Naval Construction and Engineering
Ship Design and Technology Symposium

Wednesday, April 27, 2011

MIT Faculty Club, 50 Memorial Drive, Building E52-Sixth Floor

0800 – 0900	Registration and continental breakfast
0900 – 0915	Welcome and Opening Remarks
0915 – 1000	Research Briefs
1000 – 1030	Break and Poster Sessions (featuring student theses and projects)
1030 – 1200	Student Design Project and Research Briefs
1200 – 1230	Break and Poster Sessions (featuring student theses and projects)
1230 – 1400	Lunch Buffet and Keynote Address
1400 – 1500	Student Design Project and Research Briefs
1500 – 1530	Break and Poster Sessions (featuring student theses and projects)
1530 – 1630	Student Design Project and Research Briefs
1630 – 1645	Closing Remarks

History

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

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

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

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

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

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

MIT Naval Construction and Engineering Program Description

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

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

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

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

Vice Admiral Kevin M. McCoy
Commander, Naval Sea Systems Command

A native of Long Island, N.Y., Vice Admiral McCoy graduated from the State University of New York at Stony Brook in 1978, with a Bachelor of Science Degree in Mechanical Engineering.

At sea, McCoy served aboard USS *Daniel Webster* (SSBN 626) and as repair officer aboard USS *Ly Spear* (AS 36). In these assignments he earned his submarine engineering duty qualification and his surface warfare qualification. He was also awarded the Claud A. Jones Award from the American Society of Naval Engineers as "Fleet Engineer of the Year" during his tour onboard *Ly Spear*.

Ashore, McCoy served in numerous assignments in the Naval Shipyards, including assignment to Mare Island, Charleston, Norfolk, Puget Sound and Portsmouth Naval Shipyards. From 2001-2004, he served as the 80th commander of Portsmouth Naval Shipyard. McCoy earned a master's degree in Mechanical Engineering and an engineer's degree in Naval Engineering from the Massachusetts Institute of Technology. He also earned a Masters in Business Administration Degree from Emory University.

Upon selection to flag rank, McCoy served as assistant deputy commander of Industrial Operations of the Naval Sea Systems Command from 2004-2005. From 2005-2008, he served as the Naval Sea Systems Command’s chief engineer. In June 2008, he was confirmed by the U.S. Senate for promotion to the rank of vice admiral and was assigned as the 42nd commander, Naval Sea Systems Command.

Rear Admiral Joseph F. Campbell

Deputy Commander for Logistics, Maintenance and Industrial Operations, Naval Sea Systems Command

Rear Admiral Joseph F. Campbell was born in Lancaster, Pa., and raised in Newark, Del. He graduated from the University of Pennsylvania with a Bachelor of Science degree in Mechanical Engineering in 1980 and later earned a Naval Engineer's degree and Master of Science in Mechanical Engineering from the Massachusetts Institute of Technology. He is a registered Professional Engineer in the State of Delaware.

Campbell was commissioned as an Engineering duty officer in May 1980 via the NROTC program and reported for duty on board the USS HOLLAND (AS 32) in Holy Loch, Scotland. Follow on waterfront assignments were at Pearl Harbor Naval Shipyard, Supervisor of Shipbuilding Newport News, Trident Refit Facility, Kings Bay and Norfolk Naval Shipyard. He also completed two staff tours at Commander Submarine Force, U.S. Atlantic Fleet. In November 2003 he returned to Norfolk Naval Shipyard as the 101st Shipyard Commander. In May 2006 Campbell was nominated for appointment to flag rank, and in July 2006 reported for duty as deputy director, Fleet Readiness Division (OPNAV N43B) in the Office of the Chief of Naval Operations at Washington, D.C. Campbell then became the Fleet Forces Command, director of Fleet Maintenance (N43) in May 2008 and reported as the deputy commander, Logistics, Maintenance and Industrial Operations, Naval Sea Systems Command in June 2009.

Campbell has been awarded the Legion of Merit, Meritorious Service Medal, Navy and Marine Corps Commendation Medal and the Navy and Marine Corps Achievement Medal in addition to numerous campaign and unit awards.

Rear Admiral Thomas J. Eccles

Chief Engineer and Deputy Commander for Naval Systems Engineering, Naval Sea Systems Command

Rear Admiral Eccles was born on Johnson Air Force base in Japan and raised in Wallingford, Conn. He graduated from the Massachusetts Institute of Technology in 1981.

Eccles served at sea aboard USS Richard B. Russell (SSN 687) and USS Gurnard (SSN 662). As an engineering duty officer, he held positions at Mare Island Naval Shipyard, in the Navy's Deep Submergence Systems Program, and he had two tours in the Virginia Class Submarine Program, directing design and construction. He was executive assistant to the commander, Naval Sea Systems Command.

Eccles was Seawolf program manager through the delivery of USS Jimmy Carter (SSN 23), where his team was awarded the Meritorious Unit Commendation, then program manager for Advanced Undersea Systems, responsible for research and development submarines, submarine escape and rescue systems, and atmospheric diving systems. As a commander he was program manager for the design and construction of the unmanned autonomous submarine Cutthroat (LSV 2).

Eccles' previous flag officer assignments included deputy commander for Undersea Warfare and Undersea Technology in NAVSEA, and commander of the Naval Undersea Warfare Center, before becoming NAVSEA's chief engineer in September 2008.

In 2010 Eccles led the U.S. technical team supporting the Republic of Korea joint international investigation into the loss of the warship Cheonan. Also in 2010, he was appointed to the National Academy of Engineering committee examining the Deepwater Horizon explosion and oil spill in the Gulf of Mexico.

Eccles' education includes four degrees from MIT including a bachelor's in Electrical Engineering, a master's in Mechanical Engineering, the professional degree of Naval Engineer, and a master's in Management of Technology from MIT's Sloan School. He serves on the Visiting Committee in MIT's Department of Mechanical Engineering. He is a graduate of the Naval War College, the Defense Systems Management College, and the foreign policy program Seminar XXI, and was elected to the Society of Sigma Xi. He is qualified in submarines, and as a deep sea diver and salvage officer. His decorations include the Legion of Merit (3), the Meritorious Service Medal (4), and other individual and unit awards.

Mary C. Boyce

Gail E. Kendall Professor of Mechanical Engineering
Head of Department

Professor Boyce earned her B.S. degree in Engineering Science and Mechanics from Virginia Tech; and her S.M. and Ph.D. degrees in Mechanical Engineering from the Massachusetts Institute of Technology. She joined the M.I.T. faculty in 1987. Professor Boyce teaches in the areas of mechanics and materials. Her research areas focus primarily on the mechanics of elastomers, polymers, polymeric-based micro- and nano-composite materials, lattice- structured materials, natural materials, and biological macromolecular networks, with emphasis on identifying connections among microstructure, deformation mechanisms, and mechanical properties. She has published over 100 journal papers in the field of mechanics and materials; and has mentored 36 SM Thesis students and 18 PhD students.

Professor Boyce has been the recipient of several awards and honors recognizing her research and teaching efforts, including the MIT MacVicar Faculty Fellow, the Department of Mechanical Engineering Keenan Award for Teaching, the Spira Award for Teaching, the NSF Presidential Young Investigator Award, the ASME Applied Mechanics Young Investigator Award, Member-at-Large of the USNCTAM, Chair of the ASME Applied Mechanics Division, Fellow of the American Academy of Mechanics, Fellow of the ASME, and Fellow of the American Academy of Arts and Sciences.

Michael S. Triantafyllou

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

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

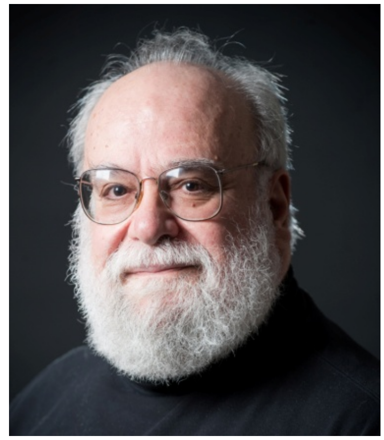
Assistant Professor (1979-83), Associate Professor (1983-90), Professor (1990-2004), Department of Ocean Engineering, MIT. He has published in the areas of dynamics and control of marine systems, experimental fluid mechanics, and biomimetics: M.S. Triantafyllou & G.S. Triantafyllou, 1995, “An Efficient 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, and the Intern. Society for Offshore & Polar Engineers. Honors and Awards include: William I Koch Professorhip in Marine Technology (since 2008), Cover of *Science* (2003), RoboTuna on permanent exhibit at the Museum of Science, London (since 1998); prototype *RoboTuna* in national traveling exhibit on robots, Science Museum of Minnesota (2003-2004). Visiting Professor, ETH Zurich (1999), NTU Athens (1994, 2000), NTH Norway (1993), Kyushu U. (1986). *Discover Magazine* Awards for Technological Innovation (1998). ABS/Linnard Prize for best paper in the *Transactions of SNAME* (1997). Highlight Paper of 1995 *Scientific American*. H. L. Doherty Professorship in Ocean Utilization (1983-1985).

Chryssostomos Chryssostomidis

Doherty Professor of Ocean Science and Engineering

Professor of Mechanical and Ocean Engineering



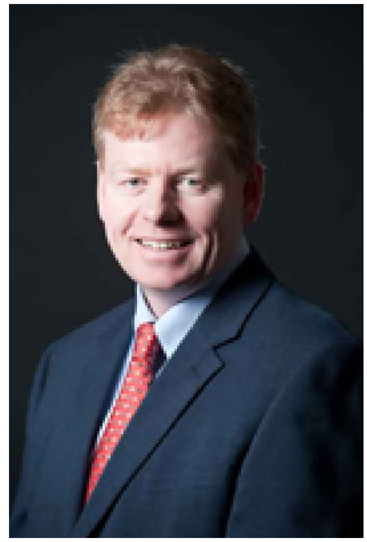
Educated at MIT and at the University of Newcastle-upon-Tyne in naval architecture, Professor Chryssostomidis was appointed to the MIT faculty in 1970 and became a full professor in the Department of Ocean Engineering in 1982. That same year he was appointed director of the MIT Sea Grant College Program where in 1989 he established the MIT Sea Grant Autonomous Underwater Vehicles (AUV) Laboratory to develop technology and systems for advanced autonomous surface and underwater vehicles. He served as Department Head of the department of Ocean Engineering where he established the Ocean Engineering Teaching Laboratory from 1994 to 2002. He has been director of the MIT Ocean Engineering Department Design Laboratory since its inception in the early 1970s. In 2003, with MIT Sea Grant staff, he created the Sea Perch Program, funded by the Office of Naval Research. The Sea Perch program trains educators across the United States and around the world to build a simple, remotely operated underwater vehicle, or ROV, made from PVC pipe and other inexpensive, easily available materials.

Professor Chryssostomidis has received a number of acknowledgments of outstanding contributions to his field. Among them is his appointment as Naval Sea Systems Research Professor from l985 through l987. Prior to that in l975 and l976 he served as Von-Humboldt Scholar at Ruhr University, Bochum, Germany. Since January 1993 he has held a new professorship, the Henry L. and Grace Doherty Professor of Ocean Science and Engineering. In 1994 he was elected as Fellow of the Society of Naval Architects and Marine Engineering. In June 2001 he led the Nisyros, Greece scientific cruise and in August 2001 he was the team leader of the MIT AUV Laboratory expedition to Barati, Italy. He led the AUV Laboratory scientific cruises in Argentario Italy (2002), and Kythira Greece (2004).

His publications display his wide range of interests including design methodology for ships, vortex-induced response of flexible cylinders, underwater vehicle design, design issues in advanced shipbuilding including the all electric ship and T-Craft, conceptual study of a ship for sub-seabed nuclear waste disposal and abyssal ocean option for waste management. He receives research support from the Office of Naval Research, the National Science Foundation, the Naval Sea Systems Command, and the National Oceanic and Atmospheric Administration. Professor Chryssostomidis has served on several National Research Council Advisory committees focusing on shipbuilding and marine issues.

John Leonard

Professor of Mechanical and Ocean Engineering



Professor John Leonard is a member of the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL). His research addresses the problems of navigation and mapping for autonomous mobile robots. He holds the degrees of B.S.E.E. in Electrical Engineering and Science from the University of Pennsylvania (1987) and D.Phil. in Engineering Science from the University of Oxford (formally 1994). He studied at Oxford under a Thouron Fellowship and Research Assistantship funded by the ESPRIT program of the European Community.

Prof. Leonard joined the MIT faculty in 1996, after five years as a Post-Doctoral Fellow and Research Scientist in the MIT Sea Grant Autonomous Underwater Vehicle (AUV) Laboratory. He has participated in numerous field deployments of AUVs, including under-ice operations in the Arctic and several major experiments in the Mediterranean. He has served an associate editor of the IEEE Journal of Oceanic Engineering and of the IEEE Transactions on Robotics and Automation. He is the recipient of an NSF Career Award (1998), an E.T.S. Walton Visitor Award from Science Foundation Ireland (2004), and the King-Sun Fu Memorial Best Transactions on Robotics Paper Award (2006).

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-orientated 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*.

Alexandra H Techet

Associate Professor of Mechanical & Ocean Engineering

Prof. Alexandra (Alex) Techet is currently an Associate Professor of Mechanical and Ocean Engineering (with Tenure). She received her B.S.E. in Mechanical and Aerospace Engineering in 1995 from Princeton University and her graduate degrees from the MIT/WHOI Joint Program in Oceanographic Engineering. In 2002, 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. Prof Techet has served on the MIT/Woods Hole Joint Committee on Applied Ocean Physics and Engineering and developed project-based-learning experiences for first-year undergraduates.

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. 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.

Pierre Lermusiaux

Doherty Associate Professor in Ocean Utilization

Pierre F.J. Lermusiaux is an Associate Professor of Mechanical Engineering and Ocean Science and Engineering at MIT. He obtained a Ir./B. in Mechanical Engineering from Liege Univ. in 1992 and a Ph.D. in Engineering Sciences from Harvard Univ. in 1997. He has held a Fulbright Foundation Fellowship. He was awarded the Wallace Prize at Harvard in 1993, and presented the Ogilvie Young Investigator Lecture in Ocean Engineering at MIT in 1998. He was awarded the MIT Doherty Chair in Ocean Utilization (2009-2011) and the 2010 Ruth and Joel Spira Award for Distinguished Teaching by the School of Engineering at MIT.

He has made outstanding contributions in data assimilation, as well as in ocean modeling and uncertainty predictions. His research includes 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, optimization and control of autonomous ocean observation systems, 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 has organized several major meetings. He is associate editor in three journals and has more than sixty refereed publications.

Franz S. Hover

Finmeccanica Career Development Professor in Engineering

Franz S. Hover received his BSME from Ohio Northern University and the MS and ScD degrees from the Joint Program in Applied Ocean Physics and Engineering at the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology. He was a consultant to industry and then a member of the research staff at MIT, where he worked in fluid mechanics, biomimetics, and marine robotics.

Professor Hover is currently Finmeccanica Assistant Professor at the MIT Department of Mechanical Engineering, with research focusing on design methodologies for ocean engineering.

Captain Mark S. Welsh, USN

Professor of the Practice of Naval Construction and Engineering

Captain Welsh was appointed Professor of the Practice of Naval Construction and Engineering at Massachusetts Institute of Technology in July 2008. He is the Director of the Naval Construction and Engineering program, commonly called the 2N program, within the Mechanical Engineering Department at MIT.

Captain Welsh was born in East St. Louis and raised in Keyesport, Illinois. He enlisted in 1978 in the U.S. Navy nuclear power program. As a second-class Electrician's Mate (EM2), he was selected for the two-year NROTC program and attended the University of Missouri-Columbia. He received a Bachelor of Science in Electrical Engineering and was commissioned an Ensign in the Engineering Duty Submarine Option program.

He completed Submarine Officer Basic School and served on USS SNOOK (SSN 592). After completing Submarine Warfare qualifications, he transferred to the Engineering Duty community and reported to Massachusetts Institute of Technology. Captain Welsh graduated from MIT earning the degrees of Naval Engineer and Master of Science in Electrical Engineering and Computer Science.

Captain Welsh completed his Engineering Duty qualification at Portsmouth Naval Shipyard where he served as Ship Superintendent for the overhaul of USS SAND LANCE (SSN 660), Senior Ship Superintendent for the refueling overhaul of USS L. MENDEL RIVERS (SSN 686), and Docking Officer.

His subsequent assignments include: Deputy R&D Manager for the VIRGINIA class Submarine Program Office; Associate Professor of Naval Construction & Engineering in the Ocean Engineering Department at MIT; Deputy Director, Naval Sea Systems Command Submarine Advanced Development Division; Program Manager for the Navy's next generation large-scale research vehicle, CUTTHROAT (LSV 2); Ohio Class SSGN Program Technical Director; and Director, Engineering Duty Officer Assignment Branch and Engineering Duty Officer Community Manager at the Naval Personnel Command. Prior to his appointment at MIT, he served four years as Commander, Naval Surface Warfare Center, Crane Division in Crane, Indiana.

Captain Welsh is a member of several professional societies. His personal awards include the Legion of Merit, the Meritorious Service Medal (3 awards), the Navy Commendation Medal (2 awards), and the Navy Achievement Medal (4 awards).

Captain Welsh married Katherine Sue Stack of Edwardsville, Illinois in 1978 and they currently reside in Clinton, MA. They have two daughters; Heather, a Registered Nurse and graduate of George Mason University and Holly, an Environmental Scientist and graduate of Virginia Tech. They also have six grandchildren.

Commander Pete Small, USN

Associate Professor of the Practice of Naval Construction and Engineering

Commander Peter D. Small was commissioned in 1995 from the NROTC at the University of Virginia where he earned a Bachelor of Science Degree in Mechanical Engineering. He has also earned a Master of Science Degree in Operations Research in 2002 from Columbia University and a Master of Science Degree in Mechanical Engineering and a Naval Engineer Degree in 2005 from the Massachusetts Institute of Technology. He is a licensed Professional Engineer in the Commonwealth of Virginia.

Upon completion of Navy nuclear propulsion training, Commander Small reported to USS L. MENDEL RIVERS (SSN 686) where he served as Chemical and Radiological Control Assistant, Damage Control Assistant, and Communications Officer and conducted dry-deck shelter operations on two deployments to the Mediterranean Sea and Arabian Gulf. He then served as Assistant Professor of Naval Science and Nuclear Programs Officer at the State University of New York (SUNY) Maritime College and Fordham University. In 2005, Commander Small reported to the Supervisor of Shipbuilding, Conversion and Repair, Newport News, Virginia where he was the Project Officer for the Pre-Commissioning Units (PCU) NORTH CAROLINA (PCU 777) and NEW MEXICO (PCU 779) new construction, USS OKLAHOMA CITY (SSN 723) Docking Selected Restricted Availability (DSRA), and the USS TOLEDO (SSN 769) Depot Modernization Period (DMP). From 2008 to 2010 he served as Deputy Ship Design Manager and Aft Project Officer in NAVSEA PMS397, the OHIO Replacement program office.

In September of 2010 Commander Small was appointed Associate Professor of the Practice in the Mechanical Engineering Department at the Massachusetts Institute of Technology and currently serves as the Academic Officer of the graduate Naval Construction and Engineering (Course 2N) curriculum.

Commander Small's decorations include the Meritorious Service Medal, Joint Service Commendation Medal, Navy Commendation Medal (three awards), Navy and Marine Corps Achievement Medal (four awards), Navy Unit Commendation, National Defense Service Medal (two awards), Armed Forces Expeditionary Medal, and Sea Service Deployment Ribbon (two awards).

He is married to the former Stacy McLaurin of Burke, Virginia. They have two daughters, Clara and Elena, and reside in Belmont, Massachusetts.

Deep Sea Ocean Research Vessel (DSORV)

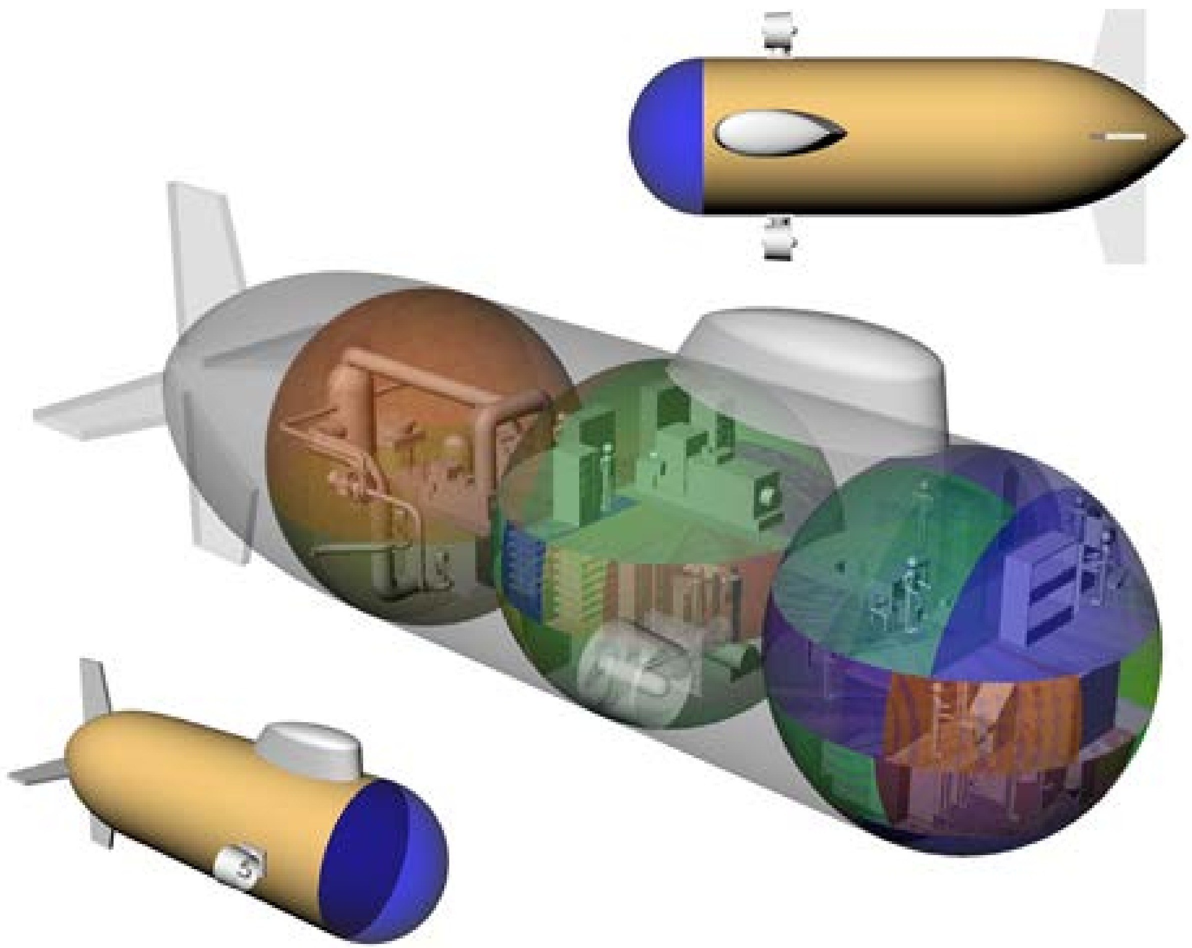
LT Darrin Barber, USN; LT Rich Hill, USN

Since the deactivation of the NR-1 on 21 November 2008, there are no deep-diving US Navy submarines that can currently complete scientific and military missions. NR-1's missions have included search, object recovery, geological survey, oceanographic research, and installation and maintenance of underwater equipment. NR-1's unique capability to remain at one site and completely map or search an area with a high degree of accuracy has proved to be a valuable asset on several occasions. Recent events such as the oil leak in the Gulf of Mexico, have demonstrated the continued need for a research submarine capable of operating at depths greater than the original NR-1. The need to restore the capability to explore the deep ocean environment formed the basis of the Deep Sea Ocean Research Vessel (DSORV) design project.

While the design process for the DSORV followed that of other MIT submarine designs, several unique technologies were explored due to the unique deep-diving requirements. The foundation for many of these design requirements were based on the Rand study, "A Concept of Operations for a New Deep-Diving Submarine" completed in 2003.

The 6,000 foot depth requirement drove the design towards a spherical pressure hull. HY-100 was chosen to reduce the manufacturing complexity and this combination allowed sufficient weight supportability. Additionally reducing weight was the choice of podded propulsion, a gas turbine emergency generator, the use of Lithium-ion batteries and an unmanned engineroom. By reducing weight better accommodations and greater stores were achieved, therefore increasing the level of autonomy to that of current fleet submarines, a significant improvement over the previous NR-1 design. Furthermore, many systems leveraged off of the latest *USS Virginia* design, reducing acquisition, maintenance, and training costs.

While the cost estimate of approximately $1Billion yields an unlikely design given current economic constraints, the design did establish a feasible marriage of several new concepts which focus on reducing weight and cost while maintaining capability.



Ship Characteristics	
Parameter	**Value**
Overall Length	38 meters
Displacement (submerged)	2360 metric tons
Beam	10 meters
Draft	9.45 meters
Reactor Core Rating	5 MW
Emergency Power Gas Turbine	360 KW Allison model 250
Pressure Tolerant Battery Rating	1000 KW-hr
Endurance	60 Days
Maximum Speed (15 min burst)	15 knots
Sustained Speed	10 knots
Max Operating Depth	6000 ft
Ship Cost	$1 B (yr 2005)
Accommodations	30

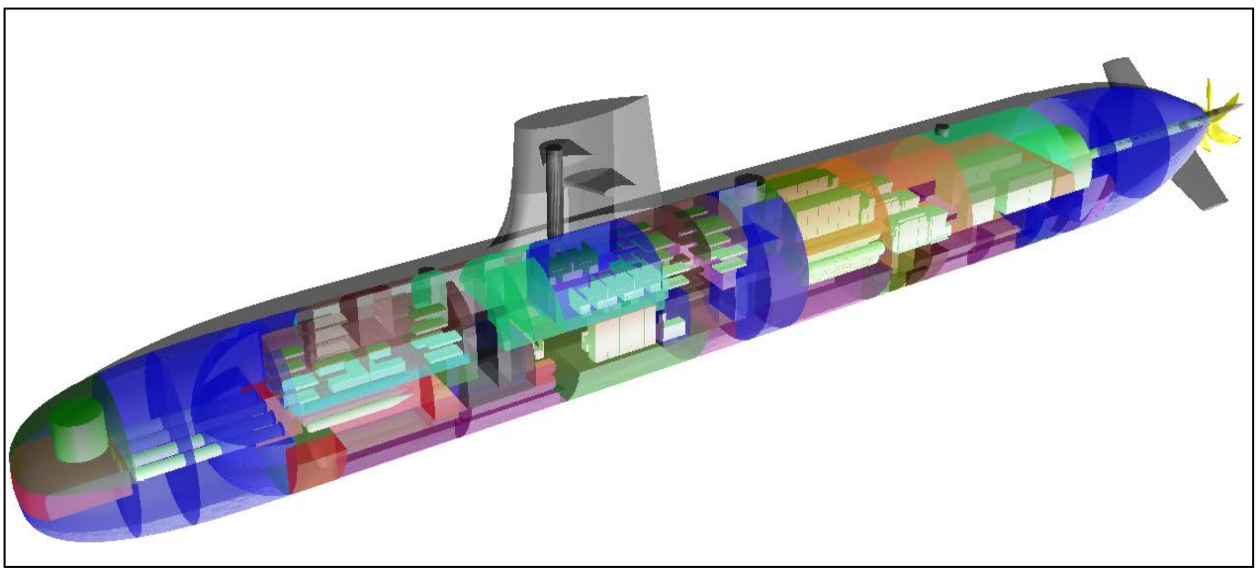
Collins Class Replacement (CCR) SSK

CDR Gregory Fennell, USN; LT Ethan Fiedel, USN; LT Iason Dimou, HN

The Royal Australian Navy's (RAN) *Collins* class submarine has entered the second half of its design life and the RAN has begun their design process for their next-generation submarine. In the early stages of this process, several open-source documents were produced by the Australian government that identified their needs and priorities; using these documents and knowledge acquired from MIT and professional experience, an initial design for a *Collins* Class Replacement (CCR) was created.

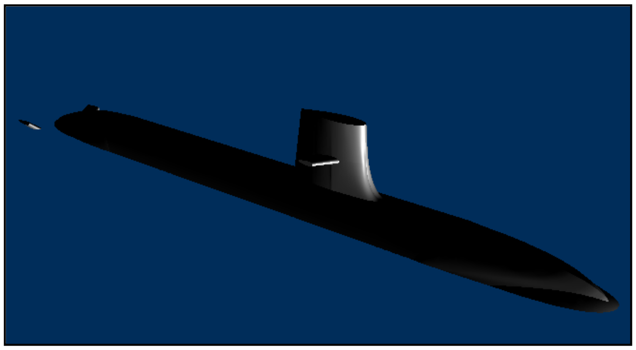
To ensure maritime security "in the Asia Pacific Century[1]," the Australians require a long-range, high-endurance, multi-mission-capable, cost-effective submarine. To meet these requirements, various Air Independent Propulsion (AIP) technologies, payload, structural, and arrangement configurations were considered. Utilizing tools such as Paramarine™, MATLAB®, ADINA©, and an MIT-developed Mathcad model, and using data available on the *Collins* as a baseline, the CCR was designed to balance these requirements. Four of the major design features combined into the CCR were: inclusion of a high-power, Fuel Cell AIP system, use of Li-Ion batteries in place of Lead-Acid batteries, utilization of non-penetrating vice penetrating periscopes, and optimization of hull structure for shallower operating depths. The analyses and decisions regarding these design features enabled further development of hydrostatic, propulsive, and cost modeling.

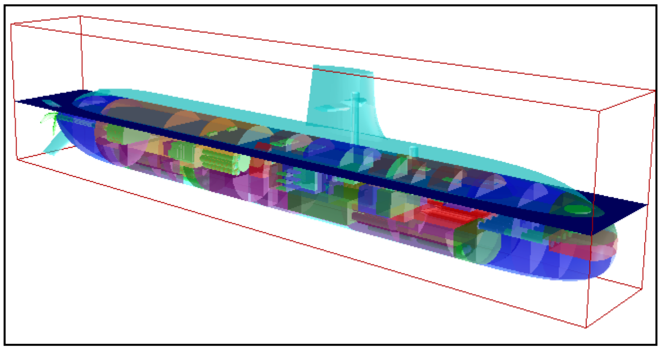
The final product represents a feasible solution to Australia's needs; with respect to endurance and mission capability, the CCR will succeed the *Collins* in the 21st century.

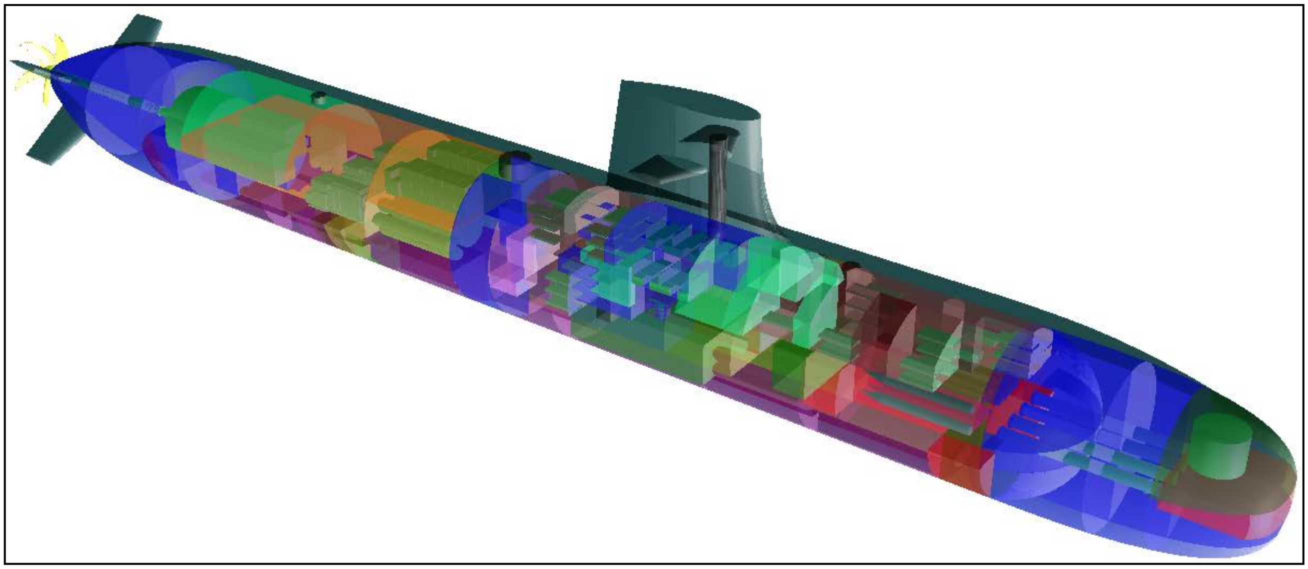


[1] *Defending Australia in the Asia Pacific Century: FORCE 2030*. Australian Government: Department of Defence

CCR Key Parameters	
LOA:	84.1m (276.0ft)
Max Beam:	8.4m (27.5ft)
Pressure Hull Length:	63.4m (208.0ft)
Hullform Depth:	15.9m (52.0ft)
Design Depth:	200.0m (656.2ft)
Maximum Depth:	300.0m (984.3ft)
Hull Material:	HY-80
Shaft Horsepower:	5200kW (6970hp)
Designed Submerged Operating Load:	600kW
Armament:	4 Torpedo Tubes
Weapons Loadout	20 Weapons
Submerged Speed:	20 kts
Surfaced Speed:	13.8 kts
Crew:	45
Accommodations:	51
Surfaced Disp:	3548mt (3492LT)
Submerged Disp:	4107mt (4042LT)
Reserve Buoyancy: (% of Sub Disp)	13.6%
Margin Lead:	320mt
Cost (FY10):	AU$2.9 B







Littoral Centric Nuclear Hybrid Submarine (LCSS (H))

LCDR Weston Gray, USN; LT Brian Heberley, USN

The LCSS (H) concept was born of the forecasted submarine shortfalls coinciding with the construction of the OHIO replacement submarines. To maintain a submarine force near the currently required 48 fast attack submarines, the LCSS (H) was designed to be a low cost ship to supplement the VIRGINIA class submarines in some littoral missions. To further reduce the costs and minimize the design effort, which will coincide with the OHIO replacement design, as many of the VIRGINIA class features as possible were utilized. These common components consist primarily of the torpedo room, sail, sonar dome and equipment, command and control stations, and radio room in addition to the hull diameter and floating deck design. The key features and capabilities of the submarine were prioritized based on a survey of submarine line officers representing 165 years of combined experience.

The LCSS (H) is a hybrid submarine meaning that all operating power can come from the reactor or from the battery for short period of time. In addition, battery power can be used to supplement the submarine's speed to provide a sprint speed of nearly 21 knots as compared to the 15 knot sustained speed. This design provides for several advantages. The first advantage is a short engine room due largely to the slow speed and the elimination of main engines. The Integrated Propulsion System also allows more effective use of the large hull diameter, for this displacement submarine, to minimize the engine room length.

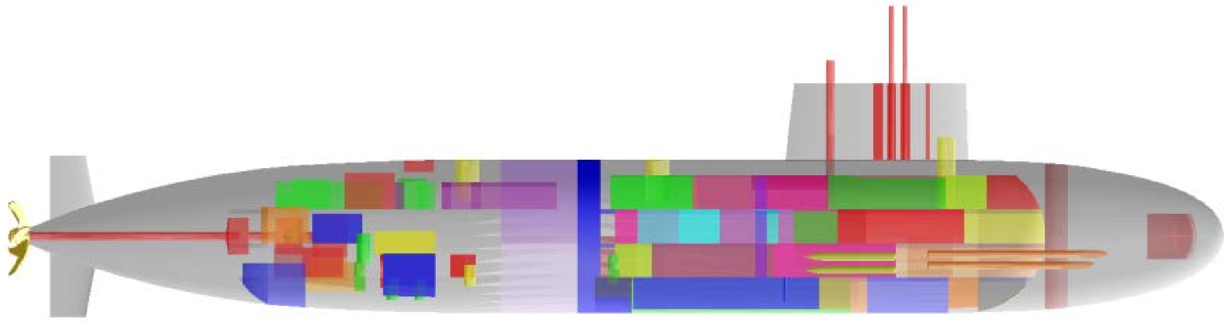
The primary mission set for this submarine consists of the littoral missions: Intelligence, Surveillance, and Reconnaissance (ISR), Anti-Submarine Warfare (ASW), Anti-Surface Warfare (ASuW), Mine Warfare (MIW), limited STRIKE, and very limited Special Operations Forces (SOF) support. These missions are consistent with the project thesis of supplementing the VIRGINIA submarines and not replacing them. Combatant Commanders can utilize the LCSS (H) to perform the above missions when the expanded mission set and/or capabilities of a VIRGINIA class submarine are not required.

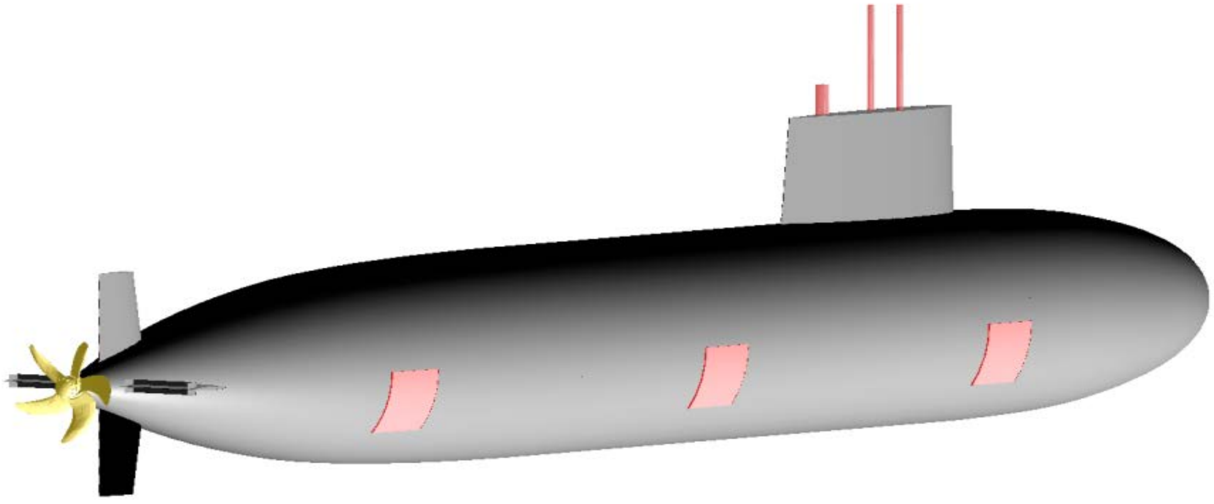
To enhance the littoral operational capability of the LCSS (H), the submarine is equipped with several key features. To increase maneuverability at low speeds, a pump driven hovering system is used. A vertical bow thruster was also included although plans were made to accommodate bow planes vice the thruster if required. A five-bladed propeller was also used for three reasons. The first reason was to enhance slow speed maneuverability in general and backing specifically. Second, the slow speed of the submarine should allow the design of a very quiet propeller. Finally, the propeller was planned to further reduce the cost of the submarine as a whole.

The overall cost of the submarine was estimated to be $1.44 billion dollars (FY05) using a weight based cost model. However, this type of costing may not capture all of the cost savings associated with utilizing a simplified design without several costly components such as a thin line towed array, vertical weapons tubes, and propulsor. Additional cost savings are possible based on the similarity to VIRGINIA class submarines and the continuation of those learning curves.

The LCSS (H) was designed as the frigate of the submarine force to accomplish vital tasking that does not always require the full capabilities (and cost) associated with a VIRGINIA class submarine. This submarine is less expensive to construct and requires less manning which is critical to maintaining 48 fast attack submarines during the coming decades. The summary of ship's characteristics is shown on the following page.

Ship Characteristics			
DIMENSIONS		**PERFORMANCE**	
Length, Overall	268.6 ft	Sustained Speed	15 knots
Beam	34 ft	Sprint Speed	20.9 knots
Displacement	5465 LT	Service Life	25 Years
ACCOMMODATIONS		**MACHINERY SYSTEMS**	
Crew	97	26.5 MW Nuclear Reactor	
SPECIAL FEATURES		2 – 2.65 MW Turbine Generators	
15,000 lbf Bow Thruster		10,000 hp Permanent Magnet Motor	
5 Blade Propeller		1000 VDC Electrical Distribution Bus	
Pump Hovering System		180 cell VRLA-B battery	





Scalable, Common, Affordable, Modular Platform (SCAMP)

LT Jon Page, USN; LT Eric Brege, USN; LTJG Emmanouil Sarris, HN

The Secretary of the Navy (SecNav), Chief of Naval Operations (CNO), and Commander, Naval Sea Systems Command have all listed Total Ownership Cost Reduction to be one of their stated priorities for both 2009 and 2010. This priority no doubt stems from the economic crisis the world just went through in addition to the increasing cost of acquiring, maintaining, and modernizing ships. These aspects coupled with the desire to shrink instead of expand the defense budget creates quite an opportunity to implement powerful and lasting changes to the acquisition and maintenance processes and standards for the surface fleet.

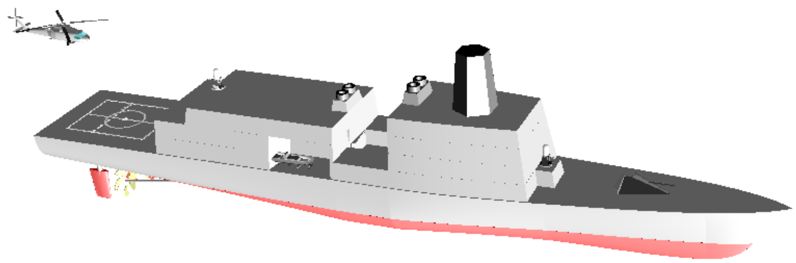
The proposed platform, SCAMP, was created under these pretexts. The goal of the SCAMP was to decouple the Hull, Mechanical, and electrical (HM&E) and Combat Systems portions of the acquisition process as much as possible. The SCAMP aimed to accomplish this through modularity, standard interfaces and the use of existing fleet equipment (commonality), and the postulation of new design standards such as cable and piping highways (supporting the scalability concept). Further, the SCAMP aims to reduce life cycle cost through the inclusion of real options via design flexibility. These options will reduce required contractor man-hours in the future for maintenance and modernization of the proposed platform, instead moving the required man-hours to intermediate level or removing the need entirely.

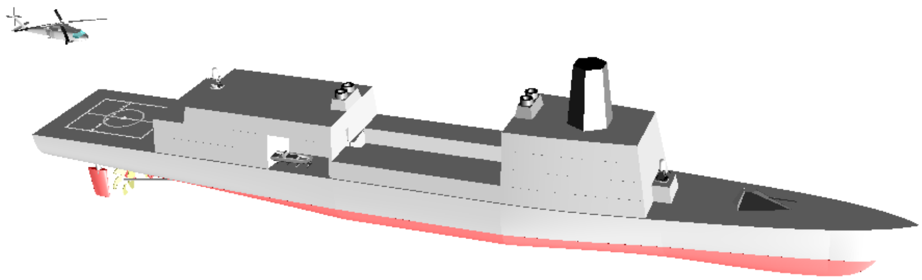
The proposed platform can replace or reinforce the current combatant classes of ships. The SCAMP can scale from about 7,000 metric tons (MT) to about 9,500 MT, enveloping the Oliver Hazard Perry, Arleigh Burke, and Ticonderoga class surface combatants. The SCAMP will be able to carry out all the common missions of both these classes as well as incorporating enough modularity to accomplish uncommon mission requirements. The aim is to meet the SecNav's and CNO's goals of a diverse fleet capable of responding to an ever changing threat environment that creates ever-changing requirements of naval vessels.

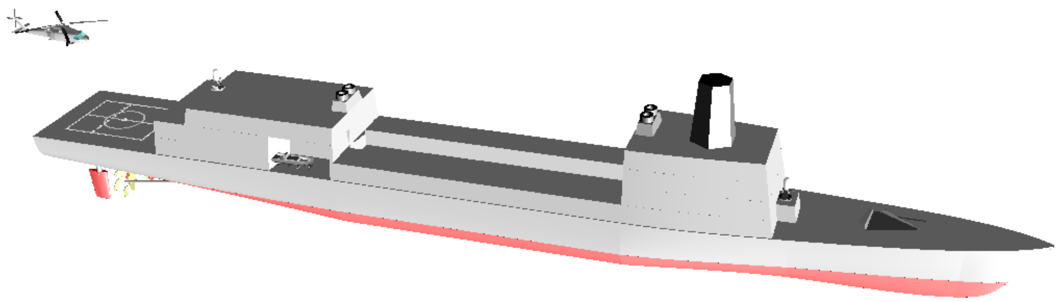
This project successfully creates 5 variants of a baseline platform, and runs evaluations and analysis on 3 of them (the smallest, the middle variant, and the largest). The SCAMP uses fleet common components in both engineering and combat systems, incorporates an IPS, scales from a 1-module variant to a 5-module variant while staying within all strength and seakeeping criteria, and provides adequate space, volume, and service life allowances for future expansion of mission capabilities of the platform. Despite an estimated R&D budget to accomplish all this that is about 150% higher than that of the DDG 51, the overall Acquisition Cost of the lead ship of the class is 96% that of the DDG 51 due to Procurement savings in Government Furnished Equipment (GFE) costs. Also, for a class size of 71 vessels, the SCAMP's Program Acquisition Unit Cost (PAUC) is estimated at 70% of the PAUC of the DDG 51 class. These savings are even greater when compared to the Ticonderoga class, but the class is more expensive than the Oliver Hazard Perry class, albeit with more installed capability.

The following table illustrates some of the similarities and differences between the Oliver Hazard Perry, Arleigh Burke, and Ticonderoga class surface combatants and the 1, 3, and 5 module variants of SCAMP.

Ship Characteristics						
	1 Module	Frigate	3 Module	Destroyer	5 Module	Cruiser
LOA [m]	135.00	124.40	155.00	153.40	175.00	172.80
Beam [m]	20.00	13.70	20.00	18.00	20.00	16.80
Depth [m]	11.80	9.10	11.80	12.70	11.80	12.90
Draft [m]	6.43	4.40	5.93	6.20	5.58	6.70
Max Speed [knots]	20	29	20	31	20	30
Endurance [nm]	4000	3469	4000	3700	4000	3800
Full Load [MTON]	7300	4453	8087	9145	8915	9426
Hull Area [m2]	5745	2332	6714	3995	7683	6738
Super Area [m2]	2969	1542	3198	1876	3427	2335
Hull Volume [m2]	18442	106789	21716	22126	24992	26993
Super Volume [m2]	9376	4350	10100	5403	10825	6820
Installed SHP [KW]	60400	31269	60400	74974	60400	64160







Fleet Rehabilitation and Modernization (FRAM) of an FFG-7 Oliver Hazard Perry Class Frigate

LCDR Greg Crawford, USN; LTjg Tim Emge, USN; LT Evangelos Koutsolelos, HN

The role of small surface combatant in the U.S. Navy is planned to be filled by the Littoral Combat Ship (LCS) in the years to come. Due to limited shipbuilding funds and the increasing cost of the LCS and its mission modules, there is reason to believe that the intended goal of 55 LCS may never be achieved. In order to bridge the gap and provide small surface combatants that are capable of fulfilling some of the LCS missions, a fleet rehabilitation and modernization (FRAM) of the FFG-7 class frigates is proposed. The portion of the LCS mission set which the FFG-7 FRAM could fulfill includes anti-piracy, counter-narcotics, counter-terrorism, humanitarian assistance/disaster relief, and global fleet station.

A list of potential modifications was created based on the requirements of the mission set, and using weighted sum and analytical hierarchy process decision methods, a preferred concept was created. The preferred concept used the baseline FFG-7 hullform. The propulsion plant was changed to maximize fuel economy and thereby decrease lifecycle cost due to reduced top end speed requirement. Superstructure modifications were made to reduce the converted ship's radar cross-section, which is beneficial for a ship intended to operate in coastal waters. Along with the superstructure modifications, the topside equipment configuration was altered including the removal of the 76 mm cannon and placing a 30 mm Bushmaster above the pilothouse. All these modifications would be in addition to service life extension work that would be required to extend these ships 10-20 years.

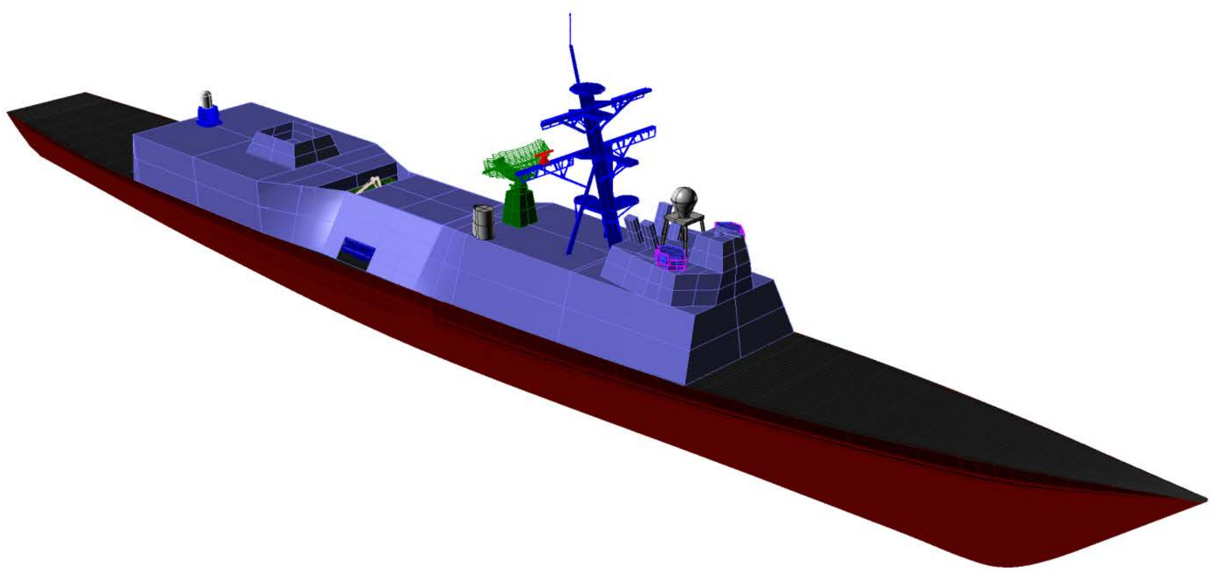
The propulsion plant modification to the converted ship increased endurance by 50% over the baseline FFG-7 while only giving up 17% in maximum speed. The location of the Bushmaster cannon provides an anti-surface warfare weapon with a greater arc of fire that is more maintainable and much lighter than the 76 mm. The structural integrity of the pilothouse was also analyzed in depth due to the weight of the Bushmaster and found to be adequate.

The cost of the converted ship was estimated based on the weights removed and added to the ship. The estimated cost of the modifications is $94-126 million. This does not include the service life extension work required. The largest cost is the propulsion plant modifications; however the added efficiency could pay for itself in fuel savings over the expected service life taking into account the number of operating days and increasing fuel cost.

While the FFG-7 FRAM will not have all the capabilities of LCS, there are a number of LCS missions that it can fulfill satisfactorily. It is considerably less expensive than the construction cost of the LCS and its mission modules. Also there is the added benefit that the FFG-7 FRAM can be delivered faster than the LCS thereby having more ships available now for a lower cost.

The table below summarizes the characteristics of the modified and baseline ships.

Characteristics	FRAM	Baseline
Displacement (Full Load)	**4,092 LT**	**4,100 LT**
LBP	**408 ft**	**408 ft**
Length Overall	**453 ft**	**453 ft**
Beam	**45 ft**	**45 ft**
Draft	**15.8 ft**	**16 ft**
Propulsion	**(2x) Caterpillar (CAT) 3618 diesels Single shaft with Controllable Pitch Propeller**	**(2x) GE LM2500 gas turbines Single shaft with Controllable Pitch Propeller**
Speed (max)	**25 kts**	**29 kts**
Speed (endurance)	**20 kts**	**20 kts**
Endurance	**5541 nm**	**3500 nm**
Crew	**179**	**189**
Air Radar	**SPS-49**	**SPS-49**
Surface Radar	**SPS-73**	**SPS-55**
Navigation	**VMS/ECDIS-N**	**Paper Charts**
Communications	**LINK-16**	**LINK-11**
Sonar	**SQS-56 SQR-19**	**SQS-56 SQR-19**
Weapons	**Mk46 30 mm Bushmaster II cannon 20mm CIWS (Block 1B) 2 Mk32 ASW Tubes with torpedoes**	**OTO Melara 76 mm cannon 20mm CIWS (Block 1B) 2 Mk32 ASW Tubes with torpedoes**
Helicopters	**2 SH-60 LAMPS III Seahawk**	**2 SH-60 LAMPS III Seahawk**



LPD-17 to LSD (X) (Modified Repeat)

CDR Ken Shepard, USN; CDR John Campbell, USN;
LT Andrew Privette, USN; LTjg Chris MacLean

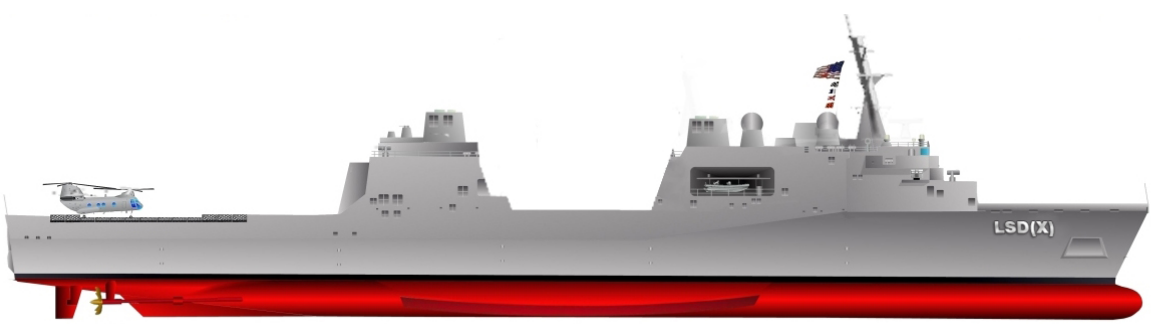
Of the 12 active dock landing ships (LSD) in the United States Navy (USN), eight were commissioned between 1985 and 1989. The Marine Corps and Navy officials require an amphibious force consisting of 12 LSDs to meet the 2.0 Marine Expeditionary Brigade (MEB) Amphibious lift goal. The first of the USS WHIDBEY ISLAND (LSD-41) class is scheduled for decommissioning in the 2015, and a number of replacement concepts are being considered.

This study evaluated using the ongoing USS SAN ANTONIO (LPD-17) class production line as a basis for a modified repeat to meet the role currently filled by the LSD 41/49 class of ships. This modified repeat was designed with cost as a primary driver for design decisions. The final design removed the aviation hangar facilities, a large portion of the aft superstructure, removed many Radar Cross Section Reduction (RCSR) features, and reduced the Command, Control, Computer and Information (C4I) systems. The current LPD-17 data, arrangements, weights, and drawings were modified to transform the ship into a LSD variant. This variant was analyzed for structural strength and stability along with various seakeeping scenarios to determine feasibility.

Based on this study, the LPD-17 can be utilized as a basis for an LSD-41/49 class replacement. The LSD(X) is a feasible solution from both an economic and capability perspective and can meet all LSD-41/49 mission objectives.

The table below summarizes the characteristics of the modified ship.

LSD (X) General Characteristics			
LBP	668 feet	C_p	0.638
LOA	683.7 feet	C_x	0.943
Beam	104.7 feet	Endurance @ 20 knots	10000 NM
Full Load Displacement	25,145 Tons	Shaft Horsepower	41,600 hp
Full Load Draft	23 feet	Max Speed	22.5 knots
Light Ship Displacement	18427 Tons	Main Engines	4 – Colt Pielstick PC 2.5 diesel engines
Crew	345	Shafts	2
KG Margin	9%	Screws	Controllable Pitch
LSD (X) General Landing Force Information			
Office Accommodations	54	Helicopter Landing Spots	2
Enlisted Accommodations (E-7 or above)	36	Operational CH-46 equivalents	0
Enlisted Accommodations (E-6 or below)	405	JP-5	215,000 gallons
Surge Accommodations	48	Gasoline	10,000 gallons
Vehicle Square Feet	37,450 sq. feet	Cargo Volume	28,295 cubic feet



Maritime Interdiction Combatant (MIC)

LT Eric Thurkins, USN; LT Kip Wilkins, USN;
LTJG David Cope, USN; LTJG Petros Voxakis, HN

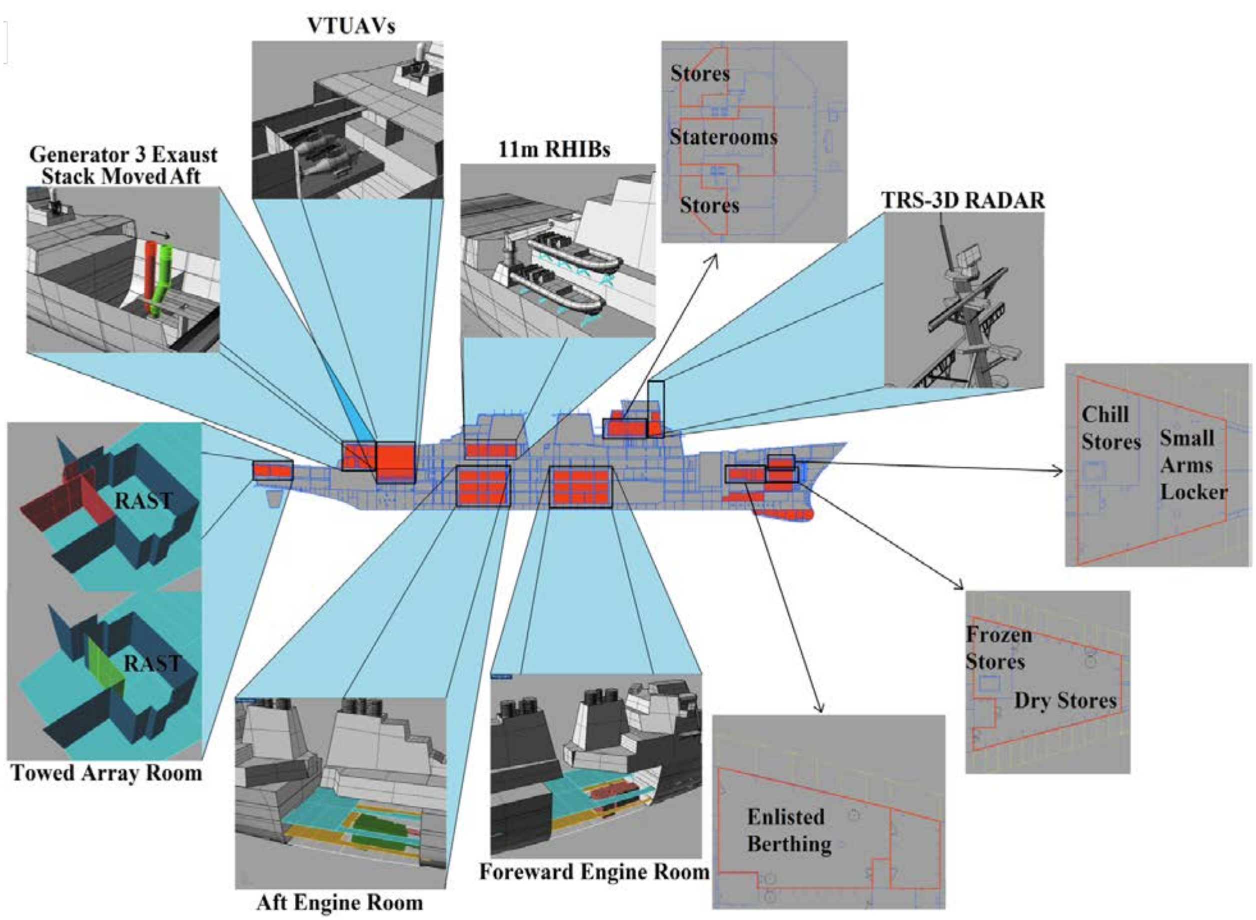
The US Navy is currently engaged in several low-level conflicts around the globe. These missions include anti-piracy, counter-narco terrorism, ocean platform defense, humanitarian assistance, and maritime dominance. Although they are minor compared to national conflicts, they are vital to maintaining the sea lanes of communication and restricting the flow of money to violent non-state actors. The vessels tasked with this duty, the FFG 7, the DDG 51 and occasionally the CG 47, while adequate, are not ideal for countering the threat. The presence of a dedicated Maritime Interdiction Combatant (MIC) would supplement the fleet's aging FFG 7 fleet and the two classes of Aegis ships (DDG 51 and CG 47) that are in high demand for Theater Ballistic Missile Defense and other large, regional threats. The MIC provides an extended endurance platform well suited for conducting persistent surface surveillance and swift maritime interdiction.

The purpose of this project was to develop a modified-repeat of the Arleigh Burke Guided Missile Destroyer (DDG 51) Flight IIA, reconfiguring the vessel as a Maritime Interdiction Combatant. The overarching goals were to reduce acquisition and life-cycle costs and enhance the vessel's organic maritime interdiction and surveillance capabilities while maintaining an adequate level of the Flight IIA's air defense and anti-submarine warfare capabilities. This was accomplished through the replacement of the SPY-1D(V) radar and SQS-53C SONAR with similar, though less capable systems currently employed by the US and NATO Navies. The MIC hosts larger, more capable rigid hull inflatable boats, automated small arms, fully integrated vertical takeoff and landing unmanned autonomous vehicles. Internally, the vessel has increased medical, berthing and stores facilities to accommodate aviation detachments, boarding teams, medical personnel and potential detainees. An alteration of the current DDG 51 IIA engineering plant to a more efficient configuration increased endurance, vital for long loitering times in the Area of Responsibility. The study revolved around current DDG 51 IIA data, arrangements, structure, weights, and drawings. In the Analysis of Alternatives, the merits of several variants were compared and a final design concept was selected. Modifications to the parent DDG 51 IIA vessel were made as necessary to develop the MIC concept into a final design. To ensure the technical feasibility of the new vessel, structural, stability, and seakeeping analyses were carried out.

The results of this study show that the DDG 51 IIA is well suited for a modified-repeat to the Maritime Interdiction Combatant and presents an estimated acquisition cost savings of $0.3 billion per ship and an estimated life cycle cost savings of $0.8 billion for a production run of 15 ships. The results show that the highly capable MIC would perform well against such low level threats as pirates and drug traffickers while still maintaining a moderate level of the DDG 51 IIA's air defense and anti-submarine capabilities.

The table below summarizes the characteristics of the modified ship, while the picture shows the changes that were made to the original ship design.

MIC Characteristics vs DDG-51 Flight IIA		
Property	**MIC**	**DDG 51 IIA**
LBP (ft)	471	471
LOA (ft)	509.5	509.5
Beam (ft)	59	59
Displacement Full Load (LT)	9,015	9,200
Displacement Light Ship (LT)	6,977	7,025
GM_T (ft)	5.00	4.60
VCG (ft)	24.19	24.60
Maximum Speed (kts)	29.4	31+
Range (nm)	6,156	4,543
Installed Power (BHP)	81,000	105,000
Total Ship Crew	267	281
Acquisition Cost	$1.457 Billion	$1.750 Billion
Lifecycle Cost	$29.369 Billion	$30.138 Billion



2011 2N Student Theses

Shipboard Condition Based Maintenance and Integrated Power System Initiatives

LT Darrin Barber, USN

Prof. Steven Leeb
Thesis Supervisor

Beginning in 1999, the Department of Defense (DoD) has mandated that all military divisions develop and implement methods to reduce total ownership costs (R-TOC) of force structure and readiness. The R-TOC program was established in response to longstanding concerns about the adverse impact of defense budgetary and operational trends on force structure and readiness. Declining procurement funds are resulting in a rapidly aging and potentially inefficient and unsupportable inventory. Rising operations and support (O&S) costs consume higher portions of defense budget and leave even less available for modernization. This thesis was used to evaluate the potential for cost savings on two fronts, maintenance and fuel.

A potential cost savings could be had through the implementation of condition based maintenance (CBM), the process of conducting maintenance based on the equipment's condition vice a predetermined periodicity based on previous experience. To support this cost saving initiative, a method for electrical-based condition monitoring using shaft speed oscillation was explored to assess the health of an electrical load. Experiments involved rigorous testing in the laboratory environment as well as shipboard testing aboard the US Coast Guard Cutter Escanaba (WMEC-907).

In addition to the exploration of CBM techniques, concepts that could potentially improve fuel economy were investigated. For this evaluation a test platform was constructed to allow for the testing of revolutionary methods of generating propulsion from an integrated power system.

Naval Engineer
Master of Science in Electrical Engineering and Computer Science

Design and Construction of a Low Cost, Modular Autonomous Underwater Vehicle

LT Eric Brege, USN

Prof. Chryssostomos Chryssostomidis
Thesis Supervisor

Over the next 5 years, MIT Sea Grant is tasked with locating and photographing *Didemnum Vexillum*, an invasive species which threatens New England fishing habitats. Didemnum research is conducted in the photosynthesis zone of the coastal shelf using photography and radiometry instruments.

In order to streamline Didemnum research, a new, low cost and modular AUV was designed and built to replace Odyssey IV as the primary Didemnum research vehicle. This new AUV is a shallow cruising vehicle with a depth rating of 100 meters. With a weight of less than 50 kg, the AUV can easily be launched and recovered by hand from Sea Grant's 25 ft vessel. Although specifically designed to support Didemnum research, the AUV incorporates a flexible and modular design which allows it to be reconfigured for existing Didemnum missions or upgraded with additional sensors and payload. Incorporating a separate, interchangeable Lithium-Polymer Battery pack allows the vehicle to achieve both a high mission duty cycle and extended bottom time. The Didemnum Cruiser also serves as a prototype for future vehicles in the AUV Lab.

Naval Engineer
Master of Science in Mechanical Engineering

Particulate Matter Emissions from a DISI Engine under Cold Fast Idle Conditions for Gasohol Fuels

LT Iason Dimou, HN

Prof. Wai K. Cheng
Thesis Supervisor

In an effort to build internal combustion engines (ICE) with both reduced brake-specific fuel consumption (BSFC) and better emission control, engineers developed the direct injection spark ignition (DISI) engine. DISI engines combine the specific higher output power of the spark ignition engine with the better efficiency of the compression ignition engine at part load. Despite their benefits, DISI engines still suffer from high hydrocarbon, NO_x and particulate matter (PM) emissions. Until recently, PM emissions have received relatively little attention, despite their severe effects on human health, which are related mostly to their size. Previous research indicates that almost 80% of the PM is emitted during the first few minutes of the engine's operation (cold-start-fast-idling period). A proposed solution for PM emission reduction is the increase of the ethanol content in the fuel. This research measures experimentally the effect of ethanol content in the fuel on the PM formation in the combustion chamber from a DISI engine during the cold-start period. A novel sampling system has been designed and combined with a SMPS in order to measure the particulate matter number (PN) distribution from only 15 cm after the exhaust valves of a modern DISI engine, for a temperature range from 0 to 40°C, under low load operation. Seven gasohol fuels have been tested with the ethanol content varying from 0% (or E0) to 85% (or E85). For E10 to E85, PN increases modestly when the engine coolant temperature (ECT) is lowered. The PN distributions, however, are insensitive to the ethanol content of the fuel. The total PN for E0 is substantially higher than the gasohol fuels, at ECT below 20°C. However, for ECT higher than 20°C, the total PN values (obtained from integrating the PN distribution from 15 to 350 nm) are approximately the same for all fuels. This sharp change in PN from E0 to E10 is confirmed by running the tests with E2.5 and E5. The midpoint of the transition occurs at approximately E5. Because the fuels' evaporative properties do not change substantially from E0 to E10, the significant change in PN is attributed to the particulate matter formation chemistry.

Naval Engineer
Master of Science in Mechanical Engineering

System Design and Manufacturability of Concrete Spheres for Undersea Pumped Hydro Energy or Hydrocarbon Storage

CDR Gregory Fennell, USN

Prof. Alexander Slocum
Thesis Supervisor

Offshore wind and energy storage have both gained considerable attention in recent years as increased wind capacity is installed, less attractive/economical space remains for onshore wind, and power-plant ramping, transmission cable capacity constraints and other integration issues make wind power integration with the existing power grid more costly as wind penetration increases. In order for offshore wind to maintain a stead supply to the power grid without increasing these integration issues and costs, some form of large-scale energy storage is required.

For water depths greater than 50m, floating wind turbines are expected to be more economical than wind turbines mounted on pilings or stands. The greater water depths in which floating wind turbines are located provide an opportunity for a unique energy storage concept that takes advantage of the hydrostatic pressure at ocean depths to create a robust pumped storage device. Coupling this energy storage system, either with a floating wind farm or as a storage-only power plant, provides a far more consistent and predictable power plant that could ultimately lessen the cost of large-scale wind integration, consistently reduce fossil fuel use, and reduce greenhouse gas (GHG) emissions by load-leveling onshore generation.

The US Department of the Navy's goal for renewable energy supply to shore facilities is 50% by 2020; implementing large-scale energy storage will increase the reliability of renewable energy supply and reduce the risk of power loss caused by natural disasters. Various scenarios evaluated offshore major US Naval bases including San Diego and Hawaii show promise for the technical and economic feasibility of this undersea energy storage concept, with cost-per-kilowatt-hour competitive with current energy storage technologies.

The same type of device structure can be used for undersea hydrocarbon storage during periods of hurricane/tropical storm shut-in's at oil wellheads, maintaining wellhead production without risking personnel or environmental safety due to storm evacuations at the rigs on the ocean surface.

Naval Engineer
Master of Science in Mechanical Engineering

Cooling System Early-Stage Design Tool
For Naval Applications

LT Ethan Fiedel, USN

Prof. Chryssostomos Chryssostomidis
Thesis Supervisor

This thesis utilizes concepts taken from the *NAVSEA Design Practices and Criteria Manual for Surface Ship Freshwater Systems* and other references to create a Cooling System Design Tool (CSDT). With the development of new radars and combat systems equipment on warships, comes the increased demand for the means to remove the heat generated by these power hungry systems. Whereas in the past, the relatively compact Chilled Water system could be tucked away where space was available, the higher demand for chilled water has resulted in a potentially exponential growth in size and weight of the components which make up this system; as a result, the design of the cooling systems must be considered earlier in the design process. The CSDT was developed to enable naval architects and engineers to better illustrate, early in the design process, the requirements and characteristics for the Chilled Water system components. Utilizing both Excel and Paramarine software, the CSDT rapidly creates a visual model of a Chilled Water system and conducts pump, damage, cost, weight, and volume analyses to assist in further development and design of the system.

Several case studies were run to show the accuracy (<12% error when compared against SWBS data), capability and flexibility of the tool, as well as how new electronic and mechanical systems can affect the parameters of the Chilled Water system.

Naval Engineer
Master of Science in Mechanical Engineering

Identifying and Analyzing the Hiring Process for the Department of Veterans Affairs, Veterans Health Administration

LT Ethan Fiedel, USN

Prof. Deborah Nightingale
Thesis Supervisor

This thesis utilizes ideas taken from different Systems Engineering modeling tools to model the hiring process for the U.S. Department of Veterans Affairs (VA), Veterans Health Administration (VHA). This model is a guide for understanding the current state of the hiring process and shows that inadequate Position Descriptions (PD) are not the primary reason why the VA cannot meet the 80 day window set forth by U.S. Office of Personnel Management (OPM). Additionally, the model can assist in identifying potential areas for reducing the overall process timeline and be used as a training tool to illustrate how the hiring process progresses. Existing models only show major steps in the process which can mask sources of delay, communication issues, and confusion. The developed model delves deeper into those major steps, showing individual sub-steps, accountability, timelines, and data flows. Data for the model was obtained by direct observations, interviews, analysis from data collected by the VHA, and documents released by the VA and OPM. When fully developed, the model allowed for the conduction of case studies on three different positions within VHA; these case studies illustrate that the inability to meet the hiring process timeline is only partially due to issues with the PD and that other factors (namely internal reviews and classification delays) have a significantly greater effect in the resulting timeline. The model itself and recommendations provided, such as establishing priorities, targeting specific areas of time delays, improving communication, and providing access to compartmentalized knowledge can help the VHA to achieve a streamlined and compressed hiring timeline.

Master of Science in Engineering and Management

Nuclear Tanker Producing Liquid Fuels from Air and Water

LT John Galle-Bishop, USN

Dr. Charles Forsberg	Prof. Michael Driscoll	Prof. Mark Welsh
Thesis Supervisor	Thesis Supervisor	Thesis Reader

Emerging technologies in CO_2 air capture, high temperature electrolysis, microchannel catalytic conversion, and Generation IV reactor plant systems have the potential to create a shipboard liquid fuel production system that will ease the burdened cost of supplying fuel to deployed naval ships and aircraft. Based upon historical data provided by the US Navy (USN), the tanker ship must supply 6,400 BBL/Day of fuel (JP-5) to accommodate the highest anticipated demand of a carrier strike group (CSG).

Previous investigation suggested implementing shipboard a liquid fuel production system using commercially mature processes such as alkaline electrolysis, pressurized water reactors (PWRs), and methanol synthesis; however, more detailed analysis shows that such an approach is not practical. Although Fischer-Tropsch (FT) synthetic fuel production technology has traditionally been designed to accommodate large economies of scale, recent advances in modular, microchannel reactor (MCR) technology have to potential to facilitate a shipboard solution. Recent advances in high temperature co-electrolysis (HTCE) and high temperature steam electrolysis (HTSE) from solid oxide electrolytic cells (SOECs) have been even more promising. In addition to dramatically reducing the required equipment footprint, HTCE/HTSE produces the desired synthesis gas (syngas) feed at 75% of the power level required by conventional alkaline electrolysis (590 MW_e vs. 789 MW_e). After performing an assessment of various CO_2 feedstock sources, atmospheric CO_2 extraction using an air capture system appears the most promising option. However, it was determined that the current air capture system design requires improvement. In order to be feasible for shipboard use, it must be able to capture CO_2 in a system only ¼ of the present size; and the current design must be modified to permit more effective operation in a humid, offshore environment.

Although a PWR power plant is not the recommended option, it is feasible. Operating with a Rankine cycle, a PWR could power the recommended liquid fuel production plant with a 2,082 MW_{th} reactor and 33% cycle efficiency. The recommended option uses a molten salt-cooled advanced high temperature reactor (AHTR) coupled to a supercritical carbon dioxide (S-CO_2) recompression cycle operating at 25.0 MPa and 670 ^oC. This more advanced 1,456 MW_{th} option has a 45% cycle efficiency, a 42% improvement over the PWR option. In terms of reactor power heat input to JP-5 combustion heat output, the AHTR is clearly superior to the PWR (31% vs. 22%).

In order to be a viable concept, additional research and development is necessary to develop more compact CO_2 capture systems, resolve SOEC degradation issues, and determine a suitable material for the molten salt/S-CO_2 heat exchanger interface.

Master of Science in Nuclear Science and Engineering
Master of Science in Naval Architecture and Marine Engineering

DC to DC Power Conversion Module for the All-Electric Ship

LCDR Weston Gray, USN

Prof. Chrys Chryssostomidis	**Prof. James L. Kirtley**
Thesis Supervisor	Thesis Supervisor

The MIT end to end electric ship model is being developed to study competing electric ship designs. This project produced a model of a Power Conversion Module (PCM)-4, DC-to-DC converter which interfaces with the MIT model. The focus was on the Medium Voltage DC (MVDC) architecture, and therefore, the PCM-4 converts a MVDC bus voltage of 3.3, 6.5 or 10 kVDC to 1 kVDC. The design describes the transient and steady-state behavior, and investigates the naval architecture characteristics. A modular architecture, similar to SatCon Applied Technology's Modular Expandable Power Converters, was selected as the best balance for the wide variation in loads experienced. The model consists of a standard module that can be paralleled internally to provide for a wide range of system power requirements. Naval architecture parameters, such as weight, volume, efficiency, and heat load, were compiled into a parametric format allowing a reasonable approximation of actual weight and volume as a function of rating and efficiency and heat load as a function of loading. All of the parameters were evaluated for dependence on the MVDC bus voltage. Verification of the model was pursued through comparison to available simulations of similar power electronics to ensure that the model provided reasonable time response and shape. Finally, the model met all requirements with the exception of efficiency which was slightly lower than the requirement although several ideas were presented to improve efficiency.

Naval Engineer
Master of Science in Electrical Engineering and Computer Science

Analysis of the Operational Impacts of Alternative Propulsion Configurations on Submarine Maneuverability

LT Brian D. Heberley, USN

Prof. Michael Triantafyllou
Thesis Supervisor

In an effort to develop submarine designs that deliver reduced size submarines with equivalent capabilities of the current USS *VIRGINIA* (SSN-774 Class) submarine, a joint Navy/Defense Advanced Research Projects Agency (DARPA) called the Tango Bravo (TB) program was initiated in 2004 to overcome technology barriers that have large impact on submarine size and cost. A focus area of the TB program is propulsion concepts not constrained by a centerline shaft.

This thesis investigates the operational impacts that a conceptual propulsion configuration involving the use of azimuthing podded propulsors has on a submarine. Azimuthing pods have been used commercially for years, with applications on cruise ships being quite common although their use on large naval platforms has been nonexistent to date. The use of such systems on a submarine would allow for the removal of systems related to the centerline shaft; freeing up volume, weight, and area that must allocated and potentially allowing the submarine designer to get outside the speed-size-resistance circular path that results in large, expensive platforms. Potential benefits include having the pods in a relatively undisturbed wake field - possibly increasing acoustic performance as well as increased operational maneuvering characteristics.

For this thesis a submarine maneuvering model was created based on analytical techniques and empirical data obtained from the DARPA SUBOFF submarine hullform. This model was analyzed for two configurations:

- A centerline shaft configuration utilizing control surfaces for yaw and pitch control
- A podded configuration utilizing pods for propulsion as well as yaw and pitch control

The maneuvering characteristics for each configuration were investigated and quantified to include turning, depth changing, acceleration, deceleration, and response to casualties.

Naval Engineer
Master of Science in Mechanical Engineering

Development of a Representative Volume Element of Lithium-Ion Batteries for Thermo-Mechanical Integrity

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Prof. Tomasz Wierzbicki
Thesis Supervisor

The importance of Lithium-ion batteries continues to grow with the introduction of more electronic devices, electric cars, and energy storage. Yet the optimization approach taken by the manufacturers and system designers is one of test and build, an approach that nearly every other industry has long abandoned. A computational model is required to reduce the expensive build-test cycle and allow safer, cheaper batteries to be built. The path to building this computational model will involve many different processes and one of those processes dictates the homogenizing of the interior of the battery casing by treating the interior as a homogenized Representative Volume Element. This thesis explains this process and outlines a procedure for the development of this particular model for both cylindrical and prismatic/pouch cells.

Over twenty different mechanical tests were performed on fully-discharged cylindrical and pouched/prismatic lithium-ion batteries, in casings and without casings, under multiple loading conditions. These included lateral indentation by a rod, axial compression, through-thickness compression, in-plane unconfined compression, in-plane confined compression, hemispherical punch indentation and three-point bending. Extensive testing on the battery cell and jelly roll of 18650 lithium ion cylindrical cell, combined with the use of analytical solutions to estimate material properties of the cell, yielded the development of a finite element model. It was found that the suitably calibrated model of high density compressible foam provided a very good prediction of the crash behavior of cylindrical battery cell subjected to high intensity lateral and axial loads.

For the prismatic/pouch cell, the measured load-displacement data allowed calculation of the individual compression stress-strain curves for the separator as well as the active anode and cathode materials. The average stress-volumetric strain relation was derived from averaging the properties of individual layers as well as from direct measurement on the bare cell. This information was then used as an input to the FE model of the cell. The model was composed of shell elements representing the Al and Cu foil and solid elements for the active material with a binder lumped together with the separator. Very good correlation was obtained between LS-Dyna numerical simulation and test results for the through-thickness compression, punch indentation, and confined compression. Closed form solutions were also derived for the latter three problems which helped explain the underlying physics and identified important groups of parameters. It was also demonstrated that a thin Mylar pouch enclosure provided considerable reinforcement and in some cases changed the deformation and failure mechanism.

Naval Engineer
Master of Science in Mechanical Engineering

Flexibility in Early Stage Design of US Navy Ships: A Real Options Analysis

LT Jonathan Page, USN

Prof. Richard de Neufville	**Prof. Mark Welsh**
Thesis Supervisor	Thesis Supervisor

This thesis explores some design options for naval vessels and provides a framework for analyzing the benefit of these flexibilities. Future demands on Navy warships, such as new or changing missions and capabilities, are unknowns at the time of the ship's design. Therefore, ships often require costly engineering changes throughout their service life. These are expensive both fiscally – because the Navy pays for both engineering and installation work – and operationally – because either a warship cannot carry out a desired mission need or is carrying out a mission for which it was not initially designed. One method of addressing uncertainty in capital assets is by imbedding flexible options in their architecture. The thesis offers early stage design suggestions on flexibilities for naval platforms to incorporate pre-planned repeats of the platform with new or different missions. Then, the thesis uses a Real Options Analysis framework to evaluate the value of including these switching options in early stage design. The analysis uses the MIT Cost Model for early stage design to determine acquisition and life cycle costs. The model is modified to support this analysis by allowing a simulation of possible mission changes and their severity distributed stochastically over a realistic time horizon. Subsequently, the model calculates these affects on life cycle cost. The most important result is the value of the Real Options framework for evaluating these managerial options. This framework can extend to the subsystem level or to the system-of-systems level. In this application, the model predicts that, on average, a flexible platform should not only cost less to build, but also reduce maintenance and modernization costs by 35% per ship over its life cycle. Therefore, counter-intuitively, building a less-capable ship with the flexibility to expand capabilities or switch missions actually provides greater expected utility during its service life.

Naval Engineer
Master of Science in Engineering and Management

Naval Ship Propulsion and Electric Power Systems Selection for Optimal Fuel Consumption

LTJG Emmanouil Sarris, HN

Prof. Mark Welsh	**Prof. Olivier de Weck**
Thesis Supervisor	Thesis Reader

Although propulsion and electric power systems selection is an important part of naval ship design, these decisions often have to be made without detailed ship knowledge (resistance, propulsors, etc.). Propulsion and electric power systems have always had to satisfy speed and ship-service power requirements. Nowadays, increasing fuel costs are moving such decisions towards more fuel-efficient solutions. Unlike commercial ships, naval ships operate in a variety of speeds and electric loads, making fuel consumption optimization challenging.

This thesis develops a program in Matlab® environment, which identifies the propulsion and ship-service power generation systems configuration that minimizes fuel consumption for a given operating profile. Mechanical-driven propulsion systems with or without propulsion-derived ship-service power generation, separate ship-service systems and integrated power systems are analyzed. The program comprises modeling of hull resistance using the Holtrop-Mennen method requiring only basic hull geometry information, propeller efficiencies using the Wageningen B series and prime movers fuel efficiencies. The program provides the flexibility to skip the hull resistance estimation and the propeller selection parts, depending on information availability. Propulsion and ship-service power generation systems configuration is optimized using the genetic algorithm.

ASSET's model of DDG-51 Flight I destroyer was used for modeling validation. Optimal fuel consumption results are compared against the existing configuration for DDG-51 Flight I destroyer using a representative operating profile.

Naval Engineer
Master of Science in Engineering and Management

Optimized Design and Structural Analysis of a Non-Pressurized Manned Submersible

CDR Ken Shepard, USN

Dr. John Leonard	**Prof. Mark Welsh**
Thesis Supervisor	Thesis Supervisor

The U.S. Navy's non-pressurized manned submersible (NPMS), the SEAL Delivery Vehicle (SDV) MK 8 Mod 1, remains the United States military's most elite and clandestine method for inserting and extracting Special Operation Forces from the maritime environment. However, in its existing configuration it is unable to meet the growing demand of future missions. A recent SDV optimization study conducted by Charles Stark Draper laboratory investigated cost-effective modifications within the existing hull to meet the new performance requirements required by Naval Special Warfare Group Three (NSWG-3). This project developed a parametric and structural analysis model of a NPMS which is based on the SDV optimization study's design concept, as an initial design tool to evaluate future NPMS designs. Based on a set of design requirements, the parametric model runs several constrained optimizations to generate a SolidWorks solid model of the hull and variable ballast tanks. ANSYS finite element software is then used to perform goal driven optimizations of the solid model to further refine the structural elements. The end product is an optimized solid model of the hull structure and variable ballast tanks that meets the specified set of design requirements. The approach combines the rapid solutions obtained from a parametric mathematical model with the more accurate, but computational intensive, finite element optimization method.

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

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