to employ.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

**Build Environment Pressure Effects on Selective Laser Melting (SLM)  
Processing of Select Engineering Alloys**

**CDR Jonathan S. Gibbs, USN, P.E.**

<b>Prof. A. John Hart</b>	<b>Prof. Joe Harbour</b>
Thesis Advisor	Committee Member
<b>Prof. C. Cem Tasan</b>	<b>Prof. Ken Kamrin</b>
Committee Member	Committee Member

Selective laser melting (SLM) is rapidly being adopted for additive manufacturing (AM) of metal components and can achieve locally high density and near-net shape geometric accuracy. The dynamics of the meltpool and stability of the melt track upon cooling are critical to the microstructure, porosity, and final properties of the solidified material. Current literature is replete with optimization of SLM scan parameters, yet there is need to develop a more fundamental understanding of how meltpool dynamics influence the SLM process, which may lead to new means of process control. Recent studies also indicate the potential to develop superior microstructure and resultant mechanical performance of the as-built print when compared to heat treated parts or even cast material (in both percent elongation and ultimate tensile strength). This thesis employs the use of a two custom-built SLM testbed printers to examine the influence of scanning strategy to the porosity and microstructure in Ti-6Al-4V. Further, the thesis investigates the influence of ambient gas pressure on the meltpool and solidified track to elucidate how pressure may be used as a control variable to influence surface quality, porosity, and material loss due to evaporation for exemplary alloys such as 316L stainless steel and Inconel 718.

**Doctor of Philosophy in Mechanical Engineering**

## Next Generation Probabilistic Prediction Model of Submarine Propulsion Shaft Life

**LCDR Daniel Huynh, USN**

<b>Prof. Alex Slocum</b>	<b>Prof. Ronald Ballinger</b>
Thesis Supervisor	Thesis Supervisor

With the development of the U.S. Navy's new COLUMBIA class ballistic missile submarine, the Navy plans to implement a new longer operational inspection interval for the propulsion shaft system, attempting to double the current 6-year inspection interval for the OHIO class of submarine it is replacing. However, an initial study conducted predicts unsatisfactory levels of failure at this interval due to corrosion fatigue, although with a high level of uncertainty. This thesis curtails that uncertainty by developing a robust probabilistic model of the COLUMBIA class submarine propulsion shaft in order to more accurately predict probabilities of failure.

To improve upon previous efforts and reduce uncertainty, all the components and various failure modes of the propulsion shaft were first identified. While the most likely scenario involves water ingress and a wetted propulsion shaft leading to corrosion, pitting, and cracking, other factors that could contribute to shaft failure include damage during install or failure of cathodic protection systems. Using literature, these failure modes were approximated with equations and statistical distributions and ultimately combined to form a complete probabilistic model of the propulsion shaft system. While this model was designed with the COLUMBIA class of submarine in mind, it can be tailored and easily modified to apply to a broad range of shafting systems, including other classes of submarines, conventional surface ships, and even offshore platforms.

Failure probabilities for the submarine shaft were predicted using Monte Carlo simulations. To calibrate the model, shaft inspection data from current OHIO class ballistic missile submarines at Portsmouth Naval Shipyard (PNSY) were compared to outputs from the probabilistic model, adjusting distributions and variables as appropriate to match target parameters. While these inspections have typically taken place at approximately the 6-year operational interval, the validated model can be used to predict propulsion shaft failures at a range of inspection intervals.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

# **Engineering and Human Factors Analysis of a Novel One-Atmosphere Diving Suit Joint**

**LT David Ingraham, USN**

<b>Prof. Alex Techet</b>	<b>Prof. Joe Harbour</b>
Thesis Supervisor	Thesis Reader

An Atmospheric Diving Suit (ADS) is a one person anthropomorphic submersible which is used to facilitate undersea work while keeping the diver/operator at atmospheric pressure thus removing them from the harmful physiological effects associated with diving at depths. Most ADS in use today have limited range of motion/mobility due to the combination of cylindrical joints utilized. The joint discussed in this thesis differs from cylindrical joints, widely in use today, in that it is a bellows type joint which allows sixty degrees of motion in a plane. The engineering required to allow this joint to operate under pressure is to maintain a specific volume in the joint through its range of motion. A change in volume correlates to work being done and under pressure, deep in the ocean, this would result in the joint being locked in the position associated with the smallest volume. This research will explain the engineering behind maintaining the volume through a range of motion. Material selection will be discussed as well. Finally, a human factors analysis will be performed and results discussed.

This thesis continues the work that has been completed in conjunction with a Small Business Technology Transfer (STTR) contract funded by the Office of Naval Research (ONR) between the Massachusetts Institute of Technology and Midé. The elbow joint prototype, developed and manufactured by Midé, was tested in a rig, designed and built at MIT, consisting of a water tank with the joint completely submerged. Range of motion for 15 subjects was captured using image processing software and a qualitative interview was conducted to capture the experience for users with different anthropomorphic measurements.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

# **An Automatic, Multi-Fidelity Framework for Optimizing the Performance of Super-cavitating Hydrofoils Using Gaussian Process Regression and Bayesian Optimization**

**LT Benjamin Parker, USN**

<b>Prof. Michael Triantafyllou</b>
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Thesis Supervisor
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Computer automated design of complex physical systems is often limited by the computational resources required for the high precision solvers. Determining an optimum design necessitates high accuracy simulations due to the multi-dimensional design space and the interconnectedness of the constraint and objective quantities. This paper will present an automated framework for iterating through a design loop that includes both physics-based computer simulations and surrogate model training using machine learning techniques. To alleviate the computation burden and efficiently explore the design space, a surrogate model for each quantity of interest that cannot be found deterministically will be utilized. Further reduction of the computational cost is accomplished by utilizing both low- and high-fidelity data to build the response surfaces. These response surface models will be trained using multi-fidelity Gaussian process regression. The models will be iteratively improved using Bayesian optimization and additional high-fidelity simulations that are automatically initiated within the design loop. In addition, Bayesian optimization will be used to automatically determine the optimum kernel for the Gaussian regression model. The feasibility of this framework is demonstrated by designing a 2D super-cavitating hydrofoil and comparing the optimum shape found with a known benchmark design. This automated multi-fidelity Bayesian optimization framework can aid in taking the human out of the design loop, thus freeing manpower resources and removing potential human bias.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

# **Adaptive Sequential Sampling for Extreme Event Statistics in Ship Motions**

**LT Kevin Stevens, USN**

<b>Prof. Themistoklis Sapsis</b>
Thesis Supervisor

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.

**Naval Engineer**

**Master of Science in Mechanical Engineering**

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