NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER) FY15 ANNUAL REPORT

Prepared by

Lyla Englehorn, Faculty Associate – Research

October 2015

Approved for public release: distribution unlimited

Prepared for: Raymond R. Buettner Jr., CRUSER Director

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)***	**2. REPORT TYPE**	**3. DATES COVERED** ***(From-To)***
30 September 2015	Technical Report	1 Oct 2015 – 30 Sept 2015

4. TITLE AND SUBTITLE
Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) FY15 Annual Report

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Lyla Englehorn, MPP

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Naval Postgraduate School (NPS)
1 University Circle
Monterey CA 93943

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Deputy Undersecretary of the Navy – PPOI
100 Navy Pentagon Room 5E171
Washington, DC 20350

Office of Naval Research (ONR)
One Liberty Center, 875 North Randolph Street, Suite 1425
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
DUSN/ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release: distribution unlimited

13. SUPPLEMENTARY NOTES
This report is not the work of one author, but a compilation of event reports and funded research summaries for FY15

14. ABSTRACT
The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems (UxS) education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems (UxS) in military and naval operations. This FY15 annual report summarizes CRUSER activities in its fifth year of operations (2015), and highlights future plans.

15. SUBJECT TERMS
robotics, unmanned systems, UxS, UAV, USV, UGV, UUV

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			
UNCLASS	UNCLASS	UNCLASS	UU	189	Lyla Englehorn
					19b. TELEPHONE NUMBER ***(include area code)*** 831-656-2615

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

THIS PAGE INTENTIONALLY LEFT BLANK

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

Ronald A. Route	Dr. Jim Newman
President	Acting Provost

The report entitled *"Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) FY15 Annual Report"* was prepared for the Office of Naval Research (ONR), One Liberty Center, 875 North Randolph Street, Suite 1425, Arlington VA 22203-1995

Further distribution of all or part of this report is authorized.

This report was prepared by:

____

Lyla Englehorn, MPP
Faculty Associate – Research

Reviewed by:

____

Raymond R. Buettner Jr., PhD
CRUSER Director

Released by:

____

Jeffrey D. Paduan, PhD
Dean of Research

THIS PAGE INTENTIONALLY LEFT BLANK

Unclassified; distribution is unlimited

CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER):

FY15 Annual Report

CRUSER
Consortium for Robotics and Unmanned Systems Education and Research

NAVAL POSTGRADUATE SCHOOL

Prepared by Lyla Englehorn, CRUSER Director of Concept Generation
for Dr. Raymond R. Buettner Jr., CRUSER Director
and Dr. Timothy H. Chung, CRUSER Deputy Director

NAVAL POSTGRADUATE SCHOOL

October 2015

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

EXECUTIVE SUMMARY

From Technical to Ethical…

From Concept Generation to Experimentation…

Since 2011 the Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) has sought to create and nourish a collaborative environment and community of interest for the advancement of unmanned systems (UxS) education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative designed to build an inclusive community of interest around the application of UxS in naval operations. CRUSER seeks to catalyze these efforts, both internal and external to NPS, by facilitating active means of collaboration, providing a mechanism for information exchange among researchers and educators with collaborative interests, fostering innovation through directed programs of operational experimentation, and supporting the development of an array of educational ventures.

CRUSER captures a broad array of issues related to emerging UxS technologies, and encompassing the successful research, education, and experimentation efforts in UxS currently ongoing at NPS and across the naval enterprise. Controls, sensors, design, architectures, human capital resource requirements, concept generation, risk analysis, cybersecurity, and field experimentation are just a few interest points. In February 2013 the CRUSER community of interest reached the 1,000-member mark, and continued to grow. As a demonstration of CRUSER's relevance and reputation, as of 28 September 2015 the CRUSER community of interest included just over 2,500 members from government, academia and industry.

In FY15 CRUSER's primary focus shifted from creating a self-sustaining community of interest to impacting the larger naval and defense communities. Support to individual professors provided direct impact on teaching in the NPS classroom. CRUSER supported classroom projects designed provide input for larger naval wargames as well as providing direct feedback to operators and engineers in the fleet and at warfare centers. Workshops on the ethics of employing UxS, cost models for unmanned maritime systems, and *The Future of Just War* conference put critical (non-technological) issues under the spotlight for examination by hundreds of academics, warriors and policy makers. CRUSER funded research projects have led the way, working closely with NAVAIR, in developing methods to accomplish critical research using operational risk methodologies for flight safety. This has led to NPS successfully flying the world's first 50 UAV autonomous swarm; and conducting flight, surface and submerged operations in extreme environments. CRUSER members are on innovation teams and advisory boards across the naval and defense enterprise. CRUSER has also taken on an important advisory role with CRUSER leadership conducting reviews and/or providing input, by request, to the Joint Staff, Deputy Secretary of Defense and Secretary of the Navy.

This FY15 Annual Report provides a summary of activities during CRUSER's fifth year of operation and highlights future plans.

I. BACKGROUND

From Technical to Ethical
From Concept Generation to Experimentation

The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems in military and naval operations

CRUSER encompasses the successful research, education, and experimentation efforts in unmanned systems currently ongoing at NPS and across the naval enterprise. Controls, sensors, design, architectures, human capital resource requirements, concept generation, risk analysis, cybersecurity, and field experimentation are just a few interest points.

Major aligned events starting in FY11 through FY15 are plotted along major program innovation threads (*see Figure 1*) starting with concept generation workshops, developed in technical symposia, and demonstrated in field experimentation to test selected technologies. These activities each have separate reports, and are available upon request. However, research and education will continue to include a broader landscape than just mission areas.

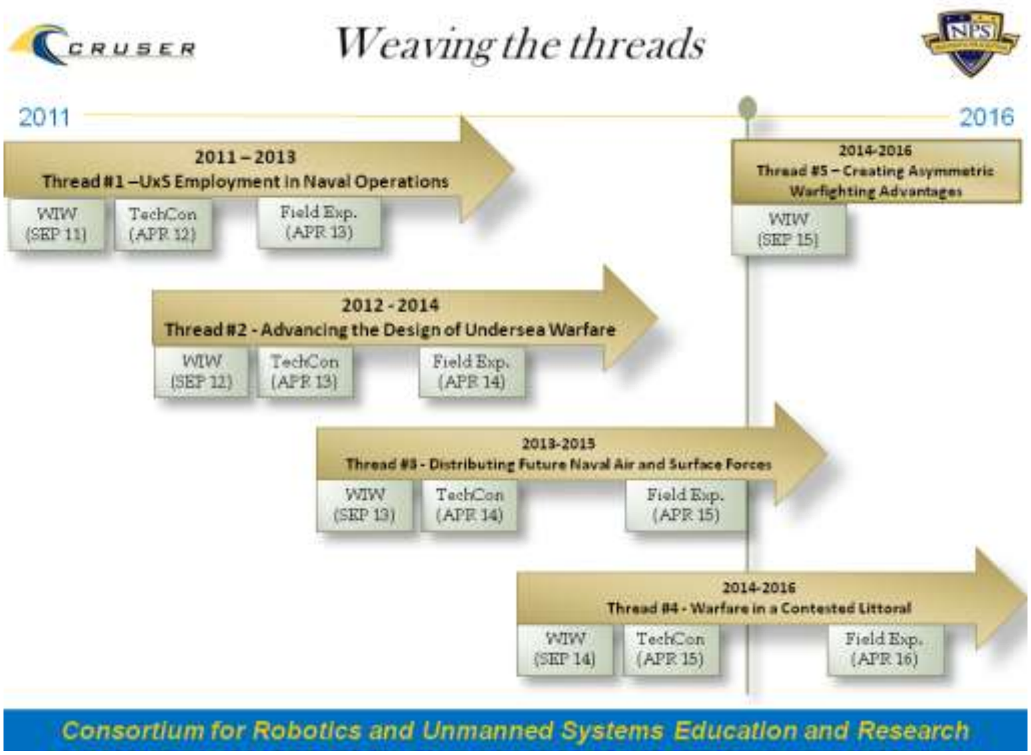


Figure 1. CRUSER program innovation threads as of September 2015

A. VISION

At the direction of SECNAV, NPS leverages its long-standing experience and expertise in the research and education of robotics and unmanned systems to support the Navy's mission. The CRUSER program grew out of the SECNAV's unmanned systems prioritization, and concurrent alignment of unmanned systems research and experimentation at NPS. CRUSER serves as a vehicle by which to align currently disparate research efforts and integrate academic courses across discipline boundaries.

CRUSER is a facilitator for the Navy's common research interests in current and future unmanned systems and robotics. The Consortium, working in partnership with other organizations, will continue to inject a focus on robotics and unmanned systems into existing joint and naval field experiments, exercises, and war games; as well as host specific events, both experimental and educational. The Consortium currently hosts classified and unclassified websites and has established networking and collaborative environments for the community of interest.

Furthermore, with the operational needs of the Navy and the Marine Corps at its core, CRUSER will continue to be an inclusive, active partner for the effective education of future military leaders and decision makers. Refining existing courses of education and designing new academic programs will be an important benefit of CRUSER, making the Consortium a unique and indispensable resource for the Navy and highlighting the educational mission of NPS.

Specific CRUSER goals continue to be:

- Provide a source for unmanned systems employment concepts for operations and technical research;
- Provide an experimentation program to evaluate unmanned system employment concepts;
- Provide a venue for Navy-wide education in unmanned systems;
- Provide a DoD-wide forum for collaborative education, research, and experimentation in unmanned systems.

CRUSER takes a broad systems and holistic approach to address issues related to naval unmanned systems research and employment, from technical to ethical, and concept generation to experimentation. A plethora of research areas inform and augment traditional technical research in unmanned systems, and aid in their integration into fleet operations.

B. MANAGEMENT

CRUSER is organized as a regular NPS research project except with a more extensive charter than most reimbursable projects. It has both an oversight organization and coordination team. The Director, with the support of a lean research and administrative staff, leads CRUSER and executes the collaborative vision for the Consortium. The Director encourages, engages, and enhances on-campus efforts among all four graduate schools and existing centers and institutes. Faculty and students from all curricula with an interest in the development of unmanned systems are encouraged to contribute and participate.

CRUSER continues to build upon existing infrastructure involving research in robotics and unmanned systems, including the Center for Autonomous Vehicles Research (CAVR), and the Center for Network Innovation and Experimentation (CENETIX). These and other programs continue to be major partners in CRUSER research endeavors. The strong interdisciplinary approach of the Consortium is supported by active interest in the Operations Research, Mechanical and Aerospace Engineering, Information and Computer Sciences, Systems Engineering, Electrical and Computer Engineering, Space Systems, Physics, Applied Mathematics, Oceanography, Meteorology, Defense Analysis, and Business Administration Departments at the Naval Postgraduate School. Externally, CRUSER leverages NPS's substantial experience in building collaborative communities to create a dynamic learning environment that engages fleet operators, government experts, industry leaders and academic researchers around the naval unmanned systems challenges.

Courses and educational resources contribute to an integrated academic program. CRUSER augments this holistic academic approach by providing diverse topics and aligned projects for courses not traditionally associated with unmanned systems focus areas such as: cost estimation of future systems; data mining large sensor data sets; and manpower and personnel implications of unmanned systems. CRUSER also purchased classroom supplies to support unmanned systems related courses on the NPS campus.

The Director guides the activities of CRUSER such that they are continually aligned with the unmanned systems priorities of the Navy and Marine Corps. The Director reports to the NPS Dean of Research, and continues to serve as a conduit between associated faculty and students at the Naval Postgraduate School and partnering institutions and agencies.

The Director is supported by an NPS Advisory Committee comprising the NPS Dean of Research, the Undersea Warfare Chair, the Expeditionary and Mine Warfare Chair, the Assistant Chief of Staff for Aviation Activities, the Senior Information Dominance Officer, the Senior USMC Officer, the Surface Warfare Chair, and the NWDC Chair of Warfare Innovation. This committee ensures that the fleet and its operations remain a primary consideration in CRUSER activities to include the selection of research and educational activities funded by CRUSER.

C. FY15 PROGRAM ACTIVITY SUMMARY

The CRUSER FY14 Annual Report concluded with a list of proposed FY15 activities. Now that FY15 is at a close, we have concluded the third innovation thread, are developing the fourth, and have just begun a fifth thread as planned. Additional progress on planned activities in FY15 included:

- CRUSER continued to fund the integration of robotics and unmanned systems issues into appropriate courses and developed educational materials that will enable the Navy and Marine Corps officers afloat to become familiar with the challenges associated with the development and operational employment of these systems.

- CRUSER hosted the fourth installment in the Robo-Ethics Continuing Education Series (RECES) focused legal, social, cultural, and ethical issues for operators, acquisition professionals. CEUs were available to participants in this event (April 2015).

- CRUSER hosted a fourth NPS CRUSER Technical Continuum and the fifth annual Robots in the Roses Research Fair to demonstrate technologies to aid in the concepts generated the fall concept generation workshop, showcase the current research, and host STEM events for local K-12 children (April 2015).

- CRUSER sponsored experimentation of the most promising technologies from the TechCon held in FY14.

- In place of the proposed Research Expo, CRUSER participated as an exhibitor at the ONR Naval Future Force S&T Expo in February 2015 in Washington DC to share the progress and outcomes along the first four programmatic Innovation Threads: UxS employment in Naval operations, advancing the design of undersea warfare, distributed air and surface forces, and warfighting in the contested littorals.

- CRUSER supported summer internships from the service academy students to work in labs across NPS.

- CRUSER funded 65 NPS student trips in FY15 to participate in research and experimentation dealing with all aspects of unmanned systems.

- CRUSER continued Community of Interest database generation, monthly newsletter production and distribution, and monthly community-wide meetings.

- CRUSER hosted and participated in STEM outreach events relevant to robotics education.

- The CRUSER supported rapid prototyping center, the RoboDojo, opened to the NPS campus community (July 2015).

- CRUSER hosted the “Creating Asymmetric Warfighting Advantages” Warfare Innovation Workshop to start the fifth programmatic innovation thread (September 2015).

- CRUSER worked to develop online classroom presentations to promote better understanding of the employment of robotic and unmanned systems.

- CRUSER continued development of a strategy for graduate and non-graduate education across the naval enterprise with regards to robotic and unmanned systems.

II. PRIORITIES

Concept generation, education, research, experimentation, and outreach are all basic tenets for CRUSER. To support the four CRUSER goals, various activities and research initiatives will occur, ranging from unmanned systems innovation symposia and technical symposia to experimentation and research projects. To support the four CRUSER goals, various activities and research initiatives will occur, ranging from unmanned systems innovation symposia and technical symposia to experimentation and research projects. The six-year funding expectation for CRUSER is:

FY11	FY12	FY13	FY14	FY15	FY16
$200K	$1.4M	$2.3M	$4.5M	$4.375M	$5M *

** Anticipated*

Activities for each year are briefed to the Advisory Board and require approval from the sponsor.

FY11 was considered the CRUSER stand up year. With the initial funding, CRUSER was established with a Director, Director for Research and Education, Director of Concept Generation and Innovation, and Operations Manager. A CRUSER Community of Interest was created with over 250 members joining from across DoD, academia, and industry within a month of the creation of the web site (http://CRUSER.nps.edu). An information exchange portal (wiki) was created, and monthly newsletter started. CRUSER co-sponsored the Future Unmanned Naval Systems (FUNS) Wargame, and held the first Robots in the Roses Research Fair, as well as several STEM events. CRUSER also supported exploration of UxS as operational decoys, and the Advanced Undersea Weapons Systems (AUWS) Systems Engineering Analysis Capstone Project. A final FY11 Annual Report was released in December 2011 summarizing these activities.

FY12 was CRUSER's first full year in operation and as a transition year, continued many items started in FY11 such as the Community of Interest database, which was over 550 members midway through FY12. The monthly newsletter, monthly VTC meetings, and online presence to include a SIPR site were maintained and expanded. Community-wide monthly meetings were available at NPS, or via VTC or dial-in to allow for collaboration with those are not located at NPS. Funding was provided to eight NPS faculty members to research many aspects of unmanned systems, and included the joint ONR/NPS Seaweb at-sea experimentation program with Singapore. CRUSER sponsored a Warfare Innovation Workshop (WIW) in Naval Unmanned Systems, focusing on revolutionary Concept Generation using evolving technologies. Three teams of NPS students and early career engineers from Navy Labs, academia and industry participated alongside a team with more experienced NPS faculty and engineers from Navy Labs, academia and industry. Five selected focus areas were the basis for presentations that refined those concepts at the first CRUSER Technical Continuum (TechCon) held in coordination with the Tenth International Mine Warfare Technical Symposium in Monterey, California. Two of the proposals were taken on to experimentation in FY13. CRUSER continued to provide a discussion venue for new Navy unmanned and robotic initiatives. For example, hosting initial discussions for the Navy's Robotics Education Continuum in conjunction with the CRUSER Technical Continuum provided an opportunity to align unmanned systems education at USNA, NPS and NWC. Additionally CRUSER hosted a Legal, Social, Cultural, and Ethical continuing education seminar for operators, acquisition professionals, and engineers in the Washington D.C. area in coordination with OPNAV N2/6 and ONR.

FY13 saw the completion of the first innovation thread. CRUSER continued many activities from FY11 and FY12 such as the Community of Interest database, which was over 1100 members midway through FY13, a monthly newsletter, monthly VTC meetings, and online presence to include a SIPR site. In FY13 funding was again given to eight NPS faculty members to research many aspects of unmanned systems, and included continued work in the joint ONR/NPS Seaweb at-sea experimentation program with Singapore. CRUSER sponsored four midshipmen from USNA to complete summer internships in various labs. CRUSER held the second event in the Robo-Ethics continuing education series for operators, acquisition professionals, and engineers in September 2013 to continue the discussion begun during the January 2012 event held in Washington DC. Community-wide monthly meetings continued to be available at NPS, or via VTC or dial-in to allow for collaboration with those are not located at NPS. CRUSER sponsored two Warfare Innovation Workshops (WIW) during FY13 focusing on the second innovation thread: Advancing the Design of Undersea Warfare. Teams of NPS students and early career engineers from Navy Labs academia and industry presented over 40 concepts. Seven selected focus areas were the basis of presentations at the NPS CRUSER Technical Continuum (TechCon) held in April 2013. From those two days of presentations, four of the presentations were funded for experimentation in FY14.

FY14 was the first year at full funding and execution. CRUSER continued many items started in previous years such as the Community of Interest database, which hit over 1,300 members midway through FY14. The monthly newsletter, monthly VTC meetings, and an expanded and improved online presence are program activities that will continue to mature. Community-wide monthly meetings are available at NPS, via VTC, via the NPS distance learning platform, or dial-in to allow for collaboration with those who are not located at NPS. CRUSER sponsored a Warfare Innovation Workshops (WIW) during FY14 focusing on our third innovation thread: Distributing Future Naval Air and Surface Forces. Four teams of NPS students and early career engineers from Navy Labs, academia and industry generated many innovative concepts. Selected focus areas from the WIW were refined at the NPS CRUSER TechCon 2014 held in April. From those two days of presentations, six proposals were funded for experimentation in FY15. The fourth annual Robots in the Roses Research Fair served as the concluding event of the annual TechCon in April 2014. In May 2014, CRUSER held two panels at the Navy-sponsored Eleventh International Mine Warfare Technology Symposium and also hosted a TechExpo in conjunction with the symposium on the final day. The TechExpo allowed symposium participants to participate in a poster session showcasing the work of NPS faculty and students, and offered lab tours of various unmanned systems or robotics labs across NPS.

FY15 started with CRUSER at "flank speed" selecting a full roster of projects to seed. Our September 2014 Warfare Innovation Workshop started the fourth programmatic Innovation Thread and continued the cross campus, cross curriculum work of the Warfare Innovation Continuum through the NWDC NPS Chair of Warfare Innovation. In February 2015 CRUSER socialized the work of our funded researchers at the ONR Naval Future Force S&T Expo in Washington DC, and then launched into our next discussion in the Robo-Ethics Continuing Education Series (RECES). April 2015 also brought together over 200 members of our technical community of interest for our annual TechCon, where we heard development proposals for concepts generated during the past few Warfare Innovation Workshops, as well as research reports from experimentation funded in FY14. CRUSER continued to support the field experimentation venue at Camp Roberts CA, and several NPS CRUSER researchers tested prototypes for proof of concepts several times during the year. CRUSER as a program really hit its stride this fiscal year in the greater community consciousness, and was tapped for subject matter expert input from the DoD and beyond.

Funding in FY15 was granted to 30 NPS faculty members to study many diverse aspects of unmanned systems including increasing education opportunities in addition to research. CRUSER also funded 28 NPS students to travel in FY15 to participate in research, and experimentation dealing with all aspects of unmanned systems to help develop the next generation of military officers.

Primary objectives in FY15 were to continue to provide:

- seed money for concept development
- DoD-wide experimentation programs,
- an education venue,
- a source of concept generation,
- and a DoD-wide forum for collaboration

The remaining sections of this report will address each of these objectives.

A. RESEARCH AND EXPERIMENTATION

At the direction of the SECNAV, NPS continues to leverage long-standing experience and expertise in the research and education of robotics and unmanned systems to support the Navy's mission. CRUSER was established to serve as a vehicle by which to align currently disparate research efforts across the NPS campus as well as among our academic partners and greater community of interest. Funding in FY15 was granted to projects led by NPS faculty members to explore many diverse aspects of unmanned systems.

In September 2014, CRUSER made its third call for proposals to seed research topics. The stated funding period was 1 October 2014 through 30 Nov 2015, and the funding levels were set at $75,000 to $150,000 per proposal. Like in prior years, researchers were again asked to submit proposals in one of the following general subject areas:

- **Technical:** Power, Sensors, Controls, Communications, Architectures, Human Factors, Information Processing and Dissemination
- **Organization and Employment:** Human Capital Requirements, Risk Analysis, Force Transition, Acquisition, Policy, Concept Generation evaluation and Authorities
- **Social, Cultural, Political, Ethical and Legal**
- **Experimentation**
- **Defense against threat unmanned capabilities**

At the beginning of September 2014, 43 proposals totaling over $4.7 million in requests were considered for CRUSER funding. The CRUSER advisory committee selected 38 projects, and granted $3.3million in total to support their work in FY15 (see Table 1). Nineteen proposals totaling $2.2 million were presented at TechCon 2014. Of those, CRUSER funded 6 for a total of $715k. After the release of the Call for Proposals, research dates were adjusted to be 1 October 2014 to 30 September 2015 to account for end of fiscal year government accounting requirements.

Proposals were accepted in two tracks, education and research. The education proposals are noted in Table 1, and project summaries are included in the next section of this report with the other education related activities.

Table 1. FY15 CRUSER funded projects (alphabetical by principal investigator last name)

PROJECT TITLE	PRINCIPAL INVESTIGATOR
Unmanned Maritime System Lifecycle Costing Workshop	Angelis
Representation of Unmanned Systems in Naval Analytical Modeling and Simulation	Blais
Unmanned Systems Network to Support Vessel Boarding Operations	Bordetsky
Network Optional Warfare (NOW): Optical Signaling and Data Compression for Improved Stealth, with Design of Experiments for Evaluating Operational Concepts	Brutzman
Glider-Measured Underwater Bioluminescence for Submarine Minefield Navigation	Chu
Enabling Capabilities and Technologies for Swarm UAS Autonomy	Chung
[EDUCATION] RoboDojo	Chung/Tsolis

Cumulative Energy Estimation for Optimal Planning of ISR Mission of Cooperative Autonomously Soaring Gliders	Dobrokhodov
Robotic Outposts to Support Persistent AUV Operations	DuToit
AUV Operations in Extreme Environments: Under-Ice Operations	DuToit
[EDUCATION] Agent Library of Unmanned Vehicles	Giachetti
Modeling Swarm Failsafe Behaviors with Monterey Phoenix	Giammarco
Testing Small Multi-Rotor Unmanned Aerial Systems as Platforms for Atmospheric Measurements	Guest
[EDUCATION] Unmanned Systems Grasping: A Laboratory Based around Arm Grasping	Harkins
Short Range Wireless Power Transfer (WPT) for UAV/UAS Battery Charging – Phase II	Jenn
Cooperative Underwater Sensing with Aqua-Quad	Jones
[EDUCATION] Applications of a mobile acoustic source for Tactical Oceanography	Joseph
[EDUCATION] Towards Autonomous ISR missions by a team of cooperating Gliders	Kaminer
Computational Solutions for Real-time Optimal Maneuvering of Unmanned Vehicles	Kang
Intelligent Sensing for Autonomous Coordinated Maneuvers	Kragelund
Phase III Interim Flight Clearance	Millar
C2 Models of Next Generation Unmanned Aircraft Systems	Nissen
Using Small Unmanned Aerial Systems as Electronic Warfare Platforms - Providing the Tactical Ground Commander the Electromagnetic Advantage	Pace
LDUUV Life Cycle Management	Paulo
Stratified wakes induced by submerged propagating objects: detection using Unmanned Underwater Vehicles.	Radko
Autonomous Aerial Vehicles with Robotic Manipulation Capability	Romano
Combined Unmanned Underwater Vehicle Efforts in a Large-Scale Mine Warfare Environment	Sanchez
[EDUCATION] CRUSER Data Farming Workshops	Sanchez
Investigating the Navy's Logistics Role in Department of Defense International Humanitarian Assistance Activities	Sanchez
[EDUCATION] Robotic system software engineering classroom case study	Shebalin

Real-time undersea networking using acoustic communications for improved UUV positioning and collaboration	Smith
[EDUCATION] Future Challenges for Just War Theory: International Conference	Strawser
Using Autonomous Wave Gliders to Quantify Near-Surface Turbulence and EM Ducting Conditions	Wang
[EDUCATION] Development of instructional tutorials, online wiki, and videos in support of Robotics and Rapid Prototyping	Whitcomb/Tsolis
[EDUCATION] Development of Control System Course Content for Interdisciplinary Applications in Robotics	Yakimenko
Rapid FDC Resupply Using a Projectile-Launched Guided Parafoil	Yakimenko

Some of these projects are complete, others are underway, and a few have yet to begin work as the period of performance ends on 31 December 2015. These research summaries include work as of 30 September 2015, are listed in alphabetical order by primary Principal Investigator (PI) last name, and each has a POC listed for further inquiry. Education track project summaries follow in the next section of this chapter.

1. Unmanned Maritime Systems Life Cycle Cost Study

The DoD uses a vast array of unmanned systems to deliver new and enhanced capabilities to the warfighter. The Navy currently has a number of unmanned maritime systems (UMS) that perform a variety of missions including mine countermeasures, maritime security, hydrographic surveying, environmental analysis, special operations, and oceanographic research. Many of these systems were rapidly developed and fielded to meet immediate warfighter needs. In most cases, unmanned systems are no different from manned platforms and require investments in reliability and maintainability to provide availability at an affordable cost. However, reliability, maintainability, and life-cycle costs (LCC) have been secondary considerations for most UMS programs. As the programs mature and become operational, the Navy must understand the total life-cycle cost of the system to determine their affordability.

Figure 2. Warfare Innovation Workshop held on the NPS campus exploring unmanned maritime systems life cycle costs (March 2014).

The total ownership cost of unmanned maritime systems has not been well developed, primarily due to lack of experience with operational systems and lack of sustainment cost data. It is unclear whether life cycle cost models for manned systems can be adapted to estimate ownership costs for UMSs because the relationship between traditional cost drivers and UUV operations & sustainment (O&S) costs is not well understood. In addition, cost models for UMSs will be based on cost drivers that may be unique to UUV operations and maintenance. As a result, a cost model specific to UMS O&S cost needs to be developed.

This study focused on identifying and understanding the cost drivers for unmanned underwater vehicles (UUV) O&S and building a cost model for UUV O&S cost. The first step was to identify high-level cost drivers based on subject matter expertise. To do this a warfare innovation workshop was held in March 2015. The goal of the UMS LCC WIW was to identify Operations and Support (O&S) cost drivers for UMS based on current and future operations. The WIW brought together subject matter experts (SME) with UMS experience from various programs with NPS students to broaden perspectives and gather real world insights to support and inform the study of UMS LCC.

The workshop succeeded in identifying major cost drivers for UUV O&S costs (results are documented in a separate report). The study team also used the results of the workshop to develop a cost model for UUV O&S based on the O&S cost model provided by OSD/CAPE. The next steps are to collect data and information from SMEs to estimate the cost of the various O&S elements in the model, determine if the cost drivers identified in this workshop are significantly correlated to UUV O&S cost and develop cost estimating relationships based on those cost drivers. A team of NPS systems engineering students is currently working on collecting data and information from SMEs for their capstone project to be completed in March 2016. Finally, uncertainty information will be obtained from SMEs and operational data to incorporate uncertainty and risk in the cost model to better understand and manage UUV O&S cost.

POC: Diana I. Angelis (diangeli@nps.edu)

2. Representation of Unmanned Systems in Naval Analytical Modeling and Simulation

Combat models are used in preparing data supporting Quadrennial Defense Reviews for Naval system acquisition and future force structure decisions. For example, the Navy has been adding capabilities to the Synthetic Theater Operations Research Model (STORM) originally developed by the US Air Force. Similarly, the Army and Marine Corps employ a specific analytical model called the Combined Arms Analysis Tool for the 21st Century (COMBATXXI) to evaluate major proposed changes in materiel and associated warfighting operations and tactics. Over the past several years, the employment of unmanned systems in military operations has grown rapidly, with projections for continued growth in funding and procurement in coming years. The rapid adoption of unmanned systems has been heralded with announcements of significant improvements to warfighter effectiveness, through tactics, techniques, or procedures. However, there is concern that these claims are not well supported by analytical processes and findings.

The purpose of this study was to investigate current and planned capabilities of critical Naval analytical models, such as STORM and COMBATXXI, to identify improvements needed in representations of unmanned system capabilities thereby improving the scope and value of studies conducted using such tools. The study serves as an initial effort to bring improved representations of unmanned systems into analytical environments, recognizing that it is part of a larger need to bring such representations into other environments as well, such as into gaming environments for concept exploration, into constructive simulations for experimentation and mission planning, and into training environments for low-level (operator) to high-level (staff) skill development.

The study found that simulations such as STORM, COMBATXXI, and the Naval Simulation System (NSS, added to the study to examine a level of representation in Naval operations more similar to the level of representation in COMBATXXI) are largely deficient in representations of such emerging systems, making it difficult to conduct studies investigating future force structures (e.g., 2020 and beyond) that demand planning and acquisition decisions in the near-term. Instead, decisions currently are being made without an analytical basis able to show the benefits, limitations, and challenges (manpower, training, logistics, combat service support, vulnerabilities, etc.) of introduction of such systems into the battlespace. Analyst-level mechanisms exist in COMBATXXI and NSS to enable development of better resolutions, but a critical shift in perspective is needed. That is, key to representation and analysis of the employment of unmanned systems in future warfighting is the ability for the models to discern the difference in performance of human systems (individuals, teams, crews) and the performance of unmanned systems, where the latter vary in levels of human engagement (i.e., remote controlled, tele-operated, semi-autonomous, and fully autonomous systems). Current modeling representations of humans and human-controlled systems, such as platforms, weapons, vehicles, etc., are surprisingly "robotic" in behavior. In this sense, current representations are arguably more faithful to requirements for modeling autonomous unmanned systems than to modeling human systems. The deficiency, in effect, is even more pronounced in the representation of manned systems, which has been a weakness in combat models since their inception. In addition to addressing the need for greater fidelity in the representation of unmanned systems, the study discusses state-of-the-art in representation of human systems, providing recommendations for improvements addressing representations of unmanned systems, human systems, and mixed teams of humans and unmanned systems, to provide a foundation for improvements that will enable studies to distinguish the performance and effects of various mixes of these entities in future warfare.

POC: Curtis Blais (clblais@nps.edu)

3. Unmanned Systems Network to Support Vessel Boarding Operations

The goal for this project is to explore novel self-organizing unmanned systems network capable of assisting SOF and USCG units in boarding a non-compliant vessel. It is expected that such a network would support the boarding team search of illicit materials on board the ship, cargo area rapid surveillance, rapid site exploitation, and boarding team casualty assistance. The study had been structured through the series of feasibility and constraints analysis field experiments, two which are already completed and the last one scheduled to be conducted in San Francisco Bay on 26-30 October 2015.

Figure 3. Vessel boarding partner crews networking via the UAV aerial node.

In the first field experiment conducted on 16-19 June 2015, we successfully explored the possibility of deploying above the deck UAV for becoming the temporal networking hub between the small craft patrol and vessel boarding teams interdicting the target. The unmanned rotorcaft performed as networking hub above the deck allowing the partner teams, engaged in the operation, one conducting the hostile vessel boarding, and the other providing for fast patrol boats assistance, to form the robust self-healing mesh network. Across the mesh, the VBSS and small craft crews were able to share the threat finding situational awareness data and communicate the vessel boarding findings with the reachback experts. The figure above (see Figure 3) illustrates one of the trial steps. Concurrently we've explored the appearance of two cube satellites in the area of action for getting the threat finding alert information and downloading it at the remote subject matter expert site. We used a unique formation of cube satellite robots (see Figure 4) at the remote location to simulate the process in real time and space of the experiment threat interdiction action (see Figure 5).

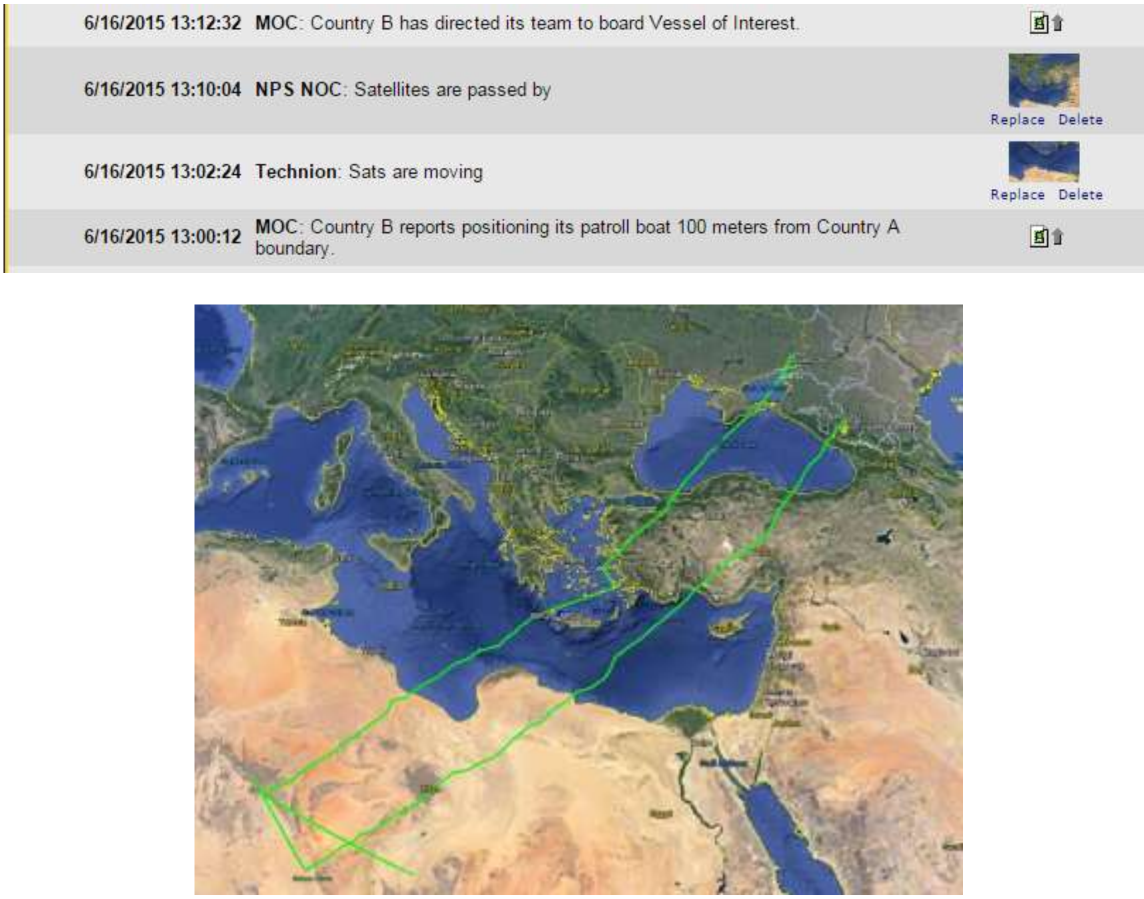


Figure 4. Cube Satellite nodes (top) integration in the UAV-relayed vessel boarding network (bottom).

The opportunity of bringing autonomous UGV-centered vessel search network by remotely controlling it via the orbital node across the over horizon distances, is been explored in the next field trial on March 16-19. The experiment successfully demonstrated ability of using an autonomous cubesat as a communication platform to relay messages between distant unmanned platforms. The figure below illustrates successful way point transfer via remote cube satellite robot to the CENETIX UGV for guiding the UGV in moving from one location to another.

Figure 5. Technion Robotic Cube Satellite formation flown above the vessel boarding area.

The development effort and series of bench and field trials, conducted in July-September time period allowed to finalize the development of innovative two-way networking mechanism for subsurfaces divers and unmanned vehicle communication using the networking by the near field touch model (see Figure 6). The system is already a part of the MIO networking testbed environment.

Figure 6. Cube Sat way point operation of remote UGV (top), CENETIX UGV (bottom left), and Technion Robotic Cube Satellite (bottom right).

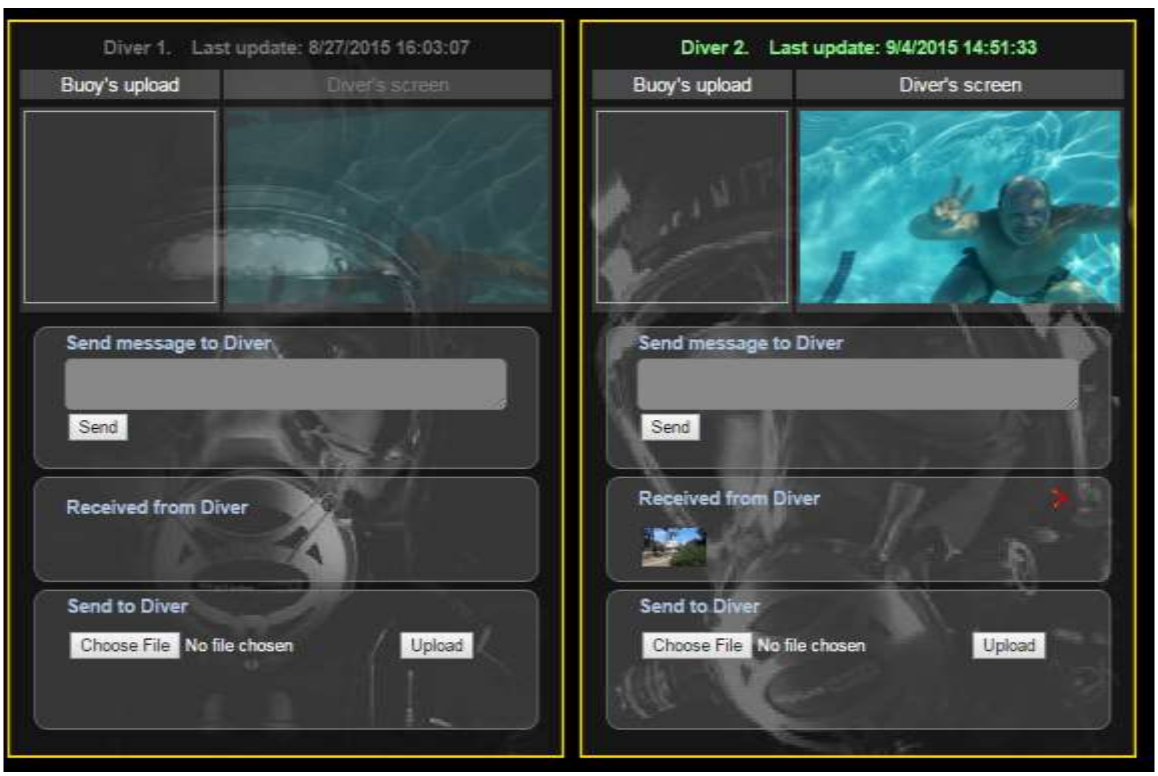


Figure 7. Communicator for near-field touch two-way networking with divers and unmanned systems.

Our next trial in October is set up to explore the following unmanned systems and manned-unmanned teaming elements addition to the vessel boarding network:

1) Subsurface diver-Unmanned Underwater Vehicle (UUV) networking,

2) Micro Tactical Ground Robot (MTGR) from Roboteam Corp, which can climb staircases and lay down smaller autonomous relays or sensing nodes, while following Boarding Team members or moving forward to a target area,

3) Autonomously moving miniature relay nodes, which are placed (ejected) by the MTGR or thrown by a Boarding Team member. The autonomously moving relay nodes are based on the IRIS devices from Roboteam,

4) Altogether, in addition the remote UUV, the combination of such relay UGV nodes would allow the boarding team members to extend their ad hoc mobile network to the denied areas, providing an additional video and threat sensing vessel surveillance.

POC: Dr. Alex Bordetsky (abordets@nps.edu)

4. Network Optional Warfare (NOW): Optical Signaling and Data Compression for Improved Stealth, with Design of Experiments for Evaluating Operational Concepts

Figure 8. Mike Bailey with 20x telephoto lenses working with the GoPro Hero 4 cameras. Modifying the camera cases to hook up cabling allowed for full image throughput to our Java-based QR tactical decision aid (TDA).

Naval forces do not have to be engaged in constant centralized communication. Deployed Navy vessels have demonstrated independence of action within coordinated operations for hundreds of years. Littoral operations, unmanned systems, and single-purpose ships pose a growing set of naval challenges and opportunities. Network-optional warfare (NOW) can be achieved through efficient communications, signaling stealth, and deliberate tactical messaging.

Figure 9. Test rig components include standard computer display monitor, 20x lens from Torrey Pines, GoPro4 camera with 4K resolution, Standard COTS cable connectors, Microsoft Surface3/Windows8 tablet, and NPS-written open-source Java software with live video display/interface and QR code generator, reader. Tripod mount, can ride on dolly.

Quick Reaction (QR) Codes are standardized symbol blocks that can be used for single messages of various sizes or to create a streaming data channel. This year saw multiple areas of progress.

- Open-source Java codebase in version control for sharable editing and improvements.
- Video card software drivers library added for flexible hardware configurations.
- Designed, constructed and tested portable test rigs to facilitate further capability development.
- Added streaming communications capability to single-line chat application, sets stage for development of optical streaming protocols.
- Tested novel 20x telephoto lens from Torrey Pines with networked GoPro 4 cameras.
- Demonstrated visual range of 13m-20m for readable pixel resolution of 24”-square display.

We expected longer effective range capabilities, but the new-lens improvements were undercut by the very-wide-angle GoPro lens. Nevertheless this remains progress in the right direction, and we remain optimistic that viewing and streamability across campus (Spanagel Hall to Glasgow Hall) remains feasible. Next steps learned from this progress:

- Utilize a variety of digital cameras now becoming available, connected directly or remotely.
- Utilize lenses with much-smaller field of view (FOV) and much higher magnification, such as range finders and telescopes.
- Propose imagery tests with existing Navy assets such as Littoral Combat Ship (LCS) optics.
- Contributed to in-depth student analysis project as part of Joint C2 Capstone Course, comparing Network Centric Warfare (NCW) and Network Optional Warfare (NOW) approaches.
- Developed and submitted detailed technical proposed continuing this multi-year line of work.
- Proposed overarching themes, challenges for annual NPS Warfare Innovation Continuum (WIC).

Project resources are maintained online at

https://wiki.nps.edu/display/NOW/Optical+Signaling

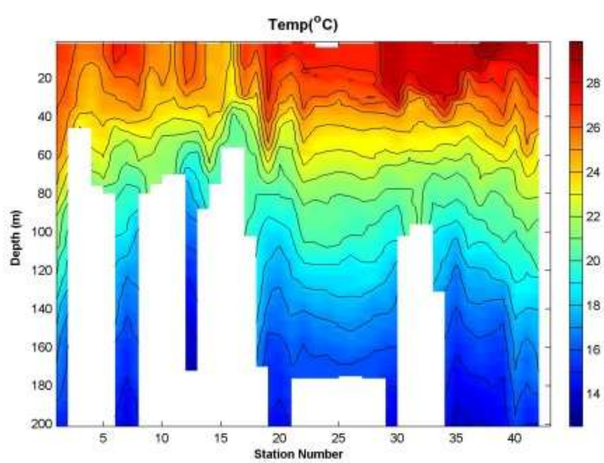
Short-range tuning and testing in Watkins Hall comes next. Next steps will be across the quad and possibly across campus. Proposed work for FY16 includes adding trackers to the rig and bringing them down to JIFX.

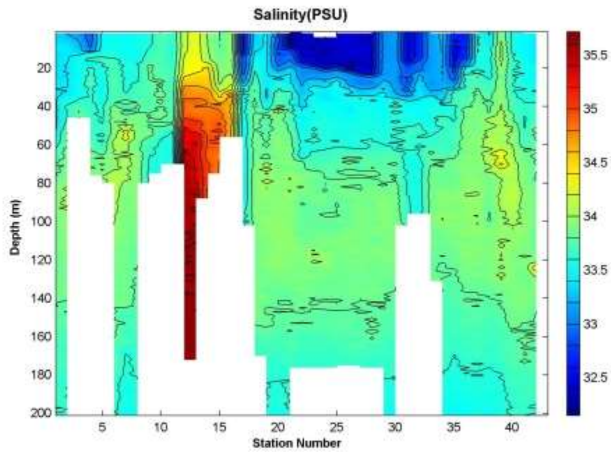
POC: Don Brutzman (brutzman@nps.edu)

5. Glider-Measured Underwater Bioluminescence for Submarine Minefield Navigation

Figure 10. Artist rendering of glider-measured underwater bioluminescence for submarine minefield navigation.

We achieve the goal of this project to develop tools/algorithms to effectively analyze seagliders' underwater bioluminescence, optical, and hydrographic data with NPS student officers being heavily involved. Temporal and spatial patterns of temperature, salinity, and optical characteristics such as bioluminescence, fluorescence, and light transmissions have been analyzed (see Figure 11). Horizontal maps of each variable are produced to aid in submarine minefield navigation. Specifically, the maximum values of bioluminescence and minimum for light transmission as well as their corresponding depths have been determined and analyzed. Additionally, histograms of these maxima and minima are found. Furthermore, the horizontal and vertical correlations among variables are identified.





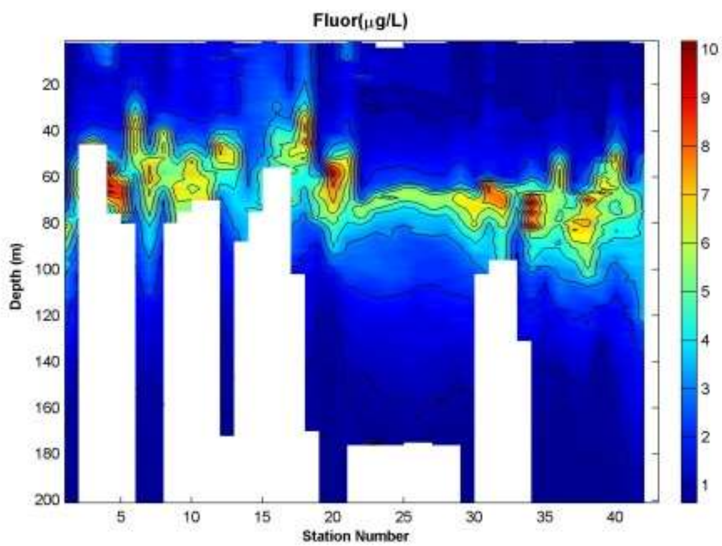


Figure 11. Vertical cross sections of temperature, salinity, and fluorescence along glider tracks.

In FY15 five NPS students (LCDR Ramon Martinez, LT Sean Sharp, LT Mary Doty, LCDR Hyewon Choi, and LT Nuri Karaaslan) have been working on various aspects on the project for their MS degrees in METOC, Physical Oceanography, and USW:

Ramon P. Martinez (2014) *Bio-Optical and Hydrographic Characteristics of the western Pacific Ocean for Undersea Warfare Using Seaglider Data*. MS in Meteorology and Oceanography, December 2014.

Sean M. Sharp (2015) *Impact of Time-Varying Sound Speed Profiles with Seaglider on ASW Detection Ranges in the Strait of Hormuz* (SECRET), MS in Undersea Warfare, September 2015.

Mary E. Doty (2015) *Analysis of Bioluminescence and Optical Variability in the South China Sea for Naval Operations Using Ship and Seaglider Data* (RESTRICTED). MS in Meteorology and Oceanography, anticipated December 2015.

Nuri Karaaslan (2015) *Mediterranean Sea Thermohaline Structure and Circulation Identified from In-situ and Seaglider Data*. MS in Meteorology and Oceanography, anticipated December 2015

Hyewon Choi (2015) *Japan/East Sea Thermohaline Structure and Circulation Identified from In-situ and Seaglider Data*. MS in Physical Oceanography, anticipated December 2015

POC: Peter C. Chu (pcchu@nps.edu)

6. Enabling Capabilities and Technologies for Swarm UAS Autonomy

The NPS Advanced Robotic Systems Engineering Laboratory (ARSENL) team broke the known record for simultaneously flying autonomous aircraft during a recent field test at Camp Roberts, California. The team successfully flew 20 autonomous planes on May 15th, nearly doubling its own record of 12 aircraft set in February. Then, in July the ARSENL team decided to beyond 20 and fly the maximum amount of planes their interim flight clearance would allow - 30 unmanned aerial vehicles (UAVs). They successful flew 30 UAVs on 16 July 2015.

Figure 12. ARSENL team members launching a "flying wing" at Camp Roberts, July 2015

The aircraft used are flying wings made of Styrofoam and outfitted with hobby-grade components. Each plane is also equipped with an autopilot that can perform waypoint-based navigation and a secondary computer that communicates with other aircraft as well as ground systems, and coordinates cooperative flight.

For both the 20 and 30 plane missions of UAVs, once launched, each plane autonomously flew to an assigned position in one of two vertical "stacks," with a small altitude offset from its neighbors. The planes were then split into two "sub-swarms" and each was commanded to begin a follow-the-leader behavior. Two aircraft designated themselves as leaders based on relative altitude, one per sub-swarm, and began flying along a pre-programmed course. All remaining aircraft immediately started following their respective leaders based on shared awareness of each other's positions. The followers used no a priori knowledge of the leaders' intended courses. Finally, each aircraft was commanded to land autonomously.

From a research and development perspective, these aircraft provide a viable solution for exploring autonomous fixed-wing aerial vehicles at large scales. Using primarily commercial off-the-shelf hardware and open-source software, each vehicle costs less than $1,000 in parts (not including cameras or other sensors). Most of the custom parts, such as mounting brackets and landing skids, are 3D printed, further reducing manufacturing costs and allowing for iterative improvements to the aircraft design.

Even the process of physically preparing 30 planes for flight and launching them is an area of challenge. The current aircraft are electric and have a maximum flight time of less than 60 minutes. In order to have the last plane in the air before the first one must land requires a launch interval of less than two minutes. Preparation time on the ground with the aircraft powered further limits time in the air. The team has iteratively improved the pre-flight process over the past six months, further automating software and mechanical checks and simplifying pre-launch procedures wherever possible. Just months ago, a single plane typically took 20 to 30 minutes to prepare for flight and five or more minutes to launch; now, each aircraft can be prepared in just over five minutes and the time between launches is just over a minute.

Figure 13. The ARSENL Team at Camp Roberts, July 2015

The ARSENL team flew 50 UAVs the last week of August 2015. Results will be forthcoming.

POC: Dr. Timothy Chung (thchung@nps.edu)

7. Cumulative Energy Estimation for Optimal Planning of ISR Mission of Cooperative Autonomously Soaring Gliders

Operational efficiency of multiple cooperative UAVs in an ISR mission significantly depends on the optimality of mission planning that accounts for the energy constraints and the onboard sensors coverage. In a long endurance or a persistent ISR mission a new class of autonomous platforms, capable of silent and long endurance flight, is required. In the ongoing project the UAVs are implemented by a novel class of soaring gliders capable of harvesting energy from the convective air (thermal soaring) and the solar photo voltaic (PV) panels. The cooperation is enabled by sharing the information about the detected energy sources (strength, location, motion) over the airborne MANET network. During the daylight hours the gliders harvest potential energy from thermals and electric energy from the PV panels, and save electric energy in onboard batteries. While at night, they minimize the electric energy drain for onboard avionics and keep looking for vertical gradients of air velocity; if a vertical gradient is found, they harvest this energy to extend the flight.

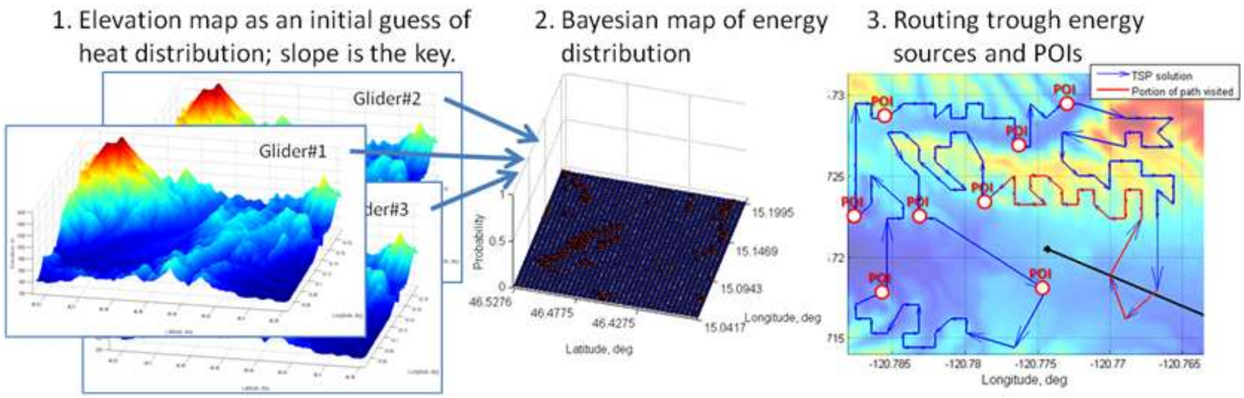


Figure 14. Convolution of knowledge into energy map and its use in the path routing.

In an envisioned scenario the ISR analyst plans a mission of multiple autonomous gliders such that either the feasibility of the desired mission is immediately assessed, or the number of gliders and the mission horizon are automatically adjusted to optimally fit into the predicted value of cumulative energy resources. Furthermore, the ability of cooperative gliders to build and share in real time the geospacial energy distribution maps, allows the entire flock of airborne UAVs to optimally distribute the aircraft to serve the ISR objectives, and to optimize their path both to the energy sources and to the ISR points of interest (POI).

For this class of aircraft the predictive methods of estimating the onboard energy become the most critical factors in planning of persistent ISR mission. Therefore, we develop a new approach to the estimation of the cumulative energy of autonomous soaring gliders that can be used as an optimization metric in the mission planning phase. The developed metric combines the cumulative mechanical (kinematic and potential) and electrical (stored in batteries) sources of energy, which for a known glider UAV are expressed either in the form of nominal achievable time or reachable distance; the form depends on the phase of the mission. Nominal value of the metric is calculated with the assumption of "no wind" conditions. When in actual flight, the wind is accounted for by MacCready approach. When the geospatial energy map is updated during the flight, as a result of Bayesian inference of knowledge from multiple cooperative aircraft, the resulting "hot spots" of energy and the ISR mission POIs become georeferenced, see Figure. This map synchronously represents the goals of ISR, achievable travel time/distance of each glider, and potentially available energy sources along the route. Based on this energy map, each glider solves online a route optimization task that results in a trajectory (commanded path and velocity) that serves the energy harvesting and ISR mission objectives simultaneously. Since the same algorithm is running onboard of each glider in the fleet and the "knowledge" is shared over the network, the entire system represents a distributed intelligent flock capable of significantly higher operational utility.

As a first step toward onboard mission replanning, we implemented two trajectory-planning approaches that take into account the limited computational resources and the desire to guarantee a feasible trajectory planning solution. First approach implements a version of Travelling Salesman algorithm. The second approach significantly modifies a near-optimal RRT* path planning algorithm by integrating the knowledge of distributed energy density map; the gradient of the energy density function is what makes the algorithm a novel solution. This modification addresses one of the significant shortcomings of the RRT* approach that is the low convergence rate of obtaining an optimal solution. In both approaches, the necessary frequency of replanning is a valuable question that will be addressed at the next "operations research" (OR) step.

As a result of developing and integrating onboard of these algorithms an operational system consisting of two PV-equipped gliders is developed. Flight testing of single glider running TSP solution has been successfully accomplished as a part of the MSc student research. The future plans are focused on OR type concepts and the flight testing aspects of the work.

POC: Vladimir Dobrokhodov (vndobrok@nps.edu)

8. Robotic Outposts to Support Persistent AUV Operations

Autonomous underwater vehicles (AUVs) have not yet reached their full potential for undersea warfare operations. Current AUVs (and unmanned systems more generally) require launch and recovery and logistics support from manned surface platforms (e.g., LCS). The logistics tail required to support unmanned operations in dangerous areas can quickly defeat the purpose of going unmanned in the first place. If unmanned vehicles could be deployed and sustained without a manned surface platform, the additional logistics associated with supporting and protecting the surface platforms could be eliminated. One concept for achieving increased persistence without burdening manned support vessels is an “undersea garage,” or robotic outpost. This research effort emphasized navigational issues associated with an undersea garage. Specifically, this involved the deployment and recovery of a temporary undersea garage that permitted intervention and feature relative navigation.

Figure 15. ACQUAS is used for crew monitoring and detailed site investigation during the deployment and construction of an underwater structure.

Precision control is required for AUV operations around the robotic outpost. Two classes of AUVs are considered: a torpedo-shaped AUV (longer-range, longer duration missions, but limited maneuverability, especially a low speeds) and a hovering-capable AUV (localized operations requiring high levels of precision, including detailed inspections, recoveries, and intervention). Adaptive control techniques were investigated and deployed on the hover-capable ACQUAS (Agile Close-Quarters Underwater Autonomous System). Two techniques were investigated for the heave channel: Model-Reference Adaptive Control (MRAC), and L1 Adaptive Control (L1AC). The experimental results are very encouraging, and demonstrated the ability of the approach to adapt to changing configurations (e.g., mid-mission buoyancy changes due to intervention tasks, and precise control even with poor hydrodynamic models). Continued research is required to extend the implementation to full-vehicle control.

Figure 16. Semi-autonomous collaboration decreased the burden on divers during exploration tasks. ACQUAS carried samples and documented scientific tag locations.

Precise relative navigation, as needed for docking and intervention, require accurate navigation relative to a fixed object. For these operations, relative localization is required (as opposed to geo-rectified localization). Furthermore, some user communities desire passive and/or directional and rapidly-attenuating active sensors for this purpose. Two techniques were investigated: using camera data to accurately track ego-motion relative to known features in the operating environment, and using imaging sonar over short ranges to perform relative navigation. For the former, the AprilTags augmented reality library was applied to dynamically position ACQUAS relative to a deployed mock-outpost dock and to autonomously fly into the dock. This was performed in autonomous mode in a harbor environment, and semi-autonomously in the open-ocean (during a field deployment in Key Largo, FL). High currents (>3kts) prevented the testing of autonomous docking in the ocean. For the latter, data-sets were gathered and are currently being processed to evaluate the applicability of Visual Odometry techniques to short-range imaging sonar data during autonomous mission execution close to the sea-floor, as well as precise relative navigation. These datasets include operations close to structures, divers, and natural terrain during the field deployment in Key Largo, FL. The emphasis on short-range sonar facilitates coverts operations, but also has the advantage of allowing for higher-frequency sensors (which provide higher resolution images and attenuates faster) as well as higher data-rates (short-range sonar pings take less time to acquire). Initial results are very promising.

Figure 17. ACQUAS shuttles tools and gear between work sites and the Aquarius habitat, delivering science samples to an awaiting Aquanaut.

The current implementation also allows for sensor-assisted tele-operation. This allows for non-expert operators to utilize the vehicle for detailed inspections and other complex tasks. This was demonstrated during the NASA NEEMO mission deployment in Key Largo, FL, where control of the system was provided inside a saturation diving facility (Aquarius) to an Astronaut. ACQUAS was used by the Astronaut to monitor crew members on dives, perform detailed inspections, carry tools, collaboratively document and gather samples, and provide navigational assistance to the dive team. The system has also been used to recover objects (including AUVs and oceanographic equipment) in semi-autonomous mode, provide great data sets to continue work on fully-autonomous recovery and intervention capabilities.

POC: Noel du Toit (nedutoit@nps.edu)

9. AUV Operations in Extreme Environments: Under-Ice Operations

Figure 18. (from left to right) Tad Masek, Dr. Douglas Horner, Dr. Noel Du Toit and Dr. Dale Andersen pictured with the NPS REMUS 100 and SeaBotix VLBV 300.

Changing climactic conditions impact national security considerations and priorities. In no place is this more apparent than in the Polar Regions. The reduction in the polar ice cap will dramatically change how these regions are utilized and protected. The Naval Postgraduate School (NPS) Center for Autonomous Vehicle Research (CAVR) is leading the way in the development of advanced control, sensing and navigation capabilities suited for deployment in extreme environments to support the monitoring of these regions with autonomous vehicles.

Figure 19. Camp setup at "icebox one."

In February 2015, NPS students, faculty and collaborating scientists gathered in Pavilion Lake, British Columbia to conduct under-ice research with autonomous underwater vehicles (AUVs) through the support of CRUSER and the Office of Naval Research (ONR). The goals of the research were four-fold:

1) develop navigational techniques without reliance on GPS;

2) develop deliberative and adaptive controllers that enable robust under-ice operations with changing vehicle configurations;

3) develop and test advanced real-time surveying and 3D mapping capabilities;

4) gain experience in under-ice operations in preparation for missions to Lake Untersee, Antarctica in October 2015 and ICEX16 in the Arctic Circle in March 2016.

Figure 20. Screen shot from video of deployment and recovery of the NPS REMUS AUV.

Pavilion Lake is approximately 250km northeast of Vancouver and provides an ideal initial location for under-ice research. Over the last fifteen years it has been the home for extensive NASA-funded research. The lake is home to a large population of freshwater microbialites that represents some of the earliest life forms on Earth. These are of particular interest to astro-biologists in the search for life in the solar system and beyond.

NPS Research Associate Professor and Co-Director of CAVR, Dr. Douglas Horner, sees the lake as an ideal initial testing location. "The lake's bathymetry is incredible. It varies from 60 to 4 meters in depth in less than 300 meters distance. It provides a unique opportunity for testing the AUV's ability to collect sensor data while avoiding potentially hazardous obstacles in the building of an accurate map." The lake's topology can be used by the AUV to its navigational advantage. This is known as terrain relative navigation (TRN) and can be used so that the AUV is not as reliant on GPS and can stay underwater longer. The eventual goal is to turn this capability 'upside down' and use sonar and complimentary sensors on the underside of the ice at the polar caps to reduce AUV positional uncertainty.

Figure 21. NPS THAUS AUV deployed at "icebox one."

NPS Research Assistant Professor, Dr. Noel Du Toit, is interested in the ability of AUVs to provide accurate surveys in highly challenging and dynamic 3D environments. "Operating under-ice creates challenges not normally considered by the AUV community: you are operating in a fully 3D environment – whereas the ocean floor is considered 2.5D – and you are always close to objects – whether the ice, other vehicles, or the bottom. Thus, precise vehicle control, particularly relative to your environment, becomes crucial. LT Nick Valladarez and I have been working on precise AUV control using adaptive control techniques that allow accurate control of the vehicle, even when the system configuration changes mid-mission. This has been applied to a tethered, hovering AUV, called THAUS. Furthermore, these microbialite structures are fascinating, adding small-scale features to the underlying lake topology that can further be used to our navigational advantage. Plus, we get to support some really interesting science."

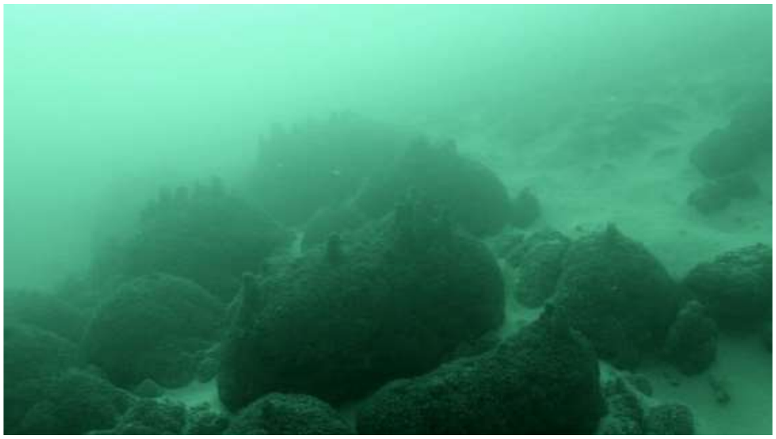


Figure 22. Examples of microbialites in Pavilion Lake imaged by the Tethered Hovering Autonomous Undersea System (THAUS).

Dr. Dale Andersen has been leading polar expeditions for 35 years. He is a leading expert on polar environmental conditions and operations. Furthermore, as an expert in polar diving, he sees the benefit – and detractions – associated with autonomous vehicles in this environment. “The AUVs are great. They permit unprecedented access and speed to the monitoring and surveying of undersea areas of interest. Also, they provide an additional layer of safety by providing situational awareness to diver support teams during scientific dives. That said, I still believe there is a critical role for humans during these scientific expeditions: the robots can help ups pick the best sites to do science, and even carry our tools; but, ultimately, machines cannot replace human intuition.”

This unique team has successfully demonstrated the first of a series of experiments that combines together science and engineering objectives to hopefully provide a glimpse of science and exploration of the future that is heavily reliant on autonomous vehicles to accomplish mission objectives.

POC: Noel du Toit (nedutoit@nps.edu)

10. Modeling Swarm Failsafe Behaviors with Monterey Phoenix

In FY15, Monterey Phoenix (MP) research for CRUSER broke new ground in developing a tool that produced informative analysis results for a UAV Swarm CONOPs model. MP is a new behavior modeling approach that separates behaviors and interactions within a model, to provide a new capability for exposing undesirable behaviors latent in a design. MP restructures the very process by which system behaviors are modeled to generate an exhaustive set of use case scenarios up to a specified scope limit, computing every combination of behaviors in and among interacting systems.

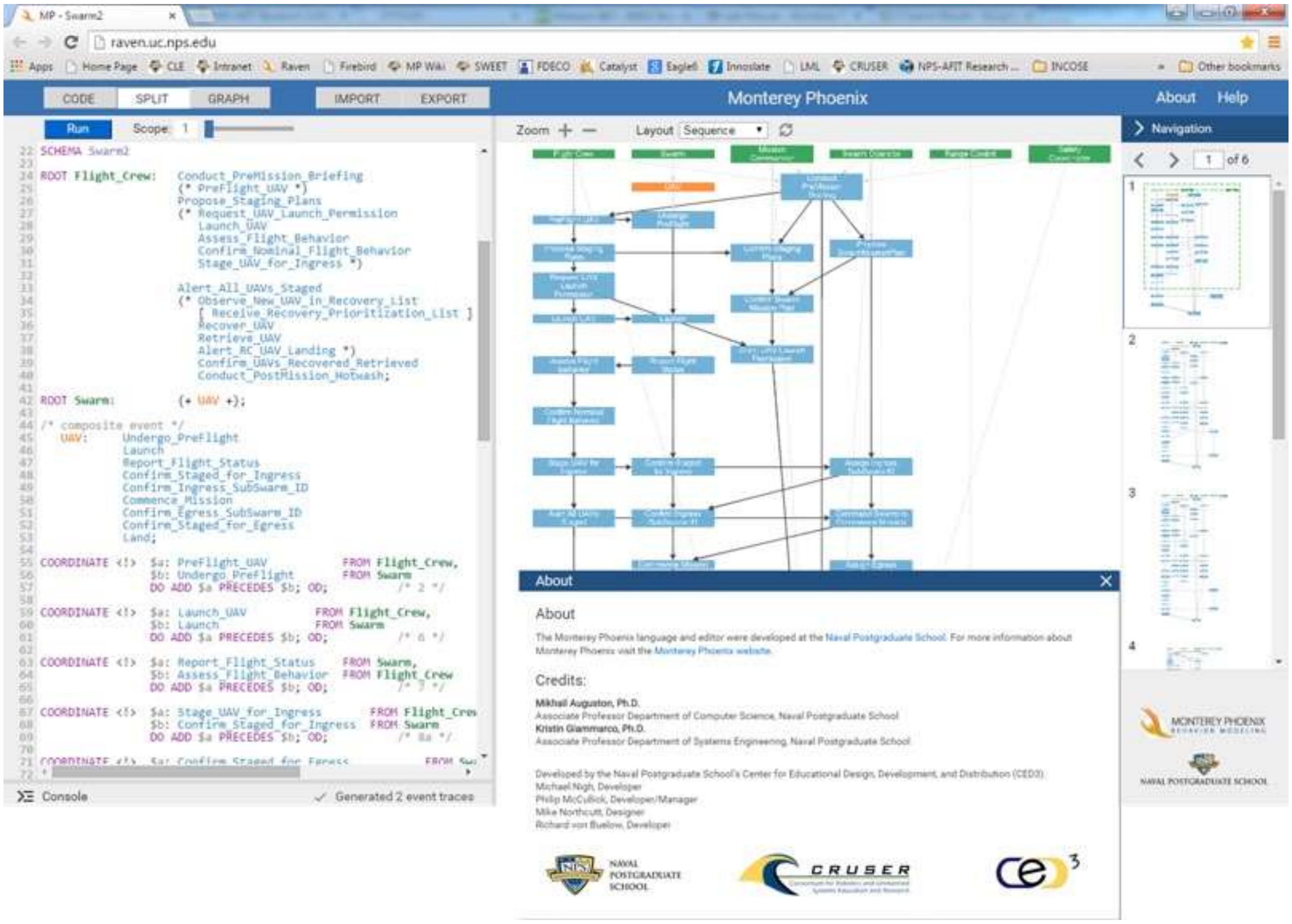


Figure 23. The Monterey Phoenix Analyzer, showing a subset of the UAV Swarm CONOPs model. Code on the left is visualized on the right upon selecting Run.

Spring of 2015 saw the debut of the Monterey Phoenix Analyzer, a functional and user friendly tool with a side by side code editor and visualizer (see Figure 23). Publicly available at http://firebird.nps.edu, the MP Analyzer provides the whole community of learners and educators with a powerful new behavior modeling capability that exceeded expectations for near term functionality, including but not limited to the following main features at the time of this writing: code editor with syntax highlighting; code execution by an efficient new MP event trace generator; force, swim lane and sequence diagram visualizations; graph navigation aids; event hiding and collapsing for creating tailored views; a model and graph import and export capability; a host of keyboard shortcuts that streamline the user experience; and a collection of preloaded example models. This tool operates through a web browser with no installation required. The MP Analyzer is an academic tool meant to inspire industry to integrate the MP approach into existing model based systems engineering methods and tools, so that existing user bases can start to take advantage of exhaustive scenario generation at a small scope. As a first step in this technology transition, a CRADA between NPS and the Rivera Group was established to enhance the Eagle6 MP prototype tool, publicly available at (http://eagle6modeling.riverainc.com/model.php). The MP Analyzer is now used in three courses at NPS, featuring example models of unmanned systems developed for CRUSER.

The MP Analyzer enabled rapid and repeatable analysis of a UAV Swarm Concept of Operations (CONOPS), which was modeled at the business process level of abstraction, and resulted the following insights and improvements:

- Absence of needed messages and message confirmations to the correct recipients (e.g., UAV launches without permission from Mission Control).
- Events modeled in sequence when they could occur concurrently (e.g., preflighting may occur while staging plans are being reviewed).
- Missing involvement from actors that ought to be involved in certain events (e.g., Range Control should be alerted when UAVs take off).
- Too much detail for a given level in the model (e.g., an abstract "Perform_Mission" event in the CONOPs can later be substituted with any UAV Swarm mission, rather than hard-coding in just one mission).
- Absence of constraints that ought to be imposed on the actor behaviors or on the timing thereof (e.g., UAVs landing before being commanded to do so).
- A lack of proper triggers to guide the timing and ordering of the execution of events (e.g., UAVs landing before the Recovery Prioritization List is delivered).

In the remainder of FY15, the Swarm UAV model is expected to produce possible failure modes and corresponding failsafe behavior specifications for events such as low power/fuel, loss of GPS, loss of power, payload failure, control surface failure, autopilot failure, and combinations thereof. The FY16 way forward is to extend these models to produce an entire library of UAV swarm use cases to enable UxS researchers to try before they fly, in a safe and comparatively inexpensive simulation environment designed to help live-testing engineers avoid many of those "why didn't we think of that?" moments in the field.

POC: Kristin Giammarco (kmgiamma@nps.edu)

11. Developing and Testing Quadrotor Unmanned Aerial Vehicles as Platforms for Atmospheric Measurements

The US Navy's ability to characterize atmospheric parameters that affect passive and active radio, optical and acoustic systems, and networking of these systems is woefully inadequate, especially since the Navy's upper-air radiosonde (weather balloon) measurement program was terminated in 2010. The computer models that are used to forecast these parameters are hampered by lack of inputs on key low level features such as evaporation ducts and large variations near coastlines. In order to address this issue, we have been testing the concept of using miniature quadrotor unmanned aerial vehicles (QUAVs) as platforms for meteorological sensors, in this case a radiosonde. The primary focus of this year's effort was to quantify the accuracy of this measurement system in order to evaluate its suitability as an operational and/or research measurement tool.

Figure 24. The InstantEye Unmanned Aerial System with radiosonde meteorological sensing system attached.

During FY15, Dr. Guest and MS student LT Christopher Machado performed a series of experiments at Camp Roberts CA that involved flying an InstantEye QUAV alongside a calibrated meteorological tower in order to determine the effect of various altitudes and meteorological situations on measurement accuracy. Several potential sources of error were identified; the most significant was the mixing of air due to the rotors which causes the sensors to sample air that originated at a different level from the actual vertical location of the QUAV. During stable atmospheric conditions, when the surface of the ground is colder than the adjacent air, natural turbulence is suppressed and large vertical temperature gradients often form just above the surface, particularly during light wind situations. In these cases, the rotor wash from the QUAV effectively mixed the surrounding air when it was closer than 1.3 m, smoothing out the temperature gradient and making it difficult to differentiate between levels. Above 2 m in stable conditions, temperature measurements were warmer than expected; suggesting air is originating from as high as 2 m above the QUAV location. During unstable atmospheric conditions, when the surface temperature is warmer than the air and natural turbulence is enhanced, the turbulence and mixing induced by the rotors appeared to be a negligible effect that is effectively "overwhelmed" by the natural turbulence and the accuracy was better than the radiosonde manufacturers claim of 0.5 C. In all conditions the rotors introduce a pressure error of 0.12 hPa which is equivalent to about 1 m elevation. When within a few centimeters above the surface, ground effects cause the pressure to increase as much as 0.60 hPa (5 m altitude error).

Figure 25. InstantEye/Radiosonde alongside calibrated meteorological tower.

Although the rotor wash introduced errors by mixing air and moving it to different elevations, it also has the positive effect of ventilating the radiosonde sensors, which minimizes radiational contamination (i.e. heating of the sensors by the sun). Without the ventilation, the sensed air temperature can be 5 C too high, but with the ventilation this was reduced to less than 0.2 C.

These experiments were performed in an extreme environment, in terms of vertical temperature gradients; therefore the quantified errors were larger than would occur in normal circumstances. Significant errors greater than the radiosonde manufacturer claims only occurred in the very lowest levels, within 2 m of the ground surface.

Because of the dry environment at Camp Roberts, the air humidity was low and no significant vertical gradients were measured by the tower; therefore we were not able to quantify the accuracy of the humidity measurements in regions with strong vertical gradients directly. However, many of the results regarding air mixing and movement from different levels due to rotor effects determined from temperature measurements can be extrapolated to humidity measurements.

To our knowledge, this is the first time a careful accuracy test has been performed on an outdoor QUAV atmospheric measurement system. These results will have significant implications for the meteorological measurement research community and also show that the accuracy is more than sufficient for Navy operational use. These positive results have spurred the researchers to continue working toward their ultimate goal of using this system to perform atmospheric measurements from research vessels and, potentially, operationally from Navy gray ships. We have been working with NAVAIR and NPS support to obtain an Interim Flight Clearance (IFC) for flight operations over international waters, including from ice floes in the Arctic Ocean. Unlike Camp Roberts, strong humidity gradients exist most times over the ocean and therefore we hope to be able to directly quantify the humidity accuracy in our future research. We have submitted a CRUSER proposal for FY16 which will continue to support our efforts to develop methods and quantify the accuracies of this sensing system in marine environments including from Arctic ice floes.

POC: Peter S. Guest (pguest@nps.edu)

12. Short Range Wireless Power Transfer (WPT) for UAV/UAS Battery Charging – Phase II

The Phase II (FY15) work is a continuation of Phase I (FY14) research tasks. The research investigated several approaches to wireless power transmission (WPT) for battery charging of unmanned vehicles. The research has looked at radiative and reactive WPT concepts for battery charging. New coil and mating concepts were explored for the application of an inductive WPT system to the REMUS vehicle. The concept was simulated in a commercial software package, and some hardware fabricated and measured in the Microwave Laboratory. The hardware developed included coils, compensation networks, and rectifying circuits. The software simulations and measured data were in good agreement. It was demonstrated that the addition of ferrite plates to the coils increased the efficiency and reduced the system's sensitivity to coil spacing and misalignment. At the conclusion of this year's project, a fully operational inductive charging network using commercial off-the-shelf (COTS) hardware will be built. The demonstration system will be limited in some of its capability because of safety regulations (radiation and power), and the limited capability of the COTS hardware.

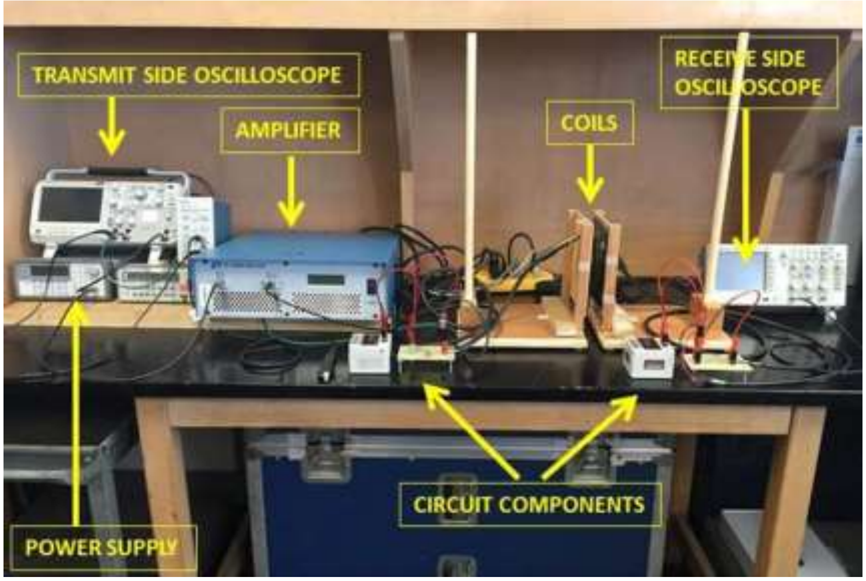


Figure 26. Wireless power transfer battery charging demonstration system.

Research was also conducted on a radiative short range charging system with adaptive antenna beamforming. Potentially this configuration could service multiple clients (UAVs) simultaneously. The base station and client antennas will operate in each other's near field region, so it is necessary to use phase corrections to focus the beam. Commercial software was used to determine the optimum near field excitation of the antennas. Because of the array element patterns, the most efficient approach is to use "subarray excitation" on the base station side so that multiple focus points can be set on the client array.

In support of the hardware demonstration a new signal generator was purchased (replacing one from the 1960s). Two thesis students have been involved in the research, one graduating in September 2015 and the other in June 2016.

POC: David Jenn (jenn@nps.edu)

13. Cooperative Underwater Sensing with Aqua-Quad

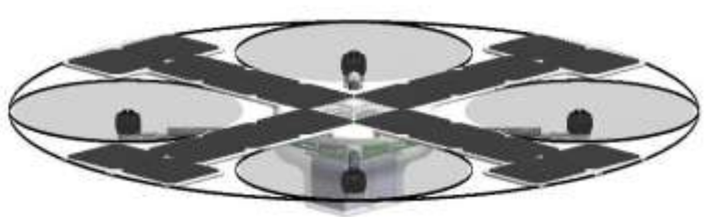


Figure 27. CAD model of the complete Aqua-Quad prototype. Outer diameter is roughly 1m, and total weight is roughly 3.5kg. The lower enclosure is shown semitransparent, with the pair of Lithium battery packs shown at the bottom.

A small fleet of Aqua-Quad SUAS are in development to support a variety of mission sets, including cooperative underwater sensing. The unique aircraft is a hybrid-mobility design, spending most of its time as a surface drifter, and part of its time in the air to relocate or to gain a height advantage for long range communications. Additionally, the design is energy-independent, meaning that it acquires all of the energy necessary to operate from the environment through the use of photovoltaic cells and high energy density Lithium batteries. A CAD drawing of the prototype aircraft is shown in the figure (see Figure 27).

Figure 28. The "dry" prototype airframe currently undergoing flight testing in the USL motion capture (MoCap) space.

During 2015 JIFX field experiments, a test vehicle was flown to characterize the motor and propeller performance, and evaluate sensing equipment to be used in the development of the Aqua-Quad prototype. Test flights are currently underway on a "dry" version of the prototype airframe (see Figure 28). An initial water-tight enclosure has been fabricated using additive manufacturing, with buoyancy and stability experiments underway. Modifications to the enclosure design are being done to lighten the design using alternate materials where possible.

A 20-cell solar array has been fabricated using research-grade SunPower E60 cells rated at 24% efficiency. Nominally the array should provide a peak power of about 70W. Work is underway to optimize the array support structure, taking into account, weight, aerodynamics, and structural considerations, and of course, survivability in a harsh ocean environment. The prototype enclosure and array are shown in the figure (see Figure 29). The superstructure is fabricated using additive manufacturing and Carbon fiber tubes. Efforts are underway to replace much of the printed material with CNC cut or molded composites to reduce weight and structural flexibility.

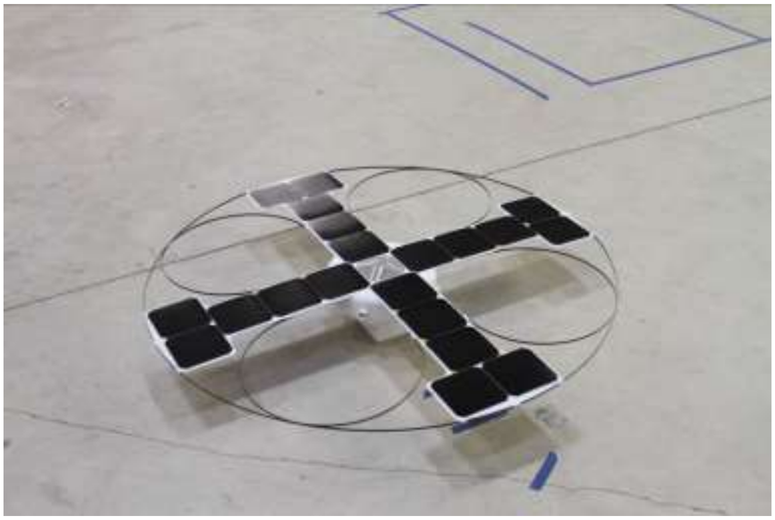


Figure 29. The prototype water-tight enclosure and array support structure. The Carbon fiber rings provide additional structural support for the array, and aid in preventing sensor-line tangling in the structure if the aircraft gets tumbled in rough seas.

An outstanding thesis looking at optimized mobility strategies and cooperative sensing for target localization using the Aqua-Quad was awarded to LT Dillard in December 2014. LT Dillard also presented his results in the Menneken Lecture series for USW. Currently, LT Cason is working on a thesis related to the integration and use of acoustic sensors hung under the Aqua-Quads on long, thin cables. The effort is directed at determining performance for detecting and tracking targets based on sensor depth. Additional efforts are being directed toward isolating surface noise from the sensor due to wave motion on the floating Aqua-Quad.

POC: Kevin Jones (kdjones@nps.edu)

14. Computational Solutions for Real-time Optimal Maneuvering of Unmanned Vehicles

The goal of this research project is to develop computational methodologies and algorithms for the real-time optimal maneuvering of unmanned vehicles. Different from autopilot controllers that focus on stability and robustness, the optimal control emphasizes the performance of the vehicle so that a cost function is minimized or maximized. Performance maneuvers often result in challenging trajectories that require specially designed feedback controllers. They have a wide spectrum of applications such as battlefield maneuvers of UAVs, minimum-time pointing of autonomous weapon systems, and maximizing the probability of success for UAV missions.

An experienced human pilot can remotely control a UAV to fly challenging trajectories. However, a real-time autonomous control of UAVs for performance maneuvers is difficult. The required computational load for the real-time feedback control is very high and it is difficult to guarantee a fast convergence of the algorithm. In this project, we explore a new approach based on causality free methods, a recent breakthrough in the computational mathematics of partial differential equations. The algorithm consists of two parts, the off-line computational algorithm to solve HJB equations for the design of a feedback control-law and the on-line algorithm for real-time feedback control using interpolations. In this design method, the compute-intensive work can be separated from the on-line computation. The required on-line computations are simply polynomial interpolations on a sparse grid, which is fast without computational convergence issues.

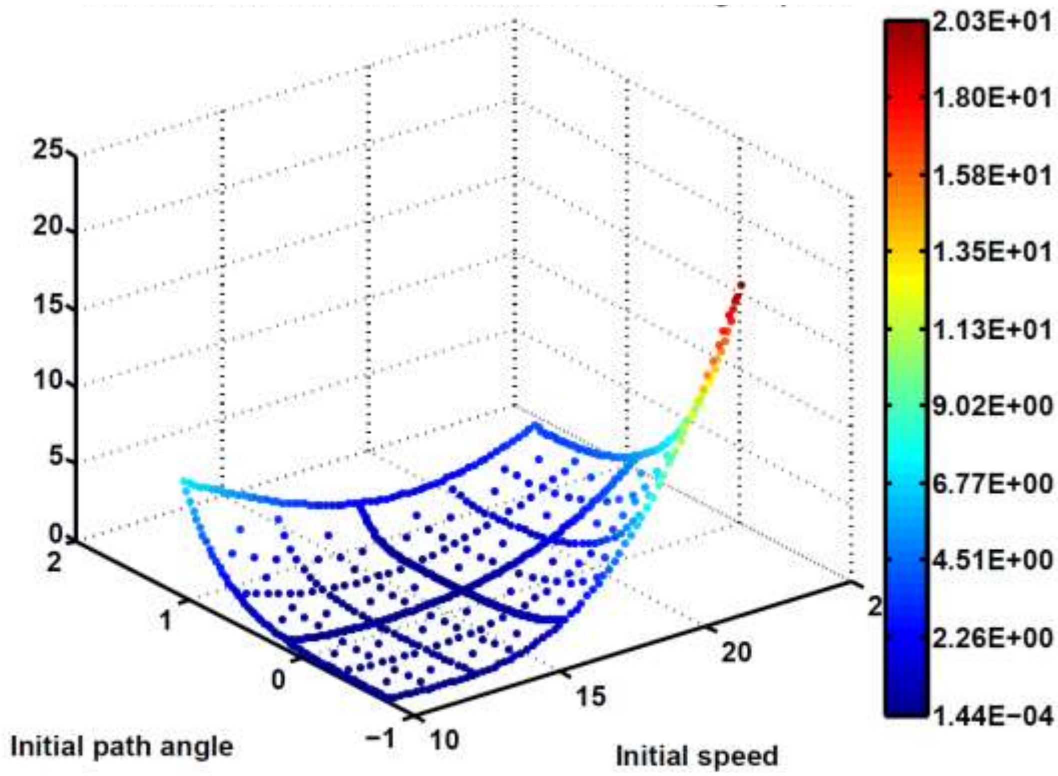


Figure 30. Cost function – effort needed to reach the target speed.

A control system model of a foam Unicorn wing is used as a numerical testbed. It is a seven dimensional nonlinear system with three control inputs, the throttle, the vertical lift, and the bank angle rate. A cost function is used which results in fast acceleration or deacceleration of the UAV to a given final speed. This type of trajectories requires a high angle of attach or steep diving. Some trajectories show that the UAV deaccelerate from the maximum speed to the minimum speed within about two seconds. Out-of-plane maneuvers that make fast deacceleration while turning almost 180 degrees are also generated.

More specifically, the design method consists of a sparse grid in the task space, a two-point boundary value problem (TPBVP) derived from the Pontryagin maximum principle, a Lobatto IIIa algorithm that numerically solves the TPBVP with a given error tolerance, and a set of polynomials that serves as the basis of interpolations in feedback. For the example of fast deacceleration, the sparse grid has about seven hundred points. It is significantly smaller than the size of the corresponding traditional dense grid, which consists of more than ten thousand points. For real-time feedback control, a model predictive control scheme is combined with polynomial interpolations in the simulation. A large number of trajectories randomly generated in a given region were numerically tested to validate the closed-loop controller for optimal performance. In a different example, the rigid body attitude control that has a six dimensional task space with more than ten thousand grid points, off-line computations were carried out using five hundred CPUs in the NPS Hamming supercomputer. This is to verify the perfect parallelism of the off-line computation required by the design method.

POC: Wei Kang (wkang@nps.edu)

15. Intelligent Sensing for Autonomous Coordinated Maneuvers

The objective of this research is to develop optimal motion planning algorithms for a team of heterogeneous autonomous vehicles performing a sensing mission. By incorporating each vehicle's unique sensor and maneuverability characteristics, these algorithms generate vehicle trajectories which leverage individual platforms' strengths to accomplish the team's overall sensing mission more efficiently. A relevant application motivating this research is wide-area mine countermeasures (MCM) operations. Under one future operational concept, an unmanned surface vessel (USV) works with a team of autonomous underwater vehicles (AUVs) to conduct all three phases of MCM: detection, reacquisition/identification (RAI), and neutralization. This research is investigating the use of a USV equipped with forward-looking sonar and acoustic communications (acomms) to accomplish phases one and two concurrently, e.g. the USV performs initial long-range detection and also provides targeting data to the AUVs performing RAI. This construct has the potential to reduce current operational timelines, which rely on separate, sequential MCM phases.

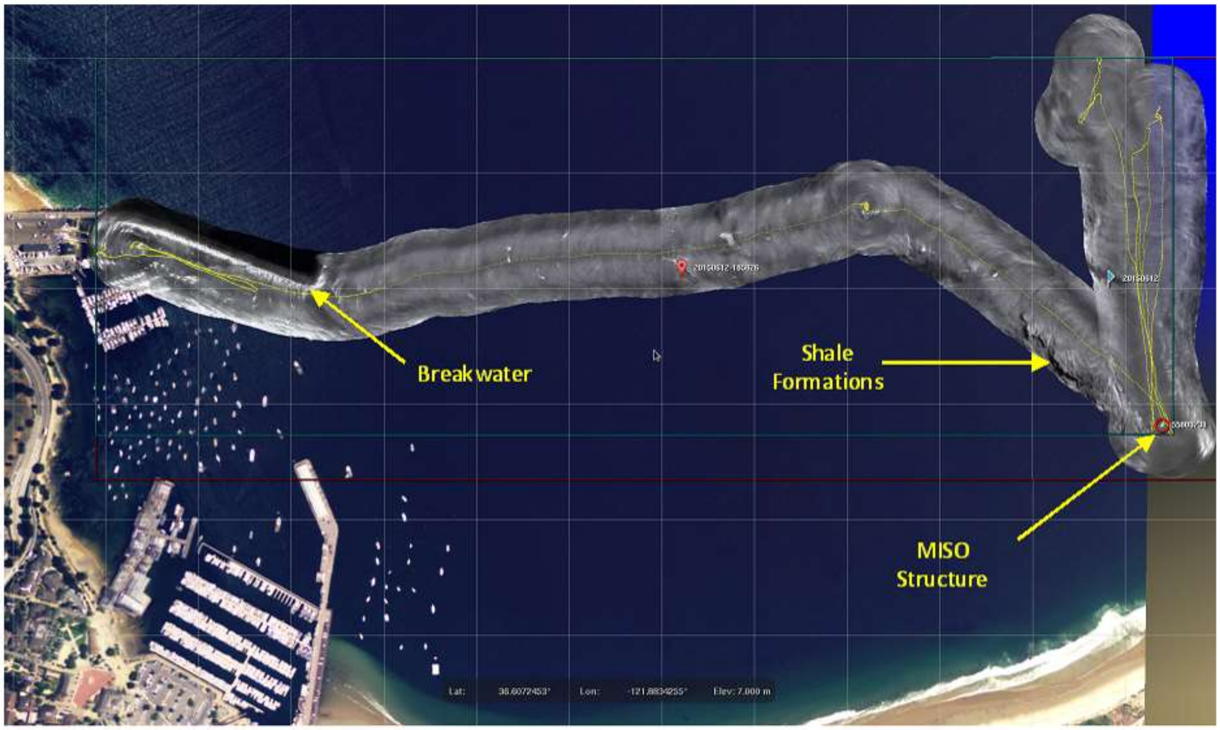


Figure 31. ATLAS bottom survey from Monterey harbor to NPS MISO location, 12 June 2015.

Experimentation with actual Naval platforms and sensors is a major thrust of this research. The Center for Autonomous Vehicle Research (CAVR) operates three REMUS 100 AUVs and two SeaFox USVs, one of which has been modified to deploy an Autonomous Topographic Large Area Survey (ATLAS) sonar system. The ATLAS is a sophisticated, long range, wide swath sonar used for bathymetric mapping and automated target detection. One goal of this project was to experimentally characterize this sensor's target detection capabilities from a surface platform for use in motion planning algorithms. Several experiments were conducted in Monterey Bay to assess ATLAS's ability to automatically detect objects as a function of platform motion, beam angle, water depth, target size, etc. For these experiments, SeaFox conducted surveys of several pre-deployed underwater objects, as well as the NPS Department of Oceanography's Monterey Inner Shelf Observatory (MISO). In addition, CAVR collected live ATLAS imagery of an underwater vehicle for use in future AUV tracking applications. USV platform motion and sonar beam angle for a given water depth were identified as the most significant factors on detection performance during these experiments. Initial probabilistic detection models for the ATLAS have been developed for optimal motion planning algorithms which minimize the probability of not detecting targets in a given operational area. Similar probabilistic detection models have been developed for the side scan sonar used by the REMUS 100 AUVs. Optimal motion plans for successful mine detection and identification by this vehicle team therefore require coordinated maneuvers which allow both vehicles to successfully observe each target with their own sensor. Simulation results for these motion plans are being submitted in a manuscript for the 2016 American Control Conference.

CAVR has also conducted preliminary acomms testing from a surface platform to a surrogate AUV in order to identify the most effective ranges and depths for USV-AUV communications. These experiments utilized commercially-available micromodems developed by Woods Hole Oceanographic Institution (WHOI), the same acoustic modems incorporated into the REMUS 100 AUVs. Under the above operational concept, a SeaFox USV would use its ATLAS to detect potential targets at long ranges, and then provide target cueing to a REMUS AUV via the WHOI micromodem. This capability will enable in-stride launch (e.g. by a "marsupial" USV/AUV team) or real-time redirection of RAI missions by a supervisory USV. CAVR plans to develop and experimentally validate this concept of operations further in the coming year.

POC: Sean Kragelund (spkragel@nps.edu)

16. Phase III Interim Flight Clearance

NPS/NAVAIR Research Collaboration Strategy: Advancing the application of systems engineering jointly with other disciplines to problems in military systems development and operation, while providing NPS students direct experience in research relevant to US Navy requirements by exploiting the technical and human resources of both organizations, and other participants.

The integrated research program undertaken by NPS and NAVAIR addressed the challenge of interim flight clearances (IFC) for NPS experimental UAS flight tests. The project originated with meetings between Dr. Millar and NAVAIR Systems Engineering seeking to identify research projects of common interest. The UAS IFC research topic was endorsed in 2013 by NAVAIR leadership as addressing current needs and the subsequent planning and execution actively involved senior NAVAIR engineers as stakeholders and participants.

Phase I of the UAS IFC program analyzed the IFC process and its external context & interfaces, comparing the IFC interactions with NAVAIR acquisition programs with those required for experimental UAS IFC. This project concentrated on NPS UAS, specifically looking at the ongoing NPS RASCAL flight tests and prospective Scan Eagle flight testing. It concluded that the IFC process for experimental UAS could be improved by specific measures fostering better communication and closer collaboration between NAVAIR and the Navy experimental UAS projects, most of which were accommodated in processing subsequent NPS IFC. However, it was agreed that the NAVAIR practice of intensive analysis of detailed technical data was unaffordable and too cumbersome for experimental UAS flight test programs. A more appropriate approach exploiting qualitative engineering judgment and historical reliability data from similar aircraft was needed.

Phase II investigated the feasibility and suitability of applying Bayesian belief networks (BBN) to form a hazard and risk assessment tool facilitating for IFC preparation for experimental UAS IFC, based on similar usage in aircraft crash investigation and early stage aerospace system development. Dr. James Luxhoj of Rutgers joined the team to bring his hazard and risk analysis expertise to bear. This work established the utility of a BBN based tool, but raised concerns on its suitability due to the complexity of the comprehensive (and rather incomprehensible) networks generated in this phase.

Phase III addressed the issue of suitability with active NAVAIR engineering involvement from AIR 4.0P Airworthiness and the Technical Area Experts (TAE) assigned to the IFC for the NRL Jackal rotary wing UAS. This yielded an improved BBN architecture and elicitation process that focused on the critical mishaps of primary concern to NAVAIR Airworthiness.

This collaborative research project was successful in demonstrating a hazard and risk analysis toolkit (HRAT) with wide application to both UAS and programs of record, including airworthiness and IFC preparation, range safety assessment, and system safety assessment. Transition to a standard work package is being pursued, potentially with an industry partner.

POC: Dr. Buettner for Dr. Millar (buettner@nps.edu)

17. C2 Models of Next Generation Unmanned Aircraft Systems

The objective of this research is to understand command and control (C2) implications of next generation unmanned aircraft systems (UAS), with particular emphasis on specifying advanced models for computational experimentation and the potential impact of Artificial Intelligence (AI) and teams of autonomous systems and people (TASP). Looking 5 - 10 years ahead of current Fleet operations and technologies, this research identifies critical C2 weaknesses and failures likely to arise through a combination of technologic advance and manned-unmanned mission integration, and it enables the means to devise, evaluate and chart alternate courses of action to address such C2 weaknesses and obviate the corresponding failures.

Figure 32. Integrating manned and unmanned missions.

Building upon previous research employing the state-of-the-art simulation system POWer to model C2 and the performance of autonomous systems (e.g., unmanned vehicles, robots, cyber applications), we seek to gain technologic insight into the next generation of UAS and to convert such insight into advanced models for computational experimentation. More specifically, we examine technologic UAS trajectories and design visions through qualitative research methods. Techniques include archival research, participant observation, and semi-structured interviews with central agencies (e.g., NAVAIR, DARPA), advanced organizations (e.g., cutting-edge UAS contractors) and educational institutions extending the state of the art (e.g. Stanford, Carnegie Mellon, Georgia Tech). The results of these investigations will enable the specification and execution of computational models for extended experimentation in the TASP domain.

Results to date have been impressive, particularly as we begin to cast considerable doubt on contemporary research and policy assuming that the next generation of unmanned aircraft will operate and behave increasingly like their manned counterparts. To the contrary, several current technology trends suggest that UAS may be diverging instead of converging, developing unique modes of operation and sets of behaviors, and challenging the integration of manned and unmanned systems. This has enormous C2 implications, which cause us to project when (not if) current C2 organizations and approaches will fail.

Additional results from this project will continue to build upon such increased insight into both the convergent and divergent capabilities of next generation UAS, as we work to specify their key structural, behavioral and performance characteristics via more advanced and refined POWer models. This will improve the fidelity of our computational experiments, enhance our ability to identify critical C2 issues, and facilitate the Fleet's capability to both anticipate and obviate such issues. By looking, with good fidelity, 5 - 10 years into the future, we strive to alert leaders to rough seas ahead and to help them navigate their way through.

POC: Dr. Mark Nissen (mnissen@nps.edu)

18. Large Displacement Unmanned Underwater Vehicle (LDUUV) Life Cycle Management

The LDUUV program needs to develop an approach to Life Cycle Management, which includes life cycle cost estimates (LCCE), particularly operating and support costs, as well as the identification and prioritization of appropriate missions (to include Intelligence Preparation of the Environment (IPOE), Anti-Submarine Warfare (ASW), Intelligence Surveillance Reconnaissance (ISR), and offensive operations) and mission payloads. To help address this need, we are conducting two studies focused on design considerations of LDUUV. Of particular interest are an examination of endurance, range, persistence, and payload hosting options. These two studies are being conducted by two Systems Engineering (SE) Master’s students as their theses, with one addressing life cycle costs and the other focusing on mission analysis.

The Life cycle cost thesis has the goals of identifying missions and payloads to create a number of mission configurations, and developing initial LCCE for each configuration and LDUUV baseline model. The mission analysis thesis goals are to use modeling and simulation to analyze one or more LDUUV missions, and to adjust values of variety of parameters to determine most significant, to include operational (range, speed, sensor types and capabilities) and environmental parameters (sea state, specifics of mission, etc.).

Previous work by the Systems Engineering Analysis (SEA) cohort 19, entitled "2024 Unmanned Undersea Warfare Concept" (completed in June 2013), is a foundational study for both student thesis projects. That cohort's development of an anti-access, area denial (A2AD) overall mission serves as the basic mission addressed by our students. More specifically, the scenario being addressed is an ISR mission, and it expands on the design and analysis of that SEA cohort. The results of both studies should contribute insight to final LDUUV design. Both students will complete their work in December 2015, and are planning an in progress review (IPR) presentation to CRUSER team members in November 2015.

POC: Gene Paulo (eppaulo@nps.edu)

19. Using Small Unmanned Aerial Systems as Electronic Warfare Platforms - Providing the Tactical Ground Commander the Electromagnetic Advantage

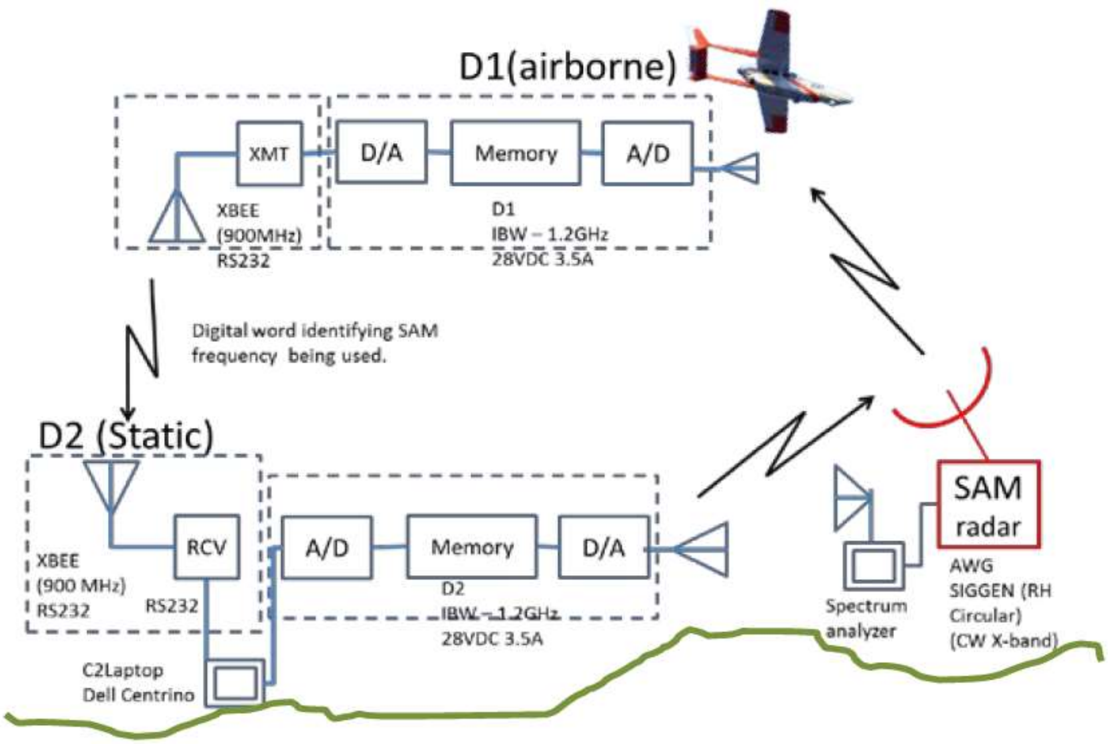


Figure 33. Network-enabled electronic warfare tip-n-tune architecture showing tuning of an airborne stand-off UAS jammer (D2) with an off-board stand-in sensor (D1) to eliminate the requirement for look-through.

The objective of this research was to continue and quantify the electronic warfare (EW) technique requirements for unmanned aerial systems (UAS) to counter CW low probability of intercept (LPI) surface-to-air missile (SAM) radar sites using digital RF memories (DRFMs). UAS network-enabled electronic attack (EA) configurations using stand-in sensors to detect and tune a stand-off jammer asset were bench-tested and flight-tested using a Cessna 337 Pelican as a UAS surrogate. The test configuration was a single segment of an overall swarm EA against an integrated air defense system. Two DRFMs (D1 and D2) were used as the airborne stand-in intercept and ground-based EA respectively. To model the LPI CW radar and operator, a spectrum analyzer (receiver) and an arbitrary waveform generator (AWG) were used. The operator's objective was to change the AWG transmit frequency when the spot jammer interference was detected. Timing information investigated included the *jammer response time* (sum of receiver latency, network latency and jammer latency) and the *radar switching time* (sum of operator decision time and radar switching time). The significance of this research was that an initial determination of network latency and its influence on the effectiveness of the EA could be determined. Small baseline, wideband direction finding (DF) antenna architectures for UAS were also investigated using photonics and neural networks. A DF resolution on the order of 1-degree was experimentally demonstrated; both bench testing and testing in the NPS anechoic chamber. The significance of this research is that the radar's angle-of-arrival can be directly determined over a large frequency range eliminating the need for frequency down-conversion.

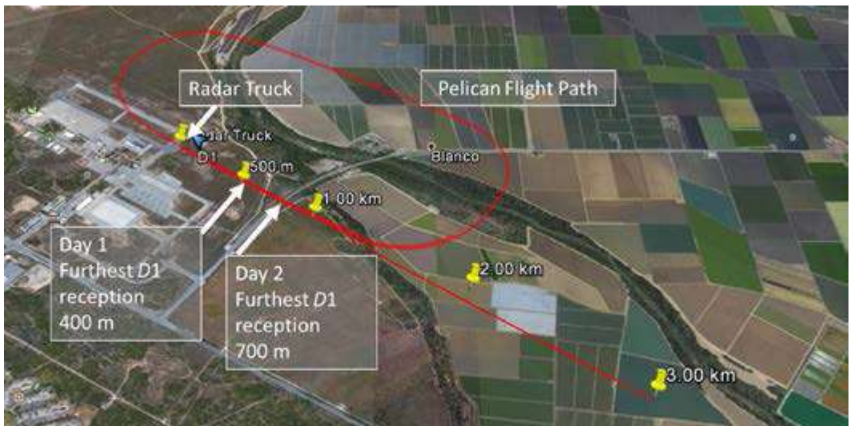


Figure 34. Overhead map of flight test area at the NPS Center for Interdisciplinary Remotely Piloted Aircraft Systems (CIRPAS), Marina, CA.

NPS student theses involved in this project include:

Humeur, R. (2015), "A New High-Resolution Direction Finding Architecture Using Photonics and Neural Network Signal Processing for Miniature Air Vehicle Applications," Naval Postgraduate School Master's Thesis, Sept, 2015.

Scudder, C. A. (2015), "Electronic Warfare Network Latency Within SUAS Swarms," Naval Postgraduate School Master's Thesis, Sept, 2015.

POC: Phillip E. Pace (pepace@nps.edu)

20. Stratified wakes induced by submerged propagating objects: detection using Unmanned Underwater Vehicles

During the current period of performance, our group made several major advances in the analysis of stratified wakes. The key accomplishments include the successful detection of the thermal signature of a wake using ship-board CTD and UUV (REMUS 100). The field experiments were conducted locally in the Monterey Bay (06/05/2015, 06/16/2015 and 08/28/2015). The stratified wake was created by towing a rigid cylindrical body behind the tow vessels (R/V Fulmar was used in both June experiments and R/V John Martin in the August experiment). The REMUS transects across the wake revealed a clearly identifiable thermal signature of the wake. The temperature pattern was elevated by 0.5-1 degree C relative to the control run and also exhibited much stronger spatial variability. The UUV-based observations are consistent with the shipboard (CTD) temperature measurements, which also reflect a general tendency for temperature to increase after the wake formation and its gravitational collapse. Importantly, both UUV-based and shipboard-based measurements revealed the surprising persistence of the wake signal. The UUV-based measurements were continuously recorded for an hour after the passage of the towed object and the wake was clearly identifiable throughout the entire observation period.

Overall, the key conclusion from our field program is that non-acoustic methods can lead to highly effective detection strategies. For logistical purposes, the Monterey Bay experiments provided the scaled-down representation of the phenomena of interest. Thus, our ability to detect the stratified wake of a relatively small-scale propagating submersible (~1m) using thermal UUV-based observations suggest that the proposed approach would be even more effective for real-world vessels and scenarios.

(a)

(b)

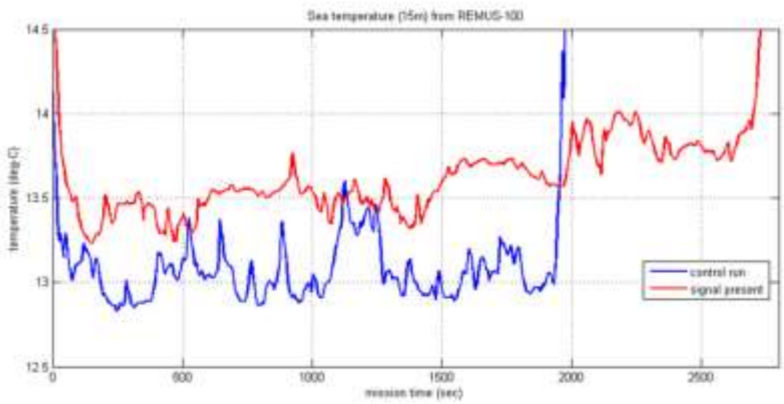


Figure 35. Wake detection experiments in Monterey Bay. (a) The deployment of the towed body from R/V Fulmar. (b) The temperature transects (REMUS-100) across the wake. The blue curve represents the control run performed without towing the submerged object. The thermal signal generated by towed body is shown in red. Note the substantial differences between the two measurements.

Our field work in the Monterey Bay was accompanied by a series of high-resolution numerical simulations and laboratory experiments (see Figure 35). These components were also highly suggestive in terms of supporting our field-based inferences and guiding future observational strategies. The subject of the MS thesis recently completed by LT Thomas Newman (December 2014) was the identification of regions of the World Ocean that are most susceptible to non-acoustic detection. His numerical experiments revealed strong geographic variability of the surface and subsurface wake signatures and emphasized the potential vulnerabilities of propagating submersibles to non-acoustic detection. The thesis by LT Hrenko (completion expected in September 2015) extends this modeling effort to examine the role of momentum imbalance (associated with submarine acceleration or deceleration) for the structure, dynamics and detectability of stratified wakes. LCDR (sel) T. Merriam (thesis expected in December 2015) is currently performing a series of laboratory experiments, analyzing the response of stratified wakes to the patterns of background stratification. LT Benbow (thesis expected in Sep. 2015) is exploring the possibilities of wake-detection using microstructure measurements of kinetic energy and thermal variance dissipation.

During the period of performance of this project, five Navy students (Newman, Hrenko, Merriam, Moody and Benbow) and one NRC post-doc (Duran) have been involved in the research activities supported by CRUSER FY15 funding. The project has already resulted in one MS thesis (LT Newman, recipient of the outstanding thesis award).

POC: Dr. Timour Radko (tradko@nps.edu)

21. Autonomous Aerial Vehicles with Robotic Manipulation Capability

In this project, we investigate the dynamics, guidance, and control of autonomous air vehicles with robotic manipulation capability for the physical interaction with other objects. The development for the dynamics, guidance, and control of autonomous aerial vehicles have been progressed in FY15. Similar work for manipulators will be also separately proceeded. Then, those are combined together for advanced missions. Toward this goal, modeling and simulation of a hexacopter with a manipulator have been implemented. Development of algorithms for guidance and control for the hexacopter is in progress. Advance control methods such as robust adaptive control and model predictive control (MPC) will be developed for advanced mission using robotic manipulation capability.

Figure 36. Artist rendering of the "Manicopter", a multicopter based robotic manipulator

1) Simulations for dynamics, guidance, and control of the hexacopter with a two link manipulator arm

    - Development of a dynamic model by Newtonian formalism and Lagrangian formalism

    - Development of a controller for the rotors of the hexacopter and the joints of the manipulator

2) Development a novel method on Identification of parameters for the hexacopter

- Identification of moments of inertia using a compound pendulum and a optical position tracking system, VICON. This method is computationally simpler than the method of direct computation of geometry and is less risky than identification by analyzing from flight data.
- Identification of the engine thrust using the compound pendulum and VICON system
- Experiments on a floating test bed using a spacecraft robot for identifying the engine torque
- Linear and nonlinear models are developed based on the identified parameters
- Simulations for hovering using the derived linear and nonlinear models are implemented to validate the identification

3) Development of a controller for translational motion of the hexacopter (in progress)

- Two layer-controller is developed for translational motion and attitude stabilization of the hexacopter.
- PID controller for translational motion
- Advanced control methods such as adaptive and/or optimal control will be applied

4) Future work

- Identification and modeling of a manipulator arm
- Development of guidance and control algorithms for the manipulator
- Development of advanced control algorithms for the combination of the hexacopter and the manipulator
- Development of advanced missions for various applications such as perching, landing, and rendezvous/docking

Detailing this work, the paper 'Identification of a hexacopter system using an optical position tracking system' was submitted 31 August 2015 for 2015 International Workshop on Research, Education, and Development on Unmanned Aerial Systems (RED-UAS 2015).

POC: Marcello Romano (mromano@nps.edu)

22. Combined Unmanned Underwater Vehicle Efforts in a Large-Scale Mine Environment

Mines are the single most effective and cost efficient weapons known to naval warfare. They are vicious tools that can block all sea trade and prevent security and supplies from entering a particular region. Minefields can take weeks, months, or even years to clear, with no real certainty of completion. To underestimate the capability of today's mines can prove fatal.

The current surface mine countermeasures (MCM) fleet is aging, yet there are no viable systems to replace it. The U.S. Navy requires an improved minehunting platform and unmanned underwater vehicles (UUVs) can meet that need. The U.S. needs support from the international community to provide MCM Commanders with enough UUVs and operators to make these missions successful. When countries form new partnerships with the U.S. it remains difficult to assess their abilities to execute MCM. This unfamiliarity makes tasking their UUVs challenging, because their skill level is unknown.

This study show evidence that it is possible to use an efficient planning design to incorporate all international UUV assets, attain desired clearance levels, and finish in a reasonable timeframe. A discrete-event simulation is used to model the execution of an MCM scenario.

This study assesses the key decision factors in mine clearance operations using UUVs of differing capabilities. It uses a discrete-event simulation to model the performance of UUVs in a large-scale MCM operation. A simulation model constructs the Q-route and sets the simulated mines. UUVs then drive search tracks inside the Q-route until the coverage is complete. Following the search, a post-mission analysis is conducted to detect and classify all mines as mine-like contacts (MILCOs) and all non- mine mine-like objects (NOMBOs). Next, all bottom contacts are reacquired and identified using a star pattern UUV search. Once all mines are identified, the explosive ordinance disposal (EOD) dive platoons neutralize them. Data are generated using a state-of- the-art design of experiments and analyzed to find the best tasking plan for the scenario. This study finds UUV altitude, track spacing, number of passes, and search speed to be decision factors that influence minehunting results, while track spacing, number of passes, search speed, and resupply are influential factors that effect mission completion times. The results show that with proper tasking, UUVs with lesser ability levels can be used appropriately and still produce acceptable levels of mine clearance, usually more quickly than a smaller cadre of highly capable vehicles. Further results shows that the coalition force outperforms in both detection effort and overall mission completion times. Consequently, this study provides evidence that a coalition UUV force is more than qualified, even with a mix of experience levels and capabilities.

THESIS ADVISED

Thompson, Andrew R., Lieutenant, U.S. Navy. "Evaluating the combined UUV efforts in a large-scale mine warfare environment" M.S. in Operations Research, March 2015. Advisor: Susan M. Sanchez, Second Reader: Jeffrey F. Hyink

POC: Professor Susan M. Sanchez (ssanchez@nps.edu)

23. Investigating the Navy's Logistics Role in Department of Defense Humanitarian Assistance Activities

The Department of Defense (DoD) is committed to foreign humanitarian assistance (FHA). Unfortunately, the U.S. Navy does not currently have a tool with which to conduct robust, quantitative analysis that will assist with planning international HA/DR. While post-disaster data are gathered and studies are conducted, it does not appear that any relevant quantitative modeling takes place. As resources become limited, it is necessary to develop a quantitative method to assess and streamline the disaster relief processes. The resulting analysis can be used to better evaluate risks or better consider alternatives when determining how to effectively use available resources while still gaining desired results.

This study focuses on the initial phases of response, where the impact of DoD's response is most profound and apparent. First, we develop a two-stage stochastic optimization model (the Asset Allocation Model, or AAM) using existing US Navy assets and developmental assets as data. Similar stochastic optimization methods have been used in past humanitarian assistance modeling efforts. These developmental assets include the ARES unmanned lift asset under concept at DARPA, a vertical takeoff and landing craft capable of delivering a payload of 5000 lbs. Second, we use several large-scale designed experiments to observe and assess uncertainty some parameters that are fixed at pre-specified values within the optimization model. For example, we vary the probabilities associated with different severities of disasters in order to assess the robustness (or fragility) of the logistics plans to the accuracy of these model inputs.

Our findings highlight the importance of ensuring adequate planning and preparation among all stakeholders. If measures put in place prior to a disaster striking can reduce the expected demand for humanitarian assistance, or help ensure quick response following the disaster, that can reduce the likelihood that demands will overwhelm responses. We also find that the AAM often has multiple solutions, and the "optimal" solutions reported by the stochastic optimization solver may not always be the best (or even particularly good) solution in terms of its cost. Further work is needed in this area.

The implications of UAV use in logistics has not fully reached its potential, but from this study we can get a glimpse of what the FHA logistics network might look like and determine what and where we will see benefits or shortcomings, we can conduct trade-off analysis. Using UAVs to deliver commodities lessens the burden placed on manned transportation means and allows for a divide-and-conquer approach to addressing the demand. The use of UAVs as logistic assets has the potential to add much benefit to FHA when saving lives and money.

THESIS ADVISED

Gardner, Maxine, Lieutenant Commander, U.S. Navy (2015) "Investigating the Naval Logistics Role in Humanitarian Logistics Activities" M.S. in Operations Research, March 2015. Advisors: Susan Sanchez and Emily Craparo, Second Reader: Ray Buettner

PRESENTATIONS

Sanchez, S. M., Gardner, M., and Craparo, E. (2015). "Simulation Experiments Involving Stochastic Optimization Models for Disaster Relief" INFORMS Annual Meeting, November 1-4, 2015, Invited Presentation, INFORMS Simulation Society sponsored session

POC: Professor Susan M. Sanchez (ssanchez@nps.edu)

24. Real-time undersea networking using acoustic communications for improved AUV positioning and collaboration

The objective of this work was to successfully develop methods for the enhancement of the navigational and positioning accuracy of autonomous underwater vehicles through a combination of autonomous surface vehicles and bottom deployed underwater acoustic seafloor positioning systems using acoustic communications protocols. By comparing the performance of each approach separately and in combination, a more thorough understanding of the versatility of such systems can be obtained.

The NPS Physics Department's Undersea Sensing System Laboratory (USS Lab) manages a small fleet of UUVs (6 Littoral Gliders originally developed by Alaska Native Technologies) capable of 15+ days of continuous operation. In addition, the USS Lab manages 2 USVs (Wave Glider SV2 systems developed by Liquid Robotics) capable of long-term continuous operation. Previous work undertaken by the NPS Seaweb program utilized a Wave Glider SV2 system with an integrated underwater acoustic modem for communication with acoustic nodes moored to the seafloor.

In this effort, new acoustic modems have been acquired and integrated onto the UUV Littoral Glider platforms, allowing them to communicate while submerged with the USV Wave Glider. The modems were interfaced with new on-board science computers, which have the ability to interface with other sensors and the glider's command-and-control system. Similarly, acoustic modems were integrated onto two USV Wave Gilders, and were capable of interfacing with the GPS data on-board. The modems have the capability to establish a two-way link, including a recording of transmit time delays and probe signal impulse response, thereby providing time-of-flight (range) to each system and direct characterization of the multipath propagation structure. By transferring the Wave Glider's GPS data, the Littoral Glider can improve its own position estimation while submerged.

Significant progress was made on this project in FY15. Two Teledyne-Benthos (TB) acoustic modems and new science computers were integrated into packages for deployments on the Littoral Glider (LG) UUVs. In addition, two Wave Glider (WG) USVs were upgraded with towfish that incorporated TB acoustic modems. The USVs were also upgraded with an additional Iridium communications link for direct connection to the acomms module in the towfish. This helped avoid communications cross-talk with the WG's command-and-control computer comms. A deck-box system capable of deploying a TB acoustic modem was also obtained and utilized during FY15 sea trials. Each of these systems had software upgrades incorporated that provided additional flexibility for research purposes, including automated ranging sequences and recording of probe pulses for propagation studies.

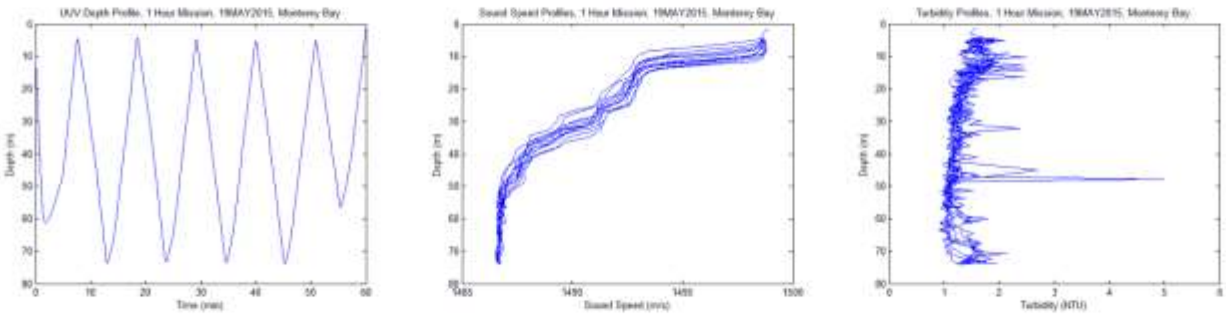


Figure 37. UUV diving depth profile (left), measured sound speed profiles (middle), and turbidity profiles (right) measured during one-hour mission on 19 May 2015.

The development of a group of reliable, autonomous, integrated platforms capable of persistent, submerged monitoring while maintaining accurate position information can be used in a variety of applications in the Navy. Such uses include ad hoc ranges for naval exercises, clandestine surveillance in operational areas, and environmental and marine mammal monitoring. In addition, the use of underwater acoustic vehicles permits monitoring large ocean regions avoiding the need of military ship navigation, providing cost savings and reduced risk of crew injuries. The results from studies with these platforms could impact future DNS architectures. SPAWAR Systems Center, San Diego has an on-going project, Deep Seaweb, which utilizes nearly identical Wave Glider USV systems as communications gateway buoys. NPS is collaborating with engineers at SSC-SD in order to obtain lessons learned, and capitalize on system improvements they have made over the course of their project.

Kevin B. Smith, Professor of Physics, is the Principal Investigator. Other members of this project team include Roberto Cristi, Professor of Electrical and Computer Engineering; LT Renato Peres Vio (Brazilian Navy), PhD Candidate, Engineering Acoustics; and Dr Eduardo Vale (Brazilian Navy), Postdoctoral Research Associate.

POC: Kevin B. Smith (kbsmith@nps.edu)

25. Using Autonomous Wave Gliders to Quantify Near-Surface Turbulence and EM Ducting Conditions

In the past two years, we have been engaged in air-sea measurements from the Liquid Robotic Wave Glider or the Sensor Housing Autonomous Remote Craft (SHARC) to the Navy. The SHARC is a capable, suitable, and advantageous moving platform for collecting near surface atmosphere and upper ocean measurements. This platform offers numerous new and exciting capabilities, including its high endurance and ability to withstand harsh conditions. Additionally, operators can steer the SHARC to areas of interest and have it remain on station. The SHARC, with its default METOC sensors, has been used by different Navy installations for environmental characterization. The measurement accuracy from these sensors, however, was not systematically evaluated in the past. In FY14, we developed a customized sensor package for the SHARC and tested the sensor performance multiple times at sea and in the lab. In addition, we used independent datasets from NDBC buoys or the NPS buoy and SHARC-based measurements to evaluate the performance of the default METOC sensor on the NPS SHARC as well as on the LRI Wave Gliders and on the SHARC operated by NAVO. The analyses of the data quality from the default METOC sensors and the NPS developed sensor package continued in FY15. We have demonstrated that the NPS sensor package developed under CRUSER is capable of producing quality environmental datasets comparable to platforms of known sensor quality. This sensor package also provides the humidity measurements not available from the LRI default METOC sensor package. We further conclude that the LRI default METOC sensor produces reasonable wind measurements, but poor temperature and pressure measurements. We further identified that the poor temperature measurements has to do with the effect of solar radiation, especially during low wind conditions when natural ventilation is minimum.

Figure 38. At-sea testing of NPS SHARC, *Mako*, with the turbulence sampling sensor package. *Mako* was deployed in the Monterey Bay on 30 July 2015.

As part of the FY15 effort, we further developed the surface flux sampling capability for the SHARC (see Figure 38). This sensor package includes the high-rate sampling of turbulence and temperature perturbations as well as a set of Inertial Motion Unit (IMU) to characterize the platform motion. The sensor package went through lab testing and one at-sea testing and shown reasonable results. A MATLAB-based algorithm has been developed to remove the platform motion for turbulence retrieval. Although more at-sea testings would be beneficial to characterize the sensor performance in different weather and oceanic conditions, the current testing has shown initial success of turbulent flux measurements from the SHARC. Unlike ship-based flux measurements, the SHARC based measurements introduces minimum flow distortion and provide concurrent measurements of oceanic surface waves, and hence providing the possibility of quantifying the air-sea-wave interaction at the air-sea interface. The addition of the flux measurement capability will greatly enhance the SHARC's potential contribution to METOC forecast and EM propagation prediction.

Our analysis also extends to the use of SHARC based measurements for Electromagnetic Wave (EM) propagation study. The SHARC measurements were used as input to an evaporative duct model and derive evaporative duct height and strength along the path of the SHARC.

One thesis work on the SHARC environmental measurements we completed in December 2014. A second thesis work is ongoing.

POC: Qing Wang (qwang@nps.edu)

26. Rapid FDC Resupply Using a Projectile-Launched Guided Parafoil

Dismounted forward disposed combatants (FDC) often carry up to twice the standard combat load of ammunition on mission. This is done due to the likelihood of numerous enemy contacts requiring significant amounts of ammunition. During extended missions they receive resupply between engagements from vehicle or aircraft. This is a time consuming event that requires the unit to pull security and potentially expose their location to the enemy. Air-dropping ammunition and/or other consumable supplies in a manner less obvious than rotary wing or ground vehicles presents an attractive alternative.

As a result of an over-a-decade effort within the Joint Precision Airdrop System (JPADS) program a series of different-weight precision aerial payload delivery systems (PADS) were developed. These PADS assured an order of magnitude better accuracy as opposed to standard non-controllable parachutes. However, the cost of JPADS PADS did not meet an objective value of being less than 6$ per pound delivered. As a consequence, these ram-air-parafoil-based systems only accounted for less than 0.5% of the total payload delivered during the recent field operation. Therefore, nowadays the major issue is the need to drastically reduce the cost of PADS. Even at the expense of their performance. Alternatively, if the cost cannot be reduced PADS performance should be improved by another order of magnitude.

Within this CRUSER research project the team of half-a-dozen NPS students explored the ways to address the aforementioned issue. Originally, we planned to redesign the Snowflake system developed at NPS earlier (see Figure 39) to allow holding logistic supplies within the projectile that could be launched and survived a harsh launch conditions. It was envisioned that compared to the aircraft-deployed system a precise projectile delivery is simpler, faster and more reliable. Although some work on a mortar or spinning artillery projectile launch has been conducted, our partner the Armament Research, Development and Engineering Center at Picatinny Arsenal opted to postpone further development of this system.

Figure 39. Snowflake aerial delivery package under the wing of UAV.

This caused a shift towards exploring different canopies and guidance/control unit architectures that could potentially be used within the aforementioned system. Several different-shape-factor systems were developed and equipped with commercial-of-the-shelf Pixhawk autopilot and customized X-Monkey autopilot. Four different type/size canopies were used: 2:1 aspect ratio 10 sq.ft and 25 sq.ft ram-air canopies, 10 sq.ft high-performance elliptical canopy, 68”-diameter 70 lbs rated quarter-spherical parachute, and 10 sq.ft 3:1 aspect ratio cross-type canopy (see Figure 40).

Figure 40. Testing various canopies of different type/size.

During seven week-long trips to Camp Roberts students from three GSEAS curricula conducted over fifty drops employing different-weight systems from two aerial platforms developed and operated by Arcturus UAV: catapult-launched / belly-landing T-20 and vertical takeoff /landing JUMP-20 (see Figure 41), both capable of carrying up to 100-lbs payload.

Figure 41. Catapult-launched and vertical-takeoff deployment platforms.

It was found that it is a cross-type single skin-canopy that offers a good alternative to ram-air parafoils in terms of the overall system cost. It was shown that in can achieve a limited control authority which may be enough to fight wind uncertainties during a controlled descent. System identification was conducted and a simple controller developed to prove this new concept. It is anticipated that this project will be continued in collaboration with the University of Missouri – Kansas City with support from the Natick Soldier Center and Draper Laboratory.

POC: Oleg Yakimenko (oayakime@nps.edu)

B. EDUCATION

The primary mission of NPS is to provide relevant and unique advanced education and research programs to increase the combat effectiveness of commissioned officers of the Naval Service to enhance the security of the United States. CRUSER education programs consist primarily of science, technology, engineering, and math (STEM) outreach events; support for NPS student thesis work; and a variety of education initiatives. These initiatives include sponsored symposia, catalog degree programs, short courses, and certificate programs. CRUSER's education work also involves surveying and aligning curricula for interdisciplinary unmanned systems education.

1. Education Track Funded Projects

As detailed in the last section, funded projects were split into two tracks – research and education. Research project summaries were included in the first section of this chapter. Education projects (see Table 2) are included below.

Table 2. CRUSER funded Education Track projects, FY15 (alphabetical by principal investigator last name)

PROJECT TITLE	PRINCIPAL INVESTIGATOR
[EDUCATION] RoboDojo	Chung/Tsolis
[EDUCATION] Agent Library of Unmanned Vehicles	Giachetti
[EDUCATION] Unmanned Systems Grasping: A Laboratory Based around Arm	Harkins

Grasping	
[EDUCATION] Applications of a mobile acoustic source for Tactical Oceanography	Joseph
[EDUCATION] Towards Autonomous ISR missions by a team of cooperating Gliders	Kaminer
[EDUCATION] CRUSER Data Farming Workshops	Sanchez
[EDUCATION] Robotic system software engineering classroom case study	Shebalin
[EDUCATION] Future Challenges for Just War Theory: International Conference	Strawser
[EDUCATION] Development of instructional tutorials, online wiki, and videos in support of Robotics and Rapid Prototyping	Whitcomb/Tsolis
[EDUCATION] Development of Control System Course Content for Interdisciplinary Applications in Robotics	Yakimenko

a. RoboDojo

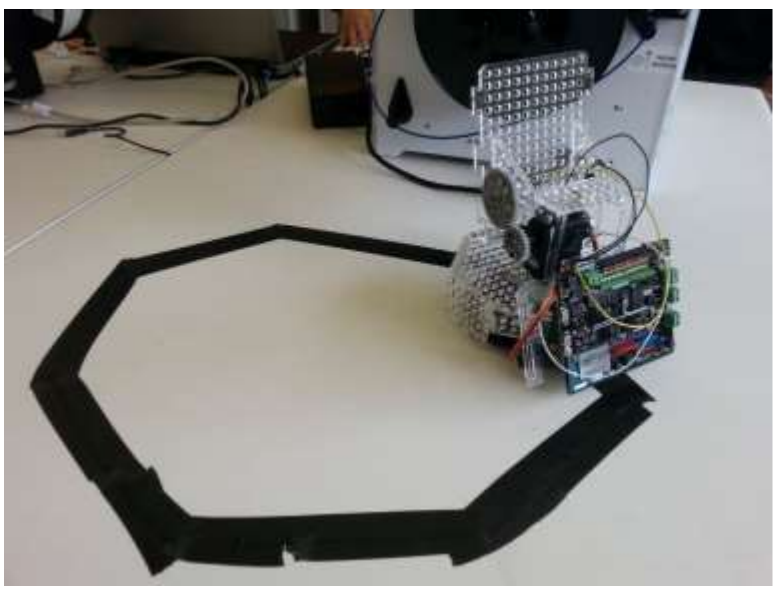


Figure 42. NPS intern robotics project, August 2015.

The RoboDojo is an open-community venue where "tinkerers" of all abilities –from novice hobbyist to expert researcher – can converge and have access to a rich array of tools, space, and hands-on training to conceive, design, fabricate, implement, and observe the creation and integration of robotics technologies. Our vision is to empower the robotics generation through an open community and venue for robotics exploration, innovation, and realization. Our mission is to offer a communal and open environment for the extended NPS family to enhance its exposure to robotics across all backgrounds and disciplines through hands-on experiences and informal learning in robotics.

Figure 43. RoboDojo ribbon cutting, 9 July 2015

The RoboDojo officially opened its doors this summer, and students and faculty from all departments on campus have visited our facility and attended our workshops. Since our July opening, we have hosted four visiting classes and have held seven workshops, and three Enrichment Week workshops are scheduled for the end of the quarter in September. Our July and August workshops focused on 3D Modeling, 3D Printing, Laser Cutting and Engraving, Arduino Programming, and "Are You Smarter than a Fifth Grader" sessions where students and their children learned about basic robotics and electronics together. We have seen a steady increase in the number of people benefiting from our lab and its resources.

Figure 44. CAD and 3D printing workshop, July 2015

Before the lab opened in July 2015, we spent extensive hours researching the kinds of equipment we should buy and the array of workshops we should offer. We visited labs on campus to speak with faculty, students, and staff, and we visited both NASA Ames SpaceShop and the San Jose TechShop. The SpaceShop has proven to be especially helpful with equipment recommendations and lab administration guidance. We initially invited TechShop down to Monterey to teach Arduino Programming here are NPS, but we have since realized that we have excellent expertise on campus to teach these types of workshops. Indeed, one Physics professor will be teaching a series of Arduino classes in the fall, and two military faculty members and one community member will join forces to teach a series of Raspberry Pi sessions. A Space Systems PhD student has volunteered to teach 3D Modeling with Solidworks, and another member has volunteered to teach a basic GitHub session. All of these focused workshops require a small investment of time but have the ability to have a high impact on students who may not have access to the equipment and the types of expertise that we offer in the lab. Another benefit of these open campus workshops is that they bring together students from multiple disciplines and backgrounds, and there is ample opportunity for cross-pollination and collaboration.

Figure 45. NPS Defense Analysis students excited about robotics opportunities.

The base budget provided by CRUSER has functioned as a force multiplier. Now that we have hosted enough events to gain visibility and to foster a base of savvy users, we have grown our abilities to reach out to the NPS community and to increase community knowledge regarding robotics and electronics. Our goal for the coming fiscal year is to seek out people who might be able to teach additional short workshops on Python Programming, Basic Networking, and the Robot Operating System (ROS), but we would welcome other suggestions or offerings that organically grow out of community interest. The Information Dominance Center of Excellence has offered funding to further outfit the lab with hardware that can support workshop offerings and robotics research, and we are seeking to further broaden our network in order to ensure that we are serving the campus and are being a true community resource.

Figure 46. "Tinkerers" of all ages, 2015

Please come by to visit us! Open Lab hours are Tuesday 0900-1300, Wednesday 0900-1300 and 1400-1700. Visit the website at https://my.nps.edu/web/robodojo/welcome. Please note that you will need to click the "Log In" button on the bottom of the page in order to see our calendar and other website items.

POC: Kristen Tsolis and Dr. Timothy Chung (robodojo@nps.edu)

b. Agent Library of Unmanned Vehicles

The research project was to build a library of agents of unmanned vehicles that students can use to support system-of-systems (SoS) engineering and system architecting of unmanned aerial vehicles (UAV) in courses, capstone projects, and theses. The AnyLogic agent-based software tool was purchase. Anylogic is a Java-based agent modeling tool. The project explored how to specify and build agents of unmanned vehicles. Agent models were developed for a UAV. The benefit of agent modeling is the one-to-one correspondence between real world objects such as UAVs and agents in the model. An agent encapsulates both data and behavior, and in the simulation the agents interact with other agents, which let the analyst observe emergent behavior in the system.

POC: Ronald Giachetti (regiache@nps.edu)

c. Unmanned Systems: A Lab-based Robotic Arm for Grasping

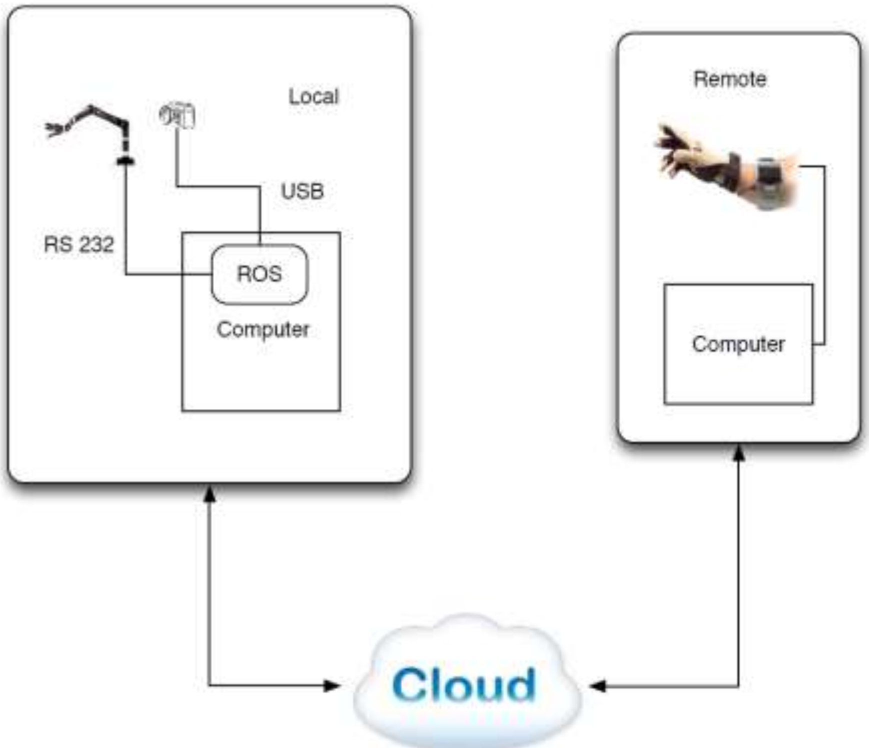


Figure 47. The NPS Kinova JACO lab architecture.

With CRUSER funding, the NPS Physics Department implements an educational robotic manipulation laboratory (RML) to explore learning opportunities for various student experiments and course work. The focus of the lab is to understand and implement the kinematics and dynamics for a six degree of freedom (DOF) Kinova JACO robotic arm, in a controlled lab environment, for various predetermined tasks under glove, and eventually, visual sensor control. The Kinova JACO robotic arm[1] was selected for its sophistication and maturity as a complex maniputor. Effector trajectory and path planning for the six DOF arm proved to be operationally and mathematically challenging.

[1] http://www.kinovarobotics.com/

Figure 48. Fully assembled glove controller with flex sensors, IMU and Arduino Uno microcontroller.

A glove controller was built and tested as a means of user interface to the JACO arm. The objective was to replace the joy stick controller with a more natural gloved controller. This controller consisted of three resistive flex sensors that were attached to the thumb and two fingers of a user's glove to mimic the JACO arm three finger effector. Additionally, an inertial sensor was attached to the back of the glove for input on spatial awareness. Tests were conducted to confirm the understanding of the flex sensor range of motion. Sensor data was recorded via an algorithm run on an Arduino Uno microcontroller, and interfaced with a Linux computer running the Robot Operating System (ROS). The spatial orientation of the glove was successfully demonstrated on the Linux computer via a ROS modeling algorithm, 3D Simulator. Third party Kinova ROS drivers were tested for glove control to the arm with limited success. As an alternative, Kinova C Sharp libraries are currently being explored as the basis for student lab algorithms that can run in a Windows operating system environment for predetermined path trajectories.

Concurrent work on the project includes the modeled design and build of a mobile platform which the JACO arm can interact on or be deployed from in the context of a battlefield concept of operations.

To conclude, JACO arm testing and glove experiments were completed. The JACO software was installed and verified for standalone operations within its range of motion. Testing of ROS and glove/manipulator interaction proved ineffective. Kinova C Sharp coding will replace ROS methods for arm control. Successful testing of the sensors on the glove confirmed regular hand movement simulation.

POC: RM Harkins (rharkins@nps.edu)

d. Applications of a mobile acoustic source for Tactical Oceanography

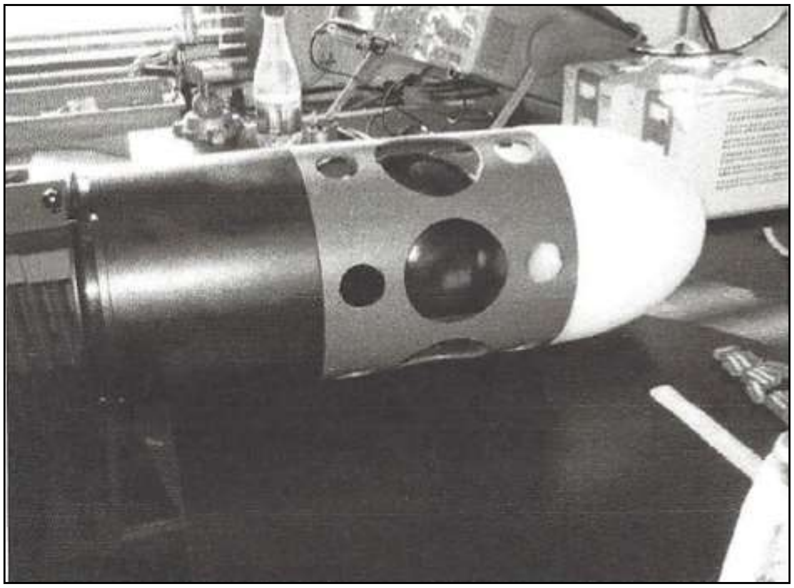


Figure 49. Proposed Woods Hole Oceanographic Institute (WHOI) design of a mobile source module to be built for use on NPS REMUS-100 AUVs.

With this effort, we proposed to develop additional Tactical Oceanography (OC4270) course content to include use of a mobile mid-frequency acoustic source module integrated onto a NPS REMUS-100 autonomous underwater vehicle (AUV) platform to conduct at-sea underwater acoustic experiments in support of course objectives and student class projects (see Figure 49). The use of a mobile MF acoustic projector broadens the scope of underwater acoustic field experiments that students will be able to conduct in the at-sea laboratory segment of the course.

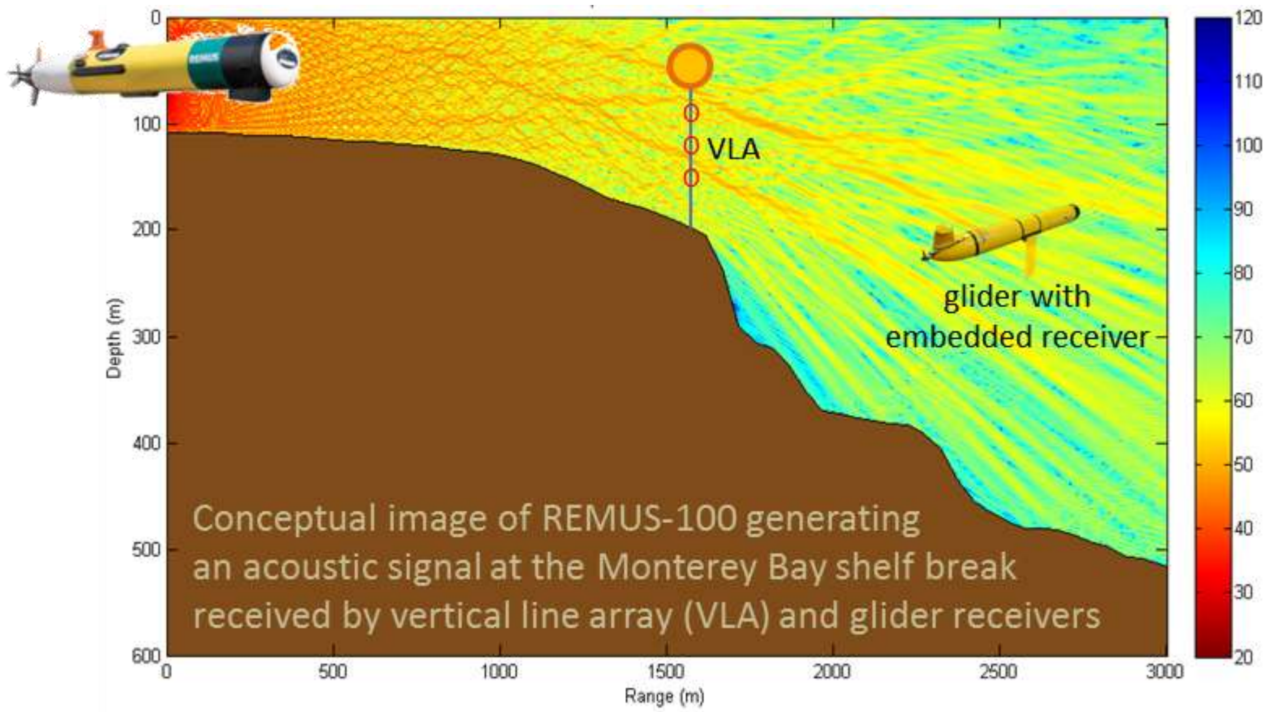


Figure 50. The mobility of a mid-frequency source mounted on a REMUS-100 AUV enables Tactical Oceanography students to conduct a variety of 3D (range, azimuth, depth) investigations of sound propagation in range-dependent environments.

The project is not yet complete due to delays in contract processing, however it is anticipated students of Tactical Oceanography, a capstone course for USW and METOC curricula student, will use the mobile source to observe the effects of the environment on sound propagation in a wide variety of range-dependent and azimuthal-dependent environments in upcoming classes (see Figure 50). A mobile source can provide continuous data over a wide combination of complex acoustic path geometries, frequencies and source depths allowing students to study tactically-relevant phenomena not feasible to study with current equipment. This capability adds aspects of tactical realism to their investigations not otherwise achievable. As examples, a mobile sound source allows observational investigations into principles of Doppler shift, acoustic tracking techniques and propagation through internal wave/soliton fields at various source receiver aspects. In addition, students will gain a hands-on experience with unmanned underwater vehicle operations and control. A mobile mid-frequency acoustic source has many USW and METOC research applications outside the classroom in support of student thesis work.

POC: John Joseph (jejoseph@nps.edu)

e. Towards Autonomous ISR by a Team of Cooperating Gliders

We have developed a set of teaching modules that have been in fact integrated into existing upper level autonomous systems courses at the MAE department. These modules are based on the recently completed research project TALES (Tactical Long Endurance System) funded by

CRUSER. Under the TALES umbrella our team has developed new cooperative algorithms for guidance navigation and control of long endurance gliders.

The lecture modules introduce students to all the key guidance, navigation and control technologies that enable a constellation of autonomous gliders to conduct a common military ISR mission requiring persistent visual surveillance of a terrain feature or of single or multiple points of interest (POI). The coursework focuses on a typical ISR mission, namely road patrol. In the presented scenario operator designates a section of a road or any other sensor path or a number of POIs where surveillance is desired and provides this information to the glider constellation. Once the designation is completed, no further operator direction or ground station interaction is necessary until the operator decides to alter the constellation's tasking (i.e. shift the constellation to another patrol mission).

The key idea is to reduce the demand upon operators to facilitate control of a system comprised of significantly more aircraft than currently fielded. In fact, currently deployed systems for tactical reconnaissance employ a single airborne ISR platform to perform this type of mission. An operator located on the ground maintains control of the aircraft and sensor payload while the aircraft is in the air and the operator's full attention is required. The continuous control arrangement of this approach has a prohibitive scaling cost for the larger numbers of individual aircraft necessary to survey wider tactical operating regions. Additionally, current tactical UAV systems primarily rely on gas powered aircraft that have limited on-station time and require ground based refueling.

The course modules developed include:

1) Cooperative thermal search by the glider constellation. This module borrows heavily from search theory.

2) Real-time trajectory generation. This module relies on the direct methods of optimal control.

3) Path following. This module is rooted in the theory of nonlinear control

4) Thermal detection and tracking. This module introduces students to Kalman filtering and then uses thermal detection and as an example of Kalman filtering application. The thermal tracking algorithms are based on classical control theory well familiar to the students

5) Condor - high fidelity glider simulation and real-time computing in Simulink. This module introduces students to the glider flight simulator Condor, the API interface between Condor and Simulink software package (extensively used in MAE) and real-time feature of Simulink.

Preliminary versions of the modules have been used in ME 4811 and ME4823 TA. For the final project in ME4823 two teams of students had to develop algorithms for executing a typical ISR mission using multiple cooperating gliders and then compare their performance. The results obtained by both groups were quite impressive and are at the moment being included in a conference paper to be submitted to the 2016 American Control Conference. In addition, the algorithms developed by students are being used to analyze endurance that can be achieved by multiple cooperating gliders in support of a project funded by USMC E20 (Energy Efficiency Office).

POC: Isaac Kaminer (kaminer@nps.edu)

f. CRUSER Data Farming Workshops

Computer experimentation is integral to modern scientific research, national defense, and in public policy debates. These computer models tend to be extremely complex, with thousands of factors and many sources of uncertainty. Data farming helps researchers understand the impact of those factors and their intricate interactions on model outcomes. Data farming is the process of using computational experiments to grow data, which can then be analyzed using statistical and visualization techniques to obtain insight into complex systems. Effective data farming draws on state-of-the-art technologies including design and analysis of experiments, high-performance computing, and data mining.

Design of experiments (DOE) techniques have been used with agent-based or discrete-event simulation models to explore the potential use of unmanned vehicles of many types—aerial, ground, surface, and underwater—for missions related to reconnaissance and surveillance, IED detection, mine detection, border security, asset protection, casualty evacuation, and more. Insights from data farming can include identifying key drivers of performance, discovery of "knees in the curve" for trade-off analysis on system capabilities, or the development of new tactics and equipping strategies to leverage new technologies. Still, many who use simulation models are not aware of the benefits that this structured "what-if" analysis might bring.

To address this issue, we scheduled two mini-workshops at NPS: one in November 2014, one in February 2015. We participated in CRUSER's TechCon 2015, with two afternoons of ongoing demonstrations open to NPS participants and visitors from local elementary, middle school, and high schools. Educational efforts in the summer involved interns from the Office of Naval Research's SEAP and NREIP programs for high school and college students, respectively. The interns investigated a variety of topics, ranging from the use of UAVs for search operations to the spread of viruses on computer networks. We finish the year with a CRUSER Data Farming team as part of the Warfare Innovation Workshop in September 2015. One mathematics student who learned of data farming from the Mini-Workshops applied these techniques to investigate power generation from piezo-electric materials. In all, six OR student theses explored the use of unmanned underwater, surface, and armed or unarmed aerial vehicles in a variety of operational settings. These are: undersea communication between UUVs and submarines, UAVs for Navy humanitarian assistance, UUVs for coalition mine clearing operations, high energy laser self-defense against UAVs, UCAVs for counter-terrorism, and USVs for asset protection.

In addition to the educational activities, the SEED Center advanced the methodology for future studies, including the two papers listed below and ongoing work on simulation metamodeling. These advances can be leveraged in future simulation studies.

PAPERS

Duan, W., B. E. Ankenman, S. M. Sanchez, and P. J. Sanchez (2015). Sliced Full Factorial-Based Latin Hypercube Designs as a Framework for a Batch Sequential Design Algorithm. Technometrics, forthcoming.

Sanchez, S. M. (2015). Simulation Experiments: Better Data, Not Just Big Data (2015). Proceedings of the 2015 Winter Simulation Conference, forthcoming.

POC: Professor Susan M. Sanchez (ssanchez@nps.edu)

g. Robotic System Engineering Classroom Case Study

After their studies are complete, NPS students may be responsible for the development and acquisition of robotics systems. To do that effectively, they will need to navigate through two DoD processes: the Joint Capabilities Integration and Development System (JCDIS) and the Defense Acquisition System (DAS). To better educate our students in both process and technology, this robotic system software engineering classroom case study is a series of educational modules that result in the development and acceptance of an actual working robotic system.

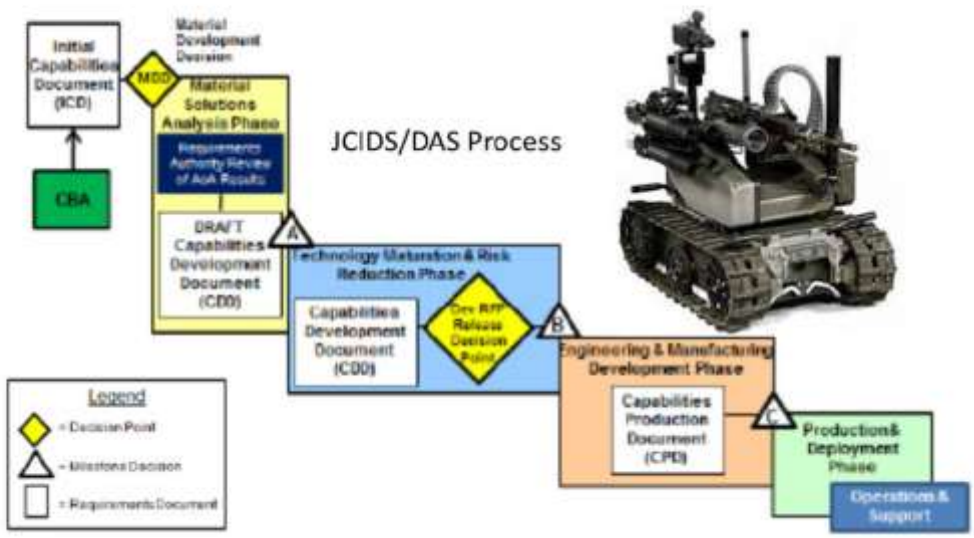


Figure 51. The Robotic System Software Engineering Classroom Case Study used to demonstrate the Joint Capabilities Integration and Development System (JCIDS) and the Defense Acquisition System (DAS).

The purpose of this project is to create a set of educational modules that illustrate how a robotics system and its software are developed within the DoD acquisition framework. It is anticipated that the end users for these modules will be NPS faculty teaching in either resident programs or in distance-learning programs. These modules will be organized as follows:

> Module 1: The robotic system as a component of a larger operational system.
>
> Module 2a: Creating a conventional requirements model of the sample robotic system.
>
> Module 2b: Creating an object-oriented requirements model of the sample robotic system.
>
> Module 3a: Defining a conventional architecture for the sample robotic system.
>
> Module 3b: Defining an object-oriented architecture for the sample robotic system.
>
> Module 4a: Detailed design of a conventional (procedural) software controller for the sample robotic system.
>
> Module 4b: Detailed design of an object-oriented software controller for the sample robotic system.
>
> Module 5a: Inspection and debugging of the software (written in C, a procedural programming language) which operates a robotic vehicle.
>
> Module 5b: Inspection and debugging of the software (written in Java, an object-oriented programming language) which operates a different robotic vehicle.
>
> Module 6: Acceptance test and evaluation of the robotic system's hardware and software.

The project involves creating a set of development artifacts (a system specification, UML-based design model, architecture and detailed design documents, source code, and test and evaluation documents) and a working hardware-software prototype which will provide the students with an integrated, insightful classroom learning experience. It should be noted that students are not expected to write any computer programs themselves, although the instructor may have students carry out supporting classroom exercises to enhance their learning experience. The plan is to develop a teaching package with four component: Instructor presentation material, student assignments, development artifacts (including source code), and working robots for instructor use in the classroom to engage the students. Because it is widely accepted and used internationally in the classroom, the working robots will be constructed using LEGO Mindstorms EV3 technology.

This case study will serve a unique classroom need. Designing, developing and acquiring autonomous systems and tele-operated robotic systems is a complicated task. Even with a simulated classroom problem, the process which allows alternative material solutions to be prototyped and evaluated is often difficult for an instructor to explain. The results of the

CRUSER Robotic System Software Engineering Classroom Case Study educational project will help make that easier.

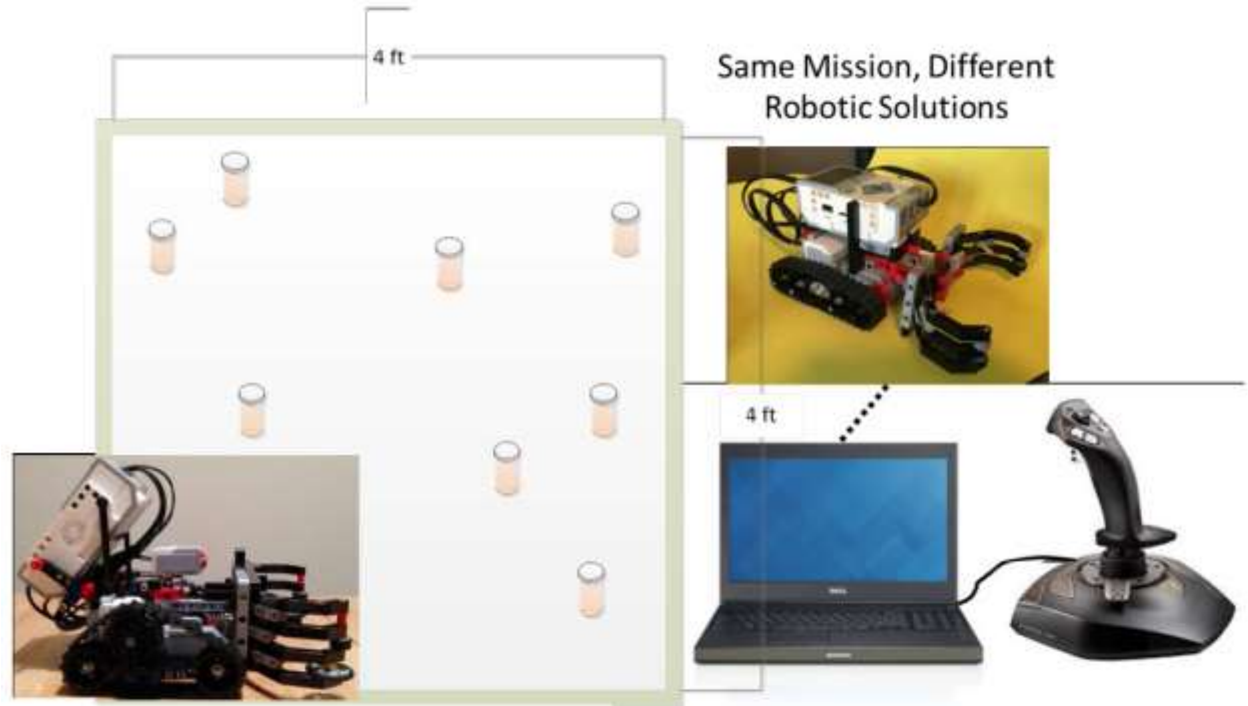


Figure 52. Alternative material solutions proposed for the same problem.

Progress to date has been very good. Two LEGO EV3 Mindstorms kits were procured, along with additional robotic sensors, batteries, storage containers, reference books, and other material for Principal Investigator use. Additionally, two more LEGO EV3 Mindstorms kits (with similar additional material) were procured for use by students who are conducting their MSSE Capstone Project during the period, April 2015 through December 2015. The Principal Investigator is an advisor to the student Capstone Project team and is having that team carry out their project independently of the PI's own prototyping, robotics systems engineering, and artifacts development. The simulated user problem is the same for both the student team and for the PI's independent efforts: to clear a small area (e.g., four-foot by four-foot) of plastic containers containing simulated radiologically hazardous material. To date, the PI has developed (using the RobotC programming environment) and successfully tested two prototypes: 1) "Wombat 1" which is tele-operated (remotely controlled through either a joystick or a gamepad controller connected to a notebook computer which communicates wirelessly with Wombat 1 using BlueTooth or Wifi); and 2) "Mantis 1" which operates autonomously using four on-board sensors. The student team has developed an Autonomous Clearance Vehicle (ACV) named "TECHMAN" which they are programming using the Java programming language and LeJos, the Lego Java operating system. The software development framework for TECHMAN is object-oriented and will be used by the students to create both a prototype autonomous vehicle (TECHMAN) and a prototype remotely controlled robotic vehicle. In 2016, the PI will integrate the student team's results with his own and will complete the CRUSER project to produce the educational presentation material, student assignments, development artifacts, and working robots.

POC: Paul Shebalin (pshebali@nps.edu)

h. *The Future of Just War: Theoretical and Practical Challenges - International Conference*

The Future of Just War: Theoretical and Practical Challenges is an international academic conference that will be held 7-9 October 2015 at the Portola Hotel in downtown Monterey, California. The conference will bring together the leading scholars in the world today working on the ethics of war, just war theory, the moral implications of the future and changing nature of warfare, and related issues. The ethical implications of new, emerging, and future military technology – specifically cyberwarfare and unmanned and robotic weapons systems – will be the focus of several sessions, papers, and panels.

The Conference Committee received over 90 paper submissions representing a wide range of quality research in these areas. After a vigorous peer-review process, 37 papers were selected for presentation at the conference. These include our five headlining keynote addresses:

1) Dr. Scott Sagan (Stanford), "Atomic Aversion and Just War Principles"

2) Dr. Jeff McMahan (Oxford), "Against Collectivist Approaches to the Morality of War"

3) Dr. Helen Frowe (Stockholm), "Reductive Individualism and the Just War Framework"

4) Dr. Adil Haque (Rutgers), "Does Just War Theory Rest on a Mistake?" further exploring the Law of Armed Conflict (LOAC)

5) Dr. David Rodin (Oxford), "The Ethics of Revolutionary War"

Interspersed between the keynote addresses, the other accepted papers will be presented in parallel breakout sessions throughout each day of the conference. These include excellent research exploring difficult ethical questions surrounding newly emerging autonomous weapons technology. Examples include Dr. Heather Roff's (Denver) paper entitled "Suffered Privilege: Command Responsibility for Lethal Autonomous Weapons Systems," and Dr. Susanne Burri's (London School of Economics) talk on "Autonomous Weapons Systems and Human Agency." Dr. Ryan Jenkins (California Polytechnic) and Dr. Duncan Purves (Wyoming) will present their recent research in "A New Problem for Moral Reasoning in Autonomous Weapons," and Dr. Keith Abney (California Polytechnic) will explore "The Relationship between *Jus Ad Bellum* and *Jus In Bello*: The Implications of (and for) Autonomous Weapons Systems."

The ethical challenges posed by the complexities of cyberwarfare will also be given a great deal of attention at the conference. For example, Dr. Edward Barrett (U.S. Naval Academy) will present "Reliable Old Wineskins: The Applicability of the Just War Tradition to Military Cyber

Operations," and Dr. Adam Henschki's (ANU) paper "Virtual Violence: Searching for a Sensible Concept" is sure to draw interest from many who work on cyberwarfare issues. There will also be a lively panel discussion on "Information Transparency, Information Warfare, and Cyber Warfare" by Drs. Andrew Bridges, Richard Wilson, and Greg Stack (Maryland). Many of the vexing legal issues raised by cyberwarfare will also be explored in research presented at the conference. For example, Law Professor Pete Stockburger (San Diego) will be speaking on "Known Unknowns – *Jus Ad Bellum* and Cyber Warfare under International Law."

Many other important research issues directly fulfilling CRUSER's mission will also be addressed at the conference. For example, Dr. J.P. Sullins (Sonoma) will give his paper "The Special Moral Concerns Posed by the Deployment of Robotic Weapons Systems," and Dr. Johannes Himmelreich (London School of Economics) will deliver "Future Drones and Responsibility in Hierarchical Groups." There will also be a fascinating panel held on "PSYOP, Hactivism, and Unlicensed Combatants" by Drs. Mark Zelcher and Steven Nichols (SUNY). The above is just a small sampling of the 37 excellent research papers that will be presented, disseminated, and vigorously debated and discussed at the conference. Finally, the conference will also have direct involvement from several current NPS students. LT Forest Crowell, for example, will be presenting his thesis on the ethical problems raised by the commodification of the Navy SEALs.

POC: Professor Bradley J. Strawser (bjstrawser@gmail.com)

i. Development of instructional tutorials, online wiki, and videos in support of Robotics and Rapid Prototyping

A CRUSER funded project to support the RoboDojo, this development work resulted in purchase, setup, and training on new prototyping tools in FY15. Laser Usage in 2015 is detailed here as an example:

Figure 53. Experiments using the laser cutter

1. Resources:

Raw Materials: ¼ inch plywood, ¼ in alderwood, ½ in plywood, ½ in alderwood, ½ in acrylic, ¼ in acrylic, cardboard, Cermark paint for ceramic and metal

2. Laser Written Materials:

Laser Safety Slides (read prior to workshop)

Laser Workshop Presentation Slides

Laser Guide

3. Knowledgeable users:

Kristen Tsolis, Gerald Scott, Tim Chung, David Garcia, JD Russo, Giovanni Minelli, Chris McManus, Scott Giles, Kevin Jones, James Calusdian, Scott Cote, Andrew Ceniseroz, Pablo Breuer, Bob Garza

4. Model number and specification details:

GCC LaserPro Spirit GLS, an 80W CO2 laser with a 37" x 24" print area.

The laser is a Class 1 laser unless the interlocks are opened. It then can function as a Class 4 laser, but we don't use it as such at the moment.

5. Types of materials for use with laser:

Currently allowed materials: acrylic, plywood, balsa, any hardwood

Not allowed: metal, shiny things, any plastic other than acrylic including PVC, PET, and fiberglass

6. How to use the RoboDojo laser:

Users sign up for a workshop, read the required laser safety slides, and answer basic laser safety questions during the laser workshop. We then cover how to create laser models and laser use before using the laser itself. Supervised laser practice is required prior to unsupervised use. Newly cleared users may become privy to combination for lock that houses laser key.

Figure 54. Student making linear motor for thesis project

7. Examples of laser projects:

Thesis project: linear motor, which was one student's method of showing some of the mechanics behind a rail gun.

Other sample projects: simple boxes, safety signs, test strips for laser power/speed settings, enclosures for lab tools.

Figure 55. Laser Test Samples: Power and Speed Settings

POCs: Kristen Tsolis and Dr. Timothy Chung (robodojo@nps.edu)

j. Development of Control System Course Content for Interdisciplinary Applications in Robotics

To address one of the specific goals of the CRUSER mission, to provide a venue for Navy-wide education in unmanned systems, a new website was developed and populated with the corresponding content (see Figure 56). This site is designated for the Joint EC/MAE/SE Dynamics and Control Laboratory at the Graduate School of Engineering and Applied Science

(GSEAS) of the Naval Postgraduate School (NPS). The prototype site is available for review at https://my.nps.edu/web/gseas-dcl/welcome.

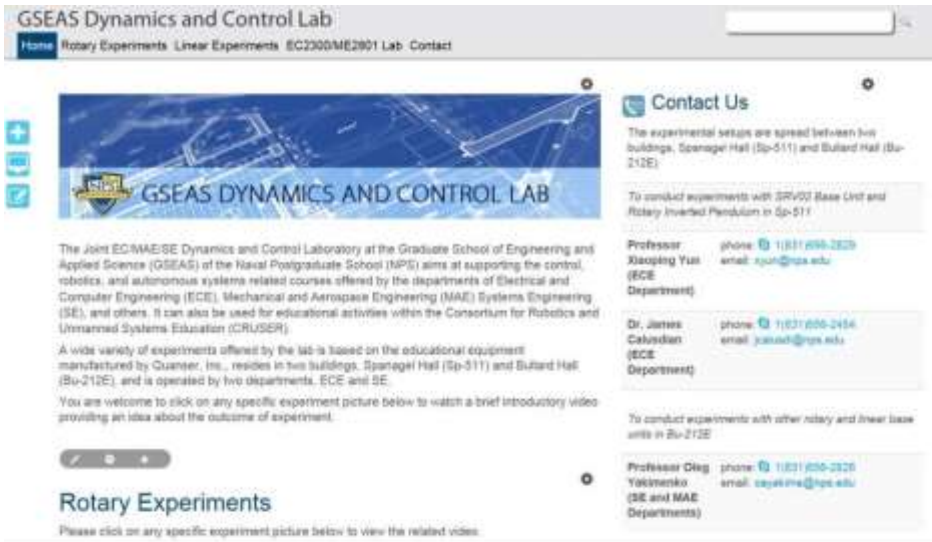


Figure 56. The main page of the GSEAS Dynamics and Control Laboratory wesite.

It is well-known that at the heart of any autonomous system is a well-designed control system to ensure the robot operates as desired. Interested students from various disciplines should therefore study theory and concepts in control systems engineering to prepare themselves for advanced courses in robotics. Hence, the Dynamics and Control Laboratory website aims at supporting the control, robotics, and autonomous systems related courses offered by the departments of Electrical and Computer Engineering (ECE), Mechanical and Aerospace Engineering (MAE) Systems Engineering (SE), and others. It can also be used for educational activities within the Consortium for Robotics and Unmanned Systems Education (CRUSER), and as such the CRUSER website will have a link to this newly developed website allowing accessing its content by all interested parties.

The website developed in collaboration with the Center for Educational Design, Development, and Distribution of NPS supports a wide variety of experiments based on the educational equipment manufactured by Quanser, Inc. and provides the brief description with a short video, full manual, quick setup, auxiliary scripts and models for each of them (see Figure 57).

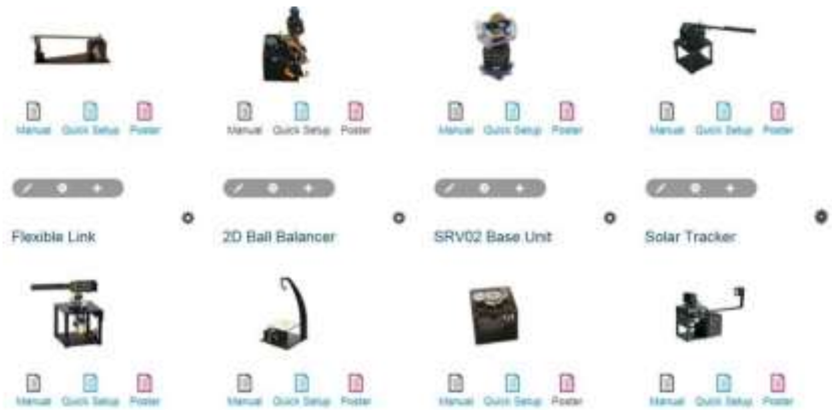


Figure 57. Examples of rotary-unit-base experiments.

For example, in a seesaw experiment (see Figure 58) a student is supposed to keep a balance by moving a cart along a rail. The same type of a system can be found in underwater gliders. The single- and multiple-stage inverted pendulum experiments allow designing robust controllers for many systems including Army's Big Dog, Segway transporters, and a vertical mast to capture incoming unmanned aerial vehicles at the ship's deck. A two-degree-of-freedom balancer allows studying attitude controllers that are widely used on space, air and sea platforms. A solar tracker experiment allows teaching concepts in unmanned systems guidance, etc.

Figure 58. Seesaw experiment and its relevance to underwater robotics.

POC: Oleg Yakimenko (oayakime@nps.edu)

2. Education Initiatives

Education initiatives in FY15 included the third event in the CRUSER Robo-Ethics Continuing Education Series, and sponsorship of several internships at NPS.

a. Continuing Education: Robo-Ethics, April 2015

This fourth activity in the full Robo-Ethics Continuing Education Series (RECES) "Exploring the Operational Limits of Military Robots" was held 14-16 April 2015. Continuing the discussion started in January 2012 with the first iteration of CRUSER Robo-Ethics, we tasked teams of junior officers to explore the operational limits of military robotics. This activity was not focused directly on ethical issues associated with the employment UxS systems but rather on the drivers of those ethical issues: employment of autonomous, remote and robotic systems to meet operational requirements. Taking the lawyers and ethicists out of the mix, we asked naval officers to develop their vision of the future battlefield without the constraints of policy, law and ethics. From this foundation we can better inform future discussions on what policies and laws should look like to enable the warfighters and what ethical issues may need to be addressed *en route* to developing such policies and laws.

Figure 59. NPS student participants in Robo-Ethics 2015, April 2015

Of the three teams of junior officers working through the activity, one was on the NPS campus in Monterey (see Figure 59), and two were on site at SSC Pacific in San Diego. A full activity report is available upon request.

b. CRUSER Interns

NPS had 86 interns through NREIP, SEAP and Hartnell College working with researchers in FY15, mostly during the summer. Four CRUSER supported projects hosted a total of 26 interns, six of whom worked with Dr. Timothy Chung on his record-breaking work on UAV swarms. CRUSER supported interns placed at NPS in FY15 represented over 20 institutions, secondary through graduate students (see Table 3).

Table 3. Institutions represented by CRUSER supported NPS interns in FY15

Colleges & Universities:	Brown University
	Bucknell University
	Cal Poly San Luis Obispo
	California State University Sacramento
	Emory University
	Florida Atlantic University

	Hartnell Community College
	LeTourneau University
	Santa Clara University
	University of California Berkeley
	University of California Davis
	University of California San Diego
Secondary Schools:	Canyon High School
	Carmel High School
	Marina High School
	Monterey High School
	Pacific Grove High School
	Presentation High School
	Santa Catalina Upper School
	York School

2. NPS Course Offerings and Class Projects

Select NPS courses contribute to CRUSER's mission by conducting class projects in various aspects of unmanned systems employment. Unmanned systems are studied directly, or introduced as a technical inject for use in strategic planning or war gaming. Beyond advancing research and concept development, these projects enhance education in unmanned systems.

a. Systems Engineering Analysis (SEA) 21, 2015

Sponsored by the CNO Warfare Integration Division Chair of Systems Engineering Analysis, this inter-disciplinary curriculum provides a foundation in systems thinking, technology and operations analysis for warfighters. Each cohort must produce a report detailing their research, and make a recommendation based on their findings. The SEA 21 cohort was divided into two teams with SEA21A tasked to study systems providing an organic over-the-horizon targeting capability to surface ships and SEA21B tasked with studying systems to provide company-sized expeditionary operations in contested littorals. Their summaries follow.

SEA21A: Adversarial advances in the proliferation of anti-access/area-denial (A2/AD) techniques requires an innovative approach to the design of a maritime system of systems capable of detecting, classifying, and engaging targets in support of organic over-the-horizon (OTH) tactical offensive operations in the 2025–2030 timeframe. Using a systems engineering approach, the SEA21A study considers manned and unmanned systems in an effort to develop an organic OTH targeting capability for U.S. Navy surface force structures of the future. Key attributes of this study include overall system requirements, limitations, operating area considerations, and issues of interoperability and compatibility.

Multiple alternative system architectures are considered and analyzed for feasibility. The candidate architectures include such systems as unmanned aerial vehicles (UAVs), as well as prepositioned undersea and low-observable surface sensor and communication networks. These unmanned systems are expected to operate with high levels of autonomy and should be designed to provide or enhance surface warfare OTH targeting capabilities using emerging extended-range surface-to-surface weapons.

This report recommends that the U.S. Navy explore the use of modestly-sized, network-centric UAVs to enhance the U.S. Navy's ability to conduct surface-based OTH tactical offensive operations by 2025.

SEA21B: The United States armed services have identified capability gaps in the areas of company-sized raid and sustainment operations in contested littoral environments. Multiple joint platform packages can be employed to provide the required mission capabilities to fill the gap. The SEA21B study identifies the operational, functional, and physical architecture and effectiveness of mission packages necessary to provide capabilities associated with littoral sustainment operations. Physical architecture configurations are evaluated using discrete event modeling. Cost and performance estimates for the mission packages are presented in order to provide the decision maker tools for identifying which alternative provides the most cost-effective solution for the needs of a scenario's stakeholders. The SEA21B report concludes by identifying potential assets that would provide cost-effective support of littoral operations. Feasible alternatives provide varying levels of effectiveness in terms of average deployment time and percentage of threats successfully affected.

POCs: Professor Jeff Kline (jekline@nps.edu), Dr. Gary Langford (golangfo@nps.edu), and Dr. Timothy Chung (thchung@nps.edu)

b. Introduction to Scientific Programming (AE2440), Fall 2015

The Introduction to Scientific Programming course offers an introduction to computer system operations and program development. The main goal of this course is to provide an overview of different structured programming techniques, along with introduction to MATLAB/Simulink and to use modeling as a tool for scientific and engineering applications. Among others the course teaches techniques for rapid prototyping of mission building / control development for unmanned vehicles.

POC: Professor Oleg Yakimenko (oayakime@nps.edu)

c. Robotic Multibody Systems (AE4820)

This course focuses on the analytical modeling, numerical simulations and laboratory experimentation of autonomous and human-in the loop motion and control of robotic multibody systems. Systems of one or more robotic manipulators that are fixed or mounted on a moving vehicle are treated. Applications are given for under-water, surface, ground, airborne, and space environments. The course reviews basic kinematics and dynamics of particles, rigid bodies, and multibody systems using classical and energy/variational methods. The mechanics and control of robotic manipulators mounted on fixed and moving bases are considered. The course laboratories focuses on analytical and numerical simulations as well as hands-on experimentation on hardware-in-the-loop.

POC: Dr. Marcello Romano (mromano@nps.edu)

d. Policies and Problems in C4I (CC4913), Spring 2015

Students in this course study the fundamental role C2 systems fulfill in operational military situations, including the full range of military operations. Analysis of the changing role of organizational structures and processes as well as technologies and impacts on C2 systems requirements and designs is central to the curriculum. Students in this course are asked to consider the complexities imposed on C2 systems as the force structure becomes more heterogeneous, as in the case of NATO and NGOs. Case studies of selected incidents and systems focus on current problems.

POC: Dr. Dan Boger (dboger@nps.edu)

e. Cyber Communications Architectures (CY3300 same as EO3730), Summer

The purpose of this course is to develop literacy and familiarity with Navy, DoD, and allied enterprise information systems and emerging technology trends. It presents basic concepts in conventional and military telephony and telecommunication networks; examines DoN implementations from intra-ship, ship-to-ship and long haul and discusses architectures and components of the GIG including both classified and unclassified networks. It discusses interoperability of diverse network architectures and the impact of mobile platforms on operations The CRUSER sponsored class project for this course had teams of students identifying the cyber architectures associated with three UUV systems from Submarine Squadron FIVE and two UUV systems from NUWC Keyport, analyzing these architectures and making recommendations to improve the security of the systems. This work included direct interaction between the students and the subject matter experts associated with each UUV system. The class produced a technical report that is being shared back with each UUV team.

POC: Associate Professor Raymond Buettner (buettner@nps.edu)

f. Introduction to Control Systems (ME2801), Fall 2014

The Introduction to Control Systems presents classical analysis of feedback control systems of dynamic systems including unmanned vehicles using basic principles in the frequency domain and in the s-domain. Performance criteria in the time domain such as steady-state accuracy, transient response specifications, and in the frequency domain such as bandwidth and disturbance rejection are introduced. Simple design applications using root locus and Bode plot techniques are addressed. Laboratory experiments are designed to expose the students to testing and evaluating mathematical models of physical systems, using computer simulations and hardware implementations.

POC: Professor Oleg Yakimenko (oayakime@nps.edu)

g. Introduction to Unmanned Systems (ME3720)

An Introduction to Unmanned Systems is an introductory graduate level course in robotics with an emphasis on learning through hands on projects. It provides an overview of unmanned aerial, surface and underwater systems technology and operations including guidance, navigation, control, sensors, filtering and mapping. All three class projects currently use a small dual water jet USV as the demonstration robot. Each project is broken down into simulation and operation sections. The first project involves the implementation of a Proportional, Integral and Derivative heading controller. The second project goal is to design and implement a cross track error controller. The final project involves real-time path planning and path following through a dynamically changing environment. Course work includes programming the robot in python.

POC: Dr. Douglas Horner (dphorner@nps.edu)

h. Autonomous Systems and Vehicle Control II (ME4811)

This course introduces multivariable analysis and control concepts for MIMO systems. Topics covered include: state observers, disturbances and tracking systems, linear optimal control, and the linear quadratic Gaussian compensator. The course also gives an introduction to non-linear system analysis, and limit cycle behavior.

POC: Dr. Isaac Kaminer (kaminer@nps.edu)

i. Marine Navigation (ME4821), Winter 2015

The Marine Navigation course presents the fundamentals of inertial navigation, principles of inertial accelerometers and gyroscopes. It also considers external navigation aids (navaids) including the Global Positioning System (GPS). This course includes derivation of gimbaled and strapdown navigation equations and error analysis. It also introduces Kalman filtering as a means of integrating data from navaids and inertial sensors. Students are required to model navigation system and test it in computer simulations as applied to a choice of underwater, surface, ground or aerial vehicle in the ideal and GPS-denied environment.

POC: Professor Oleg Yakimenko (oayakime@nps.edu)

j. Guidance, Navigation, and Control of Marine Systems (ME4822)

This course takes students through each stage involved in the design, modeling and testing of a guidance, navigation and control (GNC) system. Students are asked to choose a marine system such as an AUV, model its dynamics on a nonlinear simulation package such as SIMULINK and then design a GNC system for this system. The design is to be tested on SIMULINK or a similar platform. Course notes and labs cover all the relevant material.

POC: Dr. Isaac Kaminer (kaminer@nps.edu)

k. Cooperative Control of Multiple Marine Autonomous Vehicles (ME4823)

This course covers selected topics on trajectory generation and control of multiple marine autonomous vehicles. First part of the course addresses techniques for real-time trajectory generation for multiple marine vehicles. This is followed by introduction to algebraic graph theory as a way to model network topology constraints. Using algebraic graph theory formalism Agreement and Consensus problems in cooperative control of multiple autonomous vehicles are discussed, followed by their application to cooperative path following control of multiple autonomous vehicles. Lastly, the course covers topics suggested by the students, time permitting.

POC: Dr. Isaac Kaminer (kaminer@nps.edu)

l. Search Theory and Detection (OA3602), Spring 2015

Students in this course, Search Theory and Detection (OA3602) investigated the mathematical and computational foundations of applied probability, stochastic systems, and optimization modeling in relation to operationally relevant search scenarios, such as anti-submarine warfare, mine clearance and sweeping, and combat search and rescue. Such mission sets, to also include intelligence, surveillance, and reconnaissance (ISR); harbor security; and border patrol, are increasingly involving unmanned systems.

POC: Professor Michael Atkinson (mpatkins@nps.edu)

m. Joint Campaign Analysis (OA4602), Winter and Summer 2015

The Joint Campaign Analysis course is an applied analytical capstone seminar attended by operations research students, joint operational logistics students, modeling and simulation students, and systems engineering analysis students. It uses scenarios and case studies for officers to use the skills they have acquired in their degree programs in an operational environment. During scenario planning and quantitative assessment using warfare analysis techniques, students are asked to provide a quantitative military value assessment of unmanned systems and their concept of employment. The Winter and Summer 2015 classes were provided technologies that included the Undersea Constellation, SoSite, and CODE which use a combination of unmanned platforms, sensors, and communication networks to gain access or increase surveillance capabilities.

POC: Professor Jeff Kline (jekline@nps.edu)

n. Advanced Applied Physics Lab (PC4015), Winter and Summer 2015

Students incorporate knowledge of analog and digital electronic systems to design, implement, deploy and demonstrate an autonomous vehicle. The vehicle is required to demonstrate navigation and collision avoidance. The course is taught in a standard 12-week format. A Needs Requirement Document is presented. Design reviews are held at the 4 and 8 week period. Demonstration of Autonomy is required to pass the class.

POC: Professor Richard M. Harkins (rharkins@nps.edu)

o. Fundamentals of Systems Engineering (SE3100), Spring 2015

This course provides an introduction to systems thinking and the processes and methods of systems engineering. The course covers fundamentals of systems engineering and system architecting, requirements analysis, functional analysis and allocation, preliminary system architecture, systems analysis, system design, and the basics of test and evaluation. Students in this course have historically used spreadsheet software for modeling and analyzing requirements and conceptual design alternatives, but are now being introduced to the use of specialized automated tools for systems engineering using the CRUSER-sponsored "Lab Manual for Systems Architecting and Analysis," which demonstrates how to model the problem separately from potential solutions to that problem (including analyzing manned vice unmanned systems). (Warren Vaneman instructing)

POC: Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

p. Systems Architecture and Design (SE4150), Winter, Spring, and Summer 2015

This course provides students an opportunity to develop and practice system architecting and design skills in identifying system elements with their capabilities, designing the relationships between those elements, and predicting system behavior through those relationships. The course provides the language, terminology, concepts, methods, and tools of system architecting, modeling and design through a study of various types of architectures, architecting and design. Through the use of "A Lab Manual for Systems Architecting and Analysis," which sets an operational stage for the employment of manned or unmanned systems for search and rescue operations, students explore functional and physical architecture modeling and analysis, architecture frameworks, and object oriented modeling approaches. (Warren Vaneman instructing)

POC: Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

q. Systems Integration and Development (SE4151), Winter 2015

This course provides the student with an understanding of the context and framework for planning and carrying out integration and development, including emergent behavior, manufacturing, and production of complex systems. Topics covered include systems and SoS integration and production with consideration of multiple suitability aspects, including availability, reliability, maintainability, embedded software, human factors, producibility, interoperability, supportability, emergent behavior, life cycle cost, schedule, and performance. The CRUSER-sponsored "Lab Manual for Systems Architecting and Analysis" was used to provide students with a reference operational mission of search and rescue, as well as design and integration techniques for assessing manned and unmanned solutions for executing that missions. (Kristin Giammarco instructing)

POC: Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

r. Systems Test and Evaluation (SE4354), Winter 2015

The Systems Test and Evaluation course covers principles of test and evaluation (T&E) and the roles, purposes, functions, and techniques of T&E within the systems engineering process. The course covers all aspects of T&E throughout the life cycle of a system to include test planning, test resources, development of test requirements, selection of critical test parameters, development of measures of effectiveness and performance, test conduct, analysis of test results, and determination of corrective action in the event of discrepancies. It also covers principles of experiment design and statistical analysis of test results. Students are also exposed to several case studies and lessons learned from actual defense system tests.

POC: Professor Oleg Yakimenko (oayakime@nps.edu)

s. Formal Methods for Systems Architecting (SE4935), Spring 2015

This new course debuted in Spring 2015 to introduce the application of formal methods to system architecture model and design analysis. PhD and Master's students were exposed to theories and practices that use mathematics and formal logic for the formulation, interrogation, assessment and measurement of properties of architecture models and the designs they describe. Unmanned system models in the new Monterey Phoenix -enabled tool at firebird.nps.edu, all CRUSER-sponsored works, were introduced along with conventional modeling techniques illustrated in the "Lab Manual for Systems Architecting and Analysis," which was sponsored by CRUSER the year earlier. The aim of this course is to apply systematic and formal thinking to the development and evaluation of system architectures. Students completed individual projects demonstrating their understanding of new architecting principles and practices developed for unmanned systems models in FY15, and many went on to synthesize potential PhD research topics from their papers. The creation of this course was wholly-enabled by the products of the 2015 CRUSER research. (Kristin Giammarco instructing)

POC: Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

t. Model Based Systems Engineering (SE4930), Summer 2015

Practical systems engineering relies heavily on models during conceptualization, system definition, system design, system integration, as well as system assessment. This course addressed the use of models in all phases of the systems engineering process using the CRUSER-sponsored "A Lab Manual for Systems Architecting and Analysis" as a student learning guide. The lab manual guided the team projects to design either a UAV or a UUV (team choice), and many individual projects were also infused with new architecting principles and practices enabled by the CRUSER research in FY15. Another section of SE4930 students during the same term were briefly exposed via a guest lecture to unmanned systems modeled in Monterey Phoenix. (Kristin Giammarco instructing / Gene Paulo instructing)

POC: Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

u. Systems Architecture (SI4022), Spring 2015

Systems architects respond to user needs, define and allocate functionality, decompose the system, and define interfaces. This course presents a synthetic view of system architecture: the allocation of functionality and its projection on organizational functionality; the analysis of complexity and methods of decomposition and re-integration; consideration of downstream processes including manufacturing and operations. Physical systems and software systems, heuristics and formal methods are presented. Students attended a lecture on Monterey Phoenix, including a demo of unmanned system models, and many students in this section chose to conduct their individual research assignments in the area of systems architecting using techniques described in the CRUSER-sponsored "Lab Manual for Systems Architecting and Analysis." (Kristin Giammarco instructing)

POC: Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

3. NPS Student Theses

CRUSER community of interest members guided several NPS students as they developed and completed their thesis work throughout the CRUSER program lifetime (*included in a cumulative listing in Appendix B*). The following table (see Table 4) lists students mentored in FY15, as well as those who graduated in September 2014 as their thesis work was still in academic processing when the FY14 CRUSER report was released.

Table 4. FY15 CRUSER mentored NPS student theses

AUTHOR(s)	TITLE	DATE (year-mo)	URL
Robert Humeur, Swedish Army	A New High-Resolution Direction Finding Architecture Using Photonics and Neural Network Signal Processing for Miniature Air Vehicle Applications	2015-09	
LT Spencer S. Hunt, USN	Model based systems engineering in the execution of search and rescue operations.	2015-09	
Capt Caroline A. Scudder, USMC	Electronic Warfare Network Latency Within SUAS Swarms	2015-09	
LT Sean M. Sharp, USN	Impact of Time-Varying Sound Speed Profiles with Seaglider on ASW Detection Ranges in the Strait of Hormuz (SECRET).	2015-09	
Victoria Steward	Functional flow and event-driven methods for predicting system performance.	2015-09	
Maj Thomas M. Rice, USMC Maj Erik A. Keim, USMC Maj Tom Chhabra, USMC	Unmanned Tactical Autonomous Control and Collaboration Concept of Operations	2015-09	
Capt Patrick N. Coffman, USMC	Capabilities assessment and employment recommendations for Full Motion Video Optical Navigation Exploitation (FMV-ONE)	2015-06	http://hdl.handle.net/10945/45827

LT David Cummings, USN	Survivability as a tool for evaluating open source software	2015-06	http://hdl.handle.net/10945/45833
Capt Louis T. Batson, USMC Capt Donald R. Wimmer, Jr., USMC	Unmanned Tactical Autonomous Control and Collaboration threat and vulnerability assessment	2015-06	http://hdl.handle.net/10945/45738
LT Arturo Jacinto, II, USN	Unmanned systems: a lab-based robotic arm for grasping	2015-06	http://hdl.handle.net/10945/45879
LTJG Salim Unlu, Turkish Navy	Effectiveness of unmanned surface vehicles in anti-submarine warfare with the goal of protecting a high value unit	2015-06	http://hdl.handle.net/10945/45955
Systems Engineering Analysis Capstone SEA21A	Organic over-the-horizon targeting for the 2025 surface fleet	2015-06	http://hdl.handle.net/10945/45933
LCDR Michael C. Albrecht, USN	Air asset to mission assignment for dynamic high-threat environments in real-time	2015-03	http://hdl.handle.net/10945/45155
LCDR Vincent H. Dova, USN	Software-defined avionics and mission systems in future vertical lift aircraft	2015-03	http://hdl.handle.net/10945/45181
LCDR Maxine J. Gardner, USN	Investigating the naval logistics role in humanitarian assistance activities	2015-03	http://hdl.handle.net/10945/45189
LT Bruce W. Hill, USN	Evaluation of efficient XML interchange (EXI) for large datasets and as an alternative to binary JSON encodings	2015-03	http://hdl.handle.net/10945/45196
LT Seneca R. Johns, USN	Automated support for rapid coordination of joint UUV operation	2015-03	http://hdl.handle.net/10945/45199
LT Forest B. Mclaughlin, USN	Undersea communications between submarines and unmanned undersea vehicles in a command and control denied environment	2015-03	http://hdl.handle.net/10945/45224
LT Adam R. Sinsel, USN	Supporting the maritime information dominance: optimizing tactical network for biometric data sharing in maritime interdiction operations	2015-03	http://hdl.handle.net/10945/45257
LT Andrew R. Thompson, USN	Evaluating the combined UUV efforts in a large-scale mine warfare environment	2015-03	http://hdl.handle.net/10945/45263
LT Bradley R. Turnbaugh, USN	Extending quad-rotor UAV autonomy with onboard image processing	2015-03	http://hdl.handle.net/10945/45265
LT Nicholas D. Vallardarez, USN	An adaptive approach for precise underwater vehicle control in combined robot-diver operations	2015-03	http://hdl.handle.net/10945/45268

Laser-Based Training Assessment Team, Cohort 311-133A	Research and analysis of possible solutions for Navy-simulated training technology	2015-03	http://hdl.handle.net/10945/45245
HEL Battle Damage Assessment Team, Cohort 311-133O	Increasing the kill effectiveness of High Energy Laser (HEL) Combat System	2015-03	http://hdl.handle.net/10945/45247
HEL Test Bed Team, Cohort 311-133O	Comprehensive system-based architecture for an integrated high energy laser test bed	2015-03	http://hdl.handle.net/10945/45246
LtCol Thomas A. Atkinson, USMC	Marine Corps expeditionary rifle platoon energy burden	2014-12	http://hdl.handle.net/10945/44514
LT Brenton Campbell, USN	Human robotic swarm interaction using an artificial physics approach	2014-12	http://hdl.handle.net/10945/44531
LT Chase H. Dillard, USN	Energy-efficient underwater surveillance by means of hybrid aquacopters	2014-12	http://hdl.handle.net/10945/44551
LCDR Kathryn M. Hermsdorfer, USN	Environmental data collection using autonomous Wave Gliders	2014-12	http://hdl.handle.net/10945/44577
LT Ryan P. Hilger, USN	Acoustic communications considerations for collaborative simultaneous localization and mapping	2014-12	http://hdl.handle.net/10945/44579
LCDR Ramon P. Martinez, USN	Bio-Optical and Hydrographic Characteristics of the western Pacific Ocean for Undersea Warfare Using Seaglider Data	2014-12	http://hdl.handle.net/10945/44612
LT Mark C. Mitchell, USN	Impacts of potential aircraft observations on forecasts of tropical cyclones over the western North Pacific	2014-12	http://hdl.handle.net/10945/44619
LT Dominic J. Simone, USN	Modeling a linear generator for energy harvesting applications	2014-12	http://hdl.handle.net/10945/44669
Team MIW, SE311-132Open/	Application of Model-Based Systems Engineering (MBSE) to compare legacy and future forces in Mine Warfare (MIW) missions		http://hdl.handle.net/10945/44659
Joong Yang Lee, NTU Singapore	Expanded kill chain analysis of manned-unmanned teaming for future strike operations	2014-09	http://hdl.handle.net/10945/43944
Montrell Smith, DON Civilian	Converting a manned LCU into an unmanned surface vehicle (USV): an open systems architecture (OSA) case study	2014-09	http://hdl.handle.net/10945/44004
CDR Ellen Chang, USNR	Defining the levels of adjustable autonomy: a means of improving resilience in an unmanned aerial system	2014-09	http://hdl.handle.net/10945/43887
Chee Siong Ong, NTU Singapore	Logistics supply of the distributed air wing	2014-09	http://hdl.handle.net/10945/43969
LT Barry Scott, USNR	Strategy in the robotic age: a case for autonomous warfare	2014-09	http://hdl.handle.net/10945/43995
LT Blake Wanier, USN	A modular simulation framework for assessing swarm search models	2014-09	http://hdl.handle.net/10945/44027

Chung Siong Tng, NTU Singapore	Effects of sensing capability on ground platform survivability during ground forces maneuver operations	2014-09	http://hdl.handle.net/10945/44018
LT Nicole R. Ramos, USN	Assessment of vision-based target detection and classification solutions using an indoor aerial robot	2014-09	http://hdl.handle.net/10945/43984
Ceying Foo, NTU Singapore	A systems engineering approach to allocate resources between protection and sensors for ground systems for offensive operations in an urban environment	2014-09	http://hdl.handle.net/10945/43914
Team Amberland, Cohort 311-131O	A systems approach to architecting a mission package for LCS support of amphibious operations	2014-09	http://hdl.handle.net/10945/43992

To aid new NPS students in their search for viable thesis topics, CRUSER maintains an iterative listing of potential thesis topics related to unmanned systems.

4. NPS Student Travel

CRUSER supported 65 NPS student trips in FY15 to further their thesis work (see Table 5). NPS students were then required to give a trip report at a monthly NPS CRUSER meeting to further socialize their work. Additional student trips were funded out of individual project funds.

Table 5. CRUSER supported student travel, FY15.

Date	Student	Destination/Purpose
Sept 2015	LT Matthew Maupin	Keyport, WA site visit
Sept 2015	Robert Wright, Andrew Chaves, Fum Wei Zhong, Eugene Lee Wei Sheng, ENS Fletcher Rydalch	Mojave trip to shoot rocket
Sept 2015	LCDR Brian Roth, LCDR Jade Buckler	Silicon Valley - Continue survey of UAVs
Sep 2015	LCDR O'Brian	Field Experimentation
Sep 2015	CDR Hall	Field Experimentation
Aug 2015	Major Tom Chhabra, Major Eric Keim, Major Matt Rice	Herndon, VA - Interview with modelers
Aug 2015	CPT Simon Sanchez, Edgar Carcener,LT, USN and Stephen Kent,CPT, USMC	JIFX
Aug 2015	Andrew Chavez, Robert Wright, Fletcher Rydalch, Fum Wei Zhong, and Eugene Lee Wei Sheng	JIFX
Aug 2015	CDR Hall	Field Experimentation
Aug 2015	MAJ Stephens	Field Experimentation
Aug 2015	LCDR O'Brian	Field Experimentation

Aug 2015	LT Towey	Conference Attendance
Aug 2015	LT Hime	Conference Attendance
Jul 2015	Maj Rob Arant	Black Dart
Jul 2015	Capt Matt Zach	Pensacola, FL - Work with IHMC Pensacola
Jul 2015	LCDR Brian Roth, LCDR Jade Buckler	St Petersburg, FL - UAV Survey of In-Ovation, Inc
Jul 2015	LT Michael Youngman, USN	Hands-on thesis research with UAVs at Camp Roberts.
Jul 2015	LT Ross Eldred, LCDR Jake Jones, LCDR Michael Mitchelson	NASA NEEMO event in Key Largo, FL - 1 week each, staggered dates
Jun 2015	LCDR O'Brian	Field Experimentation
Jun 2015	CDR Hall	Field Experimentation
Jun 2015	MAJ Stephens	Field Experimentation
May 2015	CDR Hall	Field Experimentation
May 2015	MAJ Stephens	Field Experimentation
May 2015	LCDR O'Brian	Field Experimentation
Apr 2015	LCDR O'Brian	Field Experimentation
Apr 2015	CDR Hall	Field Experimentation
Apr 2015	Matt Kiefer	TechCon participation
Apr 2015	LT Towey	Conference Attendance
Apr 2015	LT Hime	Conference Attendance
Mar 2015	CDR Michael Szczerbinsk	Joint Undersea Warfare Technology Conf
Mar 2015	LT Ryan Beall	San Jose conference
Feb 2015	Capt Caroline Scudder	pick up EW equip
Feb 2015	Maj Erik Keim, Capt Matt Rice	Brief to Marine Corps Warfighting Laboratory (MCWL) and other DOD Stake holders on UTACC Concept.
Feb 2015	LCDR Nate Spurr	Exploring Unmanned System Autonomy in the DoD Symposium
Feb 2015	LCDR Nick Valladarez	Pavilion Lake, BC field experimentation
Feb 2015	Capt Caroline Scudder	Old Crows (AOC) training "EW104: Critical Thinking and Problem Solving for Electronic Warfare
Feb 2015	LTJG Taylor Whitaker	China Lake Experiment
Feb 2015	CDR Michael Szczerbinski, LCDR Jeffrey Webb	Aerojet Rocketdyne in Sacramento and talk to SMEs
Dec 2014	LT Russell Pav	NUWC Keyport Site Visit

Nov 2014	CDR Michael Szczerbinski, LCDR Jeffrey Webb	SPAWAR SD site visit - meet with undersea efffects technical SMEs (Classified)
Nov 2014	LTJG Taylor Whitaker	China Lake site visit
Nov 2014	Camp Donald Wimmer, USMC	UTACC Site visit
Nov 2014	LCDR Gardner, LT Thompson	San Francisco site visit
Nov 2014	CDR Michael Szczerbinski, LCDR Jeffrey Webb	China Lake site visit - meet with JDAM technical SMEs (Classified)
Nov 2014	LT Christopher Machado	Camp Roberts - JIFX

C. CONCEPT GENERATION

The first NPS Innovation Seminar supported the CNO sponsored *Leveraging the Undersea Environment* wargame in February 2009. Since that time, warfare innovation workshops have been requested by various sponsors to address self-propelled semi-submersibles, maritime irregular challenges, undersea weapons concepts and general unmanned concept generation. Participants in these workshops include junior officers from NPS and the fleet, early career engineers from Navy laboratories, academic and industry partners, and NWC Strategic Studies Group (SSG) Director Fellows.

1. Warfare Innovation Workshops

The first CRUSER sponsored Warfare Innovation Workshop (WIW) was in March 2011, shortly after the formal launch of the Consortium. Since that time CRUSER has sponsored seven complete workshops covering topics of interest to a wide variety of the full community of interest, and has generated nearly 500 technology and employment concepts. Workshops to date include:

1) Future Unmanned Naval Systems (FUNS) Wargame Competition, March 2011
2) Revolutionary Concept Generation from Evolutionary UxS Technology Changes, September 2011
3) Advancing the Design of Undersea Warfare, September 2012
4) Undersea Superiority 2050, March 2013
5) Distributed Air and Surface Force Capabilities, September 2013
6) Warfighting in the Contested Littorals, September 2014

7) Unmanned Maritime Systems Life Cycle Costing, March 2015

8) Creating Asymmetric Warfighting Advantages, September 2015

Our most recent workshop, Creating Asymmetric Warfighting Advantages, was held 21-24 September 2015 on the NPS campus. This NWDC and CRUSER sponsored workshop included just over 90 participants representing a wide variety of stakeholder groups.

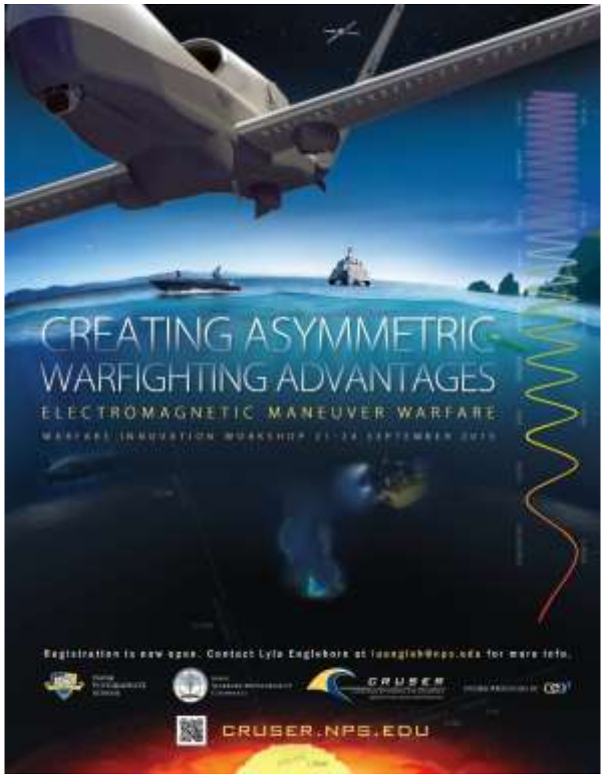


Figure 60. September 2015 Warfare Innovation Workshop, "Creating Asymmetric Warfighting Advantages"

Emerging technologies in unmanned systems; autonomy; missile systems; undersea systems; long-range, netted and multi-domain sensors; and networks create a new environment for operations on and over the sea. This changing technology environment both challenges traditional fleet operations and creates opportunities for innovative tactics, techniques, and procedures to achieve naval objectives in sea control, power projection and counter Anti-Access Area Denial (A2AD) strategies in the littorals. The 2015 workshop focused on advancing the CNO's concept of Electromagnetic Maneuver Warfare (EMW) and leveraging unmanned systems to enhance cross domain operations.

Figure 61. September 2015 Warfare Innovation Workshop

As with past workshops, participants included NPS students from across campus, as well as guests from Navy labs, other DoD commands, academia and industry. After a morning knowledge-leveling plenary briefings, team participated in an innovation seminar by NPS faculty member Dr. Neal Thornberry. Teams spent the next two days generating concepts to enhance future warfighting in the littoral environment, and presented their chosen concepts on Thursday morning. All participants earned Continuing Education Credits (CEUs) from the Naval Postgraduate School for this event. CEUs will be awarded as part of CRUSER's education mandate for any CRUSER activity that meets applicable academic guidelines.

CRUSER and Warfare Innovation Continuum leadership reviewed all the proposed concepts and selected ideas with potential operational merit that aligned with available resources. All these concepts are described fully in the September 2015 Warfare Innovation Workshop final report at the unclassified but controlled level.

Selected concepts will begin CRUSER's fifth Innovation Thread, and members of the CRUSER community of interest will be invited to further develop these concepts in response to the FY16 Call for Proposals. A final report detailing process and outcomes will be released before the end of the 2016 calendar year to a vetted distribution list of leadership and community of interest members. Technical members of the CRUSER community of interest will make proposals to test concepts in lab or field environments.

2. CRUSER Technology Continuum (TechCon), April 2015

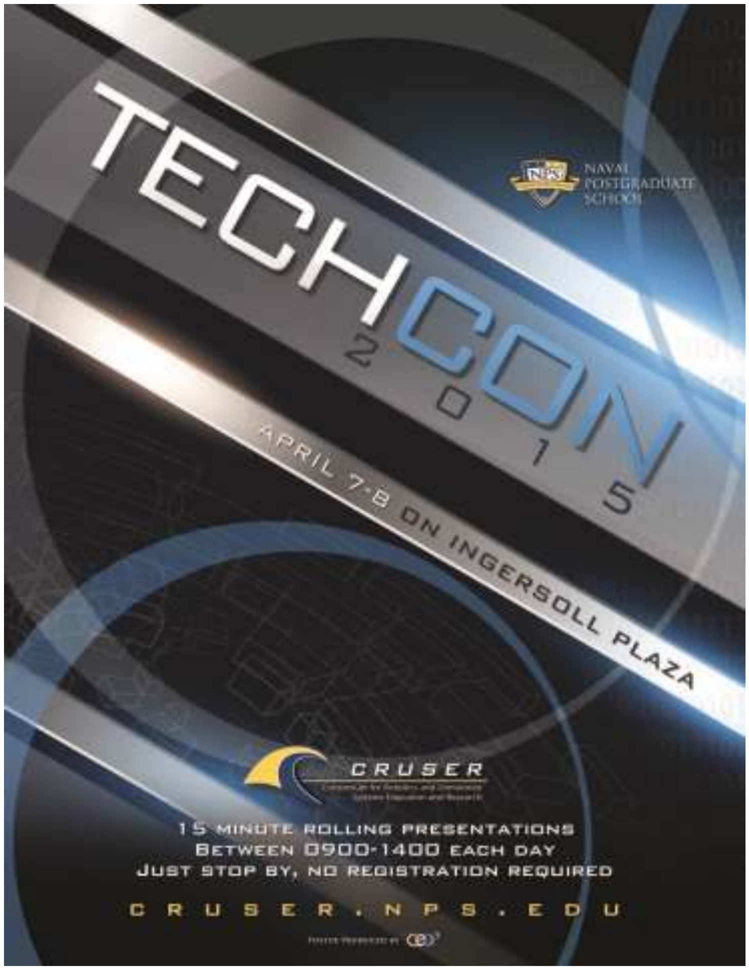


Figure 62. CRUSER Technical Continuum (TechCon), April 2015

NPS CRUSER held its fourth annual Technical Continuum (TechCon) on 7 and 8 April 2015. This event was for NPS students and faculty interested in education, experimentation and research related to employing unmanned systems in operational environments.

Tuesday 7 April 2015

900	**905**	Introduction	CRUSER Director
905	**920**	Dr Timothy Chung	Advancing Swarm and Counter-Swarm UAV Capabilities and Technologies
925	**940**	Prof Peter Guest LT Chris Machado, USN	Accurate Enough to Provide Useful Data on Electromagnetic and Meteorological Conditions in the Vicinity of US Navy Ships?
945	**1000**	Prof Xiaoping Yun Mr James Calusdian	A MATLAB Interface for the P3-DX Mobile Robot
1005	**1020**	Prof Peter Chu	Glider and Ship Measured Underwater Optical Characteristics for Naval Operations
1025	**1040**	Prof Ronald Giachetti	Agent-based Simulation of System-of-system Architectures Combining Manned and Unmanned Air Vehicles
1045	**1100**	Mr Curtis Blais	Representation of Unmanned Systems in Naval Analytical Modeling and Simulation
1105	**1120**	Prof Ric Romero	Adaptive Beamsteering for Search-and-Track Application with Cognitive Radar Network
1125	**1140**	Prof Qing Wang	Autonomous Wave Gliders for Air-sea Interaction Research
1145	**1200**	LT Shannon Zoch, USN	An Efficient Routing Protocol for Dynamic Flying Ad-Hoc Networks (FANETs).
1205	**1220**	Dr Kristin Giammarco Dr Mikhail Auguston	Advancing Model-Based Design and Assessment of Robotics and Unmanned Systems
1225	**1240**	Prof Kevin B Smith LT Renato Peres Vio, Brazilian Navy	Real-time undersea networking using acoustic communications for improved UUV positioning and collaboration
1245	**1300**	Dr Richard C. Millar LT Matt Kiefer, USN	Development of a Process for Airworthiness Assessment of Unmanned Aircraft
1305	**1320**	Prof David Jenn	Wireless Power Transmission for Battery Charging and AUV/UAV Power Applications
1325	**1340**	LT Raymond Davis, USN LT Patrick Livesay, USN	The Design and Optimization of Swarm Capable, Smart UAV Launchers
1345	**1400**	Dr Douglas Horner	AUV Operations in Extreme Environments: Under-Ice Operations

Wednesday 8 April 2015

900	**905**	Introduction	CRUSER Director
905	**920**	Dr Kevin Jones Dr Qing Wang	Low-Cost Expendable UAS with Application to Lower Atmospheric Measurements
925	**940**	LCDR Brian Judy,USN and SEA-21A cohort	Organic Surface Combatant Over-The-Horizon Targeting for 2025 and Beyond
945	**1000**	Prof Isaac Kaminer Ms Claire Walton	Optimal Motion Planning for Search of Uncertain Targets and Defense against a Swarm Attack using UxSs
1005	**1020**	Dr Kwang sub Song Prof Peter Chu	Conceptual Design of Future Undersea Unmanned Vehicle (UUV) System for Mine Disposal
1025	**1040**	Prof Noel Du Toit	Robotic Outposts: Enabling Persistent AUV Operations
1045	**1100**	LT Douglas McIntosh, USN	Preventing Encroachment by Hobby Grade Small Unmanned Aerial Systems
1105	**1120**	Prof Marcello Romano Mr Alessio Grompone	Artificial Vision Estimation of Relative Motion of Autonomous Vehicles
1125	**1140**	LT David J. Cummings, USN	Viability of Open Source Software in Department of Defense Unmanned Aerial Systems
1145	**1200**	Prof John Joseph	Application of ocean gliders in tactical oceanography: Characterizing ambient noise
1205	**1220**	Mr Sean Kragelund	Intelligent Sensing: Initial Results with an ATLAS sonar on the NPS SeaFox USV
1225	**1240**	Capt Scotty Black, USMC	The Missions, the Tactics, the Implementation: a Simulation for Aerial Combat Swarms
1245	**1300**	Dr Joshua H. Gordis Ms Claire Walton	On the use of UxVs in Seabasing Cargo Transfer
1305	**1320**	LT Fatih Sen, Turkish Air Force	The Use of Unmanned Combat Aerial Vehicles in Conjunction with Manned Aircraft to Counter Active Terrorists in Rough Terrain
1325	**1340**	LTJG Salim Unlu, Turkish Navy	Assessing the Tactical Effectiveness and Performance of Prospective ASW Unmanned Surface Vehicles in Naval Convoy Operations
1345	**1400**	Prof Susan M Sanchez	Closing Capability Gaps: Data Farming Methods for New Concept Exploration in the CRUSER Community

TechCon 2015 was intended to further concepts developed during the September 2014 Warfare Innovation Workshop, and showcase NPS student and faculty work in advancing unmanned systems. TechCon 2015 was held in a tent out on the academic quad. Presentations covered on-going student and faculty research, as well as proposals for CRUSER FY16 funding in research related to unmanned systems. The NPS CRUSER TechCon 2015 was unclassified.

D. OUTREACH AND RELATIONSHIPS

1. Community of Interest

CRUSER continued to grow its membership throughout FY15. At the end of FY11, CRUSER's first program year, the CRUSER community of interest had grown to include almost 400 members. As of March 2014 this fledgling community consisted of over 1,300 members (see Figure 63). In the two years spanning 2012-2014 CRUSER more than doubled in size, from just of 800 members in September 2012 to approximately 1630 members as of September 2014. This is largely due to CRUSER web presence and member interaction with military, academic and industry personnel during field experimentation, workshops, educational for and CRUSER monthly meetings. FY15 brought the community over the 2,000 member mark. Figure 63 graphic depicts this continued steady rise in CRUSER membership.

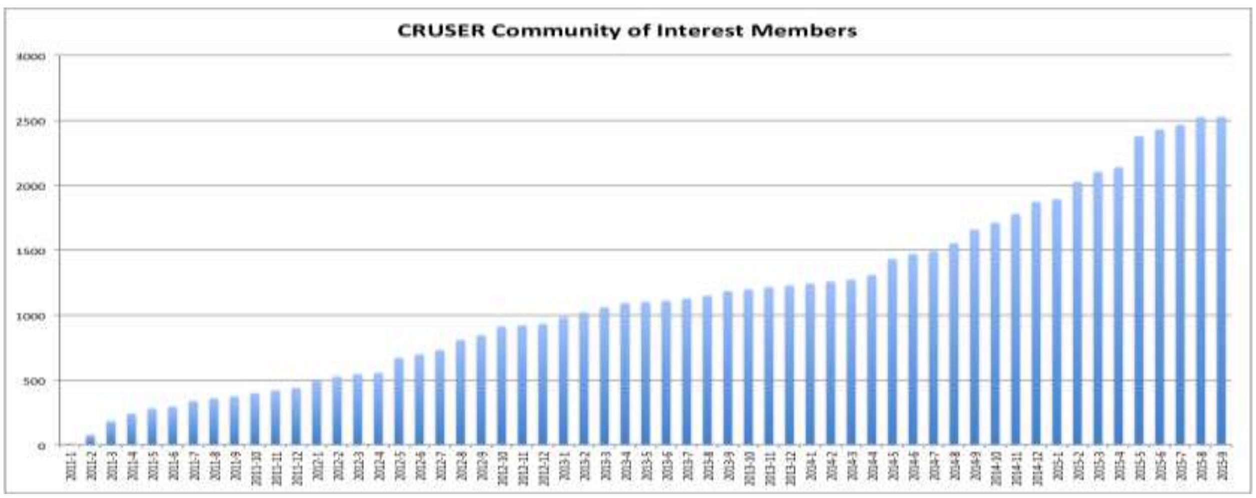


Figure 63. CRUSER community of interest growth from January 2011 to September 2015

Beyond NPS community members, the CRUSER community of interest includes major stakeholders from across the DoD, as well as significant representation from industry and academia (see Figure 64).

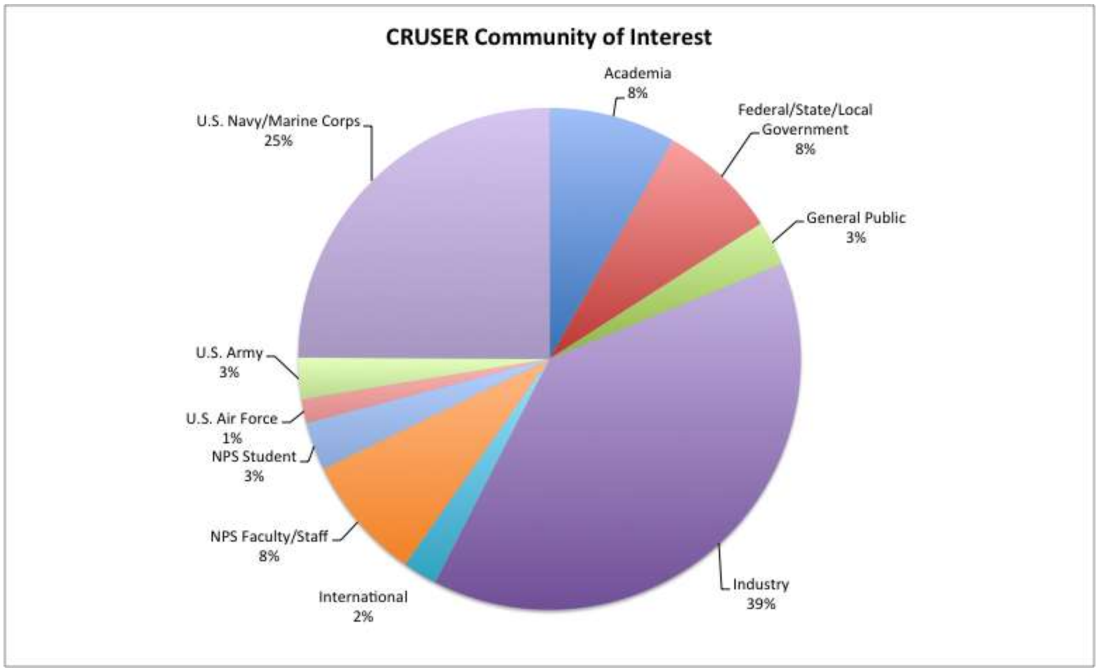


Figure 64. CRUSER community of interest breadth of membership, September 2015

CRUSER continues to produce a monthly newsletter, and accepts article submissions from the entire community. This short document (4-6 pages) is made available electronically each month to the entire community distribution list, and just published Issue 55 in September 2015. To start FY16, in October 2015 CRUSER will begin distributing the 'Unmanned Systems Sentinel' in lieu of CRUSER blog postings. This digest of unmanned systems related articles from a variety of news sources, government and public sector. Additionally, CRUSER holds a monthly community meeting on the NPS campus (see Figure 65).

Figure 65. CRUSER monthly meeting in progress, September 2013

Non-resident members may join the meeting by phone, video, or using the campus distance learning tool Collaborate.

2. 5th Annual Robots in the Roses Research Fair, April 2015

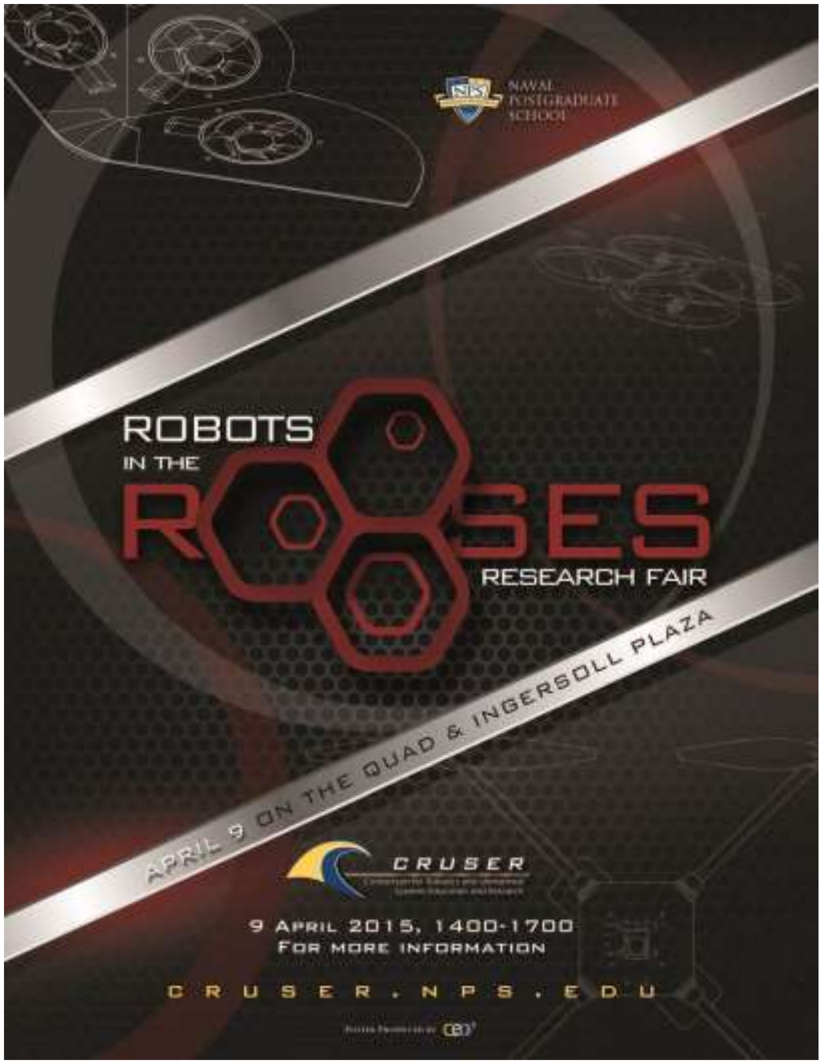


Figure 66. Robots in the Roses Research Fair, April 2015

Since 2011, CRUSER has hosted an annual research fair highlighting unmanned systems activity on the NPS campus. The invitation to this event was distributed to the NPS campus CRUSER community of interest to provide NPS students the opportunity to explore potential thesis topics involving emergent technology, and inspire younger students to approach their formal education in science, technology, engineering and math with zeal. Several hundred NPS staff, faculty, and students were joined by local community members and families on the NPS campus in Monterey.

3. ONR-Reserve Component Relationship

The Office of Naval Research – Reserve Component (ONR-RC) provided operational support to many CRUSER projects, programs, and events in FY15. Collaboration between CRUSER researchers at the Naval Postgraduate School (NPS) and ONR-RC began four years ago with personnel from the ONR-113 unit based at NPS, and has expanded to several additional ONR Reserve units.

In FY15, ONR-RC personnel participated in the CRUSER Technical Continuum and the 5th annual Robots in the Roses Research Fair and education outreach event where they led a hands-on SeaPerch activity for attendees, and answered questions on the robotics and research projects they supported. This cooperative arrangement was noted in the April 2015 issue of The Navy Reservist (TNR) Magazine:

> *"In the air warfare arena, ONR Reserve Sailors support several UAV projects – one with the Naval Postgraduate School Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) program at Camp Roberts, California. A team of Reserve Sailors is supporting the project's goal to fly 50 UAVs simultaneously and autonomously." (page 14)*

4. Community of Interest Outreach

NPS Research Associate David Place has supported the CRUSER program as an outreach agent and advocate by providing presentations at several unmanned systems conferences such as the Association of Unmanned Vehicles Systems International (AUVSI), Technology Training Corporation (TTC), and Tactical Analysis and Assessment Center (TAAC). He also shared the program with civilian and government personnel by providing CRUSER programmatic overviews at a variety of community and government events such as the MIT Executive Forum. He personally added 1000 new members to the CRUSER COI in FY15, increasing the total membership to nearly 2600. His advocacy for CRUSER and its mission, with government, academia and industry groups facilitated the growth of the community of interest in FY15 and this growth was a direct result of his outreach efforts.

In residence at the THIRDFLEET Headquarters in San Diego, Mr. Place also electronically distributes the *Unmanned Systems Sentinel*, a newsletter which highlights a multitude of unmanned systems related news articles, summaries and links pulled from a variety of media sources. In FY 15, he posted over 600 news articles on NPS's CRUSER wiki site and distributed approximately 400 articles via his Unmanned Systems Sentinels, which are ultimately made available to the entire CRUSER Community of Interest. Additionally, over the last several years he has developed his own distribution list, approximately 350 personnel, who also receive the *Sentinels*. He continuously fosters awareness for CRUSER goals and helps meet its information sharing mandate.

III. CONCLUSION

In FY15 CRUSER's primary focus shifted from creating a self-sustaining community of interest to impacting the larger naval and communities. FY15 was the second year that CRUSER was at full funding and the year demonstrated the value of a broad based, multi-institutional consortium to the naval enterprise. CRUSERs growing reputation and impact led to the community growing beyond 2500 members in the same year that it first exceeded 2000, illustrating an accelerating growth curve.

CRUSER supported just over 40 individual theses and six group capstone projects in FY15. Support to individual professors provided direct impact on teaching in 20 NPS classrooms. CRUSER supported classroom projects designed provide input for larger naval wargames as well as providing direct feedback to operators and engineers in the fleet and at warfare centers. Workshops on ethical issues involved with employing unmanned systems, cost models for unmanned maritime systems, and *The Future of Just War* conference put critical non-technological issues under the spotlight for examination by hundreds of academics, warriors and policy makers. CRUSER activities such as these also made continuing education credits available to over 100 officers from around the fleet. CRUSER funded research projects have led the way, working closely with NAVAIR, in developing methods to accomplish critical research using operational risk methodologies for flight safety. This work allowed NPS to successfully fly the world's first 50 UAV autonomous swarm; and conduct flight, surface and submerged operations in extreme environments. CRUSER members are on innovation teams and advisory boards across the naval and defense enterprise. CRUSER has also taken on an important advisory role with CRUSER leadership conducting reviews and/or providing input, by request, to the Joint Staff, Deputy Secretary of Defense and Secretary of the Navy during FY15.

A. PROPOSED FY16 ACTIVITIES

Finally, in FY16 the fourth CRUSER Innovation Thread will close out, work along the fifth thread will continue, and work will begin on the sixth thread. Proposed activities in FY16 include:

- As in past years, CRUSER will continue to fund the integration of robotics and unmanned systems issues into appropriate courses and support development of educational materials that will enable the Navy and Marine Corps officers afloat to become familiar with the challenges associated with the development and operational employment of these systems.

- CRUSER will host the fifth iteration of the Robo-Ethics Continuing Education Series (RECES) focused legal, social, cultural, and ethical issues for operators, acquisition professionals. CEUs will be available to participants in this event.

- CRUSER will host a fifth NPS CRUSER Technical Continuum to demonstrate technologies to explore development of the concepts generated the fall concept generation workshops. CRUSER TechCon 2016 will likely be scheduled the first full week of April to coincide with National Robotics Week.

- CRUSER will sponsor experimentation of the most promising technologies presented CRUSER TechCon 2015.

- CRUSER will participate in a campus STEM event designed to showcase NPS and the entire Naval enterprise for community elementary, secondary, and undergraduate students and their instructors.

- CRUSER will explore all opportunities to share the results of completed Innovation Threads with sponsors.

- CRUSER will continue to support summer internships from the service academy students to work in labs across NPS throughout FY16.

- CRUSER will fund NPS student trips in FY16 to participate in research and experimentation dealing with all aspects of unmanned systems.

- CRUSER will complete FY16 with a Warfare Innovation Workshop during NPS Thesis & Research Week on the academic calendar for 19-22 September 2016.

- CRUSER will continue Community of Interest database generation, monthly newsletter production and distribution, and monthly community-wide meetings.

- CRUSER will continue development of a strategy for graduate and non-graduate education across the naval enterprise with regards to robotic and unmanned systems.

B. LONG TERM PLANS

Continuing in FY16, CRUSER will build on program momentum to continue to influence the integration of robotics and unmanned systems concepts into educational programs across the naval enterprise to include NPS, USNA, NWC and NROTC while also expanding the number of educational opportunities available to naval officers serving in the fleet and marine forces. CRUSER will continue to support research and development with an emphasis on seeding new concepts, to include those identified in the FY15 Warfare Innovation Workshop. New activities will include a design thinking workshop focused on robotics and unmanned systems education. Additionally CRUSER will actively seek to explore the areas of C2 and man-machine combat teams to identify opportunities and areas for research to ensure that the naval forces are ready for the potentially rapid co-development of the organization to enable effective employment of these systems.

APPENDIX A: PRESENTATIONS, PUBLICATIONS AND TECHNICAL REPORTS BY NPS CRUSER MEMBERS, FY11 TO PRESENT

This cumulative list of publications and scholarly presentations is representative of those completed by NPS CRUSER members since program launch in 2011. It is not meant to be all-inclusive, only give a sense of the depth and breadth of the impact of NPS CRUSER members in the academic community.

Added in FY15 report:

Auguston, Mikhail (2014). "Behavior models for software architecture." Naval Postgraduate School Technical Report NPS-CS-14-003. Monterey, CA.

Auguston, Mikhail, Kristin Giammarco, W. Clifton Baldwin, Ji'on Crump, and Monica Farah-Stapleton (2015). Modeling and verifying business processes with Monterey Phoenix. Procedia Computer Science issue 44: Pages 345-353.

Du Toit, N.E. (2015). "Undersea Autonomy in Extreme Environments" presentation to Carmel Rotary Club, Carmel, March 2015

Du Toit, N.E. (2015). "Putting AUVs to Work: Enabling Close-Proximity AUV Operations" MBARI Seminar Series, Moss Landing, August 2015

Duan, W., B. E. Ankenman, S. M. Sanchez, and P. J. Sanchez (2015). Sliced Full Factorial-Based Latin Hypercube Designs as a Framework for a Batch Sequential Design Algorithm. Technometrics, *forthcoming*.

Dulo, D. (2015). *Unmanned Aircraft in the National Airspace: Critical Issues, Technology, and the Law.* American Bar Association: Chicago, August 2015. 368 Pages.

Dulo, D. (2015). *Unmanned Aircraft: The Rising Risk of Hostile Takeover*. IEEE Technology and Society Magazine, September 2015. http://ieeessit.org/technology_and_society/

Dulo, D. et al. (2015). *International Law and Unmanned Aircraft*. In The International Law Year in Review 2014, September 2-15. Chicago: American Bar Association.

Dulo, D. (2015). *Unmanned Aircraft Classifications: The Foundation for UAS Regulations in the National Airspace.* The SciTech Lawyer, Vol. 11, No. 4, Summer 2015. American Bar Association.

Dulo, D. (2015). *Drones and the Media: First and Fourth Amendment Issues in a Technological Framework*. Journal of International Entertainment and Media Law, Vol. 5 No. 2, June 2015.

Dulo, D. (2015). *Software or the Borg: A Starship's Greatest Threat?* Discovery News, 27 May 2015. http://news.discovery.com/space/software-or-the-borg-a-starships-greatest-threat-150527.htm

Dulo, D. (2015). Featured Guest. Wagner & Winick on the Law Radio Show, KSCO 1080. The Business Use of Drones, 12 September 2015. http://www.wagnerandwinick.com/listen.html

Dulo, D. (2015). Speaker. *Unmanned Aerial Systems: Know Before You Fly!* Wings Over Watsonville Airshow, September 2015. Watsonville, CA.

Dulo, D. (2013). Panel Member/Speaker. *Drones Incoming! Are you Ready for Unmanned Aerial Vehicles?* American Bar Association Annual Meeting August 2013, Chicago, IL. http://www.americanbar.org/news/abanews/aba-news-archives/2015/08/drone_regulationsde.html

Dulo, D. (2015). Featured Speaker. *Unmanned Aircraft: Law, and Policy Implications for Integration into the National Airspace.* National Association of Appellate Court Attorneys Annual Conference July 2015, Seattle, WA. http://naacaonline.sharepoint.com/Documents/br15.pdf

Dulo, D. (2015). Panel Member/Speaker. *Security & Information Assurance of Unmanned Aircraft: Law, Policy and Business Implications*. Law and Society Annual Conference May 2015, Seattle, WA. http://www.lawandsociety.org/Seattle2015/seattle2015.html

Dulo, D. (2015). Featured Speaker. *Unmanned Aerial Insecurity: The Liability, Security, and Policy Issues of Hostile Third Party Takeovers of Unmanned Aerial Systems*. Cyber West: The Southwest Cyber Security Summit, March 2015. Association for Enterprise Information. Phoenix, AZ. http://www.afei.org/PE/5A06/Pages/Thur.aspx

E. Capello, H. Park, B. Tavora, G. Gugleri, and M. Romano (2015). "Modeling and Experimental Parameter Identification of a Multicopter via a Compound Pendulum Test Rig." 2015 International Workshop on Research, Education, and Development on Unmanned Aerial Systems (RED-UAS 2015) *submitted*.

Giammarco, Kristin, Mikhail Auguston, W. Clifton Baldwin, Ji'on Crump, and Monica Farah-Stapleton (2014). "Controlling design complexity with the Monterey Phoenix approach." Procedia Computer Science 36 (2014): 204-209.

Giammarco, Kristin, Spencer Hunt, and Clifford Whitcomb (2015). “An Instructional Design Reference Mission for Search and Rescue Operations.” *Naval Postgraduate School Technical Report* NPS-SE-15-002. Monterey, CA.

Guest ,Peter S. (2014). “Quantifying the Accuracy of a Quad-Rotor Unmanned Aerial Vehicle as a Platform for Atmospheric Pressure, Temperature and Humidity Measurements near the Surface.” *American Geophysical Union Fall Meeting*, San Francisco California, 15-19 December 2014.

Guest, Peter S. and Christopher R. Machado (2014). “Using UAS to sense the physical environment and predict electromagnetic system performance.” *Naval Postgraduate School Technical Report* NPS-MR-15-001, Monterey CA, November 2014.

Hermsdorfer, Kate, Qing Wang, Richard Lind, Ryan Yamaguchi, and John Kalogiros (2015). “Autonomous Wave Gliders for Air-sea Interaction Research.” *19th Conference on Air-Sea Interaction*, 4–8 January 2015, Phoenix, Arizona

Michael A. Day et al. (2015). “Multi-UAV Software Systems and Simulation Architecture". In: *2015 International Conference on Unmanned Aerial Systems*. Denver, CO: IEEE, 2015, pp. 426-435.

Sanchez, S. M., Gardner, M., and Craparo, E. (2015). "Simulation Experiments Involving Stochastic Optimization Models for Disaster Relief" INFORMS Annual Meeting, 1-4 November 2015, Invited Presentation, INFORMS Simulation Society sponsored session

Sanchez, S. M. (2015). Simulation Experiments: Better Data, Not Just Big Data (2015). Proceedings of the 2015 Winter Simulation Conference, *forthcoming.*

Songzheng Song, Jiexin Zhang, Yang Liu, Jun Sun, Mikhail Auguston, Jin Song Dong, Tieming Chen (2015). “Formalizing and Verifying Stochastic System Architectures Using Monterey Phoenix,” *MODELS 2015* – Ottawa, Canada

Valladarez, N. D. and Du Toit, N. E. (2015). “Robust Adaptive Control of Underwater Vehicles for Precision Operations”, *to be presented IEEE/MTS Oceans Conference*, Washington D.C., October 2015

Venanzio Cichella, Isaac Kaminer, Vladimir Dobrokhodov, Naira Hovakimyan (2015)."Coordinated Vision Based Tracking of Multiple UAVs," *Proceedings of 2015 American Control Conference*

Venanzio Cichella, Isaac Kaminer, Vladimir Dobrokhodov, Naira Hovakimyan (2015). "Coordinated Vision-Based Tracking for Multiple UAVs," *Proceedings of 2015 International Conference on Intelligent Robots and Systems*

Venanzio Cichella, Isaac Kaminer, Vladimir Dobrokhodov, Enric Xargay, Ronald Choe, Naira Hovakimyan, A. Pedro Aguiar, and Antonio M. Pascoal (2015). "Cooperative Path-Following of MultipleMultirotors over Time-Varying Networks," to appear in IEEE Transactions on Automation Science and Engineering

Venanzio Cichella, Ronald Choe, S. Bilal Mehdi, Enric Xargay, Naira Hovakimyan, Vladimir Dobrokhodov, Isaac Kaminer, Antonio M. Pascoal, and A. Pedro Aguiar (2015). "Safe Coordinated Maneuvering of Teams of Multirotor UAVs: A Cooperative Control Framework for Multi-Vehicle Time-Critical Missions," *to appear in IEEE Control Systems Magazine*

Venanzio Cichella, Thiago Marinho, Dusan Stipanovi , Naira Hovakimyan, Isaac Kaminer, Anna Trujillo (2015). "Collision Avoidance Based on Line-of-Sight Angle," *to appear in Proceedings of 2015 IEEE Conference on Decision and Control*

Included in FY14 report:

Andersson, K., I. Kaminer, V. Dobrokhodov, and V. Cichella (2012). "Thermal Centering Control for Autonomous Soaring; Stability Analysis and Flight Test Results," *Journal of Guidance, Control, and Dynamics*, Vol. 35, No. 3 (2012), pp. 963-975. doi: 10.2514/1.51691

Auguston, M. and C. Whitcomb (2012). "Behavior Models and Composition for Software and Systems Architecture", *ICSSEA 2012, 24th International Conference on SOFTWARE & SYSTEMS ENGINEERING and their APPLICATIONS*, Telecom ParisTech, Paris, 23-25 October 2012. http://icssea.enst.fr/icssea12/

Boxerbaum, A., M. Klein, J. Kline, S. Burgess, R. Quinn, R. Harkins, R. Vaidyanatham (2012). "Design, Simulation, Fabrication and Testing of Bio-Inspired Amphibious Robot with Multiple Modes of Mobility," *Journal of Robotics and Mechatronics*, Vol. 24, No.4 August 2012.

Boucher, R., W. Kang, and Q. Gong (2014). Galerkin Optimal Control for Constrained Nonlinear Problems, *American Control Conference*, Portland, OR, June 2014.

Boucher, R., W. Kang, and Q. Gong, Discontinuous Galerkin Optimal Control for Constrained Nonlinear Problems, *IEEE ICCA*, Taichung, Taiwan, June 2014.

Brutzman, D., with T. Chung, C. O'Neal, J. Ellis and L. Englehorn (2011). *Future Unmanned Naval Systems (FUNS) Wargame Competition Final Report* (NPS-USW-2011-001) released July 2011.

Carpin, S., Chung, T. H., & Sadler, B. M. (2013). Theoretical Foundations of High-Speed Robot Team Deployment. In *Proceedings of the 2013 IEEE International Conference on Robotics and Automation*.

Chitre, M. (2012). "What is the impact of propagation delay on network throughput?" *Proc.NATO Underwater Communications Conf. (UComms)*, Sestri Levante, Italy, Sept 12-14, 2012

Chitre, M., A. Mahmood, and M. Armand (2012). "Coherent communications in snapping-shrimp dominated ambient noise environments," *Proc. Acoustics 2012* Hong Kong, vol. 131, p. 3277, May 2012

Chitre, M. (2013). "Teamwork among marine robots - advances and challenges," *Proc. WMR2013 - Workshop on Marine Robotics*, Las Palmas de Gran Canaria, Spain, February 2013

Chitre, M., I. Topor, R. Bhatnagar and V. Pallayil (2013). "Variability in link performance of an underwater acoustic network," *Proc. IEEE Oceans Conf.*, Bergen, Norway, June 2013

Chung, T. H., Jones, K. D., Day, M. A., Jones, M., and Clement, M. R. (2013). 50 VS. 50 by 2015: Swarm Vs. Swarm UAV Live-Fly Competition at the Naval Postgraduate School. In *AUVSI North America*. Washington, D.C.

Cichella, Choe, Mehdi, Xargay, Hovakimyan, Kaminer, Dobrokhodov, Pascoal, and Aguiar (2014)."Safe Time-Critical Cooperative Missions for Multiple Multirotor UAVs," Robotics Science and Systems. Workshop on *Distributed Control and Estimation for Robotic Vehicle Networks*, Berkeley, CA, July 2014.

Cichella, Choe, Mehdi, Xargay, Hovakimyan, Trujillo, and Kaminer (2014). "Trajectory Generation and Collision Avoidance for Time-Coordination of UAVs," *AIAA Guidance, Navigation, and Control Conference*, National Harbour, MD, January 2014.

Dono, T., and Chung, T. H. (2013). Optimized Transit Planning and Landing of Aerial Robotic Swarms. In *Proc. of 2013 IEEE Int'l. Conf. on Robotics and Automation*.

Du Toit, N.E.; Burdick, J.W. (2012) "Robot Motion Planning in Dynamic, Uncertain Environments," *IEEE Transactions on Robotics,* Vol. 28, Issue 1, pp. 101-115, 2012.

Economist (2013). "Underwater Networking: Captain Nemo goes online," *The Economist Magazine*, March 9, 2013

Ellis, W., D. McLay and L. Englehorn (2013). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Warfare Innovation Workshop (WIW) 2013 After Action Report: Undersea Superiority 2050*, released May 2013.

Gagnon, P. and J, Rice, G. Clark (2012). "Channel Modeling and Time Delay Estimation for Clock Synchronization Among Seaweb Nodes," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Gagnon, P. and J. Rice, G. A. Clark, "Clock Synchronization through Time-Variant Underwater Acoustic Channels," *Proc. NATO Underwater Communications Conference (UComms)*, Sestri Levante, Italy, 12-14 September 2012

Gardner, Maxine, LCDR, U.S. Navy (2014). "The Navy's Role in Humanitarian Assistance," *CRUSER TechCon 2014,* Monterey, California, April 2014.

Green, D. (2012). "ACOMMS Based Sensing, Tracking, and Telemetry," *Proc. 3rd WaterSide Security Conference*, Singapore, 28-30 May 2012

Guest, Peter S. (2014). The Use of Unmanned Systems for Environmental Sampling and Enhanced Battlespace Awareness in Support of Naval Operations, *CRUSER News*, Published at the Naval Postgraduate School, Monterey CA, January 2014.

Guest, Peter S. (2014).Using UAS to Sense the Physical Environment, presented at the *NPS OPNAV N2/N6 Studies Fair Potential Theses Topics*, Naval Postgraduate School, Monterey CA, 9 January 2014

Guest, Peter S. (2014). Atmospheric Measurements From a Mini-Quad Rotor UAV – How Accurate Are Measurements Near the Surface? *CRUSER TechCon 2014*, Monterey CA, 9 April 2014.

Guest, Peter S. (2014). How accurate are measurements near the surface? A poster presented at the *CRUSER 4th Annual "Robots in the Roses" Research Fair*, Naval Postgraduate School, Monterey CA, 10 April 2014.

Guest Peter S. (2014). Using Miniature Multi-Rotor Unmanned Aerial Vehicles for Performing Low Level Atmospheric Measurements, presented at *the 94th American Meteorological Society Annual Meeting, 18th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS) Session 8: Field Experiments*, Atlanta Georgia, 5 August 2014.

Guest, Peter S. (2014). Quantifying the Accuracy of a Quad-Rotor Unmanned Aerial Vehicle as a Platform for Atmospheric Pressure, Temperature and Humidity Measurements near the Surface, Abstract accepted for the *2014 American Geophysical Union Fall meeting*, San Francisco California, 15-19 December, 2014, abstract submitted 6 August 2014.

Guest, Peter S. (2013). "Using small unmanned aerial vehicles for undersea warfare," presented at the *NPS CRUSER Technical Continuum*, 9 April 2013.

Guest, Peter S., Paul Frederickson, Arlene Guest and Tom Murphree (2013). "Atmospheric measurements with a small quad-rotor UAV," a poster presented at the *"Robots in the Roses" Research Fair*, 11 April, 2013.

Guest Peter S. (2013). “The use of kites, tethered balloons and miniature unmanned aerial vehicles for performing low level atmospheric measurements over water, land and sea ice surfaces,” abstract accepted for presentation at the *94th American Meteorological Society Annual Meeting, 18th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS),* submitted 15 August, 2013.

Guest, Peter S., Trident Warrior 2013 (2013). “Demonstrating the use of unmanned aerial vehicles for characterizing the marine electromagnetic propagation environment,” presented at the *NPS CRSUER Monthly Meeting*, Naval Postgraduate School, Monterey CA, 11 September 2013.

Guest, Peter S., Trident Warrior 2013 (2013). “Evaporation and surface ducts,” presented at the *Trident Warrior 2013 Meeting, Naval Research Laboratory*, Monterey CA, 23 September, 2013.

Kaminer, I. (2014). "Maritime Force Protection and Herding," Presented at *ONR Science of Autonomy Workshop*, DC August 2014

Kaminer, I. (2014). "Small UAV Autonomy: Time-Coordinated Missions and Soaring Gliders," Presented at *NASA Langley Research Center* April 2014

King, S., W. Kang, and L. Xu (2014). Observability for Optimal Sensor Locations in Data Assimilation, *American Control Conference*, Portland, OR, June, 2014.

King, R. E. (2012). “Localization of a Mobile Node in an Underwater Acoustic Network,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Kline J. and L. Englehorn (2011). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Warfare Innovation Workshop (WIW) 2011 After Action Report*, released October 2011.

Kline J. and L. Englehorn (2012). *NWDC/ CRUSER Warfare Innovation Workshop (WIW) 2012 After Action Report: Advancing the Design of Undersea Warfare*, released November 2012.

Kline J. and L. Englehorn (2011). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Annual Report 2011: The Startup Year*, released December 2011.

Kline J. and L. Englehorn (2011). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Annual Report 2012: The Transition Year*, released November 2012.

Kline, J. and L. Englehorn, *Maritime Defense and Security Research Program, Final Report, 2004-2011*, Naval Postgraduate School NPS-NSI-11-01, November 2011

Lin, K. Y., Atkinson, M. P., Chung, T. H., & Glazebrook, K. D. (2013). A Graph Patrol Problem with Random Attack Times. *Operations Research*, 61(3), 694–710.

Mahmood, A., M. Chitre, and M. Armand (2012). "Improving PSK performance in snapping shrimp noise with rotated constellations," *Proc. WUWNet'12: 7th ACM International Conference on Underwater Networks & Systems*, Los Angeles, CA, pp. 1-8, November 2012

Muratore, M., Silvestrini, R. T., & Chung, T. H. (2012). Simulation Analysis of UAV and Ground Teams for Surveillance and Interdiction. *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, OnlineFirst.

Otnes, R. and V. Forsmo, H. Buen (2012). *NGAS Sea Trials*, Gulf of Taranto, Italy, September 2011, January 2012

Otnes, R. (2012). "NILUS – An Underwater Acoustic Sensor Network Demonstrator System," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Otnes, R. and J. Rice (2013). "Underwater acoustic sensor networking in NGAS 2012 sea trial at Oslo Fjord, Norway," *Proc. 1st Underwater Acoustics Conf*., Corfu, Greece, June 28, 2013

Phelps, C., Q. Gong, J.O. Royset, C. Walton, and I. Kaminer (2014 *pending*). "Consistent Approximation of a Nonlinear Optimal Control Problem with Uncertain Parameters", *Automatica*, accepted for publication.

Rice, J. (2011). "Maritime Surveillance in the Intracoastal Waterway using Networked Underwater Acoustic Sensors integrated with a Regional Command Center," invited presentation to *Small Vessel Security Threat Conference*, San Francisco CA, 29 September 2011

Rice, J. (2011). "Seaweb ASW Sensor Network," FY11 year-end project report for publication in *ONR Ocean Battlespace Sensing*, December 2011

Rice, J. and G. Wilson, M. Barlett (2012). "Deep Seaweb 1.0 Maritime Surveillance Sensor Network," *NDIA 2012 Joint Undersea Warfare Technology Spring Conference*, Undersea Sensors technical track, San Diego CA, 26-29 March 2012

Rice, J. (2012). "Node Ranging, Localization and Tracking as Functions of Underwater Acoustic Networks," *Proc. Acoustics 2012* Hong Kong, p. 91, 13-18 May 2012

Rice, J. and C. Fletcher, B. Creber, B. Marn, S. Ramp, F. Bahr (2012). “Implementation of an Underwater Wireless Sensor Network in San Francisco Bay,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rice, J. (2012). “Project MISSION – Maritime In Situ Sensing Inter-Operable Networks,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rice, J. (2012). “Weaponized Underwater Surveillance Network,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rice, J. and C. Fletcher, B. Creber, B. Marn, S. Ramp, F. Bahr (2012). “Implementation of an Underwater Wireless Sensor Network in San Francisco Bay,” *Proc. 3rd WaterSide Security Conference*, Singapore, 28-30 May 2012

Rice, J. (2012). “Seaweb Subsurface Sensor Network for Port Surveillance and Maritime Domain Awareness,” *NMIO Technical Bulletin*, National Maritime Intelligence-Integration Office, Summer 2012 issue, Vol. 3, pp. 10-14, August 2012

Rice, J. and M. Chitre (2013). “Maritime In Situ Sensing Inter-Operable Networks involving Acoustic Communications in the Singapore Strait,” *CRUSER Technical Continuum*, Monterey, CA, April 9, 2013

Rice, J. and M. Chitre (2013). “Maritime In Situ Sensing Inter-Operable Networks involving Acoustic Communications in the Singapore Strait,” *ONR Ocean Acoustics Review*, Bay St. Louis, MS, April 24, 2013

Rochholz, T. (2012). “Wave-Powered Unmanned Surface Vehicle Operation in the Open Ocean: A Station Keeping Asset for Distributed Netted Systems; PAC X: Transpacific Crossing of Wave Glider USVs,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rochholz, T. (2012). “Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks,” presented at *NDIA Undersea Warfare Technology Conference*, Groton, CT, 24-27 September 2012

Rothal, J. and A. Davis (2011). *A Sampling of NPS Theses and Reports on UxS*, produced by the Dudley Knox Library, released August 2011.

Sanchez, Susan M. (2014). “CRUSER Data Farming Workshops," *CRUSER TechCon 2014*, Monterey, California, April 2014.

Sanchez, Susan M., Paul J. Sanchez, and Hong Wan (2014). "Simulation Experiments: Better Insights by Design," *Summer Simulation Multiconference*, Monterey, California, July 2014.

Sanchez, Susan M. (2014). "Simulation experiments: Better data, not just big data." *Proceedings of the 2014 Winter Simulation Conference*, forthcoming

Shankar, S. and M. Chitre (2013). "Tuning an underwater communication link," *Proc. IEEE OCEANS Conf.*, Bergen, Norway, June 2013

Song, K.S., and P.C. Chu (2014). Conceptual Design of Future Undersea Unmanned Vehicle (UUV) System for Mine Disposal. *IEEE Systems Journal*, 8 (1), 41-51.

Streenan, A. and Du Toit, N.E. (2013) "Diver Relative UUV Navigation for Joint Human-Robot Operations", *MTS/IEEE Oceans Conference*, Sept. 23-26, San Diego, CA, 2013

Stevens, T., & Chung, T. H. (2013). Autonomous Search and Counter-Targeting using Levy Search Models. In *Proc. of 2013 IEEE Int'l. Conf. on Robotics and Automation*.

Thompson, Andrew, Lieutenant, U.S. Navy (2014). "Combined UUV Efforts in a Large-Scale Mine Warfare Environment" *CRUSER TechCon 2014*, Monterey, California, April 2014.

Walton, Claire, Qi Gong, Isaac Kaminer, Johannes Royset (2014). "Optimal Motion Planning for Searching for Uncertain Targets," *2014 International Forum of Automatic Control* (IFAC 2014)

Weiss, J.D. and Du Toit, N.E. (2013) "Real-Time Dynamic Model Learning and Adaptation for Underwater Vehicles", *MTS/IEEE Oceans Conference*, Sept. 23-26, San Diego, CA, 2013

Xargay, E., R. Choe, N. Hovakimyan, and I. Kaminer (2014 *pending*). "Convergence of a PI Coordination Protocol in Networks with Switching Topology and Quantized Measurements," *Automatica*, accepted for publication.

Xargay E., V. Dobrokhodov, I. Kaminer, A. Pascoal, N. Hovakimyan, and C. Cao (2011). "Time–Coordinated Path Following of Multiple Heterogeneous Vehicles over Time–Varying Networks," invited paper for *IEEE Control Systems Magazine, Special Issue on UAVs and Controls*, 2011.

Xargay, E., N.Hovakimyan, V.N. Dobrokhodov, I.I. Kaminer, C. Cao, I.M. Gregory (2012). "L1 Adaptive Control in Flight", chapter in a *book "Progress in Aeronautics and Astronautics Series", AIAA*, 2012.

Xu, N., G. Cai, W. Kang, and B.M. Chen (2012). "Minimum-time trajectory planning for helicopter UAVs using dynamic optimization." *IEEE International Conference on Systems, Man, and Cybernetics*, Seoul, South Korea, October 2012.

Yakimenko, O. A., & Chung, T. H. (2012). Extending Autonomy Capabilities for Unmanned Systems with CRUSER. *In Proceedings of the 28th Congress of the International Council of the Aeronautical Sciences (ICAS 2012)*. Brisbane, Australia.

Yakimenko, O.A., and Chung, T.H., "Extending Autonomy Capabilities for Unmanned Systems with CRUSER," *Proceedings of the 28th Congress of the International Council of the Aeronautical Sciences (ICAS 2012)*, Brisbane, Australia, 23-28 September 2012.

Yang, J. H., Kapolka, M., & Chung, T. H. (2012). Autonomy balancing in a manned-unmanned teaming (MUT) swarm attack. In *2012 International Conference on Robot Intelligence Technology and Applications*. Gwangju, Korea.

Zhang, Jiexin, Yang Liu, Mikhail Auguston, Jun Sun and Jin Song Dong (2012). "Using Monterey Phoenix to Formalize and Verify System Architectures", *19th Asia-Pacific Software Engineering Conference APSEC 2012*, Hong Kong 4 – 7 December 2012. http://www.comp.polyu.edu.hk/conference/APSEC2012/

APPENDIX B: CUMULATIVE THESES AND STUDENT PROJECTS SUPPORTED

This list includes thesis and projects from FY11 forward. Unclassified NPS theses are available through the NPS Dudley Knox Library and DTIC. This list is alphabetized by student last name, and separated by year of completion (chronologically backward). As of September 2015, CRUSER has supported nearly 200 master's theses and capstone projects, and one doctoral dissertation.

Added in FY15:

AUTHOR(s)	TITLE	DATE (year-mo)	URL
Robert Humeur, Swedish Army	A New High-Resolution Direction Finding Architecture Using Photonics and Neural Network Signal Processing for Miniature Air Vehicle Applications	2015-09	
LT Spencer S. Hunt, USN	Model based systems engineering in the execution of search and rescue operations.	2015-09	
Capt Caroline A. Scudder, USMC	Electronic Warfare Network Latency Within SUAS Swarms	2015-09	
LT Sean M. Sharp, USN	Impact of Time-Varying Sound Speed Profiles with Seaglider on ASW Detection Ranges in the Strait of Hormuz (SECRET).	2015-09	
Victoria Steward	Functional flow and event-driven methods for predicting system performance.	2015-09	
Maj Thomas M. Rice, USMC Maj Erik A. Keim, USMC Maj Tom Chhabra, USMC	Unmanned Tactical Autonomous Control and Collaboration Concept of Operations	2015-09	
Capt Patrick N. Coffman, USMC	Capabilities assessment and employment recommendations for Full Motion Video Optical Navigation Exploitation (FMV-ONE)	2015-06	http://hdl.handle.net/10945/45827
LT David Cummings, USN	Survivability as a tool for evaluating open source software	2015-06	http://hdl.handle.net/10945/45833
Capt Louis T. Batson, USMC Capt Donald R. Wimmer, Jr., USMC	Unmanned Tactical Autonomous Control and Collaboration threat and vulnerability assessment	2015-06	http://hdl.handle.net/10945/45738

LT Arturo Jacinto, II, USN	Unmanned systems: a lab-based robotic arm for grasping	2015-06	http://hdl.handle.net/10945/45879
LTJG Salim Unlu, Turkish Navy	Effectiveness of unmanned surface vehicles in anti-submarine warfare with the goal of protecting a high value unit	2015-06	http://hdl.handle.net/10945/45955
Systems Engineering Analysis Capstone SEA21A	Organic over-the-horizon targeting for the 2025 surface fleet	2015-06	http://hdl.handle.net/10945/45933
LCDR Michael C. Albrecht, USN	Air asset to mission assignment for dynamic high-threat environments in real-time	2015-03	http://hdl.handle.net/10945/45155
LCDR Vincent H. Dova, USN	Software-defined avionics and mission systems in future vertical lift aircraft	2015-03	http://hdl.handle.net/10945/45181
LCDR Maxine J. Gardner, USN	Investigating the naval logistics role in humanitarian assistance activities	2015-03	http://hdl.handle.net/10945/45189
LT Bruce W. Hill, USN	Evaluation of efficient XML interchange (EXI) for large datasets and as an alternative to binary JSON encodings	2015-03	http://hdl.handle.net/10945/45196
LT Seneca R. Johns, USN	Automated support for rapid coordination of joint UUV operation	2015-03	http://hdl.handle.net/10945/45199
LT Forest B. Mclaughlin, USN	Undersea communications between submarines and unmanned undersea vehicles in a command and control denied environment	2015-03	http://hdl.handle.net/10945/45224
LT Adam R. Sinsel, USN	Supporting the maritime information dominance: optimizing tactical network for biometric data sharing in maritime interdiction operations	2015-03	http://hdl.handle.net/10945/45257
LT Andrew R. Thompson, USN	Evaluating the combined UUV efforts in a large-scale mine warfare environment	2015-03	http://hdl.handle.net/10945/45263
LT Bradley R. Turnbaugh, USN	Extending quad-rotor UAV autonomy with onboard image processing	2015-03	http://hdl.handle.net/10945/45265
LT Nicholas D. Vallardarez, USN	An adaptive approach for precise underwater vehicle control in combined robot-diver operations	2015-03	http://hdl.handle.net/10945/45268
Laser-Based Training Assessment Team, Cohort 311-133A	Research and analysis of possible solutions for Navy-simulated training technology	2015-03	http://hdl.handle.net/10945/45245
HEL Battle Damage Assessment Team, Cohort 311-133O	Increasing the kill effectiveness of High Energy Laser (HEL) Combat System	2015-03	http://hdl.handle.net/10945/45247
HEL Test Bed Team, Cohort 311-133O	Comprehensive system-based architecture for an integrated high	2015-03	http://hdl.handle.net/10945/45246

	energy laser test bed		
LtCol Thomas A. Atkinson, USMC	Marine Corps expeditionary rifle platoon energy burden	2014-12	http://hdl.handle.net/10945/44514
LT Brenton Campbell, USN	Human robotic swarm interaction using an artificial physics approach	2014-12	http://hdl.handle.net/10945/44531
LT Chase H. Dillard, USN	Energy-efficient underwater surveillance by means of hybrid aquacopters	2014-12	http://hdl.handle.net/10945/44551
LCDR Kathryn M. Hermsdorfer, USN	Environmental data collection using autonomous Wave Gliders	2014-12	http://hdl.handle.net/10945/44577
LT Ryan P. Hilger, USN	Acoustic communications considerations for collaborative simultaneous localization and mapping	2014-12	http://hdl.handle.net/10945/44579
LCDR Ramon P. Martinez, USN	Bio-Optical and Hydrographic Characteristics of the western Pacific Ocean for Undersea Warfare Using Seaglider Data	2014-12	http://hdl.handle.net/10945/44612
LT Mark C. Mitchell, USN	Impacts of potential aircraft observations on forecasts of tropical cyclones over the western North Pacific	2014-12	http://hdl.handle.net/10945/44619
LT Dominic J. Simone, USN	Modeling a linear generator for energy harvesting applications	2014-12	http://hdl.handle.net/10945/44669
Team MIW, SE311-132Open/	Application of Model-Based Systems Engineering (MBSE) to compare legacy and future forces in Mine Warfare (MIW) missions		http://hdl.handle.net/10945/44659
Joong Yang Lee, NTU Singapore	Expanded kill chain analysis of manned-unmanned teaming for future strike operations	2014-09	http://hdl.handle.net/10945/43944
Montrell Smith, DON Civilian	Converting a manned LCU into an unmanned surface vehicle (USV): an open systems architecture (OSA) case study	2014-09	http://hdl.handle.net/10945/44004
CDR Ellen Chang, USNR	Defining the levels of adjustable autonomy: a means of improving resilience in an unmanned aerial system	2014-09	http://hdl.handle.net/10945/43887
Chee Siong Ong, NTU Singapore	Logistics supply of the distributed air wing	2014-09	http://hdl.handle.net/10945/43969
LT Barry Scott, USNR	Strategy in the robotic age: a case for autonomous warfare	2014-09	http://hdl.handle.net/10945/43995
LT Blake Wanier, USN	A modular simulation framework for assessing swarm search models	2014-09	http://hdl.handle.net/10945/44027
Chung Siong Tng, NTU Singapore	Effects of sensing capability on ground platform survivability during ground forces maneuver operations	2014-09	http://hdl.handle.net/10945/44018
LT Nicole R. Ramos, USN	Assessment of vision-based target detection and classification solutions using an indoor aerial robot	2014-09	http://hdl.handle.net/10945/43984

Ceying Foo, NTU Singapore	A systems engineering approach to allocate resources between protection and sensors for ground systems for offensive operations in an urban environment	2014-09	http://hdl.handle.net/10945/43914
Team Amberland, Cohort 311-131O	A systems approach to architecting a mission package for LCS support of amphibious operations	2014-09	http://hdl.handle.net/10945/43992

FY11-FY14:

Thesis project title/subject:	**NPS Student (s)**	
Applying Cooperative Localization to Swarm UAVs using an Extended Kalman Filter	Lieutenant Colonel Robert B. Davis, USMC	FY14 (SEP)
Expanded Kill Chain Analysis of Manned-Unmanned Teaming for Future Strike Operations	Joong Yang Lee, Republic of Singapore Air Force	FY14 (SEP)
Logistics Supply of the Distributed Air Wing	Mr. Chee Siong Ong, Singapore Defence Science and Technology Agency	FY14 (SEP)
Assessment of Vision-Based Target Detection and Classification Solutions Using an Indoor Aerial Robot	LT Nicole Ramos, USN	FY14 (SEP)
Optimal Estimation of Glider's Underwater Trajectory with Depth-dependent Correction using the Regional Navy Coastal Ocean Model with Application to ASW	JooEon Shim	FY14 (SEP)
Relationship between the sonic layer depth and mixed layer depth identified from underwater glider with application to ASW	LT Vance Villarreal, USN	FY14 (SEP)
] A Modular Simulation Framework for Assessing Swarm Search Models	LT Blake Wanier, USN	FY14 (SEP)
The distributed air wing	Systems Engineering Analysis Cross-Campus Study (SEA 20B)	FY14
Sea-Shore interface robotic design	LT Timothy L. Bell, USN	FY14
Achieving information superiority using hastily formed networks and emerging technologies for the Royal Thai Armed Forces counterinsurgency	LCDR Anthony A. Bumatay, USN; LT Grant	FY14

operations in Southern Thailand	Graeber, USN	
Droning on: American strategic myopia toward unmanned aerial systems	CWO4 Carlos S. Cabello, USA	FY14
Obstacle detection and avoidance on a mobile robotic platform using active depth sensing	ENS Taylor K. Calibo, USN	FY14
Improving operational effectiveness of Tactical Long Endurance Unmanned Aerial Systems (TALEUAS) by utilizing solar power	LT Nahum Camacho, Mexican Navy	FY14
Increasing the endurance and payload capacity of unmanned aerial vehicles with thin-film photovoltaics	Capt Seamus B. Carey, USMC	FY14
Power transfer efficiency of mutually coupled coils in an aluminum AUV hull	LCDR James M. Cena, USN	FY14
Tropical cyclone reconnaissance with the Global Hawk: operational thresholds and characteristics of convective systems over the tropical Western North Pacific	LCDR David W. Damron, USN	FY14
Cost-effectiveness analysis of aerial platforms and suitable communication payloads	LCDR Randall E. Everly, USN; LT David C. Limmer, USN	FY14
Characterization parameters for a three degree of freedom mobile robot	LT Jessica L. Fitzgerald, USN	FY14
Computer-aided detection of rapid, overt, airborne, reconnaissance data with the capability of removing oceanic noises	LT James R. Fritz, USN	FY14
A data-driven framework for rapid modeling of wireless communication channels (PhD dissertation)	Douglas Horner, NPS	FY14
An analysis of the defense acquisition strategy for unmanned systems	Maj Courtney David Jones, USMC	FY14
Terrain aided navigation for REMUS autonomous underwater vehicle	ENS Jacob T. Juriga, USN	FY14
Investigation of acoustic vector sensor data processing in the presence of highly variable bathymetry	LT Timothy D. Kubisak, USN	FY14

U.S. Army Unmanned Aircraft Systems (UAS)â€"a historical perspective to identifying and understanding stakeholder relationships	Donald R. Lowe, DON (Civ); Holly B. Story, DOA (Civ); Matthew B. Parsons, DOA (Civ)	FY14
Preliminary design of an autonomous underwater vehicle using multi-objective optimization	LCDR Sotirios Margonis, Hellenic Navy	FY14
Da Vinci's children take flight: unmanned aircraft systems in the homeland	Jeanie Moore, FEMA Office of External Affairs	FY14
A comparison of tactical leader decision making between automated and live counterparts in a virtual environment	MAJ Scott A. Patton, USA	FY14
High Energy Laser Employment in Self Defense Tactics on Naval Platforms [RESTRICTED]	LT Brett Robblee, USN	FY14
Optimal deployment of unmanned aerial vehicles for border surveillance	First LT Volkan Sözen, Turkish Army	FY14
Domestic aerial surveillance and homeland security: should Americans fear the eye in the sky?	LCDR Barcley W. Stamey, USN	FY14
Lightening the load of a USMC Rifle Platoon through robotics integration	LT Sian E. Stimpert, USN	FY14
Small Tactical Unmanned Aerial System (STUAS) Rapid Integration and fielding process (RAIN)	Christopher Ironhill, Bryan Otis, Frederick Lancaster, Angel Perez, Diana Ly, and Nam Tran	FY13 (SEP)
Development and validation of a controlled virtual environment for guidance, navigation and control of quadrotor UAV	Junwei Choon, Singapore Technologies Aerospace	FY13 (SEP)
An examination of the collateral psychological and political damage of drone warfare in the FATA region of Pakistan	Judson J. Dengler, U.S. Secret Service	FY13 (SEP)
Integrating Unmanned Aerial Vehicles into surveillance systems in complex maritime environments	LCDR Georgios Dimitriou, Hellenic Navy	FY13 (SEP)
Improving the Army's joint platform allocation tool (JPAT)	LT John P. Harrop, USN	FY13 (SEP)
Active shooters: is law enforcement ready for a	Captain Joel M. Justice, Los	FY13

Mumbai style attack?	Angeles Police Department	(SEP)
The rise of robots and the implications for military organizations	Captain Zhifeng Lim, Singapore Armed Forces	FY13 (SEP)
Dynamic bandwidth provisioning using Markov chain based on RSVP	Lieutanant Junior Grade Yavuz Sagir, Turkish Navy	FY13 (SEP)
Systems engineering and project management for product development: optimizing their working interfaces	Mariela I. Santiago, NUWC Newport	FY13 (SEP)
Dynamic towed array models and state estimation for underwater target tracking	LCDR Zachariah H. Stiles, USN	FY13 (SEP)
Diver relative UUV navigation for joint human-robot operations	LT Andrew T. Streenan, USN	FY13 (SEP)
Closing the gap between research and field applications for multi-UAV cooperative missions	Harn Chin Teo, ST Aerospace Ltd.	FY13 (SEP)
Enhancing entity level knowledge representation and environmental sensing in COMBATXXI using unmanned aircraft systems	MAJ James C. Teters,II, USA	FY13 (SEP)
Real-time dynamic model learning and adaptation for underwater vehicles	LT Joshua D. Weiss, USN	FY13 (SEP)
2024 Unmanned undersea warfare concept	Systems Engineering Analysis Cross-Campus Study (SEA 19A)	FY13
Mobility modeling and estimation for delay tolerant unmanned ground vehicle networks	LT Timothy M. Beach, USN	FY13
Effectiveness of Unmanned Aerial Vehicles in helping secure a border characterized by rough terrain and active terrorists	First Lieutenant Begum Y. Ozcan, Turkish Air Force	FY13
Integration Of Multiple Unmanned Systems In An Urban Search And Rescue Environment	Boon Heng Chua, Defence Science and Technology Agency, Singapore	FY13
Analysis of Ocean Variability in the South China Sea for Naval Operations	LT Mary Doty	FY13
Computer Aided Mine Detection Algorithm for Tactical Unmanned Aerial Vehicle (TUAV)	LT James Fritz	FY13

UAV swarm tactics: an agent-based simulation and Markov process analysis	Captain Uwe Gaertner, German Army	FY13
Extending the endurance of small unmanned aerial vehicles using advanced flexible solar cells	Capt Christopher R. Gromadski, USMC	FY13
The Optimal Employment and Defense of a Deep Seaweb Acoustic Network for Submarine Communications at Speed And Depth using a Defender-Attacker-Defender Model	LT Andrew Hendricksen, USN	FY13
Integrating Coordinated Path Following Algorithms To Mitigate The Loss Of Communication Among Multiple UAVs	LT Kyungnho Kim, USN	FY13
Intelligence fused Oceanography for ASW using Unmanned Underwater Vehicles (UUV) [SECRET]	LCDR Paul Kutia	FY13
Digital Semaphore: technical feasibility of QR code optical signaling for fleet communications	LCDR Andrew R. Lucas, USN *(thesis award winner)*	FY13
Effects Of UAV Supervisory Control On F-18 Formation Flight Performance In A Simulator Environment	LCDR Eric L. McMullen, USN and MAJ Brian Shane Grass, U.S. Army	FY13
Analysis of Bioluminescence and Optical Variability in the Arabian Gulf and Gulf of Oman for Naval Operations[Restricted]	LT Thai Phung	FY13
Digital semaphore: tactical implications of QR code optical signaling for fleet communications	LT Stephen P. Richter, USN *(thesis award winner)*	FY13
Design and hardware-in-the-loop implementation of optimal canonical maneuvers for an autonomous planetary aerial vehicle	LT Marta Savage, USN	FY13
Improving UXS network availability with asymmetric polarized mimo	Robert N. Severinghaus	FY13
Modeling and simulation for a surf zone robot	LT Eric Shuey, USN and LT Mika Shuey, USN	FY13
Analysis of Nondeterministic Search Patterns for Minimization of UAV Counter-Targeting	LT Timothy S. Stevens, USN	FY13
A human factors analysis of USAF remotely piloted aircraft mishaps	Maj Matthew T. Taranto, USAF	FY13

A systems engineering analysis of unmanned maritime systems for U.S. Coast Guard missions	LT James B. Zorn, USCG	FY13
Tailorable Remote Unmanned Combat Craft (TRUCC)	Systems Engineering Analysis Cross-Campus Study (SEA 18B)	FY12
Autonomous Dirigible Airships: a Comparative Analysis and Operational Efficiency Evaluation for Logistical Use in Complex Environments	LT Brian Acton, USN LT David Taylor, USN	FY12
An Interpolation Approach to Optimal Trajectory Planning for Helicopter Unmanned Aerial Vehicles	Maj Jerrod Adams, U.S. Army	FY12
Implementation of Autonomous Navigation And Mapping Using a Laser Line Scanner on a Tactical Unmanned Vehicle	Maj Mejdi Ben Ardhaoui, Tunisian Army	FY12
An Analysis of Undersea Glider Architectures and an Assessment of Undersea Glider Integration into Undersea Applications	Mr William P. Barker	FY12
Integration of an Acoustic Modem onto a Wave Glider Unmanned Surface Vehicle	ENS Joseph Beach, USN	FY12
Investigation of Propagation in Foliage Using Simulation Techniques	LCDR Chung Wei Chan, Republic of Singaporean Navy	FY12
Joint Sensing/Sampling Optimization for Surface Drifting Mine Detection with High-Resolution Drift Model	LT Kristie M. Colpo, USN	FY12
Does China Need A "String Of Pearls"?	Capt Martin Conrad, USAF	FY12
Unmanned Aircraft Systems: A Logical Choice For Homeland Security Support	Maj Bart Darnell, USAF	FY12
Multi-Agent Task Negotiation Among UAVs	Mr. Michael Day	FY12
Optimized Landing of Autonomous Unmanned Aerial Vehicle Swarms	Maj Thomas F. Dono, USMC	FY12
An Analysis of the Manpower Impact of Unmanned	LT Thomas Futch, USN	FY12

Aerial Vehicles (UAV's) on Subsurface Platforms		
Clock Synchronization through Time-Variant Underwater Acoustic Channels	LCdr Pascal Gagnon, Canada	FY12
UAV to UAV Target Detection And Pose Estimation	Capt Riadh Hajri, Tunisian Air Force	FY12
A Cost-Benefit Analysis Of Fire Scout Vertical Takeoff And Landing Tactical, Unmanned, Aerial Vehicle (VTUAV) Operator Alternatives	CDR Kevin L. Heiss, USN	FY12
Autonomous Parafoils: Toward a Moving Target Capability	CDR Chas Hewgley, USN	FY12
Design and Development of Wireless Power Transmission for Unmanned Air Vehicles	Captain Chung-Huan Huang, Taiwan (Republic of China) Army	FY12
Adaptive Speed Controller for the Seafox Autonomous Surface Vessel	LT Michael A. Hurban, USN	FY12
Coordination and Control for Multi-Quadrotor UAV Missions	LT Levi C. Jones, USN	FY12
An Analysis of the Best-Available, Unmanned Ground Vehicle in the Current Market, with Respect to the Requirements of the Turkish Ministry of National Defense	LT Serkan Kilitci, Turkish Navy LT Muzaffer Buyruk, Turkish Army	FY12
Underwater Acoustic Network As A Deployable Positioning System	ENS Rebecca King, USN	FY12
Business Case Analysis of Medium Altitude Global ISR Communications (MAGIC) UAV System	Ramesh Kolar	FY12
The EP-3E vs. the BAMS UAS An Operating and Support Cost Comparison	LT Colin G. Larkins, USN	FY12
Global Versus Reactive Navigation for Joint UAV-UGV Missions in a Cluttered Environment	ENS Michael Martin, USN	FY12
Bridging Operational and Strategic Communication Architectures Integrating Small Unmanned Aircraft Systems as Airborne Tactical Communication	Maj Jose D. Menjivar, USMC	FY12

Vertical Nodes		
The Aerodynamics of a Maneuvering UCAV 1303 Aircraft Model and its Control through Leading Edge Curvature Change	ENS Christopher Medford, USN	FY12
Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)	Maj Les Payton, USMC	FY12
Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks	LT Timothy Rochholz	FY12
GSM Network Employment on a Man-Portable UAS	LT Darren J. Rogers, USN	FY12
New Navy Fighting Machine in the South China Sea	LT Dylan Ross, USN LT Jimmy Harmon, USN	FY12
Business Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF)	LT Jason Staley, USN Capt Troy Peterson, USMC	FY12
Application Of An Entropic Approach To Assessing Systems Integration	Mr Hui Fang Evelyn Tan, Republic of Singapore	FY12
Advanced Undersea Warfare Systems	Systems Engineering Analysis Cross-Campus Study (SEA 17B)	FY11
The Dispersal Of Taggant Agents With Unmanned Aircraft Systems (UAS) In Support Of Tagging, Tracking, Locating, And Identification (TTLI) Operations	Capt Dino Cooper, USMC	FY11
Adaptive Reception for Underwater Communications	LTJG Spyridon Dessalermos, Hellenic Navy (Greece)	FY11
The Design and Implementation of a Semi-Autonomous Surf-Zone Robot Using Advanced Sensors and a Common Robot Operating System	LT Steve Halle, USN LT Jason Hickle, USN	FY11
Probabilistic Search on Optimized Graph Topologies	Major Christian Klaus, German Army	FY11

Brave New Warfare Autonomy in Lethal UAVS	LT Matthew Larkin, USN	FY11
Agent-based simulation and analysis of a defensive UAV swarm against an enemy UAV swarm	Lieutenant Mauricio M. Munoz, Chilean Navy	FY11
Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV)	LT Matthew Pawlenko, USN	FY11
Design Requirements For Weaponizing Man-portable UAS In Support Of Counter-sniper Operations	Maj Derek Snyder, USMC	FY11
Self-propelled semi-submersibles the next great threat to regional security and stability	LT Lance J Watkins, USN	FY11

APPENDIX C: COMMUNITY

This is a representative listing of the CRUSER community of interest in FY15. It is not meant to be inclusive, but is included to demonstrate depth and breadth of interest.

Academia:	
	AFIT
	Alaska Center for Unmanned Aircraft Systems Integration
	American University
	University of Washington APL
	Arizona State University
	Auburn University
	Australian Defence Force Academy
	Ben-Gurion University of the Negev
	University of California, Berkeley
	Brigham Young University
	Cal Poly SLO
	California Polytechnic Institute
	CalWestern School of Law
	Carnegie Mellon University
	Case Western Reserve University
	Chapman University
	Chosun University (South Korea)
	Cornell University AUV
	CSULB
	CSUMB
	Drexel
	Embry-Riddle Aeronautical University
	FEUP
	Florida Atlantic University
	Florida Institute for Human Machine Cognition
	French Air Force Academy
	Georgia Tech
	Howard University
	Imperial College London
	Indian Institute of Science Education and Research-Thiruvananthapuram (IISER-TVM)
	Indiana State University

Institute for Religion and Peace
JHU/Applied Physics Laboratory
Kansas State University
LSTS
Ludwig Maximilians Univeristat
Macquarie University
Marine Advanced Technology Education (MATE) Center
McGill University
Memorial University of Newfoundland
Mississippi State University
MIT
MPC
Naval War College
Netherlands Defence Academy/Eindhoven University of Technology /TNO/Delft University of Technology
New Mexico State University
North Carolina State University
Northeastern University
Northwestern University
OK State
Old Dominion University
OSU
Penn State University
PSU/APL
RPI
Saint Louis University
San Diego Christian College
SDSU
St. Mary's University
Stanford
SUNY Stony Brook
Technion
Texas A&M
The Ohio State University
Thomas Jefferson High School for Science and Technology
TUM
U South Florida
U.S. Naval Academy
UC Davis

	UCF
	UCLA
	UF
	UFL
	UK National Oceanography Centre
	University of Alaska at Fairbanks
	University of California Davis
	University of Dayton Research Institute
	University of Hawaii
	University of Idaho
	University of Iowa
	University of Maryland
	University of Michigan
	University of New Brunswick
	University of Nevada Las Vegas
	University of North Carolina at Charlotte
	University of North Dakota
	University of Notre Dame
	University of Oklahoma
	University of Pittsburgh
	University of Quebec in Montreal
	University of South Florida
	University of Southern California
	University of Texas at Arlington Research Institute (UTARI)
	University of Texas
	Utah State University
	UXV University
	Virginia Tech
	Wichita State University
Industry:	
	0cog Inc.
	2d3 Sensing
	3D PARS - 3D Printing and Advanced Robotic Solutions
	4TH Naval Warfare Flotilla
	AAI Corporation
	Abbott Laboratories
	ACADEMI
	Access Spectrum

ACE Applied Composites Engineering
ACSEAC
ACSS (Aviation Comm & Surv. Systems), LLC
ACT
ADD(Agency for Defence Development
ADS Inc
ADSYS Controls Inc
Advanced Acoustic Concepts
Aerial MOB
AeroEd Group
Aerofex Corp
Aerojet Rocketdyne
Aeroprobe Corp
Aerospace & Def INO Parts
Aerospace Analytics
Aerospace Corporation (The)
Aerovel
AeroVironment, Inc.
Affordable Engineering Services
Ag Eagle
AgriSource Data, LLC
Air Concepts Group
Air Law Institute
AIRBUS Defense & Space
Airware
Alakai Defense
ALCO
Alex
Alfresco
Alidade Incorporated
Alpha Research & Technology
Alta Devices
Altair
Altron
American Autoclave Co
AMP Research
Andro Computational Solutions
AOC Inc

AOPA (Aircraft Owners & Pilots Association
Applied Mathematics, Inc.
Applied Physical Sciences Corp
Applied Research Associates Inc.
Applied Research in Acoustics
Applied Visions, Inc.
APS
Arcturus UAV
Argon ST
Arkwin Industries, INC.
Artemis
ASV Global
ATC
ATI
Atkinson
Atlas NA
auratech
Aurora Flight Sciences
Ausley
Autonomous Avionics
AUVAC
AUVSI
Avineon, Inc.
Axiom Electronics
Bacolini Enterprises
BAE Systems
BAH
Ball Aerospace & Technologies Corp
Barry Aviation
Battelle Memorial Institute
Battlespace Inc
BBN Technologies
Be MoD
Bell Helicopter Textron, Inc.
Bicallis, LLC
Blackbird Technologies
Blackhawk Emergency Management Group
Bluefin Robotics Corporation

BMNT Partners
Boeing
Boeing
Boomerang Carnets
Booz, Allen, Hamilton
Borchert Consulting and Research AG
Bosh Technologies
Boston Engineering Corporation
Broadcast Microwave Services Inc. (BMS)
C2 Technologies Inc
C4ISR & Networks
CACI
Calvert Systems
Camber Corp
Canadian Forces Maritime Warfare Centre
CapSyn (Capital Synergy Partners, INC.)
CAST Navigation
CDI Marine
Center for a New American Security
Center for Applied Space Technology
Centerstate Corp for Economic Opportunity
CENTRA Technology, Inc.
Centum Solutions SL
Channel Technologies Group
Charles River Analytics
Charles Stark Draper Laboratory
CHHOKAR Law Group
CHI Systems
Chinwag
Chroma Systems Solutions
Cisco
Clear-Com
Clearing (The)
CNA Analysis & Solutions
CODAN Radio Communication
Colby Systems Corporation
Comphydro Inc
Compsim

Comtech Solutions LLC
Concepts to Capabilities Consulting
Conoco Phillips Company
Consolidated Aircraft Coatings
Cornerstone Research Group
Corning
Corsair Engineering
Crystal Rugged
CS Draper Laboratory
CS-Solutions Inc
CSA
CSCI - Computer Systems Center Inc.
CT Johnson & Associates
CTJA, LLC
CUBIC
Cutting Edge
Cyber Security & IS IAC (CSIAC)
CYPHY Works
D-RisQ
Daniel H. Wagner Associates
David Ricker Group, LLC
Dayton Development Coalition
DDL Omni
Defense Materiel Organisation
Del Rey Sys. & Technology Inc.
Delta Airlines
Delta Digital Video
Desert Star Systems
Design Intellignce Inc. (DII)
Devine Co
DeVine Consulting, Inc
Digital Adopxion
Digital Harvest
Diversified Business Resources, Inc.
DOER Marine
Dove Innovations
DPSS Lasers
DRA - Defense Research Associates

Draper Laboratory
DREAMHAMMER
Drone America
Drone Aviation Corp
DroneBase
DST Control
Duzuki
Dynetics
EC Wise
ECC
Elbit Systems of America
Electric Boat
Electro Rent Corporation
Elementary Institute of Science
Ellevision, LLC
Engility
Engineered Packaging Solutions
EnrGies
EPS of North America
EQC, Inc
ERA
ESRI
Esterline Control & Communication Systems
Eutelsat America
Excelis
Exelis Inc
FABLAB San Diego
Faun Trackway USA
FFI
FIRST
Five Rivers Services, LLC
FLIR Systems, Inc.
FMV
FreeFlight Robotics
FreeWave Technologies Inc.
Frost & Sullivan
Fugro Geoservices Inc.
G2 Solutions

Galois Inc.
GDEB
GDIT
General Atomics
General Dynamics
General Dynamics Advanced Information Systems
General Dynamics Electric Boat
General Dynamics Land Systems
Geospatial San Diego
GET Engineering
Getac
GL INTERNATIONAL
Global Technical Systems
Go Pro Cases
Gold Star Strategies LLC
GPH Consulting
Gryphon
GTRI
GTS Consulting
H.O. JOHNSON RESULTANTS LLC
Harris Communications
Harris Corp
Harwin
Hawaii Hazards Awareness & Resillience Program
Headwall
Hogan Lovells
Honeywell
HQ SACT
Hughes
Hydr0 Source LLC
Hyperspectral Imaging Foundation
IBM
IDA
IEEE ICSC2015
IHI
Image Insight
Implevation, LLC
IMSAR

Independent Wireless Executive
Information Processing Systems, Inc
inmarsat
Innoflight
Innovation Center
Innovative Computing & Technology Solutions, LLC
Innovative Vessel Design
Inova Drone
Inside Umanned Systems
Insight Global
Insitu
Institute for Homeland Security Solutions
Intelligent Automation
InterContinental IP
Intergraph Gov Solutions
International
Intevac
Iris Technology
iRobot
ITT Exelis
JACOBS
Janes Capital Partners
Japan Aerospace Exploration Agency
JOBY Aviation
John Deere
Joint Venture Monterey Bay
Jove Sciences, Inc.
Kitware
KNOWMADICS
Kongsberg
Kraken
Krato Defense
KSI
L-3 Advanced Programs, Inc.
L-3 Cincinnati Electronics
L-3 COM
Leidos
Leucadia Group

LIG Nex1, South Korea.
Lightspeed Innovations
Liquid Robotics
Llamrai Enterprices
Lockheed Martin
Lynntech
M Ship Co., LLC
Magnet Systems
Makani Power Inc
Management Sciences, Inc
Maplebird
Marine Acoustics
Maritime Applied Physics Corporation
Maritime Tactical Systems, Inc. (MARTAC)
Mashable
MASI LLC
Materials Systems Inc.
Materion
Mav6, LLC
MBARI
McBee Strategic
McClean Group
McKenna, Long & Aldridge LLP
McKinsey
MCR Critical Thinking Solutions Delivered
MDA Corporation
Medweb
Metal Technology
Metcon Aerospace & Defense
METI
Meyers AeroConsulting
MicroPilot
Microwave Monolithics
Mid-Atlantic Aviation Partnership (MAAP)
Miltrans
MINCO
MISTIC
MITRE Corporation

Modern Technology Solutions, Inc.
Momentum Aviation Group
Monitor National Security
Monterey County Herald
Morrison & Foerster LLP
MosaicMill
MRU Systems
MSI
Nanomotion
NASC
National Institute of Aerospace
NAVPRO Consulting LLC
NDIA
Neptune Minerals
Newport News Shipbuilding
Next Vision Stabilized Systems Ltd
Nexutech
Neya Systems LLC
NGC (Northrop Grumman Corp)
NiederTron Robotics
NLD MOD (Defence Materiel Org
NNS
Northrop Grumman
NUAIR
NWUAV Propulsion Systems
Ocean Aero
Ocean Lab
Oceaneering Technologies
ODNI
Odyssey Marine Exploration
ONE Aviation Corp.
Ontario Drive & Gear
OPNAV Safety Liason
Orca Maritime, Inc.
Orion Systems
ORYX
Oxford Technical Solutions
Pacific Science & Engineering Group

Pacific Synergistics International (PSI)
Pappas Associates
Paradigm
Parallel Wireless
Parsons
Patuxent Partnership
Paul R Curry & Associates
Perforce
Persistent Systems
PG&E
Phantom Works
Phyiscal Optics Corp
Physical Sciences Inc
Pilot Group (The)
Pixia
PMS505
Power Ten Incorporated
Praxis Aerospace Concepts International
Precision
Prescient Edge
Princeton Lightwave
Prioria Embedded Intelligence
Profit Quadro
Progeny Systems
Promia
Provectus Robotics Solutions
Proxdynamics
Proxy Technologies
q-bot
QinetiQ
Quanterion Solutions Incorporated
Quartus Engineering
R-3 Consulting
R3SSG
Radar Revolution (The)
Ramona Research
Randiance Technologies
Range Networks

Ranger Group (The)
Rapid Imaging Software
Raytheon
Red Hat
Reference Technologies Inc.
Renaissance Strategic Advisors
RFMD
Riegl USA
RIX Industries
Robotics Research
Rockwell Collins
Rocky Mountain Institute
Rolls Royce
Roving Blue
RSWN
RT Logic
RTI
Rumpf Associates International
SAAB
SAGE Solutions Group, Inc
SAIC
Saildrone
SAP NS2
SAS Federal
SAS Institute
SCD
SCD.USA Infrared
Scientific Applications & Research Associates
Scorpion Aerosystems Inc
Scoutsman Unmanned LLC
Sculpture Networks Inc.
SDG&E
Sea Phantom International, Inc
SeaBotix
Seamatica Aerospace Limited
Seapower Magazine
SebastianConran/associates
Selex Galileo Inc.

Self proprietor
Semantic Computing Foundation
Sematica Aerospace Limited
Senior Program Associate at AAAS
Senior Systems Engineering Consultant Unmanned Systems and C4ISR
Senseta Inc
Sensintel
sensonor
Sensurion Aerospace
Sentinel Robotic Solutions
SETA / ONR
Seven Seals
Shadow (Robot Company)
Shephard Media
Sierra Nevada Corp
Signal
Signature Science
Sikorsky
Silent Falcon UAS Technologies
SIMLAT
Smith Currie & Hancock
Soar Oregon
Soar Technology
Society of Experimental Test Pilots
Soliton Ocean Services, Inc.
Sonalysts, Inc
Sonitus Technologies
SPA
Sparton
Sparton Defense and Security
Spatial and Spectral Research
Spatial Integrated Systems
Spectrabotics
Spectrum Aeronautical, LLC
Spectrum Group (The)
Spinner
Spiral Technology, Inc.
SRC

SRI
ST Aerospace
Stark Aerospace Inc.
Steelman Group, Inc.(The)
Steinbrecher & Span LLP
Strategic Analysis Enterprises
Strategic Defense Solutions, LLC
Stratom
Stryke Industries
Sunhillo Performance Technologies
Sutton James
Swedish Navy Warfare Center
SwRI (Southwest Research Institute)
SYPRIS Electronics
Systems Planning & Analysis, Inc
Systems Planning and Analysis, Inc
SYZYGYX Incorporated
Tactical Air Support, Inc.
TASC
TCG
Tech Associates, LLC
Tech Incubation
Tech Source
Technology and Supply Management
Technology for Energy Corp.
Technology Training Corporation
TechSource
TECOM
Teledyne
Teledyne Brown Engineering
Teledyne RDI
Teledyne Technologies
Teledyne Webb Research
Telephonics Corporation
Teletronics
TENTECH LLC
Terrago
Tesla Foundation Group

Tethered Air
Textron Systems
TFD Europe
Thales Australia and NZ
Thales Defense & Security Inc.
Third Block Group
Tiresias Technologies
TMT ~ spg
Topcon
Torch Technologies
TorcRobotics
TP Logic
Trabus
Travelers United
Trimble
Trimble Navigation Ltd
Tucson Embedded Systems
Twin Oaks Computing
UAS Colorado
UAS Today
UASolutions Group
UAV Pro
UAV Vision
UK Defence Science and Technology Laboratory
Ultimate Satellite Solutions (UltiSat)
Ultra Electronics
Ultra-EMS
UltraCell
Ultravance Corp
UMS3
Unexploded Ordnance Center of Excellence
United Technologies Research Center
Universal Display Corporation
Unmanned Aero Services
Unmanned Power LLC
Unmanned Systems Institute
Unmanned Systems Research & Consulting LLC
Unmanned Vehicle Systems Consulting, LLC

	Unmanned World Wide
	USI
	UTC Aerospace Systems
	UxSolutions, Inc
	Van Scoyoc Associates
	VCT (Vehicle Control Technologies Inc)
	VDC Research
	Vector CSP
	Vehicle Control Technologies, Inc.
	Velocity Cubed Technologies
	Velodyne Acoustics
	Veridane
	VIA SAT
	ViaSat
	VideoBank
	VideoRay
	Virtual Agility
	Vision Technologies
	Wade Trim
	Wateridge Insurance Services
	WBB
	WBT Innovation Marketplace
	WDL Systems
	Whitney, Bradley & Brown Inc.
	Williams Mullen
	Wind River
	WINTEC
	Wounded Eagle UAS
	Wyle
	Yamaha
	Yamaha Motor Corp., USA
	Z Microsystems
	ZDSUS
	Zeuss
	Zimmerman Consulting Group
	Zodiac Aerospace
U.S. Air Force:	
	AFIAA

AFRL
AFRL/RYAA
Air Education and Training Command
COMPATRECONWING TWO
HQ USAF
Joint Counter Low, Slow, Small Unmanned Aircraft Systems Joint Test
JS J-7, Future Joint Force Development
JS/JIOR
JWAC
MI Air National Guard
PACOM
SOCOM
The Joint Staff
Twenty-Fifth Air Force
USAFA
USSOUTHCOM
USSTRATCOM
U.S. Army
526th Intel Squadron
79th IBCT
AMC/RDECOM/AMRDEC
Army Research Lab
Army S&T
Army Unmanned Aircraft Systems
ATEC
DLI
DoD Unexploded Ordnance Center of Excellence
Ft Lewis
I2WD TFE
Maneuver Center of Excellence, Maneuver Battle Lab
NATO
NORAD-USNORTHCOM (UAS-AI)
PEO GCS - RSJPO
Redstone Arsenal
Robotic Systems Joint Project Office
TACOM
TRADOC Analysis Center
U.S. Army War College

	Unmanned Systems Team, MBL
	US Army Aero Services Agency
	US Army ERDC
	US Military Academy
	USMA
	USNORTHCOM
U.S. Navy and U.S. Marine Corps:	
	1st Force Recon Co
	1st Intel Br
	3rd Marine Aircraft Wing
	9th Comm Battalion, I MEF
	Accelerated Development & Support Corp
	AOC/NWCCD
	Army Research Laboratory
	ASN(RDA)
	C3F
	Center for Naval Analyses
	CETO
	CNA
	CNAP N809A - UAS Requirements
	CNO Strategic Actions Group
	CNRC Region West
	COMCARSTRKGRU TWO
	COMDESRON 31
	COMNAVSURFOR
	COMPACFLT
	COMPATRECONWING TWO (N7)
	COMPHIBRON EIGHT
	COMSUBDEVRON
	COMSUBPAC
	COMTACGRU ONE
	COMTHIRDFLEET
	COMUSNAVSOUTH
	CRIC
	CSG2
	CVN 68
	DUSN
	Expeditionary Strike Group Three

Fleet Readiness Center SouthWest
Fleet Survey team
FNMOC
HQMC
HSC-3
HSM Weapons School Pacific
HSM-71
HSM-78
I MEF
ISR Capabilities Division
Joint Integrated Air & Missle Defense Organization
Joint Staff Remote/Unmanned Futures Office
JUAS COE
Littoral Combat Ship Anti-Submarine Warfare Mission Package Detachment 2 (LCS ASW MP DET 2)
MARCORSYSCOM
MARFORPAC Experimentation Center
Marine Corp Warfighting Lab
MCIOC
MCWL
Mine Warfare Program Office, PMS 495
MINWARA
N2N6E7
N3N5IW
N8
NAE CTO
NAS Patuxent
NAVAIR
NAVAIRWD
Naval Air Systems Command
Naval Air Warfare Center Patuxent River
Naval Air Warfare Center Training Systems Division
Naval Mine & ASW Command
Naval Oceanographic Office
Naval Postgraduate School
Naval Research Laboratory
Naval Sea Systems Command
Naval Surface Warfare Center Carderock Division (NSWCCD)
Naval Surface Warfare Center Dahlgren Division (NSWCDD)

Naval Undersea Warfare Center, Division - Keyport
Naval Undersea Warfare Center, Newport
Naval War College
NAVCENT Bahrain
NAVFAC CIOFP1
NAVFAC HQ
NAVOCEANO
NAVSEA
NAVSEA
NAVSPECWARCOM
NAVSPECWARGRU THREE
Navy Office of General Counsel
Navy PEO LMW PMS 408
Navy Recruiting District, San Diego
Navy Region Southwest
Navy Reserves
Navy Special Warfarc Command
Navy TENCAP
Navy, Office of the General Counsel
NAWCAD
NCIS
NECC
NMAWC
NMAWC Det Norfolk
NORAD-NORTHCOM
NR NSW INTEL 17
NSW Support Activity Two
NSWCIHEODTD
NSWCPCD
NUWCDIVKPT DETPAC Kauai OS//PMRF
NWC
NWDC
NWDC/DAWCWD
Office of Naval Intelligence
Office of Naval Research
ONR Global
OPNAV
OPNAV N2/N6

OPNAV N2/N6F22
OPNAV N415
OPNAV N51
OPNAV N97
OPNAV N98
PEO C4I
PEO C4I, PMW 770
PEO Littoral & Mine Warfare
PEO Littoral Combat Ship
PEO LMW PMS 495
PMA209
PMA265
PMA268 / DP Associates
PMW 750 / PEO C4I
Point Mugu Sea Range, NAVAIR
SDS-5 DET UUV
SECNAV
SOAC
SOCAFRICA
SPAWAR - Atlantic
SPAWAR SSC Pacific
SPECWARCOM
Stennis Space Center Fleet Survey Team
Submarine Officers Advanced Course
Systems Planning and Analysis, Inc.
TACTRAGRUPAC, San Diego, Ca
TRITON FIT
UCAS-D
Unmanned Patrol Squadron ONE NINE
US Naval Test Pilot School
USFF
USFFC
USMC
USMC Pentagon
USNA
USNR
USS Chung-Hoon
USS MCCAMPBELL

	UXOCOE
	UxS Cross Functional Team
	VIRGINIA Class Program Office
	VMU-3
	VR-55
	VX-30
	Warfare Analysis & Integration Department
Federal/State/Local Government:	
	Allied Command Transformation
	Argonne National Lab
	Arl Co Police
	Bakersfield PD
	Banning Police Dept
	British Consulate - General LA*
	Business Oregon
	CA Dept of Insurance Fraud
	CA DMV Investigations
	Cal EMA
	Calexico PD
	California Highway Patrol
	CBP
	CENTCOM
	Chicago Fire Dept
	City of Frisco
	Cleveland VA Medical Center
	CRIC
	CS OEM
	CSU Fresno Police
	DARPA
	Defense Threat Reduction Agency
	Department of Defense
	Department of Energy
	Department of Homeland Security
	Department of the Interior
	DIA
	DMDC
	DOS
	DOT Office of Inspector General

DTRA
Eldorado Sheriff's Office
Elk Grove PD
FAA
FEMA
FL Highway Safety
Fremont PD
GEMA/HS
Glendale PD
GWU
HHS/ASPR
HQ NORAD/USNORTHCOM
HQ TRADOC
Irvine PD
Joint Ground Robotics Enterprise (OUSD)
Joint Staff J-7
Joint Staff J6 DDC5I
Joint Staff Remote/Unmanned Futures Office
Joint Vulnerability Assess. Branch
LA County Sheriff
Lawrence Livermore National Laboratory
Marin County Sheriff
Monterey Co Sheriff
Mountain View PD
NASA
National Geospatial-Intelligence Agency
National Guard Bureau
National Transportation Safety Board
Naval Oceanographic Office
NDU
NEMA
Newport Beach Police Dept
NOAA
NSF
NSWCDD
Oakland PD
OSD
OUSD AT&L

PACOM
Placer County Sheriff
PMW 750
POST
Riverside DA Office
RS Special Research Access
Sacramento Office of Emergency Services
Sacramento Police Dept
Sacramento Sheriff
San Diego Sheriffs Department
San Leadro PD
San Mateo County Sheriff
San Mateo PD
Sandia National Laboratories
SOCOM
Sonoma County DA
State of Alaska (DOT)
State of Utah, Governor's Office Economic Development
State of Wisconsin
STRATCOM
Transport Canada Safety & Security
Tustin PD
U.S. Coast Guard Marine Safety Center
US Central Command
US Coast Guard
US Marshall
US Secret Service
US Special Operations Command
Ventura Co Sheriff
Ventura County Economic Development Association
Ventura PD
Visalia PD
WI DOJ/DCI

Miscellaneous:

Devenue International
ELG Inc
Local PD retired
Monterey County Weekly

Salinas Californian
Seaside High
The Salinas Californian
Swedish Defence Material Administration
"War Is Boring" blog

APPENDIX D: CRUSER FY15 CALL FOR PROPOSALS

The FY15 call for proposals was distributed as two distinct documents: 1) research track, and 2) education track. The call for proposals was released in early September 2014. Proposals selected for funding are summarized in section D of the full FY15 CRUSER Annual Report.

CRUSER CALL FOR PROPOSALS FY15: RESEARCH TRACK

http://CRUSER.nps.edu

PROPOSALS DUE DATE:	**22 Sept 14**
Selection Date:	**1 Oct 2014**
Funding Period:	**1 Oct 14 – 30 Nov 15**
Funding Levels:	**$75,000 - $150,000**
Proposal Types:	**Single-Year Proposals**

Research Goal: The Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) at the Naval Postgraduate School provides a collaborative environment for the advancement of educational and research endeavors involving unmanned systems across the Navy and Marine Corps. CRUSER seeks to align efforts, both internal and external to NPS, by facilitating active means of collaboration, providing a portal for information exchange among researchers and educators with collaborative interests, and supporting innovation through directed programs of operational experimentation.

Anticipated Funding Amount: Funding has not yet been received for FY15; however the purpose of this call for proposals is to prepare researchers on campus to begin work as soon as possible in the new fiscal year. It is anticipated that a minimum of $2.1 million will be available for FY15 CRUSER funded research.

- *Student travel and support is budgeted separately, so proposals should include anticipated student travel funding requirements, but not include that amount in the total requested*

Research Focus Areas: CRUSER Innovation Thread 3: Distributing Future Naval Air and Surface Forces

a) Re-seeding energy
b) C2/3 Concepts
c) Wide area decoy
d) Using UUVs to aid in submarine minefield navigation
e) Natural low frequency search methods
f) Deception and Weather Concepts
g) Asset Distribution and Employment Concepts

NOTE: Proposals for topics related to ANY robotic/unmanned sytems area will be considered.

Classification Level: Unclassified (Preferred)

Required Documents:

1. 1-page executive summary – template provided on http://CRUSER.nps.edu
2. 5-7 page proposal – template with key areas provided on http://CRUSER.nps.edu
3. Research Office Budget form
4. Research Office Proposal Routing form (including chair and dean signature)
5. Quad Chart

Submission Procedures:

- FY15 CRUSER Proposals and supporting documents should be submitted to cruser@nps.edu (Lisa Trawick, CRUSER Operations Manager). Do not submit through the Research Office.

Review and Selection Board: Proposals will be evaluated by a panel of reviewers co-chaired by the Dean of Research and the CRUSER Director. Any member of the CRUSER coordination group submitting a funding proposal will not serve on the panel.

Proposal Evaluation Criteria:

1) Student involvment
2) Interdisciplinary, interagency, and partnerships with naval labs
3) Partnerships with other sponsors' funding
4) Research related to various unmanned systems' catagories:
    a. Technical
    b. Organization and Employment
    c. Social, Cultural, Political, Ethical and Legal
    d. Experimentation
    e. Defense against threat UxS capabilities
5) New research area (seed money to attract other contributors)
6) Research topics related to ANY robotic and unmanned sytems area may be proposed, proposals related to any CRUSER innovation thread are preferred. (See website)
7) Alignment with SECNAV's DON Unmanned Systems Goals (see *CRUSER Charter* memo)

8) Researchers are members of the CRUSER Community of Interest
9) Proposals should aim to make an immediate impact on the community ($75k - $150k)

Notification: Principal Investigators (PIs) will be notified if their CRUSER research proposal was selected when FY15 funds are available.

Faculty members who receive CRUSER funds are expected to be members of CRUSER AND fully active in supporting CRUSER's goals to include (but not limited to):

- Monthly meeting attendance
- Presentations
- CRUSER News articles
- Participation at other CRUSER sponsored events, including presentations to ONR during the annual ONR CRUSER visit.
- Contributions to the CRUSER Annual Report
- Providing updated labor plans and budget projections as requested

CRUSER CALL FOR PROPOSALS FY15: EDUCATION TRACK

http://CRUSER.nps.edu

PROPOSALS DUE DATE:	**22 Sept 14**
Selection Date:	**1 Oct 2014**
Funding Period:	**1 Oct 14 – 30 Nov 15**
Funding Levels:	**$75,000 - $150,000**
Proposal Type:	**Single-Year Proposals**

Education Goal: The Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) strives to increase knowledge and understanding of robotics and unmanned systems through the innovative use of technology combined with established concepts of education. CRUSER Education Thread Concepts are designed to encourage contributions to this educational goal through the development of educational devices that can help achieve deep intellectual penetration across a broad audience base while maintaining a common theme focused on robotics and unmanned systems. The development and use of robotics and unmanned systems involve a vast and complex web of academic disciplines. Technical and ethical issues must be combined with knowledge and understanding of such diverse topics as human systems integration, information processing, information display, training, logistics, acquisition, development, C2 architectures, legal constraints, and levels of autonomy versus mission risk. These are but a small sample of potential topics that need to be addressed.

Anticipated Funding Amount: Funding has not yet been received for FY15; however the purpose of this call for proposals is to prepare researchers on campus to begin work as soon as possible in the new fiscal year. It is anticipated that a minimum of $900k will be available for FY15 CRUSER funded education proposals.

- *Student travel and support is budgeted separately, so proposals should include anticipated student travel funding requirements, but not include that amount in the total requested*

Education Focus Areas:

a) **Content**: Develop course or lecture content modules that focus on specific aspects of the CRUSER mission set. These modules may be delivered presentations, videos, demonstrations, simulations, or any format that optimizes opportunities to reach, inform and educate intended audiences.

b) **Education Sequencing Plans:**
   a. **Virtual lecture series:** Develop sequencing plans for distribution of synchronous and asynchronous web-based lectures that support the major areas of the CRUSER mission
   b. **Physical lecture series:** Develop sequencing plans for distribution of face-to-face lectures that support various areas of CRUSER mission

c) **Distributed information chunking**: Develop optimal solutions for presenting complex concepts to globally distributed personnel with limited chunks of time to spend online.

d) **Audience Identification**: Analyze the intended audience for CRUSER initiatives and determine the appropriate medium and level of detail for each demographic division

Classification Level: Unclassified

Required Documents:

6. 1-page executive summary – template provided on http://CRUSER.nps.edu
7. 5-7 page proposal – template with key areas provided on http://CRUSER.nps.edu
8. Research Office Budget form
9. Research Office Proposal Routing form (including chair and dean signature)
10. Quad Chart

Submission Procedures:

- FY15 CRUSER proposals and supporting documents should be submitted to cruser@nps.edu (Lisa Trawick, CRUSER Operations Manager). Do not submit through the Research Office.

Review and Selection Board: Proposals will be evaluated by a panel of reviewers co-chaired by the Dean of Research and the CRUSER Director. Any member of the CRUSER coordination group submitting a funding proposal will not serve on the panel.

Proposal Evaluation Criteria:

10) Student involvment
11) Interdisciplinary, interagency, and partnerships with naval labs
12) Partnerships with other sponsors' funding
13) Proposer is a teaching faculty member
14) Related to a CRUSER innovation thread. (See website)
15) Alignment with SECNAV's DON Unmanned Systems Goals (see *CRUSER Charter* memo)
16) Researchers are members of the CRUSER Community of Interest
17) Proposals should aim to make an immediate impact on the community($75k - $150k)

Notification: Principal Investigators (PIs) will be notified if their CRUSER education proposal was selected when FY15 funds are available.

Faculty members who receive CRUSER funds are expected to be members of CRUSER AND fully active in supporting CRUSER's goals to include (but not limited to):

- Monthly meeting attendance
- Presentations
- CRUSER News articles
- Participation at other CRUSER sponsored events, including presentations to ONR during the annual ONR CRUSER visit.
- Contributions to the CRUSER Annual Report
- Providing updated labor plans and budget projections as requested

APPENDIX E: CRUSER MANAGEMENT TEAM

DIRECTOR: Dr. Raymond R. Buettner Jr. is an Associate Professor in the Information Sciences Department at the Navy Postgraduate School and the NPS Director of Field Experimentation. Dr Buettner served 10 years as Naval Nuclear Propulsion Plant Operator while earning his Associate's and Bachelor's degrees. He holds a Master of Science in Systems Engineering degree from the Naval Postgraduate School and a Doctorate degree in Civil and Environmental Engineering from Stanford University. From 2003 to 2005, Dr. Buettner served on the faculty at the Naval Postgraduate School (NPS) and was the Information Operations Chair. He is the Chair of Technical Operations, in which he liaisons between NPS and the Joint Staff J39.He is the Principal Investigator for multiple research projects with budgets exceeding $6 million dollars a year, including the TNT, RELIEF, and JIFX projects. http://faculty.nps.edu/rrbuettn/about.html

DEPUTY DIRECTOR: Dr. Timothy H. Chung is an Assistant Professor of Systems Engineering at the Naval Postgraduate School. His research interests include probabilistic search optimization, degrees of autonomy for robotic systems, and multi-agent coordination for information gathering applications. His efforts lie at the interface between operations and robotics research. Professor Chung received his doctorate (2007) and M.S. (2002) at the California Institute of Technology in mechanical engineering, specializing in algorithms for distributed sensing and decision-making methods for multi-robot systems. He joined the NPS Operations Research department in 2008, transitioned to the Systems Engineering department in 2011. http://faculty.nps.edu/thchung/

DIRECTOR OF CONCEPT GENERATION: Ms. Lyla Englehorn, MPP earned a Master of Public Policy degree from the Panetta Institute at CSU Monterey Bay. She looks at issues related to policy in the maritime domain and is involved in a number of projects at the Naval Postgraduate School. Beyond her work with the Consortium for Robotics and Unmanned System Education and Research (CRUSER), she also works with the Warfare Innovation Continuum (WIC), and the NPS Graduate Writing Center. Other work at NPS has included curriculum development and instruction for the International Maritime Security course sequence for the Department of State and NATO.

DIRECTOR OF STRATEGIC COMMUNICATIONS: Mr. Steve Iatrou is a Senior Lecturer in the Information Sciences Department at the Naval Postgraduate School. He is currently the Associate Chair of Distributed Learning, Academic Associate. He received a Masters in Systems Technology from the Naval Postgraduate School (1992) and a Bachelors in Journalism and Mass Communication from the University of Oklahoma (1985).

DIRECTOR OF OPERATIONS: Ms. Lisa Trawick has been in the Air Force Reserves for 24 years and is currently serving as a Logistical Readiness Officer for the Surface Deployment and Distribution Command (SDDC). Her previous assignment was a full-time tour for 3.5 years at DFAS Internal Review (IR) as a Financial Data Analyst, where she won the DFAS IR Innovation

Award in 2008. In her civilian life she spent 12 years at Frito Lay with various roles in manufacturing/warehouse operations and as a Demand Planner. She received a Bachelors in Statistical Computing from the University of Utah (1998) and a Masters in Information Technology from the Naval Postgraduate School (2008).

DIRECTOR EMERTIUS/SENIOR ADVISORY COMMITTEE MEMBER: Mr. Jeffrey Kline, CAPT, USN (ret.), is a Professor of Practice in the Operations Research Department at the Navy Postgraduate School and Navy Warfare Development Command Chair of Warfare Innovation. He also is the National Security Institute's Director for Maritime Defense and Security Research Programs. He has over 26 years of extensive naval operational experience including commanding two U.S. Navy ships and serving as Deputy Operations for Commander, Sixth Fleet. In addition to his sea service, Kline spent three years as a Naval Analyst in the Office of the Secretary of Defense. He is a 1992 graduate of the Naval Postgraduate School's Operations Research Program where he earned the Chief of Naval Operations Award for Excellence in Operations Research, and a 1997 distinguished graduate of the National War College. Jeff received his BS in Industrial Engineering from the University of Missouri in 1979. His teaching and research interests are joint campaign analysis and applied analysis in operational planning. His NPS faculty awards include the 2009 American Institute of Aeronautics and Astronautics Homeland Security Award, 2007 Hamming Award for interdisciplinary research, 2007 Wayne E. Meyers Award for Excellence in Systems Engineering Research, and the 2005 Northrop Grumman Award for Excellence in Systems Engineering. He is a member of the Military Operations Research Society and the Institute for Operations Research and Management Science. http://faculty.nps.edu/jekline/

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems (UxS) in military and naval operations. CRUSER seeks to align efforts, both internal and external to NPS, by facilitating active means of collaboration, providing a portal for information exchange among researchers and educators with collaborative interests, and supporting innovation through directed programs of operational experimentation. This FY14 annual report summarizes CRUSER activities in its fourth year of operation, and highlights future plans.

KEYWORDS: robotics, unmanned systems, autonomy, UxS, UAV, USV, UGV, UUV

POC: Dr. Raymond R. Buettner, Jr.,
CRUSER Director

http://cruser.nps.edu

LIST OF ACRONYMS AND ABBREVIATIONS

This list is not meant to be exhaustive, and includes only the most common acronyms in this report.

A2AD	anti-access area denial (*A2/AD also used*)
ARSENL	Advanced Robotic Systems Engineering Laboratory
ASW	anti-submarine warfare
AUV	Autonomous underwater vehicle
C2	Command and control
C3	Command, control and communications
C4I	Command, control, computers, communications and intelligence
CAVR	NPS Center for Autonomous Vehicle Research
CENETIX	Center for Network Innovation and Experimentation
CEU	Continuing education unit
CNO	Chief of Naval Operations
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
DoD	Department of Defense
DON	Department of the Navy
EMCON	Emissions controlled
ISR	Intelligence, surveillance, and reconnaissance
JCA	Joint campaign analysis
JIFX	Joint Interagency Field Exploration
LDUUV	large displacement UUV
MDA	Maritime domain awareness

METOC	Meteorological and oceanographic
MILDEC	Military deception
MIO	Maritime threat detection and interdiction operations
NAVAIR	U.S. Naval Air Systems Command
NAVSEA	U.S. Naval Sea Systems Command
NPS	Naval Postgraduate School
NRL	Naval Research Laboratory
NWC	Naval War College
NWDC	Navy Warfare Development Command
ONR	Office of Naval Research
OR	Operations Research Department, NPS
QR	Quick Response (*QR code*)
RECES	Robo-Ethics Continuing Education Series
ROS	Robot operating system
ROV	Remotely operated vehicle
SEA	Systems Engineering and Analysis (*an NPS curriculum*)
SECDEF	Secretary of Defense
SECNAV	Secretary of the Navy
SME	Subject matter expert
SOF	U.S. Special Operations Forces
SSG	Strategic Studies Group
STEM	Science, technology, engineering, and mathematics
TDA	Tactical decision aid
TechCon	CRUSER Technical Continuum

THAUS	Tethered hovering autonomous underwater system
TNT	Tactical Network Testbed
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
UGV	Unmanned ground vehicle
USMC	U.S. Marine Corps
USN	U.S. Navy
USNA	U.S. Naval Academy
USV	Unmanned surface vehicle
USW	Undersea Warfare (*a battle concept and an NPS curriculum*)
UUV	Unmanned undersea vehicle
UxS	Unmanned system
WIW	Warfare Innovation Workshop

ACKNOWLEDGMENTS

The CRUSER Director thanks the entire community of interest who joined us since the program inception in March 2011.

The CRUSER Director acknowledges the continued contributions of the CRUSER leadership team: Deputy Director, Dr. Timothy H. Chung; Director of Concept Generation, Lyla Englehorn; Director of Strategic Communication, Steve Iatrou; and Operations Manager, Lisa Trawick.

The CRUSER Director appreciates the initial support and guidance as well as the continuing interest of Deputy Secretary of Defense the Honorable Robert O. Work

The CRUSER Director acknowledges the support and guidance provided by the Office of Naval Research, and recognizes our ONR Project Manager, CDR Steve Martin (USN).

The CRUSER Director acknowledges the efforts of the CRUSER Advisory Board: RADM Jerry Ellis, USN (ret) NPS Chair of Undersea Warfare; RDML Rick Williams, USN (ret), NPS Chair of Mine Warfare; CAPT J. Hyink, USN, NPS Senior Aviator; Dr. J. Paduan, NPS Dean of Research

The CRUSER Director acknowledges the extraordinary work of the first CRUSER Director, CAPT Jeff Kline, USN (ret.)