NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER) FY17 ANNUAL REPORT

Prepared by

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December 2017

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Prepared for: Raymond R. Buettner Jr., CRUSER Director
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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 FY17 annual report summarizes CRUSER activities in its seventh year of operations, and highlights future plans.

15. SUBJECT TERMS
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CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER):

FY17 Annual Report

Prepared by Lyla Englehorn, CRUSER Associate Director
for Dr. Raymond R. Buettner Jr., CRUSER Director; Dr. Brian Bingham, CRUSER Deputy Director

NAVAL POSTGRADUATE SCHOOL

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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 education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). Originally authorized by an Under Secretary of the Navy (USECNAV) memorandum dated 1 February 2011, CRUSER is an initiative designed to build an inclusive community of interest around the application of unmanned systems 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. These activities are considered to be in direct support of the Secretary of the Navy's (SECNAV) priorities regarding unmanned systems. On 16 March 2017, the Acting SECNAV issued a follow-on memorandum establishing the Deputy Assistant Secretary of the Navy – Unmanned Systems as the lead office for coordination and directed the Office of Naval Research to support CRUSER efforts through FY23.

CRUSER captures a broad array of issues related to emerging robotic and autonomy related technologies, and encompassing 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. 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 September 2017 the

CRUSER community of interest included nearly 3,200 members from government, academia and industry.

The new focus for CRUSER in FY-17 was to increase the interaction with, and impact on, other members of the naval communities associated with robotics and autonomous systems. This included direct interactions with the Deputy Undersecretary of the Navy – Management and the Deputy Assistant Secretary of the Navy – Unmanned Systems offices. As part of this focus on senior leadership interaction CRUSER leadership has advised both DUSN and DASN on matters relating to robotic and autonomous systems and actively engaged with the DASN Unmanned Community of Interest to increase the knowledge sharing and collaboration potential with members of the CRUSER COI. This enhanced engagement included broader participation by both government and industry in CRUSER activities to include both the TECHCON and Warfare Innovation Continuum Workshop. Additionally, CRUSER worked more closely with other OSD communities of interest by interacting in the field experimentation environment to include aligning field experimentation efforts with OSD sponsored activities to enable multiple collaboration activities and enhanced information sharing. Finally, CRUSER hosted the first of three planned panel sessions focused on providing novel and focused input on issues related to the increasing integration of robotic and autonomous systems across the navel enterprise. To the extent practicable, each of these activities included industry and academic participants as well as NPS and other government participants.

This Annual Report provides a summary of the many activities executed during CRUSER's seventh year of operation and serves as a consolidated archival record for the sponsors, the CRUSER team and the entire Community of Interest.

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. Funding for research activities are provided by the Office of Naval Research, other activities are funded by a variety of sources with the Deputy Assistant Secretary of the Navy for Unmanned Systems (DASN Unmanned) being responsible for coordinating funding.

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.

Figure 1. CRUSER program innovation threads as of September 2017

Major concept generation activities (FY11 through FY17) 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

A. VISION

At the direction of the SECNAV, NPS leverages its long-standing experience and expertise in research and education related to robotics and unmanned systems in support of the naval 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 domain and 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 while highlighting the educational mission of NPS.

Specific CRUSER goals continue to be:

- Shape generations of naval officers through education, research, concept generation and experimentation in maritime application of robotics, automation, and unmanned systems.
- Provide a source for unmanned systems employment concepts for operations and technical research;
- Provide an experimentation program to explore 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 variety 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 Joint Interagency Field Experimentation (JIFX) program, the Center for Autonomous Vehicle Research (CAVR), the Advanced Robotics Systems Engineering Lab (ARSENL), 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. Additionally, CRUSER leverages USECNAV and ONR relationships with external organizations to include the Deputy Assistant Secretary of the Navy (DASN) for Unmanned Systems, the Office of Naval Research (ONR), the U.S. Naval Research Laboratory (NRL), various Office of the Chief of Naval Operations (OPNAV) entities, Naval Air Systems Command (NAVAIR), Naval Sea Systems Command (NAVSEA), Marine Corps Warfighting Laboratory (MCWL), Naval Air Warfare Center (NAWC) Weapons Division, Naval Undersea Warfare Center (NUWC) Keyport, and Space and Naval Warfare Systems Command (SSC) Pacific among others.

A variety of NPS 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.

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 comprised of 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 Warfare Officer, the Surface Warfare Chair, and senior representatives of the other branches of the armed services (USMC, USA, and USAF). This committee ensures that the fleet and its operations remain a primary consideration in CRUSER activities to include the selection of activities funded by CRUSER.

C. FY17 PROGRAM ACTIVITY SUMMARY

The CRUSER FY16 Annual Report concluded with a list of proposed FY17 activities. Now that FY17 is at a close CRUSER has concluded the first four innovation threads, are developing the fifth, and have just begun a sixth thread as planned. CRUSER activities in FY17 included:

- CRUSER provided funding to 20 NPS researcher projects detailed later in this report (*see section II:A*) in addition to providing support for institutional activities, such as Interim Flight Clearances, related to robotic and autonomous systems research. CRUSER also supported follow-on and closeout funding enabled the completion of previously supported projects such as the Swarm vs Swarm aerial combat project completed by the Advanced Robotics Systems Engineering Laboratory (ARSENL).

- CRUSER continued to fund the integration of robotics and autonomous 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. This included support for integration of robotics and autonomous systems materials into both 22 individual courses as well as one major capstone projects. In addition to these campus efforts CRUSER sponsored short courses for naval engineers and scientists at SSC-Pacific in San Diego.

- CRUSER hosted its annual Technical Continuum (TechCon) in April 2017 to explore development of the concepts generated the fall concept generation workshops, as well as to provide funded researchers an opportunity to share their findings. Thirty presentations were presented over two days. For the first time, industry and government CRUSER members were invited to participate in the presentations as well as being invited to attend the event.

- CRUSER sponsored a variety of field experimentation to include the most promising technologies presented CRUSER TechCon 2016. Experimentation sponsored by CRUSER was executed at formal events such as the quarterly Joint Interagency Field Experiments (JIFX) held at Camp Roberts and the Multi-Thread Experiment (MTX) held on San Clemente Island featuring participation by operational fleet elements.

Experimentation also included off-range activities in coastal seas as well as both Arctic and Antarctic Ocean environments.

- CRUSER updated its information and collaboration mechanisms, updating its website, adding a YouTube channel for the entire COI and creating a CAC required site for information sharing with government CRUSER members. CRUSER also worked to more closely align activities with the DASN Unmanned Community of Interest to include adding CRUSER events to the DASN's Community Calendar. CRUSER continues to host, and broadcast, monthly meetings for the entire community of interest.

- CRUSER sponsored research was used to support seven conference presentations and resulting journal articles. This is a critical aspect for the CRUSER mission of exposing the larger robotics and autonomous systems community to the challenges associated with these technologies in the maritime/naval environment.

- CRUSER funded 40 student trips in support of thesis research and experimentation dealing with all aspects of unmanned systems. This was part of an effort that supported # student theses completed this year that focused on robotic and autonomous systems.

- CRUSER hosted two on-campus colloquiums in FY17 featuring thought and technology leaders Dr. Stefano Carpin, Associate Professor of Engineering at the University of California Merced; and Dr. Julie Adams, Professor of Computer Science at Oregon State University.

- In collaboration with the Warfare Innovation Continuum (WIC) CRUSER completed FY17 with a concept generation workshop "Distributed Maritime Operations" 18-21 September 2017. This workshop is described in a separate report.

- CRUSER initiated a three part continuing education series, "Just One Thing", that offers thought leaders from across the robotics and autonomous systems domains to provide input and initiate conversations regarding what they perceive to be the most important aspect of these new technologies as they relate to the naval enterprise.

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

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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. Like in FY16, CRUSER executed just over $4M in the FY17 cycle, and anticipates funding at the same level for FY18. Activities for each year are briefed to the Advisory Board and require approval from the sponsor.

FY17 brought with it the opportunity for the CRUSER team to grow, with the addition of three faculty associates and a postdoc. We also expect to add a technical support member to the team soon.

Primary objectives in FY17 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 continued to leverage long-standing experience and expertise in the research and education of robotics and unmanned systems to support the Navy's mission. CRUSER continued to serve as a vehicle by which to align currently disparate research efforts across the NPS campus as well as among academic partners and the greater community of interest. Funding in FY16 was granted to projects led by NPS faculty members to explore many diverse aspects of unmanned systems.

In late July 2016, CRUSER made its fifth call for proposals to seed research topics. The stated funding period was 1 October 2016 through 30 September 2017, and the funding levels were set at $75,000 to $150,000 per proposal.

At the beginning of September 2016 CRUSER received 46 proposals totaling just over $5.7 million. All were reviewed for CRUSER seed funding. The CRUSER advisory committee selected 20 projects, and granted just over $2.1 million in total to support robotics and autonomy related research in FY17 (*see Table 1*). All funded project summaries are included in this section of the report.

Table 1. FY17 CRUSER funded projects (*alphabetical by initial lead researcher last name*)

	Lead Researcher(s)	Project Title
1	Beery, Paulo, Williams	Investigation of Requirements and Capabilities of Next Generation Mine Warfare (MIW) Unmanned Underwater Vehicles (UUVs)
2	Bordetsky	Multi-Domain Mesh Network of Short Appearance Unmanned Nodes
3	Dobrokhodov, Jones	Cooperative Underwater Sensing with Aqua-Quad
4	Horner	Alternative PNT for Persistent Undersea Navigation
5	Horner, Monarrez	Arctic ScanEagle
6	Jenn	UAV EM Sensors for Spectrum Sensing and Propagation Environment Assessment
7	Kaminer, Kragelund	Closing the Experimental Gap in the Search and MCM Communities
8	Kaurunasiri, Alves	Bio-inspired MEMS Acoustic Sensor for Robotic Autonomous Systems Applications
9	Klamo, Kwon	Investigation of Unsteady Hydrodynamic Loads on a UUV During Near Surface Operations
10	Jones, Wang	Low-Cost Expendable UAS with Application to Low Altitude Atmospheric Measurements - Phase II
11	Nissen	C2 Design for Asymmetric Advantage: Teams of Autonomous Systems & People
12	Olsen	Multi-Modal Sensor Fusion from Autonomous Platforms with 3D Modeling
13	Romero, Pace	Network Enabled Digital Swarm Image Synthesis (NEDSIS)
14	Sanchez, Lucas	Innovations in Unmanned Technologies for Humanitarian Assistance and More

15	Thulasiraman	Study of Security Primitives for the Robot Operating System (ROS) of UAV Swarms
16	Tsolis	RoboDojo
17	Wang	Autonomous Wave Glider Based Measurements and Analyses in Support of Electromagnetic Maneuver Warfare (EMW)
18	Yakimenko (N&G)	Vision-Based Navigation and Guidance for Swarm UAS
19	Yakimenko (RECON)	Prototyping of Air-Launched Fast Recon UAS
20	Yun, Calusdian	Optimal Trajectory Generation for Small Drones Used as Micro Interceptors

Some of these projects are complete, and others were still in work as their period of performance ended on 30 November 2017. These research summaries include work as of 30 September 2017, are listed in alphabetical order by primary Principal Investigator (PI) last name, and each has a point of contact listed for further inquiry.

1. Investigation of Requirements and Capabilities of Next Generation Mine Warfare (MIW) Unmanned Underwater Vehicles (UUVs)

The U.S. Navy's Mk 18 Unmanned Underwater Vehicles (UUVs) Family of Systems (FoS) program has been met with signification positive responses from operational forces. The Mk 18 Mod 2 was forward deployed in response to an Urgent Operational Need (UON) from Commander Fifth Fleet to address minehunting needs. The capability has been retained in Fifth Fleet, and Navy Expeditionary Combat Command has established the concept of Expeditionary Mine Countermeasures (MCM) Platoons to form the operational group to employ the Mk 18 FoS. This research examined the requirements, capabilities, and operational implementation of the "next generation" of these UUVs.

The first stage of the research process was a review of existing MCM capable UUV systems. The research reviewed the US Navy UUV Master Plan, which provides programmatic goals and capabilities of existing UUVs. In particular, this research focused on UUVs that operate in the deep-water region and are capable of providing mine detection, classification, and identification capabilities. This identified five potential candidate systems for further study; the Mk 18 Mod 2, the Knifefish, the Large Displacement Unmanned Underwater Vehicle (LDUUV), the Snakehead, and the Extra Large Unmanned Underwater Vehicle (XLUUV). Among these alternatives, the Mk 18 Mod 2 was the most technologically mature, and was selected for more in depth study. Review of the UUV Master Plan indicated that current technological progression suggested multiple areas for potential alteration to the current Mk 18 Mod 2 operational capability. Specifically, the recent progression of UUV technology suggests that alternative approaches to the mission of collecting, analyzing, and transmitting sensor data from within the minefield are possible for the Mk 18 Mod 2. These changes may enable an expanded concept of operations for the system. The first potential change to the concept of operations is automation of the data processing of the detection phase of the minehunting sequence on-board the Mk 18 Mod 2 (reducing the burden on Post Mission Analysis (PMA)). The second potential change to the concept of operations is the introduction of underwater communication modes between the UUV and the ship or system performing the analysis of minehunting data. To bound the options for communication, this research chose the edge cases of no communication and constant communication, as well as a middle-ground of intermittent communication. Figure 2 below provides a summary of the six alternative concept of operations alternatives studied in this research.

		Communications Type		
		No Communication	**Intermittent Communication**	**Constant Communication**
Data Processing Location	**Off-board UUV**	**Alt 1.** Post-Mission Analysis **[Status Quo]**	**Alt 2.** Intermittent Communication with Off-board Data Analysis	**Alt 3.** Constant Communication with Off-board Data Analysis
	On-board UUV	**Alt 4.** Real Time Analysis with Physical Transfer of MILECs	**Alt 5.** Real Time Analysis with Intermittent Communication of MILECs	**Alt 6.** Real Time Analysis with Constant Communication of MILECs

Figure 2. Alternative Concepts of Operations for Mk 18 Mod 2.

The second stage of the research process was the development of an architectural representation of the key system functionality necessary to model the operational performance of the Mk 18 Mod 2. Utilizing Innoslate, a systems architecture modeling software, this research generated a hierarchical representation of the operational activities associated with each potential operational concept for the Mk 18 Mod 2. The architecture development served as a baseline for the development of a more detailed operational model, built using ExtendSim, a discrete event modeling software. The architectural analysis indicated that there were five major operational activities common to each operational concept: system initialization, minehunting search, pre-PMA, PMA processing, and data analysis. Figure 3 provides a high level visualization of the transition between each of these activities as well as the sub-activities modeled within each stage.

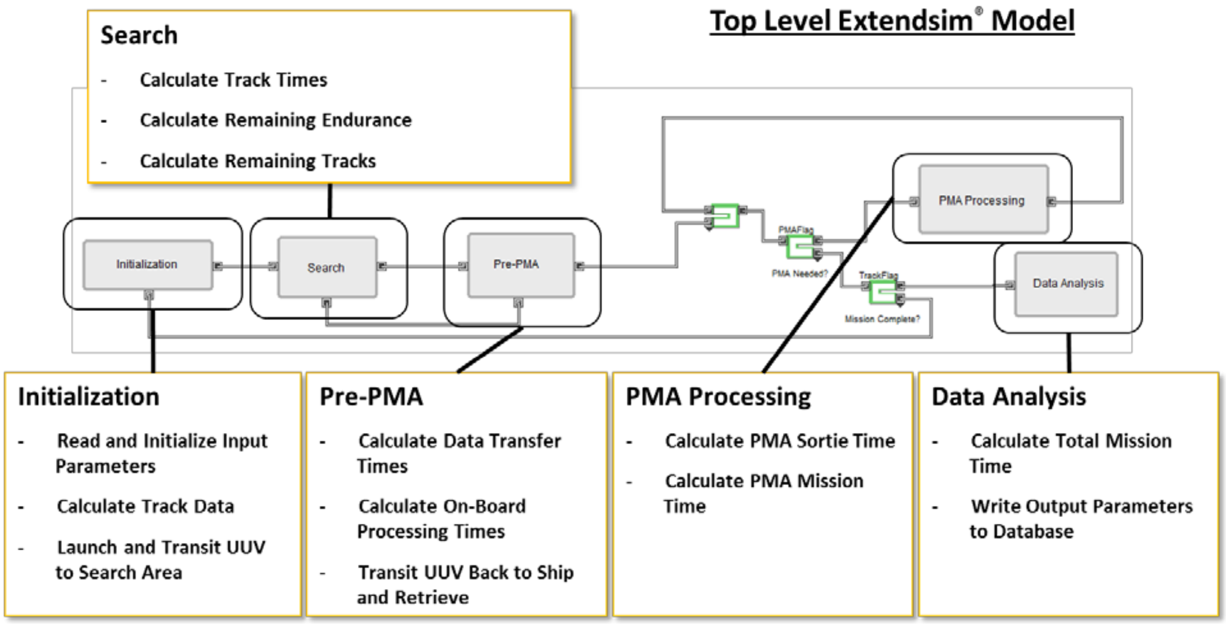

Figure 3. Discrete Event Model Representation of Mk 18 Mod 2 Operations.

Along with the alternative concepts of operations modeled in ExtendSim, this research also considered multiple system specific design parameter alterations that may impact the operational effectiveness of the Mk 18 Mod 2. Specifically, changes to the launch time, endurance, speed, dive time, surface time, recovery time, replenish time, sensor range, data collection rate, scan speed, surface data transfer rate, and sub-surface data transfer rate were all varied within the model. Currently (September 2017) model runs are being conducted, with an expected completion in October 2017. The output of those model runs will be analyzed, with analysis results presented in two phases. First, a quantitative comparison of the alternative operational concepts will be presented, with the goal of guiding future investment in on-board data processing or alternative communication modes. Second, the key system design parameters for each alternative operational concept will be identified with the goal of informing investment within a particular data processing/communication mode combination. The analysis will be completed in November 2017, with a final report and findings completed in December 2017.

POC: Dr. Paul Beery (ptbeery@nps.edu)

2. Multi-Domain Mesh Network of Short Appearance Unmanned Nodes

The Department of Defense (DOD) foresees that future adversaries will be able to detect, geolocate, and target through electromagnetic (EM) spectrum operations. If true, the current networking paradigm that uses persistent signals to support end-to-end communication sessions will be unsupportable. Using persistent signals in the future operating environment may either unnecessarily expose forces to adversaries through the networks or impair decision-making if forces cannot communicate because of the risk of detection. Put simply, the DOD must begin to reconsider the nature and behavior of its networks. CENETIX is examining “networks that do not exist” as one potential solution. CENETIX envisions networks comprised of manned, unmanned and autonomous nodes whose links connect only long enough to transmit critical information securely. The links quickly disconnect, leaving no trace electromagnetically. The idea is that an adversary cannot detect signals that do not exist. Adversaries cannot discover vulnerabilities if they cannot communicate with network nodes.

During Fiscal Year 2018, CENETIX completed an experimentation campaign that was designed to begin making observations about short-living nodes. The CENETIX team designed projectile-based mesh networking prototypes as one potential type of short-living network node. The projectile-based mesh networking prototypes were created on campus at the Naval Postgraduate School using additive manufacturing, computer-numerical control milling, and basic computer programming in a few different languages. CENETIX created five sequential prototypes, each using Virtual Extension Mesh radios, Arduino microprocessors, and small sensors.

Once the team arrived at a prototype with suitable flight characteristics, adequate protection against the forces of launching and landing, and the ability to converge on the network during flight, we used the prototypes in experiments that allowed the team to observe some of the merits and challenges of moving from persistent signal networks to cluster-based networks created only during disruption. Initial experiments successfully created the multi-domain short appearance network during the duration of the projectile's flight and passed command and control information from an unmanned remote sensor node to the operations center. In later experiments, we transmitted movement instructions to an unmanned ground vehicle from the operations center and observed that the UGV executed the instructions. Although simple in nature, these experiments allowed CENETIX researchers to observe multi-domain mesh network behavior and analyze how the protocols resident in the network interacted and affected the overall performance of the network.

CENETIX research was limited in some aspects. Our work was conducted purposefully in the unclassified domain and did not employ electromagnetic detection tools in order to attempt to geo-locate nodes during the duration of their interactions. We also did not attempt to modify manufacturer-set protocols in order to optimize results. These are appropriate threads for future work.

The CENETIX team plans to move from focusing on creating short-living nodes to shaping the behavior of short-living links in FY 2018. Projectile-based mesh nodes are simply one type of potential node that can create short-living links. There is real value in the continued evaluation of short-living link behavior and how that behavior translates on a larger scale to command and control operations in tactical environments. We believe that there is sufficient merit for future experimentation in a wide array of tactical scenarios including: littorals, urban terrain, GPS-denied environments, undersea and aerial environments.

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

3. Cooperative Underwater Sensing with Aqua-Quad

A small fleet of Aqua-Quad small unmanned aircraft systems (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 (*see Figure 4*). 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.

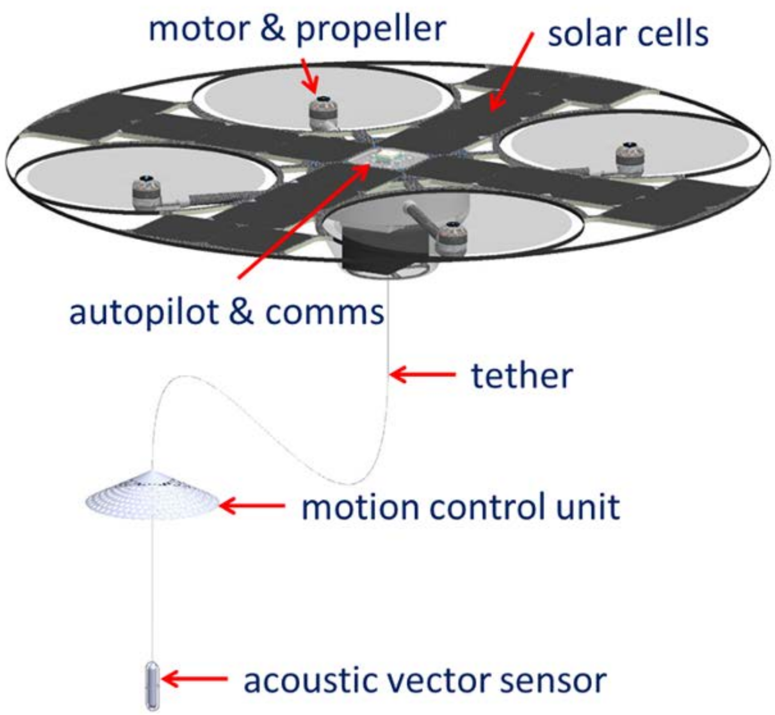

Figure 4. Prototype Aqua-Quad CAD drawing.

During FY17 research focus areas included optimization of the avionics, propulsion system, and airframe, development of design tools required to optimize the enclosure to provide up-right floating stability along with a self-righting capability, and development of a data-acquisition system and embedded software for the proposed acoustic payload. The team is looking at migrating from the Pixhawk autopilot to the new, much smaller Pixracer, which costs less, weighs less, has increased compute power, a better IMU, and a GPS unit capable of picking up 4 satellite constellations for improved precision and reliability. In the first prototype, one of the central frame plates was a printed circuit board (PCB) that included sensors for tracking power flow from solar to batteries and electronics. This plate has now been replaced with a much smaller PCB that includes a data-acquisition (DAQ) system along with power regulation for avionics and payloads, and the frame plate was replaced with a stronger, lighter Carbon fiber plate. The DAQ is an off-the shelf, very low SWaP device that is based on ARM microcontroller that retails for about $30. Components from the rapidly evolving drone-race market are being investigated as replacements for some of the propulsion system; in particular, the electronic speed controls (ESCs). Newer options are smaller, lighter, and considerably more efficient.

On the payload side, work has been performed in a collaboration with researchers in the NPS Physics department and at NUWC Keyport. The initial proposed payload is an acoustic vector sensor (VS-301 by Wilcoxon) which would notionally hang on a thin tether from the bottom of Aqua-Quad to sense at a suitable depth. The sensor produces a mix of high bandwidth analog and digital outputs that need to go through a DAQ, and then run through post-processing filters to attenuate noise, identify the signals of interest, coordinate transformation, and to reduce the data to a manageable quantity for transmission. The DAQ currently being investigated is a newer, more powerful version of the DAQ used in the power flux sampling. Based on 32 bit 180 MHz ARM Cortex-M4 processor with floating point unit It has sufficient compute power to enable concurrent ADC of multiple analog channels as well as data processing - all running in mutithreading mode. Experiments have shown that it can accurately identify known signals comprised of multiple frequencies. The performance of DFFT processing on embedded platform and the DFFT algorithm running in MatLab in computationally unrestricted Corei7 Intel CPU were compared *(see Figure 5*). The DAQ weighs less than 5g and requires less than a Watt under heavy CPU load.

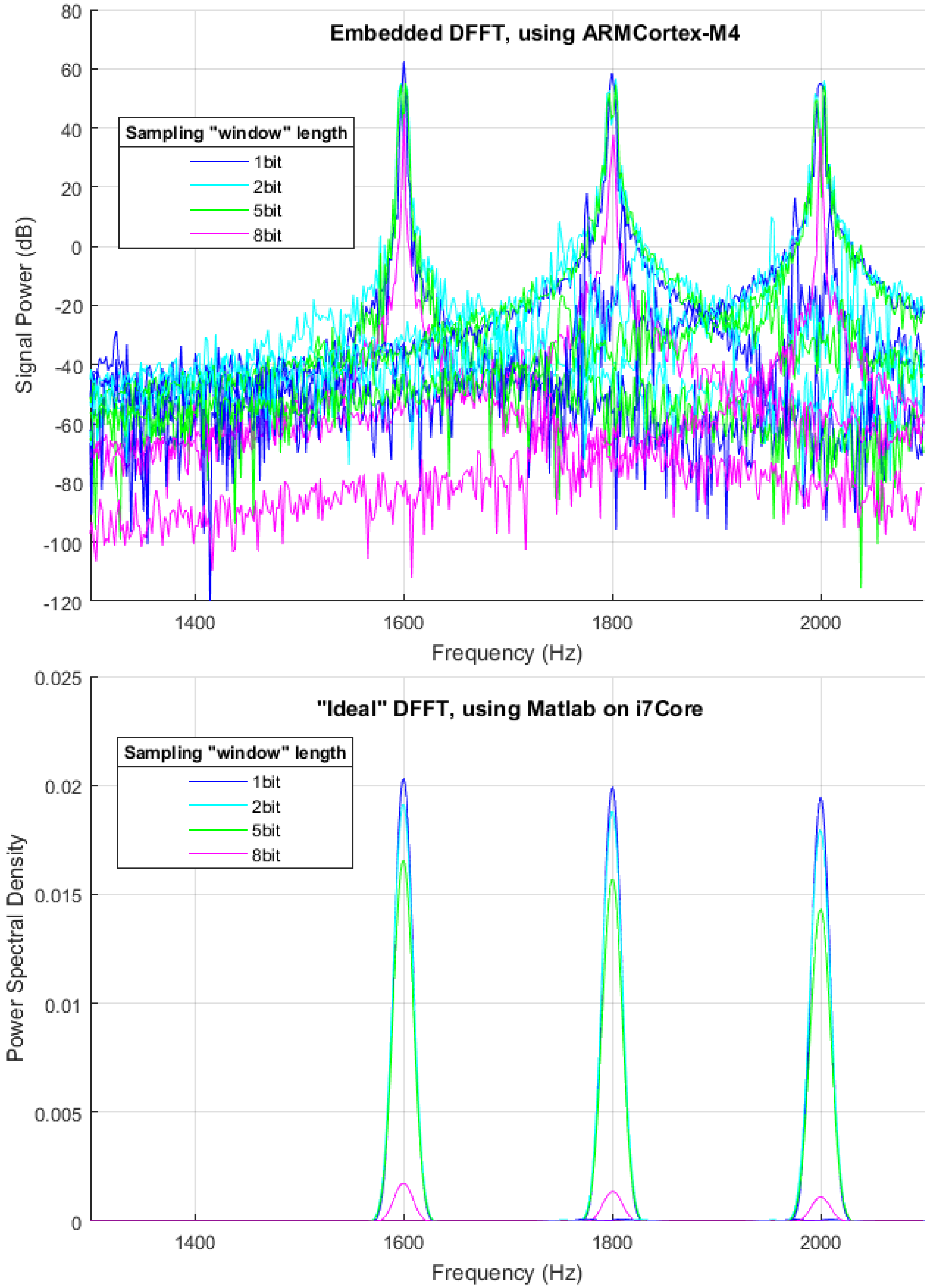

Figure 5. Performance of DFFT processing on embedded platform (top) and DFFT algorithm running in MatLab in computationally unrestricted Corei7 Intel CPU (bottom).

POCs: Dr. Kevin Jones (kdjones@nps.edu) and Dr. Vlad Dobrokhodov (vldobr@nps.edu)

4. Alternative PNT for Persistent Undersea Navigation

The goal of the research was to develop near real-time maps that enable Autonomous Vehicles to navigate for prolonged periods of time without GPS. The research focused on the development of a capability to combine the use of cameras and LIDAR sensing to detect and label 3D objects through the training of a Convolutional Neural Network (CNN). The technique is suitable for various sensor modalities including undersea.

There are three distinct phases to the approach: Automated Dataset Creation and Training, Context Discovery and Real-Time Pointcloud Classification and represents a novel, comprehensive approach to map building and object recognition. The first phase requires data collection consisting of synchronized 2d camera images with 3d pointclouds generated by LIDAR. After pointcloud segmentation, 3D-2D correlation, 2d classification, thresholding, segment transformation and neural network training, the output is a trained neural network that is capable of automatically labeling 3d LIDAR data with a object (e.g. tree, truck, stop sign, etc.). The first phase was the focus of the research project.

Data was collected on several sites including: the NPS campus, a residential Monterey neighborhood and the Multi-threaded Experiment (MTX) at San Clemente Island, CA. The results of the experimentation were promising. From Drew Watson's Master's thesis..."The dataset “Neighborhood 1” was processed through the automated pipeline and created a total of 41 labeled pointcloud segments from a collection duration of 346 seconds. Based on the following criteria, we judge the pipeline to have produced 31 correctly labeled pointcloud segments and ten incorrectly labeled pointcloud segments, representing a 75.6% accuracy...The pipeline was subsequently run on the “Neighborhood 2” dataset, which measured 317 seconds in length, and achieved greater accuracy. This second test produced a total of 35 labeled segments with 31 evaluated as “correct” and four as “incorrect.”... The aggregate performance of the pipeline, when combining the results of both datasets Neighborhood 1 and Neighborhood 2, reached the level of 81.6% accuracy. With the two collection’s combined duration of 663 seconds, the pipeline created a correctly labeled segment every 10.7 seconds and an incorrectly labeled segment every 47.4 seconds".

In summary, the research established an automated pipeline for creating labeled LIDAR data that combined the automated image classification and pointcloud segmentation capabilities of TensorFlow’s Inception-v3 and Depth Clustering. This research has potentially many uses including the automated creation of labeled datasets (that can be used for training CNNs), the ability to robotically navigate at night without 2d image sensing and the creation of semantically grounded navigational maps that can be potentially used for better robotic situational understanding and planning.

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

5. Arctic ScanEagle

This research has determined and implemented corrective actions to successfully fly Scan Eagle in the Arctic. The Arctic's harsh environment and extremely low temperatures (from -23 degrees Fahrenheit to -38 degrees Fahrenheit) are very challenging to operate in for both human beings and Scan Eagle vehicles. In order to operate in the Arctic's harsh environmental conditions, we have identified, installed and tested the Northwest 44 (NW44) engine and replaced the fuel lines that are rated for -40 degrees Fahrenheit. The NW44 is built by Northwest Unmanned Aerial Vehicles (NWUAV). The NW44 engine upgrades the functionality and flight performance of the NPS Scan Eagle fleet by providing a greater operational flight envelope, increasing the payload capability, increasing endurance due to more refueling options and providing over 300% more power available than the current engine.

The NW44 has up to 3.6 horsepower verses 1.9 horsepower and increases the total available payload power. It also provides a total of 200W of power versus the 60W, which allows for further payload development and increased capability of the overall system. The fuel injected NW44 engine also allows Scan Eagle to easily deploy with the Navy units, since it requires either Jet-A or JP8 fuel, which is commonly found on Navy installations or ships. The current Scan Eagle engine uses C-10 race fuel which in general is harder to procure, especially in remote locations and while deployed. During flight testing, with an aircraft weight of 23Kg and a target altitude of 15000 feet the NW44 reached the goal 62 minutes and 24 seconds faster.

The Northwest 44 engine was installed using the documentation provided by NWUAV. Installation and testing was conducted prior to chamber testing. All installation and testing/operation of the system was done under normal operating procedures as established by Naval Postgraduate School instructions and standard operating procedures, based on manufacturer recommended guidelines. The engine and system performance was tested at different temperatures in the environmental chamber. A qualified technician operated the environmental chamber, while a qualified operator and technician operated the Scan Eagle aircraft in an OEM cradle. The aircraft was remotely controlled from a ground control station outside the chamber. Through a series of stepped temperatures, the chamber technician incrementally decreased the chamber temperature by 10 degrees until -50 degrees Fahrenheit was reached.

There was no observed degradation to the overall system performance during our initial chamber tests at 0 Degrees Fahrenheit and -10 Degrees Fahrenheit. The system performance was reduced by 100 RPMs during the -20 Degrees Fahrenheit test and was reduced by another 100 RPMs at -30 Degrees Fahrenheit. The decrease in RPM by the NW44 was to be expected due to the decrease in temperature, but the overall system performed as anticipated. The additional stress on the system during final chamber tests, at -40 Degrees Fahrenheit and -50 Degrees Fahrenheit, resulted in an additional reduction of 300 RPMs. The lower temperatures also caused the system's avionics to malfunction resulting in a false yaw sensor reading. It is important to note, the NW44 engine at -50 Degrees was still 200 RPMs higher than the current engine operating in a normal environment. The follow-on research will examine the causes for the decrease in avionics temperature and false readings.

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6. UAV EM Sensors for Spectrum Sensing and Propagation Environment Assessment

This research investigates the use of electromagnetic (EM) sensors onboard small UAVs for assessing the state of the EM environment in real time. Rather than sensing the meteorological properties of the environment (such as temperature, humidity, etc.), signal transmissions to and from a number of sources and receivers are used to build a picture of the electromagnetic environment and the propagation conditions (*see Figure 6*).

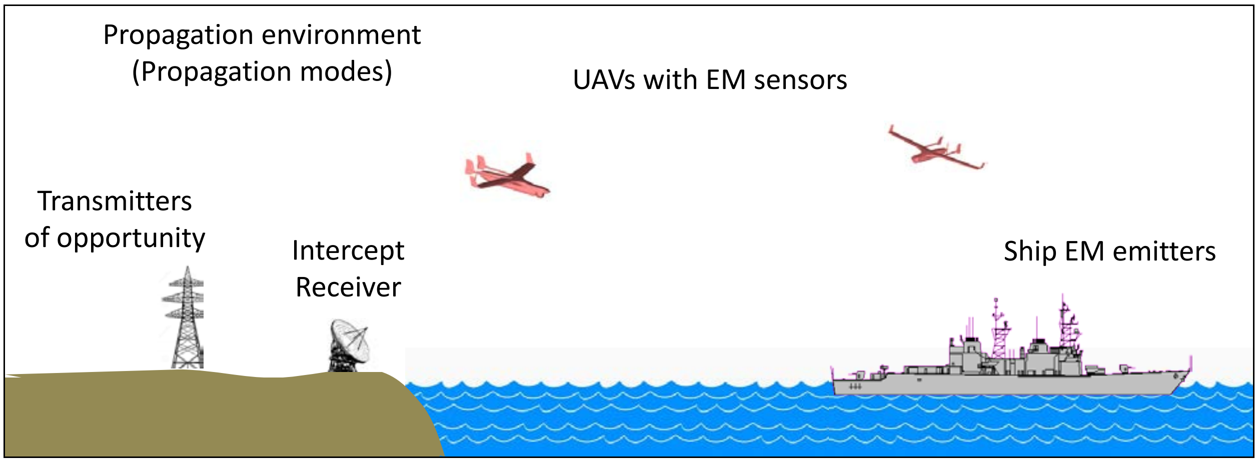
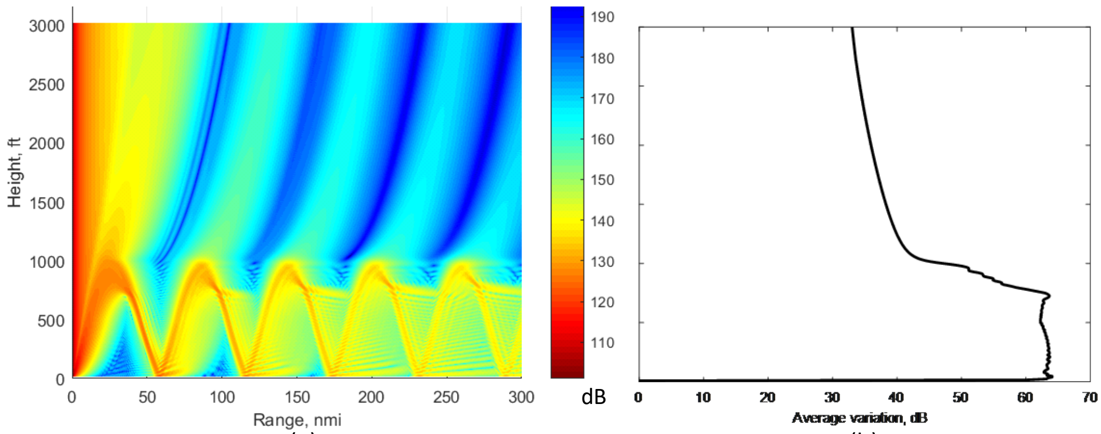


Figure 6. Concept for sensing the EM propagation environment.

There are a number of UAVs equipped with transmitters and receivers distributed throughout the environment of interest. A large number of locations are needed to obtain useful data at long distances, multiple altitudes, and in many directions. Recent developments in commercially available electronics make the concept of outfitting large numbers of UAVs with EM sensors feasible and affordable. There may also be "transmitters of opportunity" such as shore based radios, ships, buoys, manned aircraft, etc. that can be utilized. For example, there are signals from automatic identification systems (AISs), which share information on a ship's identity, position, course, speed, navigation status, and safety-related information.

The goal of the proposed sensing technique is to be able to infer the important propagation characteristics from loss measurements. We need to estimate its dependence on distance, altitude, frequency, and azimuth direction. Furthermore, we need this information for every emitter over its operating band. Software such as AREPS can take a variety of sensor data and estimate multipath, ducting, and attenuation over a path. Therefore, we have used AREPS to generate "synthetic" loss data for a wide variety of conditions. The transmission loss between points can be computed as if measurements were conducted. AREPS allows for specific system parameters to be used in the calculations, such as antenna pointing direction and polarization loss. These are important if the propagation factor information is to be extracted.



(a) (b)

Figure 7. (a) Atmospheric loss data with ducting and (b) result of simulated measurements showing evidence of a duct.

The loss data for an example with an atmospheric duct is shown in Figure 7(a). The simulated measured data was used in an atmospheric extraction procedure that compares the measurements to a series of baseline templates (they can be either measured or calculated). The processed result is shown in Figure 7(b). The presence of the duct is clearly evident. Other simulations have shown that the atmospheric gradient can be determined adequately using the simulated data.

There is ongoing work to determine the measurement system parameters and measurement protocol. A number of tradeoffs need to be made with regard to equipment capability, number of UAVs, flight patterns, sample spacing, etc. These issues are being investigated in an ongoing Master's thesis by Major Yi Kai Qiu (Singapore Air Force, June 2018).

POC: Dr. David Jenn (jenn@nps.edu)

7. Closing the Experimental Gap in the Search and MCM Communities

Over the last few years, ONR- and CRUSER-funded research at NPS has produced new theoretical results and computational methods for solving optimization problems characterized by uncertainty. The challenge of generating optimal search and detection trajectories for dynamic sensor platforms has been transformed from a long-standing theoretical question in operations research to a computationally practical task. Motion planning algorithms are now capable of incorporating vehicle dynamics, sensor characteristics, and prior environmental knowledge to produce optimal motion plans for multiple, collaborating, heterogeneous vehicles. These techniques promise to enable much more effective utilization of mobile sensor platforms in complex surveillance, reconnaissance, and mine countermeasures (MCM) applications. A remaining gap in this research, however, has been field-testing these algorithms on actual robotic platforms in operationally-relevant environments. The objective of this project is to close this gap.

The Center for Autonomous Vehicle Research (CAVR) operates several military-class unmanned vehicles, including REMUS 100 autonomous underwater vehicles (AUV), SeaFox unmanned surface vessels (USV), and ScanEagle unmanned aerial systems (UAS). The experimental objectives for this project are three-fold. First, generate optimal search trajectories for these vehicle platforms, based upon their individual sensor payloads (e.g., sonar, radar, camera) and dynamic capabilities. Second, adapt these nonlinear trajectories so they can be executed by each vehicle's autopilot hardware and software. Finally, for each vehicle and sensor pair, compare the detection performance of these optimal search trajectories against the detection performance obtained by traditional heuristic search patterns (e.g., a lawnmower area coverage pattern).

In November 2017, CRUSER will conduct a multi-domain field experiment at San Clemente Island. The primary focus of this experiment is operating a wireless mesh network of vehicles and sensors in support of Naval Special Warfare (NSW) missions. As such, this event will provide a unique opportunity to field-test our motion planning algorithms on CAVR's unmanned vehicles. Specifically, REMUS 100 AUVs will search for underwater mine-like objects with their forward looking sonars while a SeaFox USV will search for surface contacts with its radar. Both missions will support a SEAL team insertion by clearing the route from an offshore staging location to a beach landing zone. Simulation results predict that optimal search trajectories outperform standard coverage patterns, particularly under time constraints, but experimental data is neededto verify these expectations. Meanwhile, another SeaFox USV will operate as a mobile communications gateway, enabling the REMUS underwater vehicles to share data with the wireless surveillance network.

A new application of this research is the development of optimal search trajectories for "offensive" and "defensive" video surveillance of the island's roadways by three ScanEagle aircraft to prevent ambush/surprise of the SEAL team by hostile forces. A major consideration during this experiment will be maintaining the connectivity of the wireless network. The motion planning framework will address this by ensuring all aircraft search trajectories satisfy bank angle constraints needed to maintain antenna line-of-sight. Offline search trajectories will be generated for each phase of the NSW mission, from SEAL team insertion to extraction. Each phase will involve one or more aircraft cooperating to provide optimal surveillance coverage of the roadways which could negatively impact the current mission objective. During this year's experiment, CAVR researchers will initiate the transitions between pre-computed surveillance trajectories at the commencement of each mission phase. However, we anticipate that ongoing enhancements to this motion planning framework will ultimately allow surveillance assets to automatically re-plan their trajectories in real time to respond to changing mission conditions. As we continue to develop this motion planning framework, we look forward to future field experimentation opportunities to demonstrate the utility of this approach.

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8. Bio-inspired MEMS Acoustic Sensor for Robotic Autonomous Systems Applications

What makes acoustical awareness in robotic autonomous systems (RAS) difficult is the underlying complexity of the acoustic domain. The soundscape is always changing with time, and the sensors currently available for sampling are noisy and only capture a relatively small selection of the soundscape. Additionally, the soundscape itself is varies significantly from environment to environment. Altogether, this creates a very hostile perceptual domain for RASs, which are already struggling to successfully handle routine many other tasks. One attractive solution is to have signature-based sensors in order to detect the source of interest while naturally filtering any other acoustic perturbation. Our research group has developed a narrowband sensor, using micro-electro-mechanical systems (MEMS) technology, based on the mechanically coupled ears of the Ormia Ochracea fly as proof-of-concept. The motivation for the reported research is the possibility of localizing and identifying RAS sound signatures using optimized MEMS Ormia-based detectors. Under current CRUSER funding, we have been working on preparing experimental setups to record aerial drone acoustic signatures and understand the impact of the flight regime on them. Initially, a commercial drone was acquired, the Phantom III, the same type that have been used to enter the White House airspace.

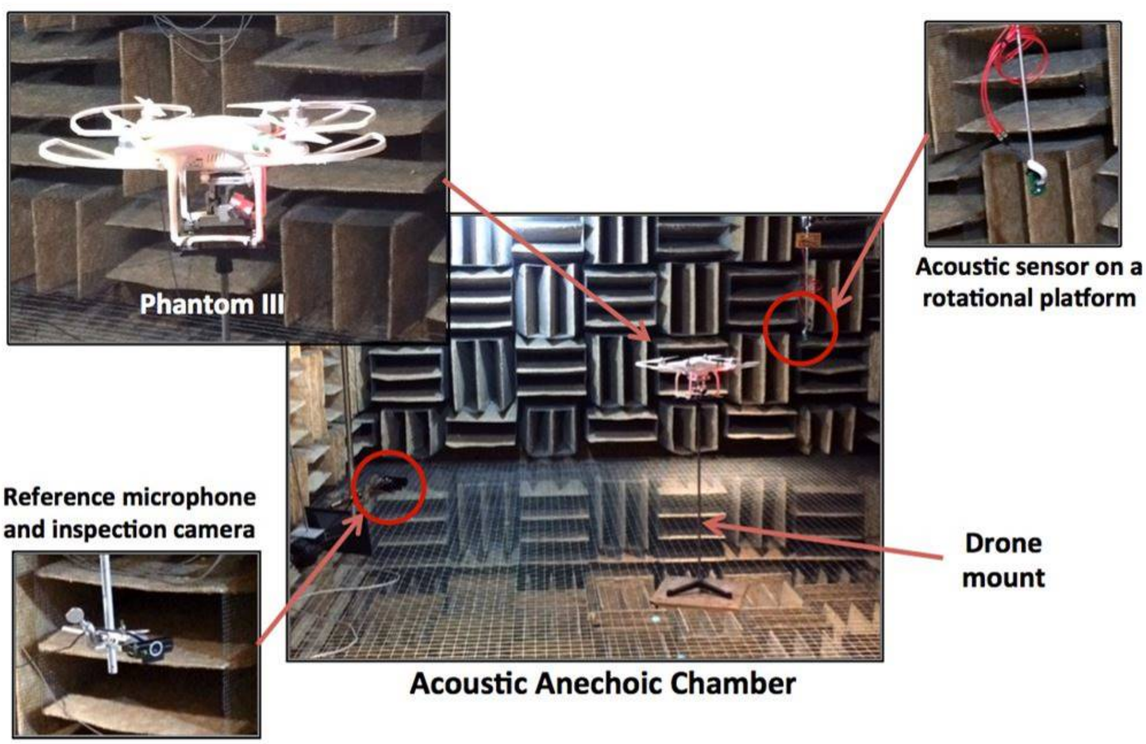

Figure 8. Experimental setup used to measure the Phantom III acoustic spectral signature in two flight regimes, hovering at 1m and full throttle (emulating hovering with full load). The same setup was used to test the directional response of one of our *Orima*-based sound sensors with bending mode peaking at 1.47 kHz.

Several experiments in anechoic environment were performed to identify specific features in the acoustic spectrum of the Phantom III. The figure above (*see Figure 8*) shows the experimental setup, where the drone was rigidly mounted to a heavy base in an anechoic chamber. The background noise was compared with the acoustic signature of the Phantom III in two hovering regimes, 1 m high, no load and full throttle, emulating max load hovering. We have identified that there are spectral features on the low frequency end that repeat in both regimes. This result should be further compared with open field measurements in order to remove noise caused by mounting the drone rigidly to the base. Also, an existing sensor designed to operate at 1.47 kHz (*see Figure 8*) was used to measure the direction of the hovering Phantom III in the anechoic chamber, as a proof-of-detection. The next figure (*see Figure 9*) shows the directional response of the sensor as a rotating platform changed the relative direction between the drone and the sensor. The drone was set to an automatic hovering mode; therefore, its power was cycling periodically due to the flight controller misinterpretation of flight regime. This effect can be noticed by the second hump on each rotation cycle (*see Figure 9*). The theoretical prediction, shows a cosine dependence of the sensor output with the angle of arrival as discussed in the FY17 proposal and assumes that the sensor is optimized to the source, which is not the case.

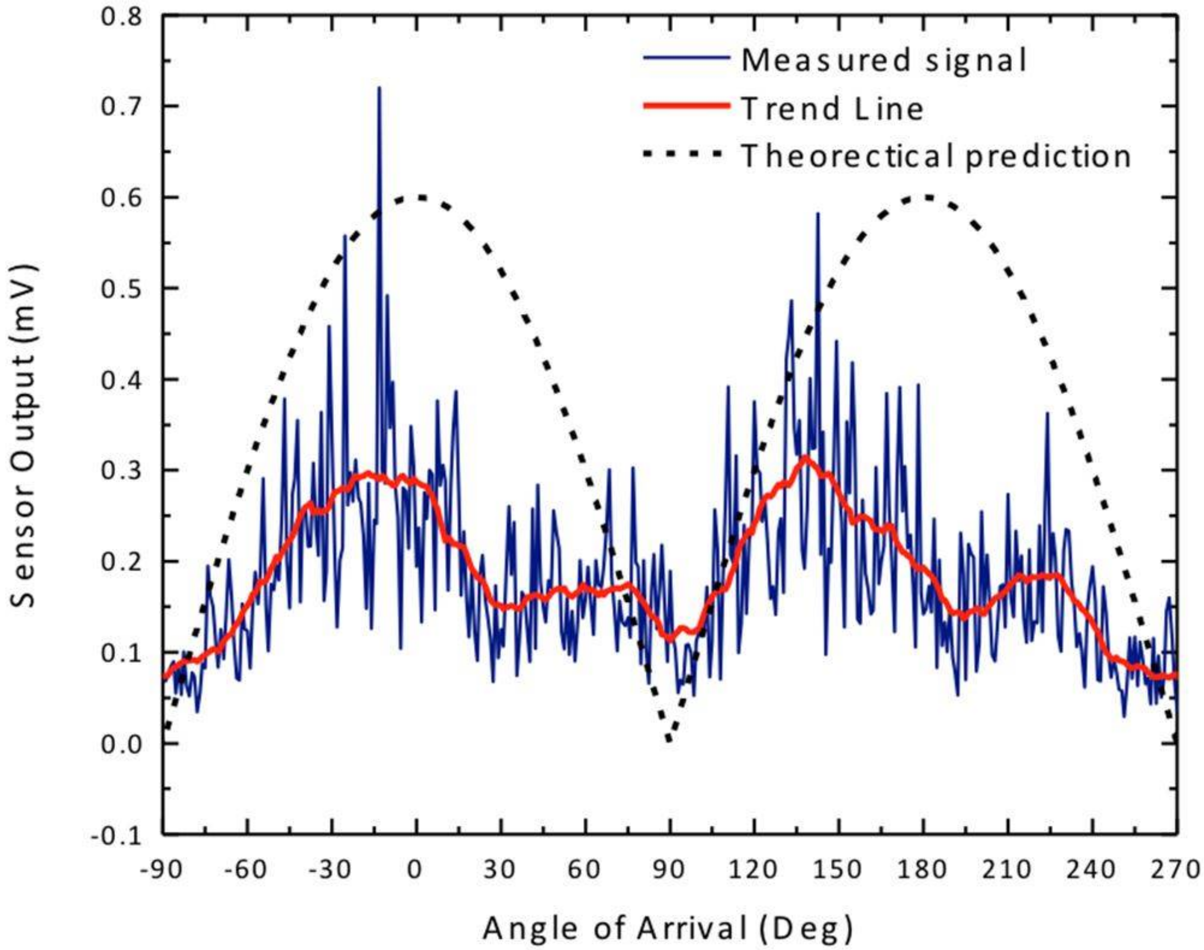

Figure 9. Directional response to the Phantom III hovering at 1m from one of our Orima-based sound sensors with bending mode peaking at 1.47 kHz. The theoretical prediction (dashed line) assumes that the sensor is optimized for the acoustic source, which is not the case.

The preliminary results obtained so far are very encouraging and we expect to finish FY17 with a collection of aerial drone acoustic signatures in several flight regimes, in an anechoic environment and at open field. Also, it is expected that noise and vibration suppression means for sensors installed in moving platforms will be studied. The remaining task would be to design sensors to detect specific signatures, selected from the collected data with the help with the CRUSER community. In this context, a continuation of this project was proposed for FY18: a specific RAS acoustic signature from the FY17 data collection will be selected and a sensor will be designed to detect that specific signature; a set of sensors will be fabricated using NPS microfabrication facilities (Clean Room); the fabricated sensors will be integrated with the readout electronics and will be integrated to acoustic signature measurement systems.

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9. Investigation of Unsteady Hydrodynamic Loads an a UUV During Near Surface Operations

There is a growing interest within the U.S. Navy to increase the use of unmanned underwater vehicles (UUVs) in a wider range of operational missions. Many of these missions will require UUVs to operate near the surface. However, this requirement could result in the UUV experiencing potentially large unsteady hydrodynamic loads from each passing wave. These loads reduce the maneuverability and controllability of the UUV since most control algorithms do not account for the effects of external hydrodynamic loads. This reduces the mission effectiveness of the UUV and could result in an unwanted surface broach, exposing the location of the UUV, or ultimately in the capture of the vehicle. In order to understand the generation and predict the severity of these unsteady loads, a multidisciplinary research effort between the Systems Engineering and Mechanical and Aerospace Engineering Departments was undertaken that included both an experimental and a numerical effort.

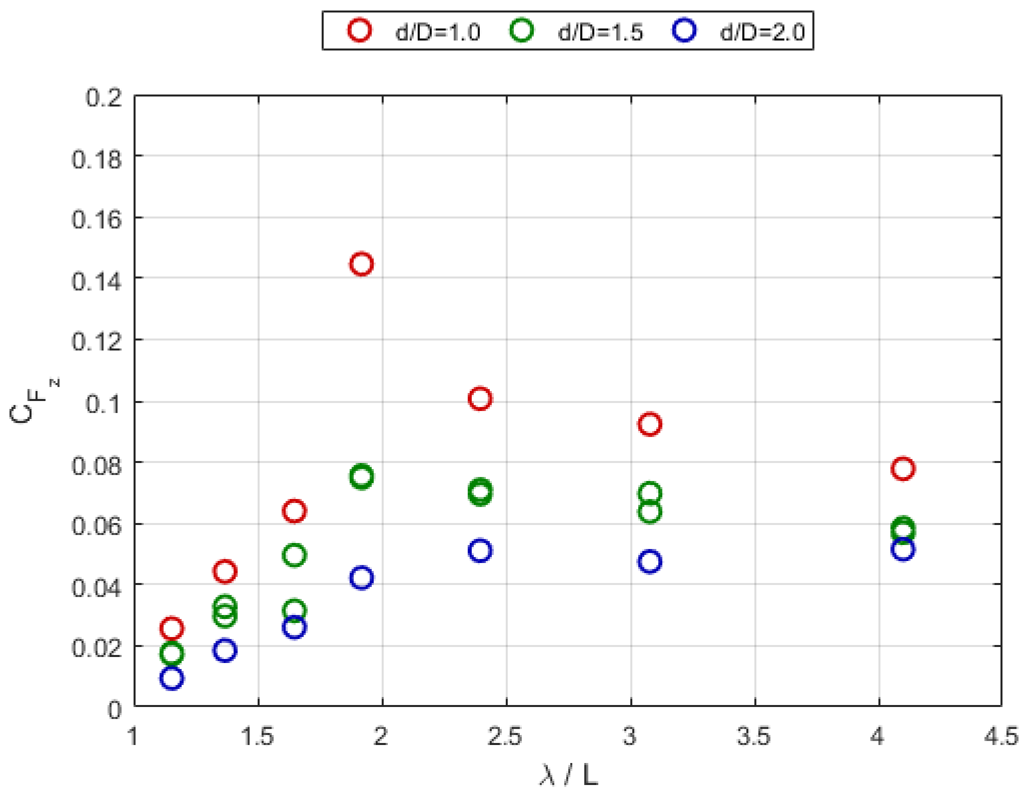

Figure 10. Experimentally measured vertical force on a circular cylinder UUV model for various wavelengths and depths.

The first part of the experimental effort involved adding a wave making capability to the existing small tow tank that resides on campus in Halligan Hall. This new capability not only directly supports this research effort but was recognized as greatly increasing the usefulness of the tow tank in general for use in various U. S. Navy research interests involving wave dynamics. The new wavemaker is based off a design used at the United States Naval Academy and consists of a wedge type plunger that rides on two vertical support rails. The wedge oscillates vertically at one end of the tank and produces traveling waves down the length of the tank. A wide range of wave conditions ranging from simple single regular waves to complex irregular seaways, such as JONSWAP, Bretschneider, and Pierson-Moskowitz, can be generated fairly accurately

For the next part of our CRUSER research effort, the unsteady loads on a near surface UUV were measured experimentally using the upgraded wave-generating tow tank. The UUV model was a four-inch diameter circular cylinder with hemispheric end caps and had a length to diameter ratio of five. A parametric study was undertaken to explore the effects of model depth and wave environment on the severity of the unsteady loads. The generated wave environment consisted of one-inch amplitude regular waves of various wavelengths. From the parametric study, we determined the magnitude of the vertical force and pitching moment on the UUV model as a function of wavelength and model depth. This increases our understanding of operating depths and wave environments that result in significant unsteady loads.

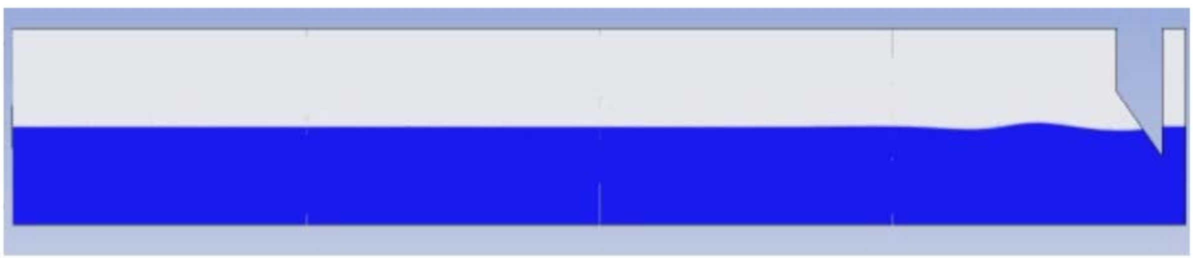

Figure 11. CFD model of the tow tank with vertical wedge wavemaker showing an initial wave being generated and starting to propagate down the tank.

The numeric effort of the CRUSER research effort involved creating a computational fluid dynamics (CFD) model to simulate the generation and behavior waves in the tow tank. This model was created in ANSYS CFX and the experimental tow tank's geometry and the plunging wedge wavemaker were duplicated as closely as possible. Duplicating the overall dimensions of the tank was a straightforward task. The generation of the waves in the tank, however, were not made by specifying an input free surface boundary condition. Rather, the wedge itself was forced to oscillate within the simulation to generate the waves. Numerous studies where undertaken to look at the effects of the mesh shape, mesh size, and time step on the simulated waves. The simulation wave results were compared to experimentally measured waves in the tow tank for the same wedge motion. The required mesh size and time step have been determined so that the CFD model accurately simulates the wave behavior.

The initial numeric studies involved a 2D model to minimize the required computational time. This model has been expanded to a full 3D model that matches the tow tank. The current focus is to add the circular cylinder UUV geometry that we experimentally tested into the ANSYS CFX model in order to simulate the forces and moments on the body. The loads predicted from the numeric simulation will then be compared to the experimentally measured loads to determine the accuracy of the simulation. We can then use the CFD model to explore the pressure and velocity of the flow around the UUV in detail to further our understanding of the dominant parameters that lead to large unsteady loads.

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10. Low-Cost Expendable UAS with Application to Low Altitude Atmospheric Measurements - Phase II

Small UAS (sUAS) are a cost-effective and easy to use solution to fill the niche between surface-based measurement platforms (e.g. buoys, WaveRider, etc.) and measurements with manned aircraft, providing a three dimensional view of the lower atmosphere. Due to their small size, sUAS can also be used in difficult to reach areas such as within a wind farm at altitudes that are difficult for tower based measurements. This project addresses a current data acquisition gap in near-surface marine atmospheric boundary layer measurements needed to validate/improve models for the prediction of electromagnetic wave propagation and atmospheric scintillation, subject areas critical to the Navy for targeting, communications, fleet protection, and development of high energy laser (HEL) weapons. The project focused on the development of small Unmanned Arial System (sUAS) platforms for sea-based meteorological sensing. The ultimate goal is to demonstrate the value of a low-cost UAS platform and its associated instrumentation that can be used to address pressing data collection needs to quantify the atmospheric effects on electromagnetic wave (EM) and electro-optical (EO) propagation in support of the Navy's Electromagnetic Maneuver Warfare (EMW) strategy.

Figure 12. Full aircraft developed in Phase I (FY16).

The bulk of the airframe development work was performed in FY16 (*see Figure 12*). In FY17, the hardware selection was further refined, with a suitable balance between performance and cost, and flexibility to meet mission-specific goals. Over several experiments and a number of flights, autopilot gains were tuned, and several flight profiles suitable for atmospheric sensing were flown. Flight speeds between 12 and 15 m/s were commanded, and profiles that minimized climbing or included frequent climbing, or with frequent turns or mostly wings-level flight were flown. For these experiments, a 65Wh battery was used. Based on energy burn rate, profiles with frequent ascent/descent segments would likely be limited to roughly 45 minutes of flight time. In flights with infrequent climbs and mostly wings-level flight, endurances of more than 90 minutes should be possible. The current configuration of the aircraft can be fitted with larger batteries for even greater endurance. With a 100Wh battery (the largest the airframe is currently rated for), a conservative flight profile might allow for flight times exceeding 2 hours. Note that these test flights took place in a region with substantial thermal activity. Results may vary when flying over water.

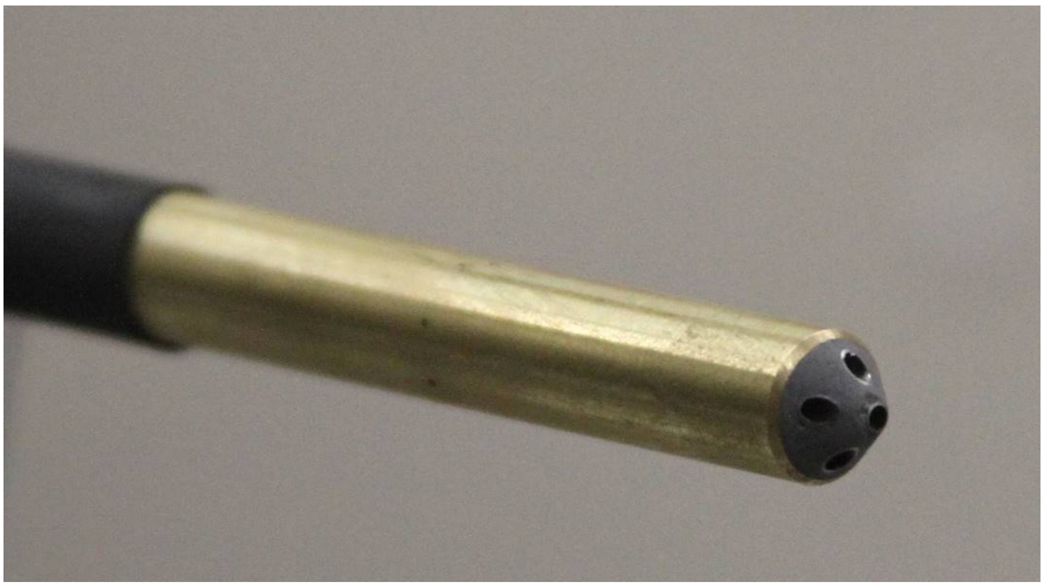

Figure 13. 5-hole probe developed in Phase II (FY17).

A 5-hole probe is a desired instrument for measuring atmospheric turbulence. While robust COTS sensors were available, the size, weight and in particular the cost of the commercial 5-hole probes was rather high. Efforts were thus made to manufacture a low-cost 5-hole probe (*see Figure 13*). A parallel effort is to design a sensor package for high-rate temperature measurements to quantify the atmospheric structure parameter, Cn2, a critical quantity to address the scintillation effects of the atmosphere on optical systems as well as HEL weapons. A fine wire thermocouple is used, which is comprised of chrome and constantan wires that are joined at a measurement junction. The advantage of this thermocouple includes high frequency response suitable for obtaining small scale turbulence perturbations. The extremely small diameter virtually eliminates solar loading and hence the need for a radiation shield. Such sensors are well-suited for temperature gradient measurements. However, the thermocouple does not provide highly accurate measurements due to its non-linear response and the need for a second temperature measurement at the cold-junction. Albeit slower responding, the more accurate Pt100 temperature sensor is deployed to measure the mean air temperature and adjust the thermocouple's mean temperature component. We chose an amplifier that has a built-in temperature reference at the cold-junction and compensates the thermocouple measurement accordingly. Since the small diameter thermocouples are fast responding, we have selected a suitable thermocouple digitizer that can interface with a powerful microcontroller (Teensy 3.6) capable of storing high-rate temperature data.

Test flights for the NPS Penguin sUAS have been planned for the week of Oct 8, 2017 at the NAVAIR Pt. Mugu Sea Range in S. CA in conjunction with the field campaign of a major EM/EO focused research project called the Coupled Air-Sea Processes and EM ducting Research (CASPER). Measurements of the NPS Penguin can be compared with shore site and ship-based measurements and copter sUAS based environmental measurements onboard a research vessel. Part of our FY17 effort involved obtaining site approvals for these test flights in order to obtain data in the marine environment. Extensive data analyses will be made after the field testing.

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11. C2 Design for Asymmetric Advantage: Teams of Autonomous Systems & People

The objective of this research is to design command and control (C2) for teams of autonomous systems and people (TASP) in a manner that enables asymmetric advantage, especially within the context of the next generation battlespace and anti-access area-denial (A2AD) environment.

This stream of research seeks to stay five to ten years ahead of practice, which enables us to anticipate both issues and opportunities in an area that remains under researched: C2 of autonomous systems (esp. unmanned vehicles, robots, Cyber applications). In great contrast with the huge effort expended to investigate the technologic characteristics, developments and advances of autonomous systems, a dearth of research addresses the corresponding C2. This is despite the quintessential importance of C2 and the fact that our current C2 strains under the load of having even two UAS, for instance, flying simultaneously in common airspace. Exacerbate such load with large numbers (e.g., swarms) of UAS, then exacerbate further with missions that integrate manned and unmanned aircraft, and one realizes quickly that our contemporary C2 organizations and approaches are likely to fail in just a few years.

Figure 14. Integrated manned-unmanned mission example.

Yet swarms are on the horizon now, as are many integrated manned-unmanned missions (*see Figure 14*) that can outperform those of either manned or unmanned alone. Indeed, an adversary with C2 capable of handling TASP missions can gain competitive advantage, even with autonomous systems that are technically inferior.

Using computational experimentation, we investigated a systematic array of UAS technologies and levels of manned-unmanned mission integration, assessing the comparative mission performance of alternate C2 organizations and approaches across multiple metrics (e.g., mission duration, errors, delays, rework, cost and risk; C2 coordination and communication load), which provide insights into why C2 breaks down and how to overcome its critical issues. Such insights enable us to anticipate key milestones in terms of C2 failure, and to lay out in advance the actions required to obviate such failure, as a road map for Fleet implementation.

Building upon leading edge research to understand the properties and behaviors of next generation unmanned aircraft systems, ongoing recent research has identified one or more alternate C2 designs (e.g., Collaboration, Edge) offering good potential to mitigate the inadequacies of current C2, and it elucidates a C2 challenge: asymmetric advantage will likely require shifting dynamically from one C2 design to another depending upon the context; that is, the same CTG or like organization may need to employ different C2 designs across the range of contexts likely in the next generation battlespace, even within the same mission set. This is particularly the case with the A2AD environment. Such dynamic redesign remains beyond our current C2 capabilities. Hence the current project centers on research along these lines.

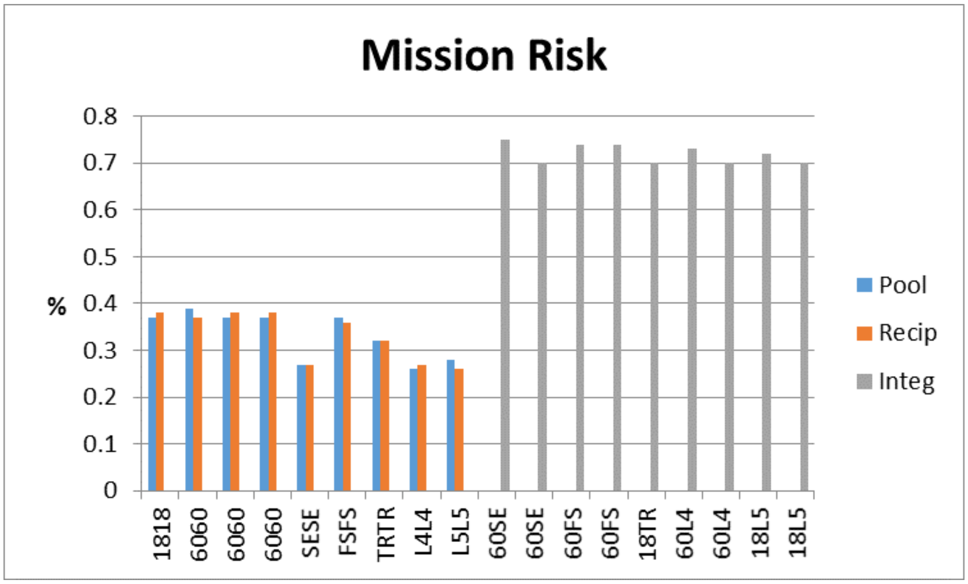
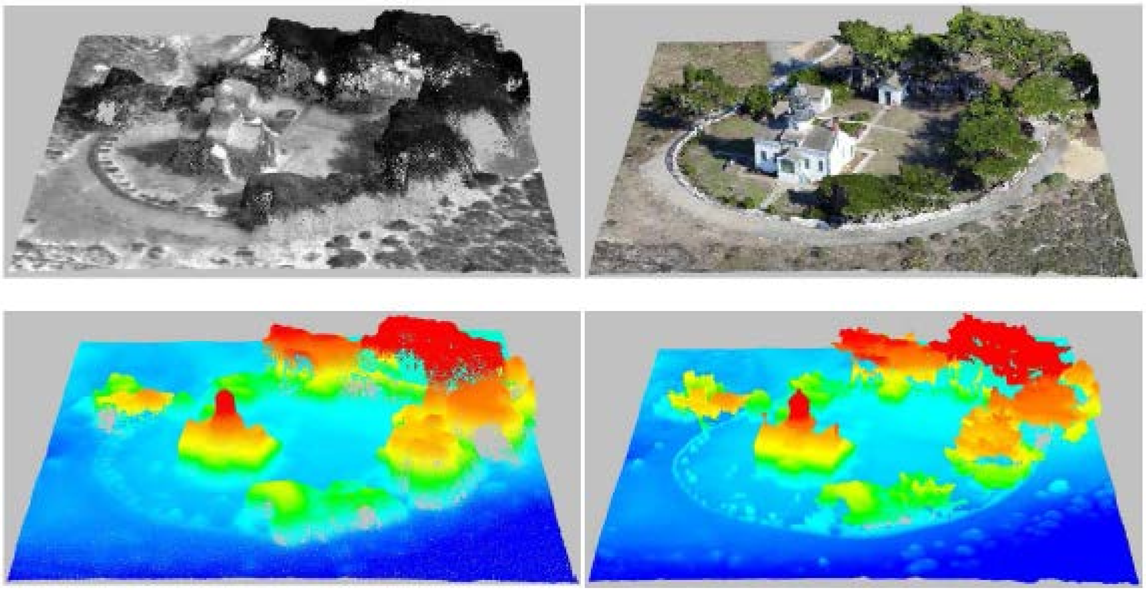


Figure 15. Discontinuous increase in mission risk with integrated interdependence.

In particular, we employ our POWer computational experimentation environment to address the next generation battlespace, and we conduct a set of computational experiments to assess the comparative efficacy of different C2 designs in the TASP domain (*see Figure 15*). The project is ongoing at the time of this report, with the simulation modeling work well underway and the analysis and technical reporting efforts scheduled for completion this fall.

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

12. Multi-Modal Sensor Fusion from Autonomous Platforms with 3D Modeling



Thermal Point Cloud colored by intensity (above) and elevation (below)

Visible Point Cloud colored by intensity (above) and elevation (below)

Figure 16. Survey of Point Pinos Lighthouse, Pacific Grove CA (October 2016).

The Remote Sensing Center acquired a DJI Inspire 1 UAS with both the Zenmuse XT (LWIR thermal) and Zenmuse X5 (visible) cameras for the purposes of 3D model creation from multiple modalities using computer vision photogrammetry. In October 2016, we surveyed the Point Pinos Lighthouse facility in Pacific Grove, CA using UAS, survey grade GPS and terrestrial LiDAR equipment. Daytime visible and thermal imagery of the lighthouse and surrounding area were successfully processed into 3d point clouds and digital elevation models using Agisoft Photoscan and Pix4D Mapper. Point cloud and digital elevation products were compared to 9 geospatially registered terrestrial LiDAR scans of the site. Apart from spatial resolution differences, results indicate that 3d content created from UAS collected LWIR thermal imagery show similar geometric accuracy as those that are RGB derived (*see Figure 16*). Additional daytime visible and nighttime thermal UAS tests were conducted in July at the Combined Arms Collective Training Facility (CACTF) located at Camp Roberts, CA. For ground control, we collected over 72 terrestrial LiDAR scans of the CACTF area as well as 12 GPS ground control points. Automatic collection of nighttime thermal imagery proved difficult due to limitations in flight control software. The site will need to be revisited and flown in a manual collection mode.

POC: Dr. Richard Olsen (olsen@nps.edu)

13. Network Enabled Digital Swarm Image Synthesis (NEDSIS)

This project is to develop an electronic warfare (EW) deception technique called network-enabled digital swarm image synthesis (NEDSIS) against threat radars and enemy platforms. Currently, we have developed a finite impulse response (FIR) architecture of complex range bin processors to be hosted on either a FPGA (Field Programmable Gate Array) or an ASIC (Application Specific Integrated Circuit) to modulate a baseband intercepted waveform. This "digital image synthesizer" (DIS) architecture has been shown to be capable of synthesizing multiple, large, false targets against high range resolution profiling radar (such as synthetic aperture radar (SAR) and inverse SAR). The DIS provides a superior RF decoy capability and provides the coherent countering of wideband imaging seekers and profiling radars. In addition, it provides an all-weather false-targeting and deception capability. The image synthesizer must synthesize the temporal lengthening and amplitude modulation caused by the many recessed and reflective surfaces of the target and must generate a realistic Doppler profile for each surface. Consequently, the synthesizer, as shown in Figure 19, contains a parallel array of (identical) complex digital modulators arranged in a FIR configuration with one modulator for each false-target range bin. The n-bit binary phase samples from each intercepted RF pulse are applied one at a time to the modulator array.

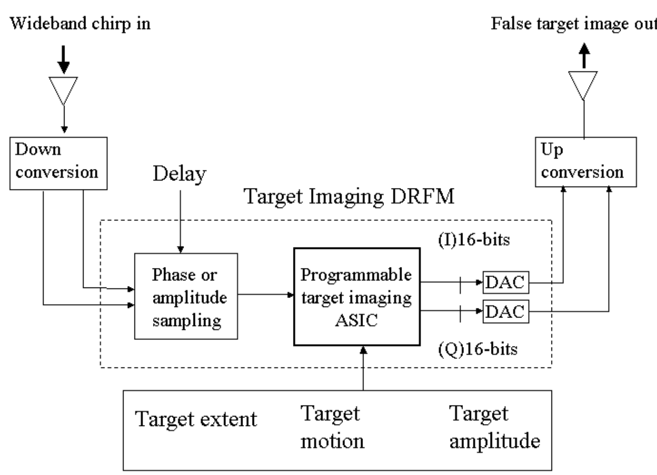


Figure 17. Block diagram of a digital image synthesizer.

During FY17, two critical components of the DIS electronic warfare architecture are being investigated. The first investigation encompasses the design of an in-phase and quadrature (I/Q) *phase converter* based on a CORDIC (Coordinate Rotation Digital Computer) algorithm. The phase converter processes the in-phase and quadrature components of the baseband signal and by using a pipelined series of steps, it produces a phase sample with a selected degree of bit resolution. Mathematical modeling is used to examine the accuracy of converting a digitized radar signal I/Q sample into a corresponding 5-bit binary phase angle. Simulations are carried out in MATLAB to determine the number of CORDIC executions and the number of fraction bits necessary for a required level of accuracy. Both the calculated angle and the actual angle are shown in Figure 20 as a function of the number of CORDIC iterations. The resulting design is implemented using the Verilog hardware description language.

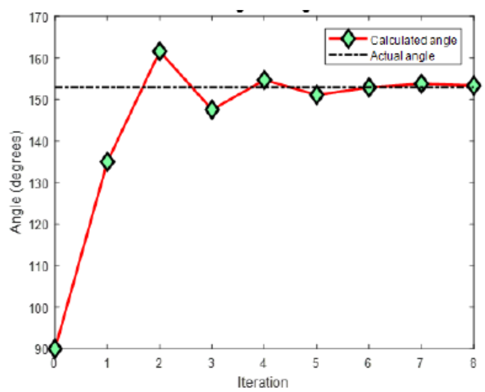
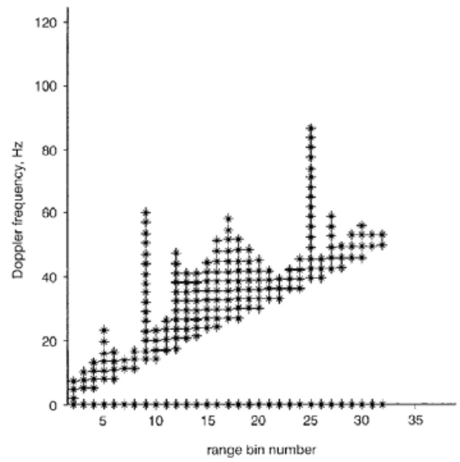


Figure 18. Cumulative angle through iterations calculate using fixed point numbers.

The second investigation concerned generating sea clutter to impose on the false targets. In order to provide a successful deception technique, the surrounding clutter must be statistically correct in power and Doppler frequency and must be spatially and temporally correlated appropriately. For the DIS to synthesize the images, each modulator in the FIR configuration requires a set of phase and gain coefficients that are derived from the range-Doppler description of the false-target (and its environment) to be synthesized. The mean power return of sea clutter is calculated using the average power of the radar cross section derived from the Naval Research Laboratory sea-clutter model. The modulation coefficients for the sea clutter are generated using the fluctuating power returns and Doppler spectra generated using a random KA distribution. The coefficients for several sea states are generated using MATLAB. Results show that by extracting more Doppler components from the Doppler spectra, the sea clutter image remains continuous as the ISAR increases its Doppler resolution, which makes the overall false target image from the DIS appear more realistic.



(a).

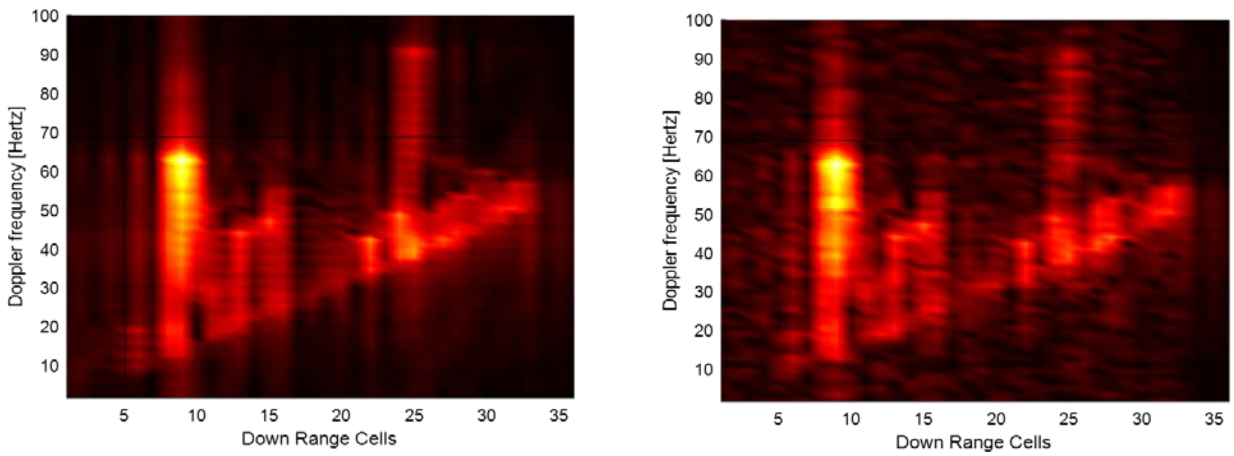


Figure 19. DIS generating the (a) Test Image within the ISAR and (b) and (c) with the addition of sea clutter [1].

References: [1] Pak Siang Ang, "DRFM CORDIC Processor and Sea Clutter Modeling for Enhancing Structured False Target Synthesis," NPS Masters Thesis, Sept. 2017.

POC: Professor Ric Romero (rnromero@nps.edu) and Dr. Phil Pace (pepace@nps.edu)

14. Innovations in Unmanned Technologies for Humanitarian Assistance and More

Data farming is the process of growing data, in smart ways, from simulation experiments. Its value for exploring innovations in unmanned technologies is that allows the analyst to test these technologies, and associated tactics, in a virtual environment where they explicitly vary a large number of factors. Factors can include technical capabilities, such as the speed, endurance, or sensor level of an unmanned aerial vehicle (UAV). Factors can also include operational or tactical decisions, such as whether to use unmanned ground vehicles, and different ways of employing multiple technologies. Simulation experiments can also be used to assess the robustness of various alternatives to many sources of uncertainty, including enemy threat capabilities, environmental conditions, weather conditions, and more. This research involves a two-pronged approach: the use of existing data farming techniques to investigate a variety of applications involving unmanned technologies, and the further development of data farming techniques for future applications.

During FY17, the SEED Center worked with six students whose theses involved studies of the capabilities and employment of unmanned systems. Kang (2017) explored a scenario inspired by the 31st Marine Expeditionary Unit's humanitarian assistance efforts in northern Japan following the 2011 earthquake and tsunami. He found that techniques using unmanned "following" ground vehicles in convoys were beneficial from an operational energy perspective; the results suggest that additional benefits might arise if convoys could travel faster using unmanned than manned following vehicles. Solem (2017) considered the benefits of using the Anti-submarine Warfare (ASW) Continuous Trail Unmanned Vessels (ACTUV) in a tactical ASW scenario. Kim (2017) conducted a feasibility analysis of UAV technology to improve tactical surveillance in South Korea's rear area operations. Akhtar (2017) looked at naval convoy protection under a multi-threat scenario, which included medium displacement unmanned surface vehicles (MDUSVs) and tactically exploited reconnaissance node unmanned aerial vehicles (TERNs). Ekman simulated sustainment for an unmanned logistics system (ULS) concept of operation in support of distributed operations, specifically seeking useful mixes and placement of small-, medium-, and large-capacity ULS. Work by Pueschel (2017) might indirectly support the development of high-endurance UAVs. His use of a data farming approach suggested compositions of solar cells that outperformed those found using other methods. If these alternatives perform as the computational model predicts, the lighter-weight solar panels can potentially increase the endurance of existing solar UAVs, or reduce the wingspan required.

In addition to these new concept explorations, we continued to advance and disseminate the methodology. We are working with collaborators at Northwestern University on advanced metamodeling methods for determining the importance of factors and interactions, as well as adaptive sequential designs. We are also working with collaborators at Purdue University on simulation analysis methods designed for model-driven big data, and seeking factor combinations that lead to simultaneous good results for multiple measures of effectiveness. These advances can be leveraged in future simulation studies.

POC: Dr. Susan Sanchez (ssanchez@nps.edu)

15. Study of Security Primitives for the Robot Operating System (ROS) of UAV Swarms

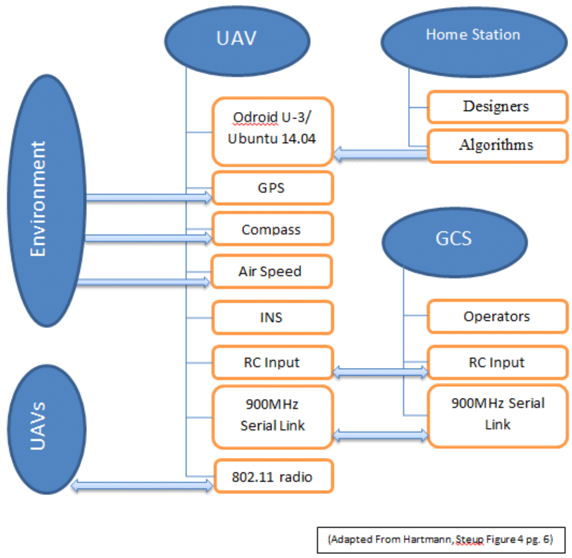


Figure 20. Representation of the UAV architecture and the various vulnerable entry points into the system. The Robot Operating System (ROS) runs on the ODroid/Ubuntu machine.

The global presence of the Navy's unmanned systems makes it increasingly vulnerable to cyber threats by non-state actors. For the past two years, the focus of our research has been the issue of cybersecurity in unmanned systems, particularly small UAV networks. In FY17, we had the opportunity to be funded through CRUSER to investigate cybersecurity of the Robot Operating System (ROS) v1. This was a continuation of work proposed in FY16. The UAV architecture shown in Figure 20 reflects the NPS ARSENL swarm. In FY17, we began an investigation into security primitives for ROSv1 that is run on the ODroid U3 payload computer as depicted in Figure 22. We first generated a vulnerability analysis for ROSv1 based on the simplified flow chart (*see Figure 21*) of messages sent from a ROS master to multiple nodes. Along with existing research, we identified major points of vulnerabilities and possible mitigations to these issues.

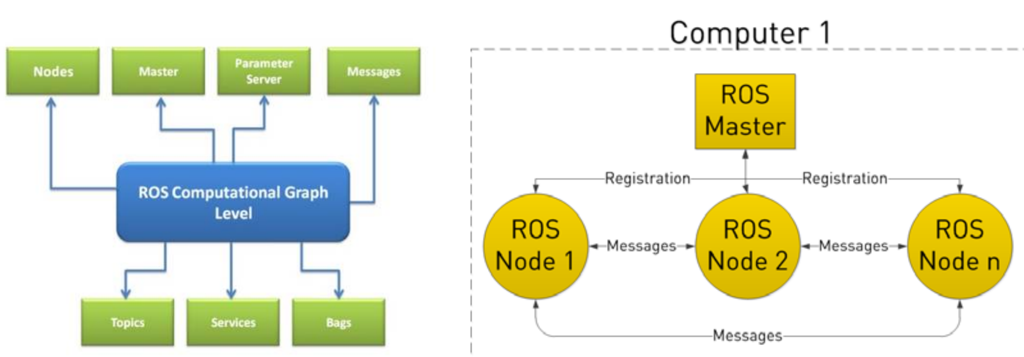


Figure 21. Components of ROS and flow chart of messages between different ROS assets.

The three main vulnerabilities of ROSv1 are as follows: 1) authentication insufficiency: lack of an authentication mechanism between a master and a node which results in an attacker getting access to the master easily; 2) communication vulnerability: lack of encryption processing which exposes the communication history between nodes and master; and 3) service hijacking: exploitation of different ROSv1 service methods. Much of this analysis required us to spend time understanding ROSv1, its implementation and commands. We spent several months investing the time to fully understand the dynamics of ROSv1. To simulate an unmanned aerial environment using ROSv1, we used the Gazebo simulation platform. Gazebo is a robotics simulator that makes it possible to test algorithms for both indoor and outdoor environments. To achieve ROSv1 integration with stand-alone Gazebo, a set of ROSv1 packages that provides wrappers around the stand-alone Gazebo was installed. They provide the necessary interfaces to simulate a robot in Gazebo using ROSv1 messages. We installed Gazebo on an Ubuntu Linux machine and ran basic experiments on a small UAV network (5 UAVs). In particular, we tested ROSv1 against basic threat models, including denial of service (DoS), spoofing and man-in-the-middle attacks. Parts of the vulnerability analysis of ROSv1 has been submitted for publication in IEEE UEMCON (Ubiquitous Computing, Electronics and Mobile Communication Conference) 2017 to be held at Columbia University, NY in October. We next looked at countermeasures to the security vulnerabilities of ROSv1. We studied Secure ROS (SROS), which was introduced at RoSCoN 2016 by the developers of ROS, Open Source Robotics Foundation (OSRF). SROS is based on ROSv1. It specifically supports cryptography including encryption and the use of X.509 PKI certificates. We installed an Ubuntu version of SROS available on the ROS wiki site and are now in the process of making SROS work within the Gazebo environment. We are currently trying to get SROS functioning so that it can be used for small simulations in Gazebo. Once simulations are run, we will look at how well SROS works against three different threat models: 1) spoofing messages via man-in-the-middle attack: since SROS uses TLS to protect all ROS related traffic, we anticipate that it will ensure that malicious actors cannot redirect or replay network traffic, nor modify or spoof messages. This tests the authentication mechanism of SROS. Additionally, if the UAV becomes compromised, previous recorded traffic cannot be decrypted due to the Forward Secrecy provided in TLS; 2) denial of service: can SROS and the use of TLS prevent a DoS attack against a UAV asset? We anticipate that experiments will show that a DoS can be mitigated when the attack is launched externally of the network. However, we will also analyze whether session hijacking is still a problem within the local networks. We also plan to mathematically analyze the cost of SROS on UAV network performance, in terms of delay and throughput. All of these tests will also be executed in the Gazebo environment. These experiments will provide a baseline security architecture for a simple UAV network. Through the use of SROS, we can ensure that aerial networks using ROS have some countermeasures against basic external network threats. We anticipate these experiments and tests to be completed by the end of November 2017.

POC: Dr. Preetha Thulasiraman (pthulas1@nps.edu)

16. RoboDojo

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 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.

Since officially opening in July 2015, students, faculty, and staff from all departments on campus have used our facility and attended our workshops. This past year, we have hosted 8 visiting classes, regularly hosted 4 classes, and have held 91 workshops and user groups. Workshop topics range from robot programming and 3D modeling to Arduino / Raspberry Pi projects and laser cutting. We have seen a steady increase in the number of people benefiting from our lab and its resources.

Figure 22. NPS students building drones in the RoboDojo, FY17.

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 types of expertise that we offer in the lab. Using workshop knowledge, students have prototyped gliders, rockets, drone components (*see Figure 22*), and many other robotics elements for experiments at Camp Roberts, China Lake, and other places. 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. Indeed, the informal community of tinkerers and robotics enthusiasts in the lab has coalesced into a campus club that has now grown to over 40 members. These students are steady users of our lab resources and continually ask for an expansion of lab offerings and equipment. Many of them volunteer to teach, to mentor each other, and to help maintain the lab itself. A subset of these students held drone building workshops and are seeking to form an NPS drone racing team, and many signed have signed on to compete in our Ant Weight Combat Robot competitions (*see Figure 23*). Are next combat robot competition is scheduled for 1 December 2017.

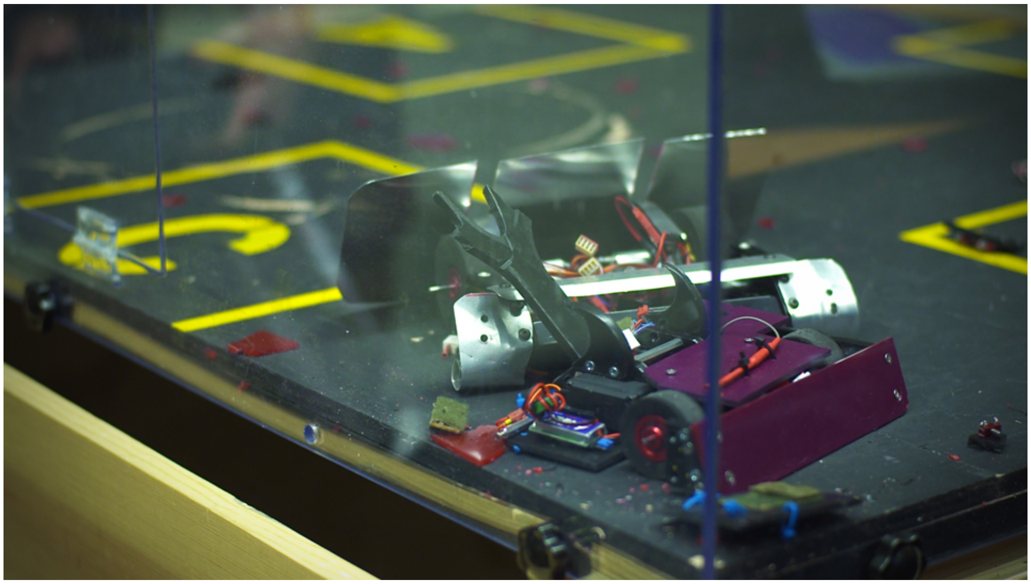


Figure 23. An Ant Weight Combat Robot immediately following an exciting competition, FY17.

The base budget provided by CRUSER has functioned as a force multiplier. OPNAV N415, the NPS Foundation, and NPS' Center for Information Warfare and Innovation (CIWI) have all donated additional funding to expand our current tool and equipment offerings in the lab, to purchase workshop supplies, and to collect materials and gear to host our combat robot competitions. 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.

Our goals for FY18 are:

1. To properly set up our newly purchased additional equipment with safety in mind,

2. To expand and to fine-tune our workshop offerings; and

3. To consider other competitions where RoboDojo workshop attendees may apply their knowledge.

We welcome additional suggestions or offerings that organically grow out of community interest.

Please come by to visit us!

Open Lab hours: Tuesday 0900-1300, Wednesday 0900-1300 and 1400-1700

Website: https://robododojo.nps.edu

--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: Professor Kristen Tsolis (ktsolis@nps.edu)

17. Autonomous Wave Glider Based Measurements and Analyses in Support of Electromagnetic Maneuver Warfare (EMW)

Improved capability to model and forecast the propagation of the electromagnetic (EM) spectrum in the battle space has very broad application throughout nearly all Navy and Department of Defense (DOD) functional areas due to the utilization of the EM energy in either active or passive manners for all sensing and communications systems as well as developing weapon systems. The key atmospheric quantity that determines the atmospheric effects on EM systems is refractivity, which denotes the property of the atmosphere that bends EM energy (e.g., radar, communications) from a straight line path and is caused by spatial variations in temperature, humidity, and pressure. Quantifying the refractivity in the Atmospheric Surface Layer (ASL) is crucial in determining properties of the evaporation duct, the most frequently occurred type of EM ducts over the ocean related to the evaporation of the ocean surface, resulting in significant moisture gradient in the lowest ~10 m layer. This water vapor gradient translates to strong gradient of the refractivity, causing radar waves to be trapped within this gradient layer, which is referred to as a duct. Predicting and diagnosing properties of the evaporative duct are known to be problematic due to underlying assumptions in the model. Model validation and improvements require large amount of observational data for mean state variables as well as their respective turbulent fluxes within the duct layer, which is between a few meter to 30 m above surface. Obtaining near surface environmental data also benefits battlespace weather forecast as one of the challenges in forecast model improvements in the coupled air-sea environment is to correctly represent the air-sea exchanges across the interface in model physics as the 'coupler' between all three components: upper ocean, surface, and lower atmosphere.

Liquid Robotics (LRI) Wave Glider, or Sensor Housing Autonomous Remote Craft (SHARC), has great potential as a platform for supporting environmental sampling to quantify RF propagation in the atmosphere. This autonomous surface vehicle is mobile and relatively easy to deploy, and is designed to power sensors continuously with onboard solar panels. When equipped for surface flux measurements, it has the great potential for significantly enhancing the flux database for future basic and applied research aimed at improving environmental forecasts at all-time scales from turbulence to climate.

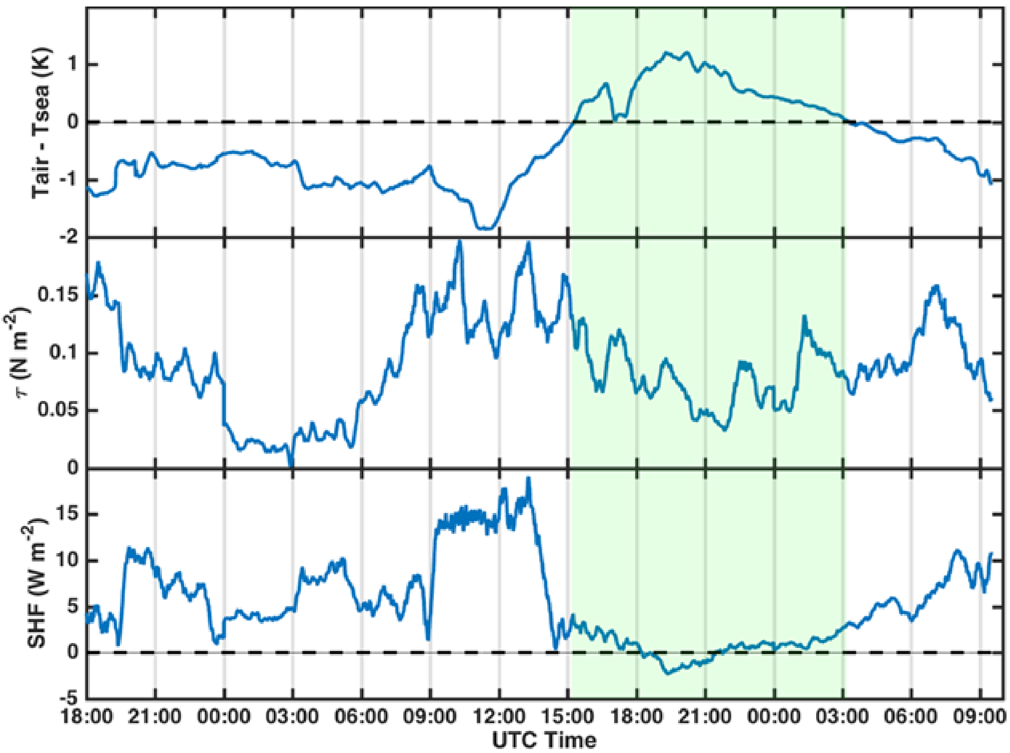


Figure 24. Air-sea temperature difference, momentum and sensible heat flux measured by NPS SHARC MAKO flux payload. Green shading represents stably stratified.

Our initial work instrumenting the SHARC resulted in a NPS SHARC payload for mean measurements and a prototype of SHARC flux payload with very encouraging results. These efforts resulted in better temperature and pressure measurements, addition of water vapor measurements, and preliminary turbulence measurements at 1 m above the immediate ocean surface. We have made extensive analyses of the previous measurements which showed reasonable turbulent flux measurements (*see Figure 24*). We also identified issues of the SHARC measurements on surface waves, which deviated from the nearby buoy measurements. Recent efforts focused on improving flux measurement payload by better water-tight payload compartment and selecting a new 3-D sonic anemometer that is better sealed from environmental moisture to use on the NPS SHARC MAKO.

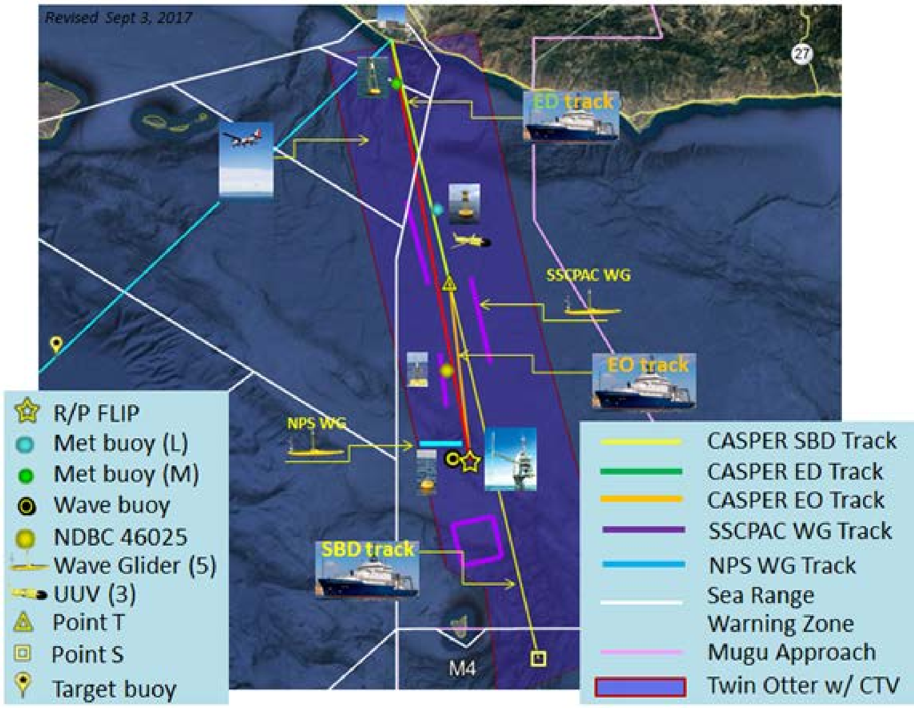


Figure 25. Coordinated measurements planned in CASPER-West including four SSC-PAC SHARCs (*thick purple lines*) and NPS SHARC MAKO (*cyan line*).

One of our FY17 efforts also involved coordination with SSCPAC on deployment of multiple SHARCs at sea for coordinated measurements to reveal the value of multi-Wave Glider coordinated missions in supporting the new era of electromagnetic Maneuver Warfare (EMW). A field deployment has planned to include four SHARCs from SSCPAC and the NPS SHARC to be deployed offshore of Pt. Mugu in Sept/Oct 2017. The measurements of the SHARCs will be part of the large field campaign (CASPER-West) to include deployment of an at-sea moored platform, a research vessel, shore sit at Pt. Mugu, the NPS CIRPAS Twin Otter aircraft, as well as multiple buoys distributed along a sampling track. The distribution and the planned SHARC ops are shown in Figure 25. The data analyses are planned immediately following the field effort. Such analyses will focus on evaluating: 1) the value of coordinated mission of multiple SHARCs in support of RF propagation; 2) the quality of the data sampling of the SSCPAC mean METOC payload and the NPS flux payload during longer period of deployment; 3) the value added by the flux payload in support evaporation duct model development.

POC: Dr. Qing Wang (qwang@nps.edu)

18. Vision-Based Navigation and Guidance for Swarm UAS

This research contributes to enabling two extremely important capabilities for future unmanned aerial systems (UAS) – GPS-free navigation and reactive collision-free guidance during swarm UAS operations based on maintaining continuous situational awareness. Hence, the two objectives were to develop algorithms allowing incorporating vision into the integrated inertial/vision navigation solution and provide UAS detect-and-track capability for close-range operations in a multi-UAS environment.

Figure 26 illustrates the idea of image-matching-based navigation (IMMAT) in the GPS-degraded or GPS-denied environment. Being equipped with a forward-looking onboard electro-optical (EO) sensor, an aircraft (UAS) captures images of the underlying area and compares them with the satellite image of the same area. This idea is somewhat similar to the Terrain Contour Matching, or TERCOM, a cruise missiles navigation system, that utilizes a pre-recorded contour map of the terrain and compares it with measurements made during flight by an on-board radar altimeter.

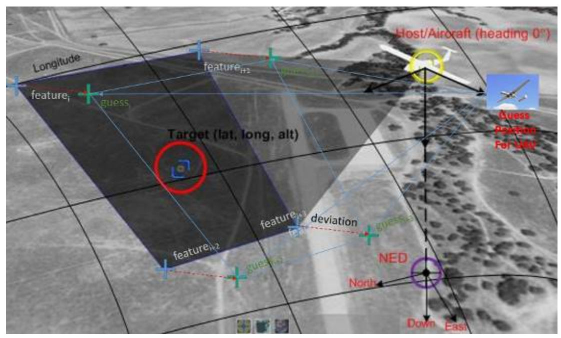
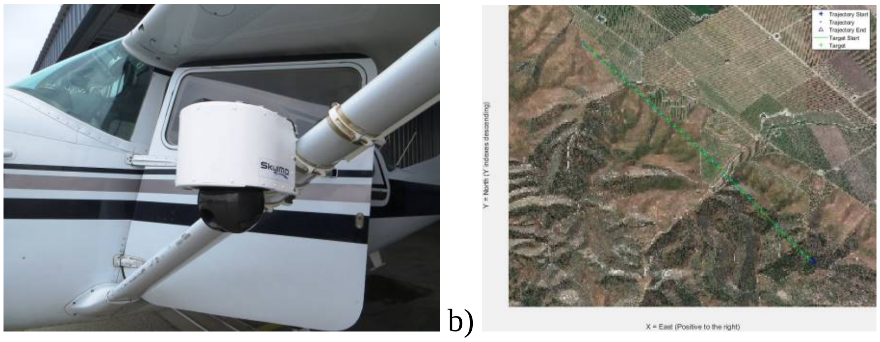


Figure 26. Illustration of the IMMAT concept.

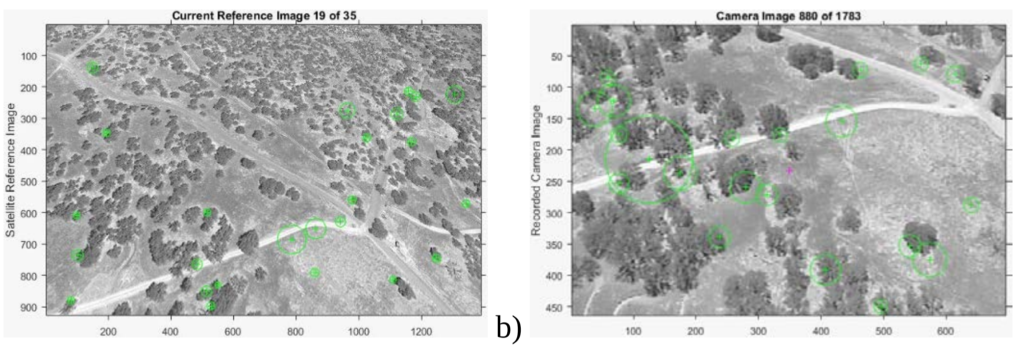
This research addressed the mathematical foundation of IMMAT and then dealt with its prototyping using available EO sensors installed on unmanned UAS flying in the restricted area and also a manned aircraft flying in controlled airspace (*see Figure 27a*). The research used satellite imagery of the expected area of operations (AO) (*see Figure 27b*) extracted from the DigitalGlobe's geospatial big data platform that provides access to 15 years' worth of geospatial data along with the tools and algorithms necessary to extract useful information from that data. Figure 28 illustrates the change of aerial camera ground footprint while varying camera zoom (which is also dependent on aircraft altitude). This defines the size of satellite imagery that needs to be processed. To speed up processing of satellite imagery the reference image library (RIL) covering AO has to be created and preprocessed beforehand. Preprocessing includes georeferencing and detecting / registering local features / descriptors unique for each particular image. Figure 29a shows an example of a preprocessed image from RIL. During the flight, aerial camera imagery undergoes the process of finding local features as well (*see Figure 29b*). Common features, correctly associated with both the satellite and aerial camera images, are then used to develop the corresponding projective transformation and ultimately determine a pose (position and attitude) of an aerial camera (aircraft) (*see Figure 30*). IMMAT also involves using Kalman filtering to provide continuous updates even when not enough matches between the two images are found.



a) b)

Figure 27. The on-board EO sensor (a), and example of intended AO (b).

Figure 28. Onboard camera footprints with different zooms.



a) b)

Figure 29. Feature matching between the satellite image (a) and camera image (b).

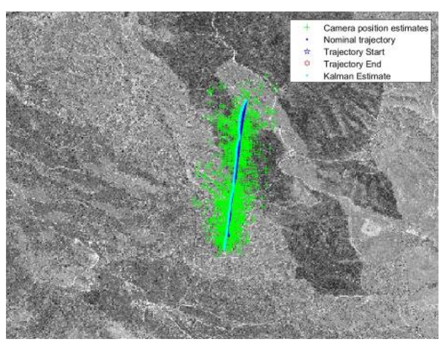


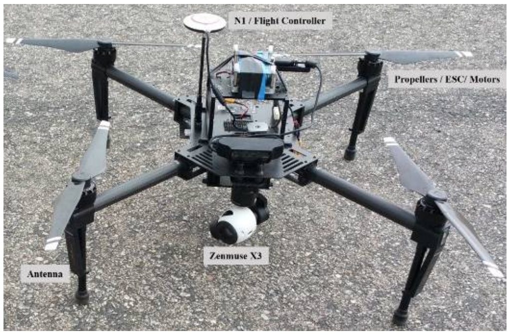
Figure 30. Example of position estimation.

Pursuit of the second objective of this research project was based on analyzing data collected during previous NPS Swarm UAS trials at Camp Roberts, CA (*see Figure 31a*). Based on these video data a team of researchers from Purdue University developed reliable off-line algorithms allowing detecting and tracking multiple moving targets in a close vicinity of UAS equipped with onboard camera (*see Figure 31b*). Specifically, the acquired video from the onboard camera is parsed into a sequence of frames to estimate the relative background motion between the frames. Then, the moving object can be extracted by compensating the motion of the background (the moving objects' salient points are identified from a background-subtracted image). The local motion of the moving objects is determined by analyzing a pixel optical flow. Candidate objects (targets) are found by classifying spatiotemporal features from the estimated local motion of the moving object, followed by the Kalman filter tracking to reduce the intermittent miss-detections and false alarms found through the camera feed.

(a)  (b) 

Figure 31. NPS Swarm UAV exercise (a), and offline multiple-target detection (b).

These algorithms were modified and tuned for on-line application and tested using one of NPS drones (*see Figure 32a*) equipped with a companion computer (*see Figure 32b*) to process onboard camera video imagery in real-time.

a) 

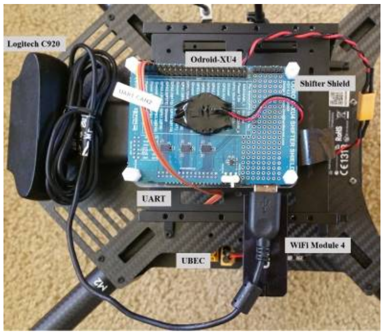
b) 

Figure 32. Test platform (a) equipped with a companion computer for real-time image processing (b).

Figure 33a shows an experiment setup when a hovering test platform was observing multiple different-sizes moving targets including two ground vehicles, two drones and moving personnel. Figure 33b shows a snapshot of real-time detection and tracking of these objects. The developed system worked very well achieving a high reliability level allowing proceeding with the next step incorporating visual detection/tracking information into the control system enabling computing and executing the corresponding evasive / attacking maneuvers.

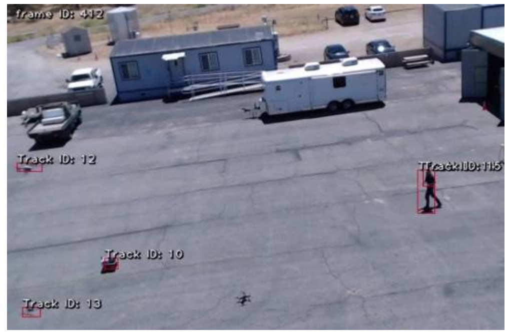
(a)  (b) 

Figure 33. Test setup (a), and real-time moving target detection and tracking (b).

The initial testing of both sets of algorithms (for GPS-denied navigation and multi-target detection/tracking) proved the corresponding concepts and demonstrated the very promising results, so that the development of both approaches is expected to be continued. The image-matching navigation algorithm was developed in cooperation with a PhD student at U.S. Army Armament Research, Development and Engineering Center at Picatinny Arsenal. The multiple-target detection portion of this research was built upon algorithms developed by Purdue University.

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

19. Prototyping of Air-Launched Fast Recon UAS

The objective of this research, responding to a Marine Corps Warfighting Laboratory (USMCWL) challenge, was to conduct the conceptual and preliminary design and prototyping of unmanned aerial system (UAS), launched and operated from MV-22B Osprey tiltrotor military aircraft, that would provide short-term aerial reconnaissance (RECON) of a landing zone (LZ) prior to Osprey arrival with the goal of supporting expeditionary assault and raid operations.

Figure 34 depicts a proposed solution when Osprey utilizes a two-stage AIM-9-based Fast RECON UAS. 15 minutes ahead of Osprey arrival (60 NM away), a booster stage accelerates Fast RECON UAS to 1,400 kts, which allows covering 22.5 NM within just 1 min. Then, the second-stage turbine-engine vehicle covers the remaining 37.5 NM flying at 400 kts for 6.5 minutes. That leaves about 8.5 min for the second-stage UAS to loiter around LZ transmitting intelligence, surveillance, and reconnaissance (ISR) data back to Osprey.

Figure 34. Fast RECON UAS concept.

Within this research a systems engineering approach was applied, and a conceptual design of the Fast RECON UAS was performed. Analysis of alternatives including cost estimates, and estimating Technology Readiness Levels (TRL) of major subsystems, components, and the system as a whole was conducted. Feasibility of proposed solution was demonstrated by developing and testing a variety of scaled prototypes. Figure 35a depicts several designs of gliders that were designed to be deployed from an AIM-9 size rocket. They were equipped with a 4k camera to demonstrate a quality of an ISR video that can be provided back to an operator at Osprey. Figure 35b shows an alternative design utilizing a 360-degree retractable camera descending under a parachute.

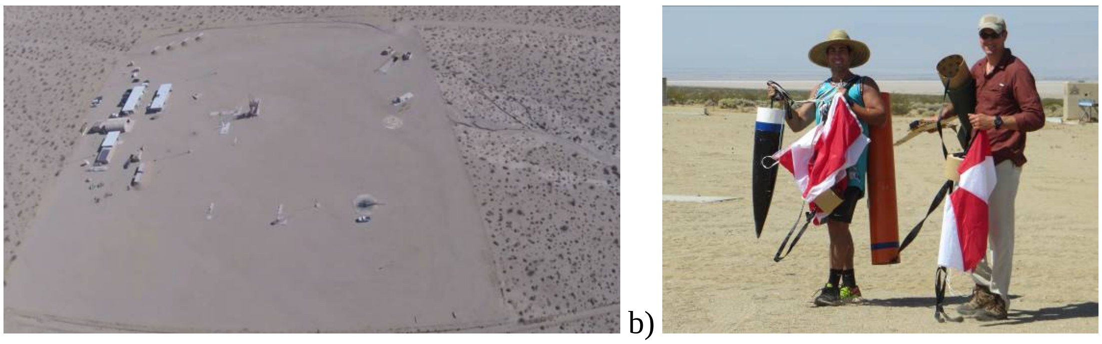
a) b)

Figure 35. Different alternatives for the Fast RECON UAS concept.

Figure 36a shows a rocket (prototype of a booster stage) ascending to the deployment altitude and Figure 36b illustrates two different systems deployed at an apogee (a glider in the left photo and 360-deg eye-in-the-sky in the right photo.). The research also involved designing a control system for the second-stage UAS to assure precise pointing capability, image stability and steady steering. Towards a latter goal a novel controllable cross-canopy parachute was developed and tested (*see Figure 36c*). A snapshot of ISR data is shown in Figure 37a, and Figure 37b depicts a successful recovery of the both stages (a student on the right carries yet another design of a glider).

a) b) c)

Figure 36. Rocket launch (a), second-stage UAS deployment (b), and steering cross-canopy (c).



a) b)

Figure 37. Sample of imagery provided back to an operator (a), and successful recovery (b).

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

20. Optimal Trajectory Generation for Small Drones Used as Micro Interceptors

Commercial and recreational use of small drones has increased exponentially in the past several years. While most drone use is productive and safe, reports of drone incidents have increased significantly. There were many reports that small drones intentionally or mistakenly flew into flight paths of commercial airplanes near airports. There were also numerous reports that small drones were found in the airspace of fire zones, preventing the effective air firefighting asset to be deployed in the most time critical moments. The Federal Aviation Administration (FAA), the agency responsible for the safe use of airspace nationwide, has taken several steps to educate the public on the proper use of unmanned aircraft. This approach to safety has its limits and best serves amateur operators who have sought out information on regulations and safety restrictions. Unlike a licensed pilot who is required to submit to regular oversight by the FAA when operating manned aircraft, no system ensures that a private citizen who builds or purchases a remotely operated drone abides by the applicable airspace regulations. A gap in enforcement capabilities remains in locations where safety of flight is critical—namely in and around controlled airspace such airports and other restricted areas.

A hazardous drone could be intercepted and removed by another drone. In this project, we seek to determine if optimal control methods outperform missile guidance control methods when applied to a quadrotor drone performing an intercept with a moving target. This is achieved by simulating the intercept of a target with a quadrotor and comparing the performance of several on-line trajectory planners. Two missile control-based trajectory planners, pursuit guidance and proportional navigation, are compared against an optimal control trajectory planner. The time and energy used by a simulated quadrotor to intercept a target are the performance measures used for comparison. The trajectory planners use a three-degree of freedom model, and the simulated quadrotor uses a six degree of freedom model. Each trajectory planner is compared in a crossing, head-on, and tail-chase geometry. All of the on-line results are compared to an off-line optimal solution. The results show that the off-line optimal control method performs better than the on-line trajectory planners, regardless of intercept geometry type. The proportional navigation planner has the best performance of the on-line trajectory planners.

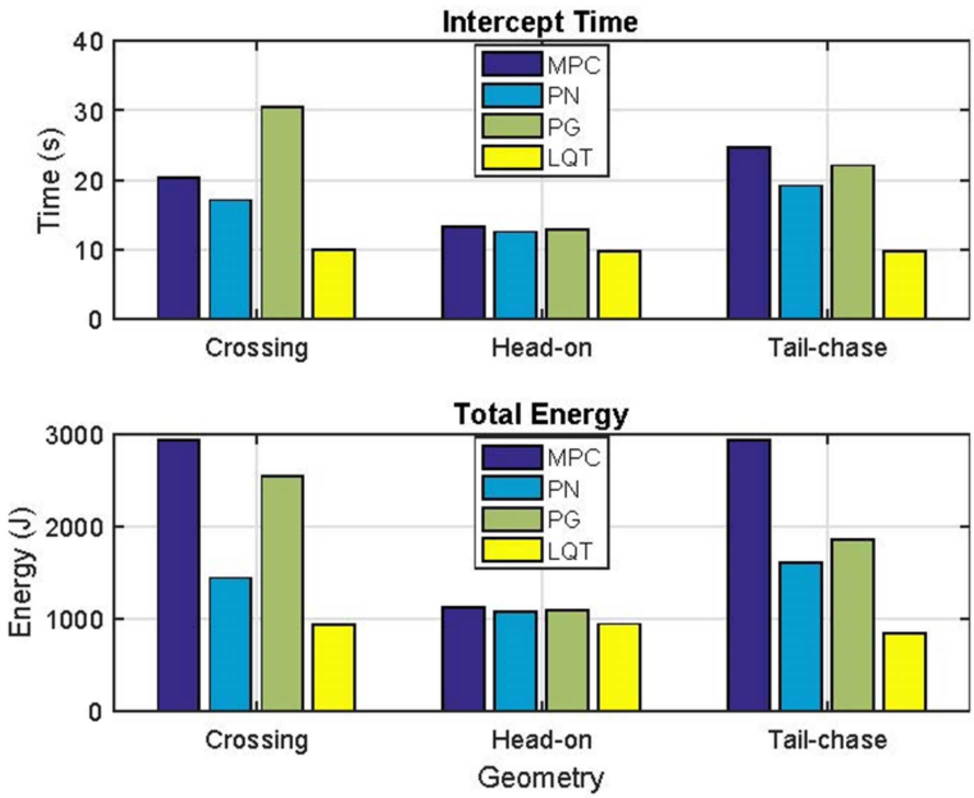


Figure 38. Comparison of the intercept time and total energy consumption for three maneuvering geometries (crossing, head-on, and tail-chase) under four motion planners: model predictive control (MPC), proportional navigation (PN), pursuit guidance (PG), and optimal linear quadratic tracker (LQT).

The trajectory planner with the best performance measure in simulation represents the best planner for actual flight trajectory planning. A set of optimal but off-line intercept trajectories are calculated as a benchmark. Each of the on-line trajectory planners including pursuit guidance (PG), proportional navigation (PN), and model predictive control (MPC) executes an intercept maneuver while the time and energy spent by a simulated quadrotor are recorded. Then, the benchmark optimal trajectories are flown by the simulated quadrotor, and the same time and energy data are recorded. A comparison of the trajectories and a summary of the flight statistics highlight the strengths and weaknesses of each planner. The optimal results when flown by the simulated quadrotor indeed show the highest intercept performance. Because this solution requires knowledge of the flight path of the target over the full simulation time, this method cannot be used to calculate an on-line command trajectory. The best on-line performance observed is the PN planner. It consistently achieves an intercept in the least amount of time and with the least amount of energy across all geometry types. The low energy consumption is consistent with the minimal maneuvering for each of the intercepts.

The next best performance after PN is both the MPC and PG planners. Their results are mixed based on geometry. For crossing geometry, MPC is faster but uses more energy than PG. This is acceptable in a situation where intercept time is more important than stretching the flight endurance of the aircraft. For head-on geometry, PG is both faster and uses less energy than MPC. The margin, however, is very small—less than a second and a 100 joule difference. Finally, tail-chase results show that PG uses less time and energy than MPC.

POCs: Dr. Xiaoping Yun (xyun@nps.edu) and Professor James Calusdian (jcalusdi@nps.edu)

B. EXPERIMENTATION

The Naval Postgraduate School (NPS) Field Experimentation (FX) Program was created to:

1) Provide an opportunity for NPS faculty and students to develop and test new technologies related to their research in an operational field environment, and

2) Provide the operational community the opportunity to use and experiment with these technologies.

Fundamental tenets of the NPS FX program include:

- **Austere by design:** the basics are provided– space to work, an airstrip, and basic communications infrastructure – it's up to participants to bring everything else needed. This captures the flavor of an operational/expeditionary environment while also reducing the cost to execute each event.

- **Collaboration is expected:** collaboration often results in unexpected and positive results therefor participants are required to collaborate fully, with proprietary, CLASSIFIED, ITARS, EARS, etc. information as the only exceptions.

- **Bounded, not controlled:** NPS provides a safe, secure, and legal sandbox in which capabilities are explored and new ideas flourish with minimal controls.

- **Inclusive by default:** everyone is welcome to apply to the event – good ideas come from everywhere. Events are advertised using a formal Request for Information (RFI) on FedBizOps.com. All participants are offered the opportunity to critique/suggest based on their observations and individual expertise.

- **Develop. Now:** goal is immediate development/adjustment – participants are expected to conduct modification/development activity at the event, in real time.

Since 2002, NPS FX events have been conducted such that maximum innovation and collaboration are encouraged between DoD, government agencies, industry, universities, and in which Special Operations Forces (SOF), National Guard, and first responder participation and feedback are utilized for effectiveness, affordability, and feasibility of new technologies.

Sponsors have included the United States Special Operations Command (SOCOM), the Department of Homeland Security, the Joint Improvised Explosives Device Defeat Organization (JIEDDO), the Joint Support Office and the Rapid Reaction Technology Office.

CRUSER, since its beginning, has leveraged the NPS FX program to provide an efficient and cost-effective method of enabling experimentation with robotics and autonomous systems in a multi-institutional, semi-structured learning environment that educates both the experimenters and the observers about the potential war fighting utility of new technologies. CRUSER sponsors have benefited by being able to leverage the existing infrastructure in support of field experimentation while FX participants benefit from the exposure to cutting-edge technologies associated with robotics and autonomous systems.

In addition to the regular participation of these events, the CRUSER and RRTO supported MTX serves as an opportunity to explore the potential of these systems to enhance the operational capability of naval warfighting elements to include Naval Special Warfare and THIRD Fleet elements. This was the case in October-November 2017 when the MTX experiment took place on, over and in the seas around San Clemente Island. A separate MTX report is available for government readers but of special interest is the potential demonstrated to enable rapid and effective validation and verification of autonomous systems explored as part of this MTX.

1. JIFX

The Joint Interagency Field Experimentation Program (JIFX) program exists to provide an opportunity for NPS faculty and students to demonstrate and evaluate new technologies related to the Department of the Navy and the Department of Defense research in an operational field environment. JIFX also provides a field experimentation resource for the Unified Combatant Commands (COCOMs) and other federal agencies. JIFX began in 2012 under the sponsorship of the Office of the Secretary of Defense and the Department of Homeland security. JIFX events are held quarterly, normally at NPS facilities on the California National Guard's Camp Roberts. In addition, State, local and international emergency management, disaster response and humanitarian assistance organizations are most welcome to help create an innovative cooperative learning environment. Summaries and results of FY17 JIFX experimentation are reported separately.

2. MTX

Planned in FY17, a maritime NPS-FX Multi-Thread Experiment (MTX) was executed on San Clement Island, California 31 October through 15 November 2017. MTX 2017 explored a realistic operational scenario in a multi-domain environment: sea, land, and air. This scenario include tactical team operations supported by a guided missile destroyer (DDG) with all sharing data over the UxS control network. The primary goal of MTX was to advance autonomy of a collaborative UxV Network Control System in a multidomain environment. The system consisted of two ScanEagles (air), two SeaFox's (surface), two REMUS 100 (subsurface), one Shield AI Quadrotor (air), and a Persistent Systems mesh network. The experiment objectives of MTX where to:

1) Initiate development of a unified framework for UxV Network Control System,

2) Support tactical unit route selection through an optimal trajectory 'template' approach for UAV road network mapping,

3) Reduce tooth-to-tail-ratio for UxV operations while harnessing the capability of these systems to more actively support the warfighter, and

4) Gather and analyze data to inform the path and priorities for the future.

The MTX 2017 team successfully completed simultaneous surveillance operations in support of the infiltration of a tactical unit on a SeaFox, using the ScanEagles and REMUS 100 vehicles as communication nodes. The mesh network was successfully transferring live video from the ScanEagles and the Shield AI Quadcopters, and NPS students were able to setup an integrated a C3F node with the mesh network.

C. EDUCATIONAL ACTIVITIES

The primary mission of the 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's core mission is to "shape generations of naval officers through education, research, concept generation and experimentation in maritime application of robotics, automation, and unmanned systems." 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 that address ethical questions and related critical issues, catalog degree programs, short courses, and certificate programs. CRUSER's support of educational activities also involves surveying and aligning curricula for interdisciplinary unmanned systems education.

1. 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. Capstone project courses are listed first. Other courses are listed alphabetically by course code.

a. Capstone Projects

Systems Engineering Analysis (SEA): 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. Systems Engineering applies the engineering thought process to the design and development of large, complex systems. Systems engineers analyze the need for a system, determine its operational concept, develop functional requirements, produce the system architecture, allocate the requirements among sub-systems, manage the design of the sub-systems, assure that the final design is integrated, assess any trade-offs made, and then implement and test the solution. Systems Analysis provides key insights for improved operation of existing complex defense systems; it examines existing systems to better understand them. This understanding is then used to determine and choose among alternatives for system design, improvement and employment. Systems analysts apply modeling, optimization, simulation, and decision making under risk and uncertainty. The curriculum was previously called Systems Engineering and Integration (SEI). It was renamed Systems Engineering Analysis (SEA) and revamped in 2002 to emphasize the role and importance of analysis. Each SEA cohort must produce a report detailing their research, and make a recommendation based on their findings.

SEA 25 PROJECT: "**Developing warfighting training to leverage web fires concepts and technologies"** Design a fleet system of systems and concept of operations for employment of a cost effective training system capable of preparing naval warfighters to employ and leverage the web fires concepts and technologies in the 2025-2030 timeframe. Consider training across warfare specialties and missions. Conduct research to provide a solid foundation of knowledge requirements for a web fires fleet concept. Complete a gap analysis by comparing current fleet training with the required training to leverage cross-domain and cross-platform capabilities in a warfighting environment. Scan for current examples of cross-domain training and current training simulation from DoD and industry. Develop a system architecture addressing participants to fill discovered gaps in meeting the knowledge requirements. Assess the proposed system against the principles of high velocity learning found in the CNO's "A Design for Maintaining Maritime Superiority." **POCs:** Professor Jeff Kline (jekline@nps.edu), Dr. Gary Langford (golangfo@nps.edu)

b. Courses

The following are courses listed in the NPS catalog from all curriculums across campus that relate to robotics and autonomy.

Introduction to Scientific Programming (AE2440): 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)

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)

Fundamentals of Robotics (EC4310): This course presents the fundamentals of land-based robotic systems covering the areas of locomotion, manipulation, grasping, sensory perception, and tele-operation. Main topics include kinematics, dynamics, manipulability, motion/force control, real-time programming, controller architecture, motion planning, navigation, and sensor integration. Several Nomad mobile robots will be used for class projects. Military applications of robotic systems are discussed. **POC:** Professor Xiaoping Yun (yun@nps.edu)

Introduction to Control Systems (ME2801): 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:** Dr. Brian Bingham (bsbingha@nps.edu)

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)

Dynamics and Control of Marine and Autonomous Vehicles I (3-2) (ME3801): First part of the course develops 6DOF equations of motion of marine and autonomous vehicles. Initially we discuss kinematics, followed by vehicle dynamics and overview of forces and moments acting on the marine/autonomous vehicles. Second part of the course introduces basic concepts of linear systems analysis as well as linear systems design using state-space techniques. All the examples used in the second part of the course are based on the model of an Autonomous Underwater Vehicle derived in the first part. The course includes a lab that further illustrates the concepts developed in class using hardware-in-the-loop simulation of an autonomous vehicle. Prerequisite: ME2801. **POC:** Dr. Brian Bingham (bsbingha@nps.edu)

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)

Marine Navigation (ME4821): 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)

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)

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)

Leadership in Product Development (MN3108): This is a product development course providing a broad framework for the leadership of end-to-end product commercialization with a student hands-on design challenge, to give students perspective and appreciation for the critical success factors and inhibitors to successful commercialization of complex products and systems. The format includes lectures, guest speakers, case studies and a design challenge. Topics include product development strategy and leadership, the front-end process, product delivery, distribution and customer support. The Design Challenge is as a multi-disciplinary system design experience. Students work in teams to design, build, test and demonstrate a real product, which in FY16 was a self-driving car autonomous system. The Design Challenge culminates with a prototype demonstration competition. **POC:** Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

Search Theory and Detection (OA3602): 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)

Joint Campaign Analysis (OA4602): 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. In a Maritime War 2030 scenario involving increased tensions and conflict in the Sea of Okhotsk, East China Sea, and Baltic Sea, students explored demanding sea control environments and the use of unmanned systems to enhance cross domain integrated fires in those environments For example, when Precision, Navigation, and Timing information is constrained, DARPA's TERN project (longrange UAV from Surface Action Group) was shown to provide longer range targeting capability and more efficient use of missiles. **POC:** Professor Jeff Kline (jekline@nps.edu)

Advanced Applied Physics Lab (PC4015): 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)

Systems Architecture and Design (SE4150): 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. **POC:** Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

Systems Integration and Development (SE4151): 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 mission. **POC:** Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

Systems Test and Evaluation (SE4354): 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)

Formal Methods for Systems Architecting (SE4935): This 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 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 in FY14. 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, 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 and the 2016 course offering informed the development of educational manuals. **POC:** Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

Model Based Systems Engineering (SE4930): 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 a UGV. Another section of SE4930 students during the same term were exposed via a guest lecture to unmanned systems modeled in Monterey Phoenix. **POC:** Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

Systems Software Engineering (SE4003): This course is designed to teach students the basic concepts of software engineering and methods for requirements definition, design and testing of software. Specific topics include introduction to the software life cycle, basic concepts and principles of software engineering, object-oriented methods for requirements analysis, software design and development. Special emphasis is placed on the integration of software with other components of a larger system. In the FY16 class, students from NAVAIR learned how to model and test the systems software architecture of a UGV using automated tools including Innoslate and Monterey Phoenix (MP). Four MP assignments were assigned and completed to teach students the basics of using this tool for exposing design errors in the CRUSER-sponsored UGV case study. **POC:** Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

Systems Architecture (SI4022): 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." **POC:** Associate Professor Kristin Giammarco (kmgiamma@nps.edu)

Robust Generation of Control Software (3-1) (SW4597): This course covers the concepts, methods, techniques, and tools needed to methodically generate robust software for system control. Specific topics include specification and analysis of control requirements, hard and soft real-time constraints, embedded software control, code generation, software reliability through software reuse and redundancy, and DoD requirements for control systems. A survey of computer-aided tools that support the generation of robust systems is provided. Prerequisite: SW4500 or consent of the instructor. **POC:** Dr. Brian Bingham (bsbingha@nps.edu)

2. Robotics Short Course Development

This ROS short course was developed with the support of the ONR, SSC Pacific and NPS-CRUSER. The course is a condensed version of a hands-on course taught at NPS - ME4823: Mobile Robot Control. The course provides an application-specific introduction to the robotics operating system (ROS) to provide practicing engineers with a first experience in the context of developing a maritime robotic application. The material is a curated set of materials and exercises, many of them freely available on the internet, assembled in a fashion to lower the barrier to entry for students. Furthermore, the course provides student's with a working ROS system so that they can start using ROS immediately, avoiding the time and effort associated with building a development environment.

The course is organized around the central goal of having each student design, build and test (in simulation) a control system for an unmanned surface vessel (USV). Upon successful completion of this course students will be able to

- understand the basics of the ROS and its role in developing unmanned systems applications,
- operate a Gazebo simulation to emulate the sensors, actuators and dynamics of an unmanned vehicle,
- use the introspection tools of ROS to interact with the simulated robot,
- integrate new sensor data into the operations of an existing robot and
- develop and test simple low-level and high-level vehicle controllers.

The course is designed in a series of discrete modules, each composed of a series of short video lectures and a hands-on assignment. Students will complete basic ROS tutorials using supplied, virtual computing environment. For instance, students are given a Gazebo simulated robot and asked to answer a series of questions which require using ROS tools to find the answer (e.g., use rqt_graph to determine connections between particular nodes). Students learn to use virtual Gazebo simulation and to interface the simulated environment with ROS. Simulation is provided using NPS simulator plugins. Students will be asked to use open-loop commands (no feedback) to command simulated USV to achieve a set of mission goals.

For the *Sensor Integration Using ROS* module students learn to parse common sensor data from common interfaces such as string messages, analog values and digital values. Given a simulated environment (robot and payload sensor) and example sensor driver, students will be asked to develop ROS node to parse raw sensor data. The assignment to introduce high-level command and control to integrate sensor data into unmanned systems operations would be to extend the control to make use of sensor data to adapt vehicle mission based on environmental data.

Vehicle control using ROS would begin with an overview of classical feedback control including a conceptual overview of proportional, integral and derivative (PID) control as it pertains to regulating the heading and velocity of a USV. Given an example of feedback control, students would be assigned to extend and tune control based on testing performance in a simulated environment. Finally, students would receive a conceptual overview of topics such local coordinate transformation, waypoint guidance and path following. Given an example of high-level control, students would need to extend and tune control based on testing performance in a simulated environment.

Deliverables associated with course module #1 (Introduction to ROS and Gazebo), described above, were developed during FY17 as a prototype. If successful we plan to incorporate feedback from the prototype to build the remaining modules in FY18. Course administrative infrastructure includes generating a request for continuing education units (CEUs) to go through NPS Academic Affairs. Appropriate record keeping would be implemented to allow for CEUs to be awarded for successful completion. Software required includes creation of a standard development environment to support the course. The development environment will include Ubuntu, ROS and Gazebo. Installation and testing of ROS/Gazebo development environment on cloud computing infrastructure (e.g., Amazon Web Services) would allow students to use ROS and Gazebo from any computing platform.

In FY17 written course materials (e.g., tutorials and demonstrations) were developed on an NPS hosted wiki. Using NPS distance learning classroom facilities, a series of short video lectures were created for each course module. Evaluation materials (quizzes and assignment evaluation) were also generated, and Sakai – the NPS distance-learning platform – was leveraged for online course delivery with planning for sustainment.

NPS faculty delivered a pilot short course at SPAWAR in late FY17. Suggested revisions and additions to course material and infrastructure based on pilot short course student feedback will be incorporated into future iterations of the course.

3. Continuing Education Panel Series

In FY17 CRUSER initiated the Continuing Education Panel Series *Just One Thing*. Within the rapidly growing domain of robotics and autonomy, this new education initiative will allow experts to advise the naval leadership as to what they believe the most important challenge will be for the naval enterprise over the next ten years. The first panel was held on the NPS campus on 19 September during the WIC Workshop for the Deputy Assistant Secretary of the Navy (DASN) for Unmanned Systems retired Marine Corps Brigadier General Frank Kelley (*see Figure 39*).

Figure 39. CRUSER Continuing Education Panel "Just One Thing", 19 September 2017.

Moderated by CRUSER Director Dr. Raymond Buettner, the September 2017 *Panel on Robotic and Autonomous Systems for the Naval Enterprise: Just One Thing* included five selected panelists and seven designated questioners (*see Table 2*).

Table 2. September 2017 *Just One Thing* panelists and invited inquisitors.

Panelists	**Inquisitors**
[1] Dr. Peter Denning, NPS Computer Science Department [2] CAPT George Galdorisi USN (ret), SSC PAC [3] CAPT William Glenney USN (ret), NWC [4] CAPT Karl Hasslinger USN (ret), General Dynamics Electric Boat [5] Dr. Mathieu Kemp, Monterey Bay Aquarium Research Institute (MBARI)	[1] Mr. Ken Amster, NAWC China Lake [2] Dr. Lori Adornato, DARPA [3] CDR Jason Canfield USN, NWDC [4] CMDR Scott Craig, Royal Australian Navy [5] CAPT Wayne Hughes USN (ret), NPS [6] Mr. Stephen Kracinovich, NAWCAD [7] Mr. Tom Urban, JHU/APL

These distinguished panelists offered the DASN their respective opinions as to the most important single thing the Department of the Navy should be doing to enable the USN and USMC to rapidly assimilate and exploit the capabilities represented by robotic and autonomous systems. Designed to challenge and explore the suggestions of the panelists, a moderated discussion session followed their prepared statements and included questions from designated domain experts. In addition to direct questions during the event, the audience members had the ability to submit questions and comments. These comments, as well as the formal statements and questions were collected and compiled into a report for consideration by naval leadership.

4. CRUSER Colloquiums

To support the primary mandate of CRUSER in pa. In FY17 CRUSER presented two CRUSER Colloquiums on the NPS campus for the community of interest.

Dr. Stefano Carpin, Associate Professor of Engineering at the University of California Merced, presented his talk “Balancing risk and performance in rapid deployment tasks” on 2 May 2016. In the rapid multirobot deployment problem a robotic swarm is tasked with the objective of positioning at least one robot at each of a set of pre-assigned targets while meeting a temporal deadline. Travel times and failure rates are stochastic but related, inasmuch as failure rates increase with speed. To maximize chances of success while meeting the deadline, a control strategy has therefore to balance safety and performance. Our approach is to cast the problem within the theory of constrained Markov Decision Processes, whereby we seek to compute policies that maximize the probability of successful deployment while ensuring that the expected duration of the task is bounded by a given deadline. To account for uncertainties in the problem parameters, we consider a robust formulation and we propose efficient solution algorithms, which are of independent interest. Numerical experiments confirming our theoretical results are presented and discussed.

Stefano Carpin received his “Laurea” (MSc) and Ph.D. degrees in electrical engineering and computer science from the University of Padova, Italy in 1999 and 2003, respectively. From 2003 to 2006 he held faculty positions with the International University Bremen, Germany. Since 2007 he has been with the School of Engineering at UC Merced, where he established and leads the UC Merced robotics laboratory.[1] He is also the founding director of UC Merced's Center for Autonomous and Interactive Systems (CAIS). His research interests include mobile and cooperative robotics for service tasks, and robot algorithms. He published more than 100 papers in international journals, conferences, and workshops, and he is a Senior Member of the IEEE. From 2010 to 2014 he was an associate editor for the IEEE Transactions on Robotics (T-RO) and in 2015 he was a guest editor for a special issue of the Autonomous Robots journal on Constrained decision-making in robotics: models, algorithms, and applications. He is an associate editor for the IEEE Transactions on Automation Science and Engineering (T-ASE), an associate editor for the IEEE Robotics and Automation Letters (RA-L), and serves as associate editor or program committee member for the major international conferences in robotics. From 2006 to 2009 he served as elected executive member of the RoboCup federation. Under his supervision, teams participating in the RoboCupRescue Virtual Robots competition won second place in 2006 and 2008, and first place in 2009. Since he moved to UC Merced his research has been supported by the National Science Foundation, DARPA, the Office of Naval Research, the Army Research Lab, the Department of Commerce (NIST), the Center for Information Technology Research in the Interest of Society (CITRIS), Microsoft Research, and General Motors.

On 1 May 2017 Dr. Julie Adams, Professor of Computer Science at Oregon State University, presented “A Science of Human-Machine Teaming: Fundamental Developments for Swarms.” Biological inspiration for artificial systems abound. While a science is emerging of how biological swarms, both spatial (e.g., fish and starlings) and colony based (e.g., honeybees), behave and how to model them, and progress has been made regarding how a single human can

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[1] UC Merced Robotics Lab: http://robotics.ucmerced.edu

influence swarms, we lack a full understanding of how a single human or individuals within an organization can influence swarms. Many unique challenges exist when attempting to emulate biological swarms and the associated capabilities that allow humans to influence them. First-response and military organizations seek to deploy swarms that obtain desired outcomes over variable-duration missions; thus, our research focuses on understanding the underlying biological phenomenon and the associated implications for human–swarm teaming. Our multiple pronged research focuses on analyzing biologically inspired communication protocols to identify correlations with swarm task performance; analyzing how factors impact humans' abilities to influence swarms, including developing systems that allow human organizations, with potentially multiple humans influencing the swarm simultaneously, to effectively team with spatial and colony based swarms.

Dr. Julie A. Adams is a Professor of Computer Science in the School of Electrical Engineering and Computer Science Department at Oregon State University. She is also the founder of the Human-Machine Teaming Laboratory at Vanderbilt University, prior to moving her laboratory to Oregon State. Dr. Adams has worked in the area of human-machine teaming for over twenty-five years. Throughout her career, she has focused on human interaction with unmanned systems, but also focused on manned civilian and military aircraft at Honeywell, Inc. and commercial, consumer and industrial systems at the Eastman Kodak Company. Dr. Adams received her M.S. and Ph.D. degrees in Computer and Information Sciences from the University of Pennsylvania and her B.S. in Computer Science and B.B.E. in Accounting from Siena College. She has over 125 referred publications and her research efforts have been featured in international news outlets including National Geographic, Scientific American Podcast, Der Spiegel, and BBC on-line. Her current work on distributed artificial intelligence is focused on optimizing mission success by developing coalition formation algorithms and methods and more recently combining coalition formation with mission planning to optimize the ability to generate acceptable mission plans in real time. She is a contributor to the National Academies report on Mainstreaming UUVs into the fleet for the CNO and is currently contributing to an Army BAST requested report on counter measures for UAVs.

5. NPS Student Theses and Travel

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 3*) lists students mentored in FY17, as well as those who graduated in September 2016 as their thesis work was still in academic processing when the FY16 CRUSER report was released.

Table 3. FY17 CRUSER mentored NPS student theses (*alphabetical by author*)

AUTHOR(s)	TITLE	DATE (year-mo)	URL
LT Robert L. Allen III, USN	*Quadrotor Intercept Trajectory Planning and Simulation*	2017-JUN	http://hdl.handle.net/10945/55627

Captain Wee Kiong Ang, Singapore Army	*Assessment of an Onboard EO Sensor to Enable Detect-and-Sense Capability for UAVs Operating in a Cluttered Environment*	2017-SEP	http://hdl.handle.net/10945/56165
LCDR Christopher M. Bade, USN	*Study of Integrated USV/UUV Observation System Performance In Monterey Bay*	2017-SEP	http://hdl.handle.net/10945/56176
LT Ryan G. Beall, USN	*Engineering of Fast and Robust Adaptive Control for Fixed-Wing Unmanned Aircraft*	2017-JUN	http://hdl.handle.net/10945/55563
Capt Carl P. Beierl, USMC and Capt Devon R. Tschirley, USMC	*Unmanned Tactical Autonomous Control and Collaboration Situation Awareness*	2017-JUN	http://hdl.handle.net/10945/55568
LT Connor F. Bench, USN	*GPS Enabled Semi-Autonomous Robot*	2017-SEP	http://hdl.handle.net/10945/56103
LT Kristjan J. Casola, USN	*System Architecture and Operational Analysis of Medium Displacement Unmanned Surface Vehicle Sea Hunter as a Surface Warfare Component of Distributed Lethality*	2017-JUN	http://hdl.handle.net/10945/55579
Capt Elle M. Ekman, USMC	*Simulating Sustainment for an Unmanned Logistics System Concept of Operation in Support of Distributed Operations*	2017-JUN	http://hdl.handle.net/10945/55593
LT Stephen M. Fleet, USN	*Effects of Mixed Layer Shear on Vertical Heat Flux*	2016-DEC	http://hdl.handle.net/10945/51696
ENS Rebecca A. Greenberg, USN	*Investigating the Feasibility of Conducting Human Tracking and Following in an Indoor Environment Using a Microsoft Kinect and the Robot Operating System*	2017-JUN	http://hdl.handle.net/10945/55606
Keng Siew Aloysius Han	*Test and Evaluation of an Image-Matching Navigation System for a UAS Operating in a GPS-Denied Environment*	2017-SEP	http://hdl.handle.net/10945/56131
LTjg Pedro R. Hayden, Peruvian Navy	*Unmanned Systems: A Lab-Based Robotic Arm for Grasping Phase II*	2016-DEC	http://hdl.handle.net/10945/51716
LT Chaz R. Henderson, USN	*Feasibility of Tactical Air Delivery Resupply Using Gliders*	2016-DEC	http://hdl.handle.net/10945/51717

LT Joshua B. Hicks, USN and LT Ryan L. Seeba, USN	*Effectiveness of a Littoral Combat Ship as a Major Node in a Wireless Mesh Network*	2017-MAR	http://hdl.handle.net/10945/52990
LT Jo-Wen Huang, Taiwan Navy	*Implementation of a Multi-Robot Coverage Algorithm on a Two-Dimensional, Grid-Based Environment*	2017-JUN	http://hdl.handle.net/10945/55624
LT Bradley A. Johnson, USN	*Using A Functional Architecture to Identify Human-Automation Trust Needs and Design Requirements*	2016-DEC	http://hdl.handle.net/10945/51726
LCDR Jake A. Jones, USN	*A New Technique for Robot Vision in Autonomous Underwater Vehicles Using the Color Shift in Underwater Imaging*	2017-JUN	http://hdl.handle.net/10945/55631
Lieutenant Commander Akhtar Zaman Khan, Pakistan Navy	*Convoy Protection under Multi-Threat Scenario*	2017-JUN	http://hdl.handle.net/10945/55566
Wei Sheng Jeremy Kang, Singapore Army	*An Engineered Resupply System for Humanitarian Assistance and Disaster Relief Operations*	2017-SEP	http://hdl.handle.net/10945/56144
Captain Sangbum Kim, Republic of Korea	*Feasibility Analysis Of UAV Technology to Improve Tactical Surveillance in South Korea's Rear Area Operations*	2017-MAR	http://hdl.handle.net/10945/53001
Maj Thomas D. Kline, USMC	*Proof of Concept in Disrupted Tactical Networking*	2017-SEP	http://hdl.handle.net/10945/56147
Mr. Sean Kragelund	*Optimal Sensor-Based Motion Planning for Autonomous Vehicle Teams (Ph.D. Dissertation)*	2017-MAR	http://hdl.handle.net/10945/53003
Maj Thomas A. Kulisz, USMC and Capt Robert E. Sharp, USMC	*Unmanned Tactical Autonomous Control and Collaboration (UTACC) Human-Machine Integration Measures of Performance and Measures of Effectiveness*	2017-JUN	http://hdl.handle.net/10945/55637
LT Matthew D. Lai, USN	*Application of Thin Film Photovoltaic Cigs Cells to Extend the Endurance of Small Unmanned Aerial Systems*	2017-JUN	http://hdl.handle.net/10945/55639
Wee Leong Lai, Singapore	*Applicability of Deep-Learning Technology for Relative Object-Based Navigation*	2017-SEP	http://hdl.handle.net/10945/56149

Lieutenant Antonios Lionis, Hellenic Navy	*Experimental Design of a UCAV-Based High-Energy Laser Weapon*	2016-DEC	http://hdl.handle.net/10945/51574
LCDR Nicholas A. Manzini, USN	*USV Path Planning Using Potential Field Model*	2017-SEP	http://hdl.handle.net/10945/56152
ENS Tyler B. McCarthy, USN	*Feasibility Study of a Vision-Based Landing System for Unmanned Fixed-Wing Aircraft*	2017-JUN	http://hdl.handle.net/10945/55652
Mkuseli Mqana, Armament Corporation of South Africa	*Terminal Homing Position Estimation for Autonomous Underwater Vehicle Docking*	2017-JUN	http://hdl.handle.net/10945/55655
Lieutenant Commander Renato Peres Vo, Brazilian Navy	*Improved UUV Positioning Using Acoustic Communications and a Potential for Real-Time Networking and Collaboration*	2017-JUN	http://hdl.handle.net/10945/55517
Lieutenant Colonel Silvio Pueschel, German Army	*Optimization of Advanced Multi-Junction Solar Cell Design for Space Environments Using Nearly Orthogonal Latin Hypercubes*	2017-JUN	http://hdl.handle.net/10945/55521
Hongze Alex See, Singapore	*Coordinated Guidance Strategy for Multiple USVs during Maritime Interdiction Operations*	2017-SEP	http://hdl.handle.net/10945/56175
Capt James Garrick Sheatzley, USMC	*Discrete Event Simulation for the Analysis of Artillery Fired Projectiles from Shore*	2017-JUN	http://hdl.handle.net/10945/55536
Solem, K.	*Quantifying the Potential Benefits of Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessels (ACTUV) in a Tactical ASW Scenario (Restricted)*	2017-MAR	restricted
Choon Seng Leon Mark Tan, Singapore	*Mission Planning for Heterogeneous UXVs Operating in a Post-Disaster Urban Environment*	2017-SEP	http://hdl.handle.net/10945/56182
Major Bruno G. F. Tavora, Brazilian Air Force	*Feasibility Study of an Aerial Manipulator Interacting with a Vertical Wall*	2017-JUN	http://hdl.handle.net/10945/55545
LT Ian Taylor, USN	*Variable Speed Hydrodynamic Model of an AUV Utilizing Cross Tunnel Thrusters*	2017-SEP	http://hdl.handle.net/10945/56183

LT Joseph B. Testa III, USN	*Vision-Based Position Estimation Utilizing an Extended Kalman Filter*	2016-DEC	http://hdl.handle.net/10945/51625
LCDR Richard B. Thompson, USN	*Confidential and Authenticated Communications in a Large Fixed-Wing UAV Swarm*	2016-DEC	http://hdl.handle.net/10945/51626
Ying Jie Benjemin Toh, Singapore	*Development of a Vision-Based Situational Awareness Capability for Unmanned Surface Vessels*	2017-SEP	http://hdl.handle.net/10945/56185
LT Marcus A. Torres, USN	*Feasibility Analysis and Prototyping of a Fast Autonomous Recon System*	2017-JUN	http://hdl.handle.net/10945/55547
Capt Michael D. Wilcox, USMC and Capt Cody D. Chenoweth, USMC	*Unmanned Tactical Autonomous Control and Collaboration (UTAC) Immediate Actions*	2017-JUN	http://hdl.handle.net/10945/55554
Team SBD Systems Engineering	*Implementing Set Based Design into Department of Defense Acquisition*	2016-DEC	http://hdl.handle.net/10945/51668

CRUSER supported 41 NPS student trips in FY17 to further their thesis work (*see Table 4*). 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 4. CRUSER supported student travel, FY17

STUDENT	**DESTINATION**	**DATE**	**PURPOSE**
Maj Brandon Daigle	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)
David Morales	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)
Brian James	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)
Scott Siggins	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)
Anthony Fera	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)
Matthew Lommel	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)

Steve Miller	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)
Matthew O'Loughlin	Las Vegas NV	November 2016	CRUSER drone team thesis site visit (observe)
Capt Elle Ekman, USMC	Arlington VA	December 2016	INFORMS Winter Simulation Conference (attend)
LCDR Lisa Gembreamlak, USN	San Francisco CA	February 2017	AFCEA/USNI West (attend), and thesis site visit (observe)
LCDR Lisa Gembreamlak, USN	Camp Roberts CA	February 2017	swarm v. swarm experimentation (observe)
Maj Thomas Kline, USMC	Camp Roberts CA	March 2017	thesis field experimentation (execute)
LCDR Alex Williams, USN	Camp Roberts CA	March 2017	experimentation (Yakimenko's student)
LT Todd Coursey, USN	Palmdale CA	March 2017	NASA Armstrong Flight Research Center site visit for thesis work
LT Ryan Beal, USN	Big Sky MT	March 2017	IEEE aerospace conference (present paper)
CPT Ang Wee Kiong, USA	W Lafayette IN, Kansas City MO	April 2017	Purdue Univ and Univ of Missouri thesis site visits (meetings)
Lai Wee Leong	Las Vegas NV	April 2017	Unmanned Security Expo @ISC West (attend)
Tan Qinling Jeanette Olivia	Seattle WA	May 2017	2017 IEEE Radar Conference (attend)
Capt Carl Beierl, USMC	Ft. AP Hill, VA	1-4 May 2017	UTACC Thesis Research ICW Developmental Test 1
Capt Michael Wilcox, USMC	Ft. AP Hill, VA	1-4 May 2017	UTACC Thesis Research ICW Developmental Test 1
Capt Robert Sharp, USMC	Ft. AP Hill, VA	1-4 May 2017	UTACC Thesis Research ICW Developmental Test 1
Maj Thomas Kuliss,	Ft. AP Hill, VA	1-4 May	UTACC Thesis Research ICW Developmental

USMC		2017	Test 1
Capt Cody Chenoweth, USMC	Ft. AP Hill, VA	1-4 May 2017	UTACC Thesis Research ICW Developmental Test 1
Mr. Steve Mullins, CIV	Indianapolis IN	June 2017	International Conference on Network Science (co-present paper)
CDR Katy Giles, USN	Waikoloa HI	June 2017	12th Annual SoSE Conference (co-authored paper)
LT Justin Davis, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
MAJ Matthew Einhorn, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
LCDR Kyle Kobold, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
LCCR Alexander Williams, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
LT Devon Cartwright, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
LT Geoffrey Fastabend, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
LT Alexander Samaniego, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
LCDR Stephan Brock, USN	Mojave, CA	2-3 JUN 2017	UAS research project experimentation
Mr. Andrew Watson, GS-14 (CS)	Wash. DC	25-27 JUN 17	Multi-agency meeting exploring the creation of a Robot Operating System (ROS)-Government initiative
LCCR Alexander Williams, USN	Camp Roberts	28-30 JUN 2017	multi-rotor testing and flight operations. Required for thesis (Yakimenko)
Maj Thomas Kline, USMC	Czestochowa POLAND	3-11 JUN 2017	multi-domain mesh network experimentation with Dr. Bordetsky

MAJ Michael "Paddy" Ferriter	Czestochowa POLAND	3-11 JUN 2017	multi-domain mesh network experimentation with Dr. Bordetsky (cancelled his trip 23MAY2017)
LCCR Alexander Williams, USN	Camp Roberts	6-8 Aug 2017	Multi-rotor testing and flight operations. Required for thesis testing and NPS research
Article I. CDR Katy Giles, USN	Chicago, IL	29 OCT-2 NOV 17	Complex Adaptive Systems Conference (present paper)
Capt Hawken Grubbs	Point Mugu	20 - 24 Sep	PMA-234 meeting with engineers and program officers involved with the thesis topic involving the Intrepid Tiger II.
Sverre Wetteland	Nellis AFB, NV	17 Sep	Conduct thesis related experiment with wireless mesh networks operating android tactical assault kit with mpu4 and 5 radios and a bgan antenna serving as an interne gateway

D. CONCEPT GENERATION

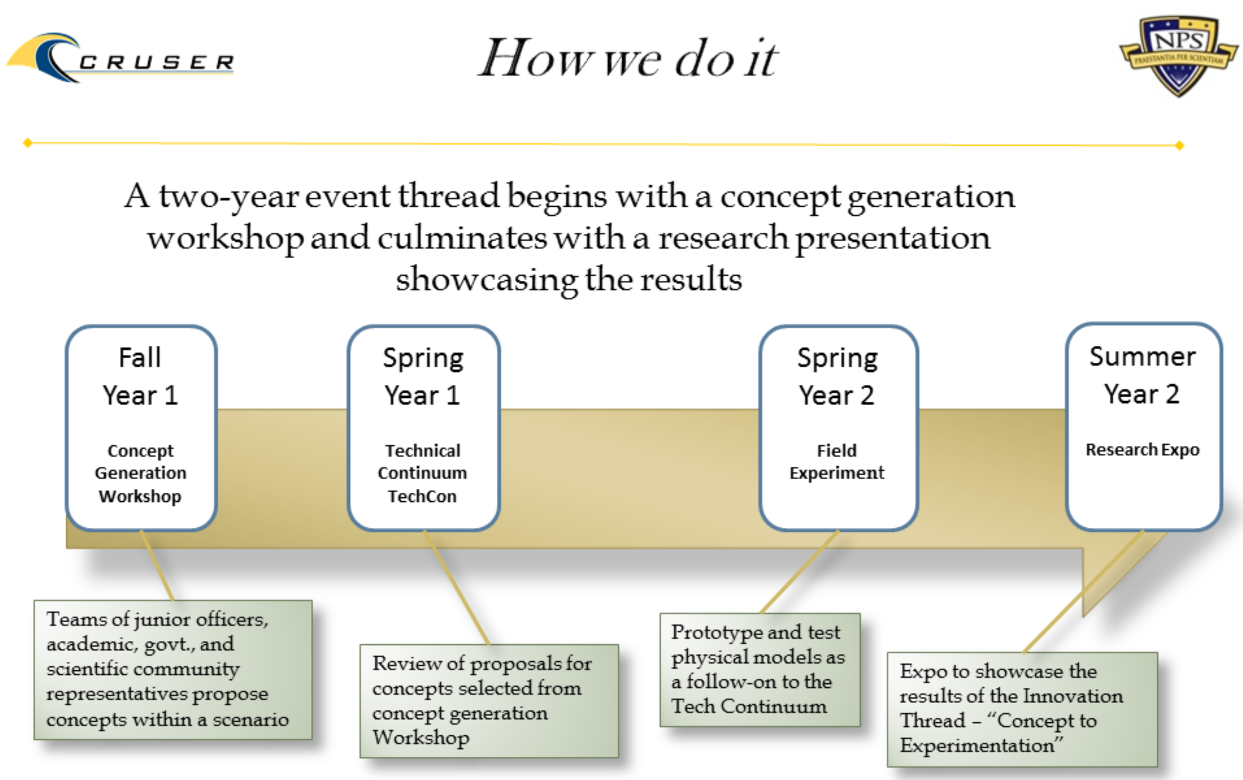

Figure 40. CRUSER innovation thread structure.

The CRUSER concept generation work initiates each new programmatic innovation thread (*see Figure 40*) and at the time of this FY17 annual report we have just launched our seventh innovation thread, Distributed Maritime Operations. 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.

1. Warfare Innovation Continuum (WIC) Workshop 2017

The first CRUSER sponsored concept generation workshop 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
9) Developing Autonomy to Strengthen Naval Power, September 2016
10) Distributed Maritime Operations, September 2017

Our most recent workshop, Distributed Maritime Operations, was held 18-21 September 2017 on the NPS campus. This workshop included nearly 100 participants representing a wide variety of stakeholder groups.

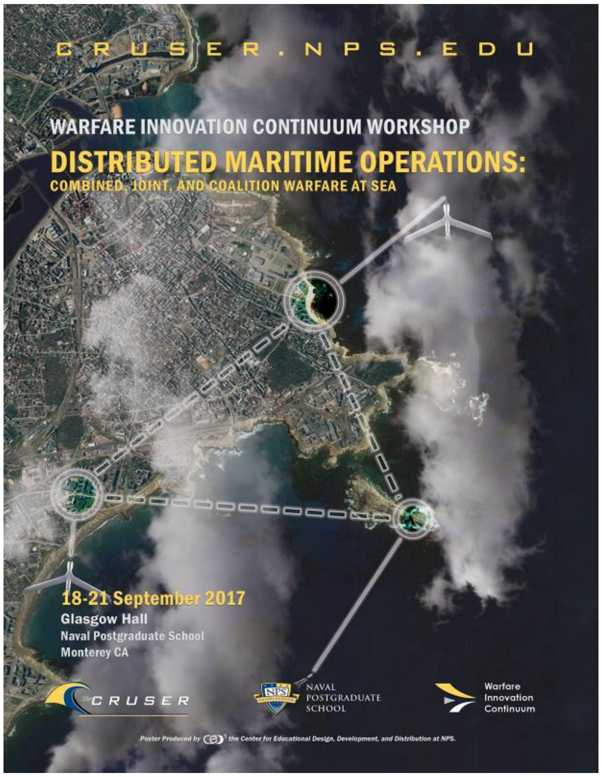

Figure 41. September 2017 Warfare Innovation Continuum (WIC) Workshop, "Distributed Maritime Operations."

This Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) sponsored Warfare Innovation Continuum (WIC) workshop was held 18-21 September 2017 on the campus of the Naval Postgraduate School (NPS) in Monterey, California. The three and a half day educational experience allowed NPS students focused interaction with faculty, staff, fleet officers, and visiting engineers from Navy labs and industry; and culminated in a morning of final concept briefs and fruitful discussion regarding the role of unmanned systems in the future naval force. This workshop also directly supported the Secretary of the Navy's (SECNAV) direction that CRUSER foster the development of actionable operational concepts for robotic and autonomous systems (RAS) within naval warfare areas.

The September 2017 workshop, Distributed Maritime Operations, tasked participants to apply emerging technologies to shape the way we fight. Within a near future conflict in an urban littoral environment concept generation teams were given a design challenge: *How might advanced autonomy, manned-unmanned teaming, emergent technologies, and unmanned systems reduce risk to the warfighter and increase mission effectiveness?* With embedded facilitators, five teams had three days to meet that challenge, and presented their best concepts on the final morning of the workshop.

Figure 42. Retired Marine Corps Brigadier General Frank Kelley, DASN Unmanned, speaking to the participants of the September 2017 Warfare Innovation Continuum (WIC) Workshop.

Participants included NPS students from across campus, as well as guests from Navy labs, other DoD commands, academia and industry. After a morning of knowledge-leveling plenary briefings, team participated in an innovation seminar based on user-centered design developed in Silicon Valley. Teams spent the next two days generating concepts to enhance future warfighting in an urban 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.

Half of the workshop participants were NPS students from curricula across the NPS campus. For this workshop, the final roster also included participants from The Johns Hopkins University Applied Physics Lab (JHU/APL), DARPA, the Royal Australian Navy, the Naval War College, Battelle, SPA Inc., Draper Labs, General Dynamics Electric Boat, Caterpillar International, and Lockheed Martin. Fleet and system commands included PMA 262, OPNAV N501, OPNAV N2N6FX, Naval Air Systems Command (NAVAIR), Naval Undersea Warfare Center (NUWC) Keyport, Space and Naval Warfare Systems Command (SPAWAR) Systems Center (SSC) Pacific, Navy Cyber Warfare Development Group (NCWDG), and Navy Warfare Development Command (NWDC). This workshop included participants from Singapore, Germany, Australia, and Bahrain. The Deputy Assistant Secretary of the Navy for Unmanned Systems was an active participant throughout the full process.

Participants were asked to propose both physical designs and concepts of operation for notional future systems' employment in a plausible real-world scenario with the intent of advancing unmanned systems concepts. From all the concepts generated during the ideation phase, each team selected concepts to present in their final briefs. CRUSER and Warfare Innovation Continuum (WIC) leadership reviewed all the proposed concepts and selected ideas with potential operational merit that aligned with available resources for further development. All concepts are described fully in the September 2017 WIC Workshop report, but in summary these concepts include:

1) **Autonomy in Support of Operations & Logistics:** this topic area includes autonomy concepts that provide direct support to warfighters in a battlespace.

2) **Man-Machine Teaming:** this topic area includes robotics and autonomy concepts to support warfighters throughout their careers.

3) **Organizational Change & Adoption:** rather than purely autonomy related concepts, this topic area includes recommendations for change at the organizational level to better leverage the capabilities that autonomy may offer in the future.

Selected concepts will begin CRUSER's next Innovation Thread, and members of the CRUSER community of interest will be invited to further develop these concepts in response to the FY18 and FY19 Call for Proposals. Technical members of the CRUSER community of interest will present proposals at a technical continuum gathering such as TechCon 2018 to test these selected concepts of interest in lab or field environments. A final report detailing process and outcomes will be released before the end of the 2018 calendar year to a vetted distribution list of leadership and community of interest members. Final results of experimentation will be presented to the Office of Naval Research (ONR) in June 2019.

2. Technology Continuum (TechCon) 2017

Figure 43. CRUSER Technical Continuum (TechCon), April 2017

NPS CRUSER held its fifth annual Technical Continuum (TechCon) on 11 and 12 April 2017. This event was for NPS students and faculty interested in education, experimentation and research related to employing unmanned systems in operational environments.

TechCon 2017 was intended to further concepts developed during the September 2016 concept generation workshop, and to showcase NPS student and faculty work in advancing work in robotics and autonomy. Presentations covered on-going student and faculty research, as well as proposals for CRUSER FY18 funding in research related to unmanned systems. The NPS CRUSER TechCon 2017 was unclassified, and live streamed by video for the non-resident CRUSER Community of Interest. All TechCon 2017 presentations are archived and available through the NPS Dudley Knox Library at https://calhoun.nps.edu/handle/10945/53346.

E. OUTREACH AND RELATIONSHIPS

1. Community of Interest

CRUSER continued to grow its membership throughout FY17. 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 33*). 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 and as of the end of FY17 on 30 September 2017 membership is 2880. Since January 2011 CRUSER membership has grown to just about 3,000 and has leveled off since March 2016 (*see Figure 44*).

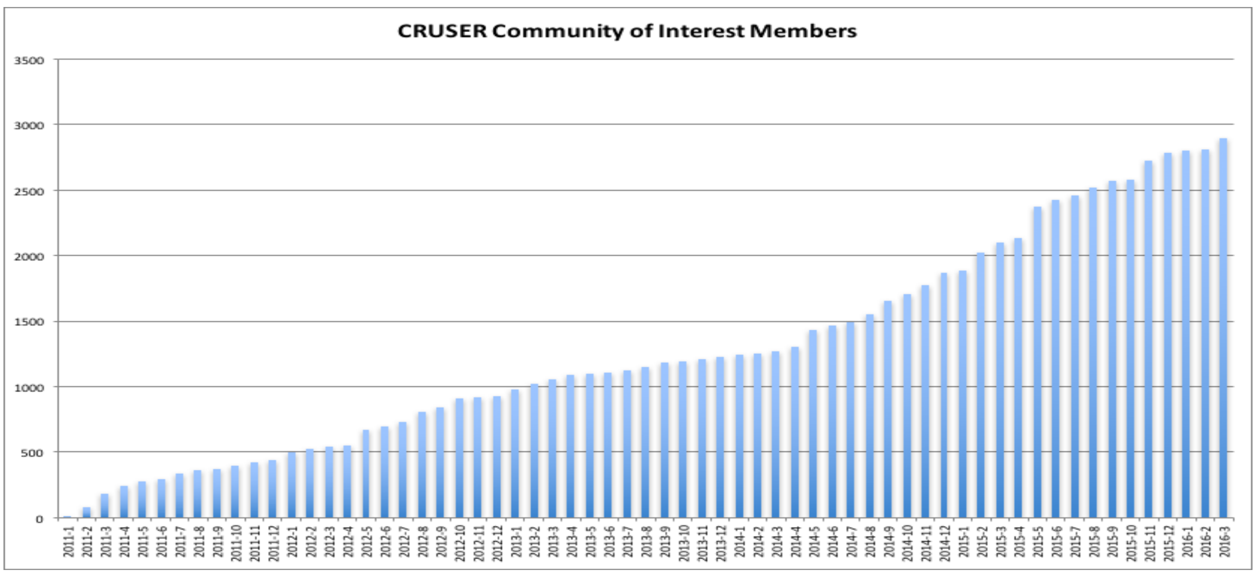

Figure 44. CRUSER community of interest growth from January 2011 to March 2016.

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 45*).

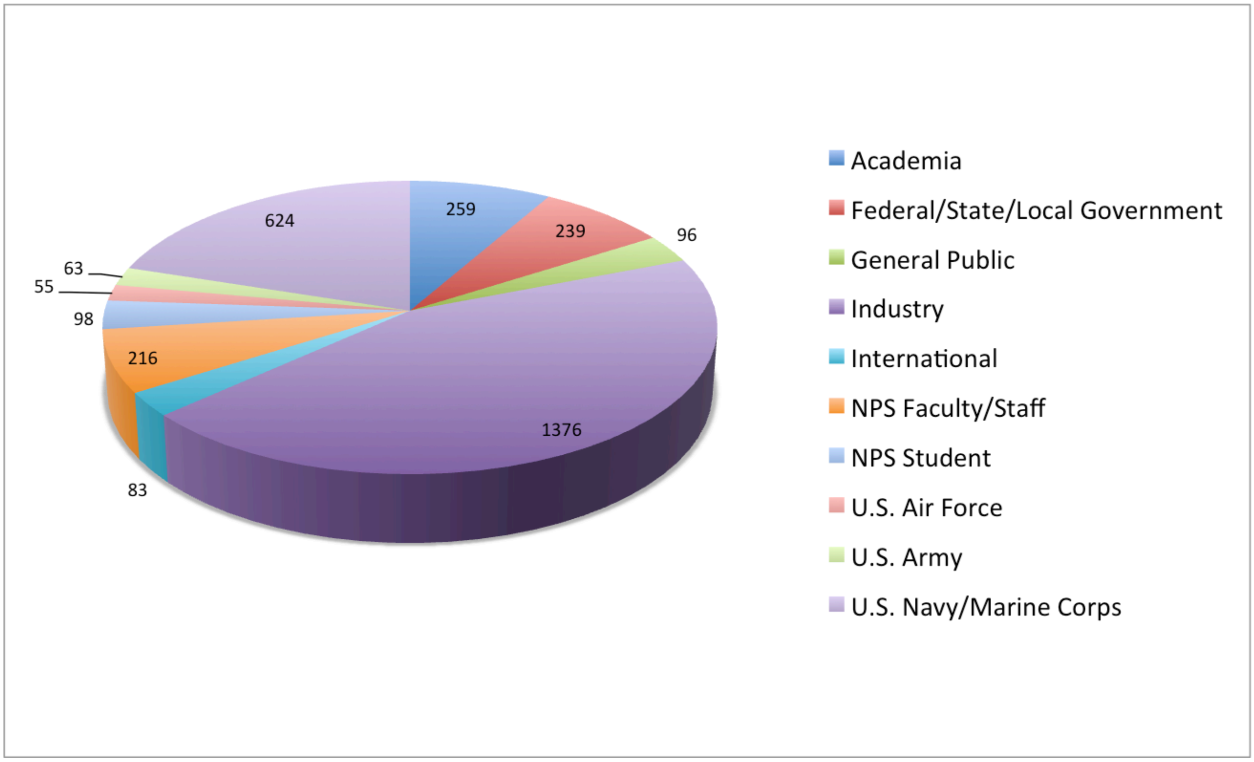

Figure 45. CRUSER community of interest breadth of membership (September 2017)

2. NPS CRUSER Monthly Meetings

CRUSER holds a monthly community meeting on the NPS campus generally on the first Monday or the month at the noon hour. Non-resident members may join the meeting by phone, video, or using the campus distance learning tool Collaborate.[2] These monthly meetings are intended as information sharing forums for the entire CRUSER community of interest, and each month feature two presentations from CRUSER funded researchers, CRUSER supported NPS thesis students, or any member of the non-resident CRUSER community that has a significant topic to share. In FY17 there were eleven NPS CRUSER monthly meetings featuring 21 presentations (*see Table 5*).

Table 5. FY17 NPS CRUSER Monthly Meeting presentations.

Date	**Presentation(s)**
3 OCT 2016	*System Engineering Department's Mojave Rocket Launch Program:* CDR Christopher Hall USN, NPS Student

[2] **Dial-in: 571-392-7703** PIN 629 103 443 905 or **Remote Connection:** https://sas.elluminate.com/m.jnlp?sid=2014002&username=&password=M.66F9FE61F58F1651000C7DFF65DA63

	CRUSER Proposal Process and Warfare Innovation Continuum (WIC) Workshop updates: Dr. Ray Buettner, CRUSER Director and Ms. Lyla Englehorn, CRUSER Associate Director
14 NOV 2016	*Fault Tolerant Control for AUVs:* LT Ian Taylor, USN – NPS Student *A Six Degree of Freedom Robotic Arm for Grasping:* LtJG Pedro Hayden, PERU – NPS Student
5 DEC 2016	*NPS Electrical and Computer Engineering Thesis Work:* LCDR Jacob Jones, USN – NPS Student *UAV Challenge Competitions:* LT Ryan Beall, USN – NPS Student
9 JAN 2017	*Augmenting the P-8A Poseidon with an Unmanned Targeting Air System for Anti-Submarine Warfare (CDR Kevin Williams USN thesis)*: Prof's Tom Lucas and Susan Sanchez – NPS Faculty *Robot Operating System (ROS) and NPS*: Dr. Brian Bingham, CRUSER Deputy Director
6 FEB 2017	*How to Conduct Research with ONR:* Dr. Frank Herr, ONR Ocean Battlespace Sensing
6 MAR 2017	*Development of an Aerial Manipulator to Assist Navy Helicopters in Vertical Replenishment:* LT Aaron Willmarth, USN – NPS Student *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) San Clemente Island Multi-Thread Experiment (MTX):* Dr. Doug Horner, Mechanical and Aerospace Engineering – NPS Faculty
11 APR 2017	*NPS Swarm v. Swarm: Advanced Robotics Systems Engineering Lab (ARSENL) to the Service Academy Swarm Challenge (SASC):* Dr. Duane Davis, Cyber Academic Group – NPS Faculty *NPS Field Experimentation (FX):* Dr. Ray Buettner, CRUSER Director
5 JUN 2017	*Catching Up with the Robo Dojo:* Kristen Tsolis, Defense Analysis – NPS Faculty *Engineering of Fast and Robust Adaptive Control for Fixed-Wing Unmanned Aircraft:* LT Ryan Beall, USN – NPS Student
10 JUL 2017	*NPS Center for Autonomous Vehicle Research (CAVR):* Dr. Isaac Kaminer, CAVR Director – NPS Faculty *Camp Roberts "Field of Dreams":* Ray Jackson – NPS Faculty
14 AUG 2017	*Wave-making capability addition to the NPS towing tank and the new research effort involving loads on a UUV operating near the surface in a wave field:* Dr.

	Joseph Klamo, Systems Engineering – NPS Faculty *Using Onboard EO Sensor to Achieve Detect and Sense Capability for UAS Operating in Cluttered Environment:* CPT Wee Kiong Ang, SINGAPORE – NPS Student
11 SEP 2017	*Field Experimentation at NPS:* Gerald Scott, Information Sciences – NPS Doctoral Student *Development of a numerical tow tank with wave generation to supplement experimental efforts:* ENS Marshall Jones, USN – NPS Student

Monthly meeting details are available on the CRUSER website (cruser.nps.edu).[3]

3. Briefings and Presentations

Over the seven years of the program CRUSER leadership team has become regarded experts on robotics and autonomy issues resulting in a high demand for briefings, formal presentations and informal discussions. These activities are an important part of the CRUSER educational effort, both providing for an exchange of information that educates all parties involved. A sampling of those that received CRUSER briefings in FY17 are included in the following table (*see Table 6*):

Table 6. FY17 CRUSER program briefings and presentations

DATE	ORGANIZATION
OCT 2016	Dr. John Pazik, Office of Naval Research (ONR)
NOV 2016	Pivotal Labs
DEC 2016	Swedish Royal Academy of War Sciences SWEDEN Dr. Wadeb Doubleday, DCTO SSC-PAC Mr. Isaac Taylor, DIUx
JAN 2017	Col Kerry Moores USMC and Jessica Todd, Warfighting Lab Incentive Fund CAPT Steve Harrison USN, Joint Undersea Weapons Program Office (PMS 404)
FEB 2017	Dr. Frank Herr, ONR

[3] Go to **cruser.nps.edu** and click on **Monthly Meeting** on the top navigation bar

	Mr. Josh Smith, Tactical Advancement for the Next Generation (TANG) JHU/APL
MAR 2017	Norwegian Defence Research Establishment (FFI) NORWAY VADM Mulloy, OPNAV N8 Dr. Wyman Williams, GTRI Jose Chavez, SPAWAR Undersea Integration Office, PMW 770 MMag Konrad Kogler, Director-General of Public Security AUSTRIA
APR 2017	LTG Walsh, USMC Dr. Tim Mavor, ONI CAPT Brian Davies USN, Commander Sub Squadron 11 Dr. Brian Hennings, Lynntech Inc. NDU Robotics and Autonomous Systems Study Team
MAY 2017	Dr. Julie Adams, Oregon State University Dr. Jude Stark, NSWC Carderock
JUN 2017	Mr. Jeff Smith, Riptide Dr. Michael Balazas, MITRE Corporation
JUL 2017	ADM Davidson
AUG 2017	Dr. Dan Chieu, JPA Mr. Lee Jahnke, ONI

4. USN Reserve Relationships

CRUSER has an ongoing relationship with two distinct reserve components - The Office of Naval Research – Reserve Component (ONR-RC), and the Strategic Sealift Office (SSO) Reserve Program. ONR-RC continued to provide operational support to many CRUSER projects, programs, and events in FY17. Collaboration between CRUSER researchers at the Naval Postgraduate School (NPS) and ONR-RC began four years ago with personnel from the ONR-113 unit, and has expanded to several additional ONR Reserve units. This is an extremely valuable relationship for CRUSER and the larger community of interest.

The SSO Reserve program evolved from the Maritime Administration (MARAD) Reserve program, and started their relationship with NPS through the Littoral Operations Center (LOC) to support the several iterations of the maritime security curriculum. As the campus liaison for the SSO reservists is also a member of the CRUSER leadership team, the SSO reservists have also been employed to support CRUSER and JIFX activities as they complete their annual duty training (ADT) at NPS. With a merchant mariner perspective, and many with recent operational experience, these reservists are quite valuable assets.

In FY17 two members of the SSO reserve community eight ONR reservists supported CRUSER programs.

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III. CONCLUSION

FY17 was the final year of CRUSER's initial mandate of operation. However, thanks to all those who have contributed to program success CRUSER has been granted another five years by (Acting) Secretary of the Navy Sean Stackley in a memorandum signed in March 2017.

A. PROPOSED FY18 ACTIVITIES

In FY18, the sixth CRUSER Innovation Thread will close out, work along the seventh thread will continue, and work will begin on the eighth thread. Proposed FY18 activities, in addition to continuing the previously described FY17 activities, will focus on three things:

1) Providing increased support to DASN Unmanned and other secretariat level activities related to robotics and autonomous systems.

2) Creating a vehicle for peer reviewed scholarly and professional information exchange for the CRUSER COI.

3) Supporting MTX activities to include at least one experiment that incorporates participation by operational forces.

B. LONG TERM PLANS

In FY18 CRUSER will continue to support research and development with an emphasis on seeding new concepts, to include those developed in the annual concept generation workshops. As a program, CRUSER expects to remain at full functioning strength for at least the next five years, and will continue to seek opportunities to connect communities and align disparate efforts developing robotics and autonomous systems across stakeholder groups. If CRUSER executes as planned a benchmark of success will be that at the end of FY22 the program will no longer be necessary, as the naval enterprise will have fully embraced robotic and autonomous systems. Until then CRUSER will continue to support the development of robotics and autonomy across the greater Naval enterprise, the DoD, and all global partners.

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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 FY17 report:

Decker, R., and Yakimenko, O. (2017). "On the Development of an Image-Matching Navigation Algorithm for Aerial Vehicles," *Proceedings of the IEEE Aerospace Conference*, Big Sky, MT, March 4-11, 2017.

Duan, W., B. E. Ankenman, S. M. Sanchez, and P. J. Sanchez (2017). "Sliced full factorial-based Latin hypercube designs as a framework for a batch sequential design algorithm." *Technometrics*, 59(1), 11-22.

Erickson, C., B.E. Ankenman, and S.M. Sanchez (2017), (2017), "Comparison of Gaussian process modeling software," *European Journal of Operational Research*, forthcoming.

Erickson, C., B.E. Ankenman, and S.M. Sanchez (2016), "Comparison of Gaussian process modeling software," *Proceedings of the 2016 Winter Simulation Conference* (extended abstract for poster session), 3692-3693.

Ghosh, S., Davis, D.T., Chung, T.H., and Yakimenko, O.A. (2017). "Development and Testing of the Intercept Primitives for Planar UAV Engagement," *Proceedings of the International Conference on Unmanned Aircraft Systems (ICUAS'17)*, Miami, FL, June 13-16, 2017.

Ghosh, S., Yakimenko, O.A., Davis, D.T., and Chung, T.H. (2017). "Unmanned Aerial Vehicle Guidance for an All-Aspect Approach to a Stationary Point," *AIAA Journal of Guidance, Control, and Dynamics*, vol.34 no.4, 2017, pp. 1239-1252. DOI: 10.2514/1.G002614.

Kaminer, I. and A. Pascoal, E. Xargay, N. Hovakimyan, V. Cichella, V. Dobrokhodov (2017). "Time-Critical Cooperative Control of Autonomous Air Vehicles," *Elsevier*, 2017

Kang, W., Yakimenko, O., and Wilcox, L. (2017). "Optimal Control of UAVs Using the Sparse Grid Characteristic Method," *Proceedings of the 3rd IEEE International Conference on Control, Automation*, *Robotics*, Nagoya, Japan, April 22-24, 2017, pp.771–776. DOI: 10.1109/ICCAR.2017.7942802.

Kragelund, Sean, Claire Walton, and Isaac Kaminer (2017). "Sensor-based motion planning for autonomous vehicle teams." *OCEANS 2016 MTS/IEEE* Monterey. IEEE, 2016.

Kragelund, Sean (2017). "Generalized Optimal Control for Networked Autonomous Vehicles in Uncertain Domains." *CRUSER TechCon 2017*. https://calhoun.nps.edu/handle/10945/53373.

Kragelund, Sean P. (2017). Optimal sensor-based motion planning for autonomous vehicle teams. *NPS PhD thesis*, Monterey, California: Naval Postgraduate School, March 2017.

Li, J., Ye, D.H., Chung, T., Kolsch, M., Wachs, J., and Bouman, C. (2017). "Multi-Target Detection and Tracking from a Single Camera in Unmanned Aerial Vehicles (UAVs)," *Proceedings of the 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Daejeon, Korea, October 9-14, 2016 and references therein.

Moore, J., and Yakimenko, O. (2017). "SimPADS: A Domain Specific Modeling Framework for Model-Based PADS DT&E," *Proceedings of the 24th AIAA Aerodynamic Decelerator Systems Technology Conference*, 2017 AIAA Aviation and Aeronautics Forum and Exposition, Denver, CO, June 5-9, 2017.

Sanchez, S. M. (2017), "Data farming: reaping insights from simulation models," *Chance*, invited contribution to a special issue on statistics in defense and national security (guest editors: A. G. Wilson and D. Banks), forthcoming.

Sanchez, S. M. and P. J. Sanchez (2017). "Better big data via data farming experiments," Chapter 9 in *Advances in Modeling and Simulation -- Seminal Research from 50 Years of Winter Simulation Conferences*, eds. A. Tolk, J. Fowler, G. Shao, and E. Yucesan. Springer, pp. 159-179.

See, H.A., Ghosh, S., and Yakimenko, O. (2017). "Towards the Development of an Autonomous Interdiction Capability for Unmanned Aerial Systems," *Proceedings of the International Conference on Unmanned Aircraft Systems (ICUAS'17)*, Miami, FL, June 13-16, 2017. DOI: 10.1109/ICUAS.2017.7991478

Thulasiraman, Preetha (2017). "Thread Driven Approach to Cybersecurity of ROS in Small UAV Networks," *IEEE UEMCON*, October 2017.

Walton, Claire, Sean Kragelund, and Isaac Kaminer (2017). "The application of 'optimal search' to marine mapping." *OCEANS 2016 MTS/IEEE* Monterey. IEEE, 2016.

Walton, Claire (2017). "Generalized Optimal Control: Motion Planning for Autonomous Vehicle Teams in Uncertain Environments." *July 2017 CRUSER Monthly Meeting*.

Walton, Claire, Sean Kragelund, and Isaac Kaminer (2017). "Issues in Multi-Agent Search: False Positives and Bayesian Map Updates." *OCEANS 2017 MTS/IEEE* Aberdeen. IEEE, 2017.

Walton, Claire, and Isaac Kaminer, Vladimir Dobrokhodov, Kevin D. Jones (2017). "New Insights into Autonomous Soaring." *56th IEEE Conference on Decision and Control*, 2017, accepted for publication

Wong C.M.K., and Yakimenko, O. (2017). "Rocket Launch Detection and Tracking using EO Sensor," *Proceedings of the 3rd IEEE International Conference on Control, Automation, Robotics*, Nagoya, Japan, April 22-24, 2017, pp.766–770. DOI: 10.1109/ICCAR.2017.7942801.

Included in FY16 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/

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.

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.

Boucher, R., W. Kang and Q. Gong (2016). “Galerkin Optimal Control” *Journal of Optimization Theory and Applications*, online DOI 10.1007/s10957-016-0918-x, 21 March 2016. Vol. 169, No. 3, pp 825 – 847.

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.

Day, Michael A. 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.

Dobrokhodov, V. and K. Jones, C. Dillard, I. Kaminer (2016). "AquaQuad - Solar Powered, Long Endurance, Hybrid Mobil Vehicle for Persistent Surface and Underwater Reconnaissance, Part II - Onboard Intelligence," for *OCEANS 2016 MTS/IEEE* Monterey, 2016, Sep. 2016

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.

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*.

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.

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.

Giammarco, K., Spencer Hunt, Clifford A. Whitcomb (2015). "An instructional design reference mission for search and rescue operations." *NPS Technical Report* (NPS-SE-15-002). Monterey, CA, September 2015.

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.

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.

Guest, P. S., O. Persson, B. Blomquist, C. Fairall (2016). "Quantifying the impact of background atmospheric stability on air-ice-ocean interactions in the Arctic Ocean during fall freeze-up" a poster presented at the *AGU Ocean Sciences Conference*, New Orleans, LA, February 21-26, 2016.

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

Jones, K. and V. Dobrokhodov (2016). "Hybrid Mobile Buoy for Persistent Surface and Underwater Exploration," *U.S. Patent 9,321,529* filed April 7th, 2014, and issued April 8th, 2016.

Jones, K. and V. Dobrokhodov (2016). “Multirotor Mobile Buoy for Persistent Surface and Underwater Exploration,” *U.S. Patent 9,457,900 B1* filed March 18th, 2016, and issued October 4th, 2016.

Jones, K. and V. Dobrokhodov, C. Dillard (2016). “Aqua-Quad - Solar Powered, Long Endurance, Hybrid Mobile Vehicle for Persistent Surface and Underwater Reconnaissance, Part I - Platform Design” proceedings of *2016 MTS/IEEE OCEANS’16*, Monterey, CA September 2016.

Jones, K. and V. Dobrokhodov, C. Dillard, I. Kaminer (2016). “Aqua-Quad - Solar Powered, Long Endurance, Hybrid Mobile Vehicle for Persistent Surface and Underwater Reconnaissance, Part II – Onboard Intelligence” proceedings of *2016 MTS/IEEE OCEANS’16*, Monterey, CA September 2016.

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

Kang, Wei and Lucas Wilcox (2015). An Example of Solving HJB Equations Using Sparse Grid for Feedback Control, *Proceedings of IEEE Conference on Decision and Control*, Osaka, Japan, December 15-18, 2015.

Kang, Wei (2015). Mitigating the Curse of Dimensionality: Sparse Grid Characteristics Method for Optimal Feedback Control and HJB Equations, arXiv:1507.04769v2, Nov. 16, 2015.

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

Kline, J. (2016). "Impacts of the Robotics Age on Naval Force Structure Planning," *Naval War College EMC Chair Symposium on Maritime Strategy* presentation and working paper, 23 March 2016.

Kolsch, M., J. Li, Dong Hye Ye, T.H. Chung, J. Wachs, C. Bouman (2016). "Multi-Target Detection and Tracking from a Single Camera in Unmanned Aerial Vehicles (UAVs)" presented at *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 9-14 October 2016, Daejeon, Korea

Kragelund, S., C. Walton, I. Kaminer, "Sensor-based motion planning for autonomous vehicle teams," in Oceans - Monterey, 2016, Sep. 2016. *Paper presented at OCEANS 2016 MTS/IEEE Monterey on September 21, 2016 and scheduled for publication in ISBN 978-1-5090-1527-6 (IEEE Catalog Number CFP16OCE-POD)*

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

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.*

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.

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

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.

Thomson, J., P. S. Guest (et al) (2016). “Emerging trends in the seas state of the Beaufort and Chukchi seas” *Ocean Modelling*, V 105, September 2016.

Thompson, R.B. and P. Thulasiraman (2016). “Confidential and Authenticated Communications in a Large Fixed-Wing UAV Swarm,” in Proc. of *IEEE 15th International Symposium on Network Computing and Applications*, pp. 375-382, November 2016.

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*

Vio, R. P. and R. Cristi, K. B. Smith (2016). "Near real-time improved UUV positioning through channel estimation – The Unscented Kalman Filter Approach" for *OCEANS 2016 MTS/IEEE* Monterey CA September 2016.

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)

Walton, C. and C. Phelps, Qi Gong, I. Kaminer (2016). "A Numerical Algorithm for OptimalControl of Systems with Parameter Uncertainty, *10th IFAC NOLCOS Conference*, Monterey, August 2016

Walton, C. and S. Kragelund, I. Kaminer (2016). The Application of 'Optimal Search' to Marine Mapping," for *OCEANS 2016 MTS/IEEE* Monterey, 2016, Sep. 2016

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.

Yakimenko, O. (2016). “UAVs and How They Work Together with Satellite Systems” presentation for *Singapore Space Challenge* 2016, 24 June 2016.

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/

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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).

AUTHOR(s)	TITLE	DATE	URL
LT Robert L. Allen III, USN	*Quadrotor Intercept Trajectory Planning and Simulation*	2017-JUN	http://hdl.handle.net/10945/55627
Captain Wee Kiong Ang, Singapore Army	*Assessment of an Onboard EO Sensor to Enable Detect-and-Sense Capability for UAVs Operating in a Cluttered Environment*	2017-SEP	http://hdl.handle.net/10945/56165
LCDR Christopher M. Bade, USN	*Study of Integrated USV/UUV Observation System Performance In Monterey Bay*	2017-SEP	http://hdl.handle.net/10945/56176
LT Ryan G. Beall, USN	*Engineering of Fast and Robust Adaptive Control for Fixed-Wing Unmanned Aircraft*	2017-JUN	http://hdl.handle.net/10945/55563
Capt Carl P. Beierl, USMC and Capt Devon R. Tschirley, USMC	*Unmanned Tactical Autonomous Control and Collaboration Situation Awareness*	2017-JUN	http://hdl.handle.net/10945/55568
LT Connor F. Bench, USN	*GPS Enabled Semi-Autonomous Robot*	2017-SEP	http://hdl.handle.net/10945/56103
LT Kristjan J. Casola, USN	*System Architecture and Operational Analysis of Medium Displacement Unmanned Surface Vehicle Sea Hunter as a Surface Warfare Component of Distributed Lethality*	2017-JUN	http://hdl.handle.net/10945/55579
Capt Elle M. Ekman, USMC	*Simulating Sustainment for an Unmanned Logistics System Concept of Operation in Support of Distributed Operations*	2017-JUN	http://hdl.handle.net/10945/55593
LT Stephen M. Fleet, USN	*Effects of Mixed Layer Shear on Vertical Heat Flux*	2016-DEC	http://hdl.handle.net/10945/51696
ENS Rebecca A. Greenberg, USN	*Investigating the Feasibility of Conducting Human Tracking and Following in an Indoor Environment Using a Microsoft Kinect and the Robot Operating System*	2017-JUN	http://hdl.handle.net/10945/55606
Keng Siew Aloysius Han	*Test and Evaluation of an Image-Matching Navigation System for a UAS Operating in a GPS-Denied Environment*	2017-SEP	http://hdl.handle.net/10945/56131
LTjg Pedro R. Hayden, Peruvian Navy	*Unmanned Systems: A Lab-Based Robotic Arm for Grasping Phase II*	2016-DEC	http://hdl.handle.net/10945/51716

LT Chaz R. Henderson, USN	*Feasibility of Tactical Air Delivery Resupply Using Gliders*	2016-DEC	http://hdl.handle.net/10945/51717
LT Joshua B. Hicks, USN and LT Ryan L. Seeba, USN	*Effectiveness of a Littoral Combat Ship as a Major Node in a Wireless Mesh Network*	2017-MAR	http://hdl.handle.net/10945/52990
LT Jo-Wen Huang, Taiwan Navy	*Implementation of a Multi-Robot Coverage Algorithm on a Two-Dimensional, Grid-Based Environment*	2017-JUN	http://hdl.handle.net/10945/55624
LT Bradley A. Johnson, USN	*Using A Functional Architecture to Identify Human-Automation Trust Needs and Design Requirements*	2016-DEC	http://hdl.handle.net/10945/51726
LCDR Jake A. Jones, USN	*A New Technique for Robot Vision in Autonomous Underwater Vehicles Using the Color Shift in Underwater Imaging*	2017-JUN	http://hdl.handle.net/10945/55631
Lieutenant Commander Akhtar Zaman Khan, Pakistan Navy	*Convoy Protection under Multi-Threat Scenario*	2017-JUN	http://hdl.handle.net/10945/55566
Wei Sheng Jeremy Kang, Singapore Army	*An Engineered Resupply System for Humanitarian Assistance and Disaster Relief Operations*	2017-SEP	http://hdl.handle.net/10945/56144
Captain Sangbum Kim, Republic of Korea	*Feasibility Analysis Of UAV Technology to Improve Tactical Surveillance in South Korea's Rear Area Operations*	2017-MAR	http://hdl.handle.net/10945/53001
Maj Thomas D. Kline, USMC	*Proof of Concept in Disrupted Tactical Networking*	2017-SEP	http://hdl.handle.net/10945/56147
Mr. Sean Kragelund	*Optimal Sensor-Based Motion Planning for Autonomous Vehicle Teams (Ph.D. Dissertation)*	2017-MAR	http://hdl.handle.net/10945/53003
Maj Thomas A. Kulisz, USMC and Capt Robert E. Sharp, USMC	*Unmanned Tactical Autonomous Control and Collaboration (UTACC) Human-Machine Integration Measures of Performance and Measures of Effectiveness*	2017-JUN	http://hdl.handle.net/10945/55637
LT Matthew D. Lai, USN	*Application of Thin Film Photovoltaic Cigs Cells to Extend the Endurance of Small Unmanned Aerial Systems*	2017-JUN	http://hdl.handle.net/10945/55639
Wee Leong Lai, Singapore	*Applicability of Deep-Learning Technology for Relative Object-Based Navigation*	2017-SEP	http://hdl.handle.net/10945/56149
Lieutenant Antonios Lionis, Hellenic Navy	*Experimental Design of a UCAV-Based High-Energy Laser Weapon*	2016-DEC	http://hdl.handle.net/10945/51574
LCDR Nicholas A. Manzini, USN	*USV Path Planning Using Potential Field Model*	2017-SEP	http://hdl.handle.net/10945/56152
ENS Tyler B. McCarthy, USN	*Feasibility Study of a Vision-Based Landing System for Unmanned Fixed-Wing Aircraft*	2017-JUN	http://hdl.handle.net/10945/55652
Mkuseli Mqana, Armament Corporation of South Africa	*Terminal Homing Position Estimation for Autonomous Underwater Vehicle Docking*	2017-JUN	http://hdl.handle.net/10945/55655

Lieutenant Commander Renato Peres Vo, Brazilian Navy	*Improved UUV Positioning Using Acoustic Communications and a Potential for Real-Time Networking and Collaboration*	2017-JUN	http://hdl.handle.net/10945/55517
Lieutenant Colonel Silvio Pueschel, German Army	*Optimization of Advanced Multi-Junction Solar Cell Design for Space Environments Using Nearly Orthogonal Latin Hypercubes*	2017-JUN	http://hdl.handle.net/10945/55521
Hongze Alex See, Singapore	*Coordinated Guidance Strategy for Multiple USVs during Maritime Interdiction Operations*	2017-SEP	http://hdl.handle.net/10945/56175
Capt James Garrick Sheatzley, USMC	*Discrete Event Simulation for the Analysis of Artillery Fired Projectiles from Shore*	2017-JUN	http://hdl.handle.net/10945/55536
Solem, K.	*Quantifying the Potential Benefits of Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessels (ACTUV) in a Tactical ASW Scenario (Restricted)*	2017-MAR	restricted
Choon Seng Leon Mark Tan, Singapore	*Mission Planning for Heterogeneous UXVs Operating in a Post-Disaster Urban Environment*	2017-SEP	http://hdl.handle.net/10945/56182
Major Bruno G. F. Tavora, Brazilian Air Force	*Feasibility Study of an Aerial Manipulator Interacting with a Vertical Wall*	2017-JUN	http://hdl.handle.net/10945/55545
LT Ian Taylor, USN	*Variable Speed Hydrodynamic Model of an AUV Utilizing Cross Tunnel Thrusters*	2017-SEP	http://hdl.handle.net/10945/56183
LT Joseph B. Testa III, USN	*Vision-Based Position Estimation Utilizing an Extended Kalman Filter*	2016-DEC	http://hdl.handle.net/10945/51625
LCDR Richard B. Thompson, USN	*Confidential and Authenticated Communications in a Large Fixed-Wing UAV Swarm*	2016-DEC	http://hdl.handle.net/10945/51626
Ying Jie Benjemin Toh, Singapore	*Development of a Vision-Based Situational Awareness Capability for Unmanned Surface Vessels*	2017-SEP	http://hdl.handle.net/10945/56185
LT Marcus A. Torres, USN	*Feasibility Analysis and Prototyping of a Fast Autonomous Recon System*	2017-JUN	http://hdl.handle.net/10945/55547
Capt Michael D. Wilcox, USMC and Capt Cody D. Chenoweth, USMC	*Unmanned Tactical Autonomous Control and Collaboration (UTAC) Immediate Actions*	2017-JUN	http://hdl.handle.net/10945/55554
Team SBD Systems Engineering	*Implementing Set Based Design into Department of Defense Acquisition*	2016-DEC	http://hdl.handle.net/10945/51668
Sean X. Hong	*Phased array excitations for efficient near field wireless power transmission*	2016-09	http://hdl.handle.net/10945/50561
LT David Armandt USN	*Controlling robotic swarm behavior utilizing real-time kinematics and artificial physics*	2016-06	http://hdl.handle.net/10945/49465
ENS Eric B. Bermudez USN	*Terminal homing for autonomous underwater vehicle docking*	2016-06	http://hdl.handle.net/10945/49385

Capt. Jerry V. Drew II USA	*Evolved design, integration, and test of a modular, multi-link, spacecraft-based robotic manipulator*	2016-06	http://hdl.handle.net/10945/49446
LTJG Alejandro Garcia Aguilar Mexican Navy	*CFD analysis of the SBXC Glider airframe*	2016-06	http://hdl.handle.net/10945/49466
CMDR Andrew B. Hall USN	*Conceptual and preliminary design of a low-cost precision aerial delivery system*	2016-06	http://hdl.handle.net/10945/49478
LTJG Serif Kaya Turkish Navy	*Evaluating effectiveness of a frigate in an anti-air warfare (AAW) environment*	2016-06	http://hdl.handle.net/10945/49504
SEA 23 Cohort	*Unmanned systems in integrating cross-domain naval fires*	2016-06	http://hdl.handle.net/10945/49381
Capt. Matthew S. Zach USMC	*Unmanned tactical autonomous control and collaboration coactive design*	2016-06	http://hdl.handle.net/10945/49417
LCDR Jose R. Espinosa Gloria Mexican Navy	*Runway detection from map, video and aircraft navigational data*	2016-03	http://hdl.handle.net/10945/48516
LT Matthew S. Maupin USN	*Fighting the network: MANET management in support of littoral operations*	2016-03	http://hdl.handle.net/10945/48561
LCDR Brian M. Roth USN and LCDR Jade L. Buckler USN	*Unmanned Tactical Autonomous Control and Collaboration (UTACC) unmanned aerial vehicle analysis of alternatives*	2016-03	http://hdl.handle.net/10945/48586
LT Manuel Ariza Colombian Navy	*The design and implementation of a prototype surf-zone robot for waterborne operations*	2015-12	http://hdl.handle.net/10945/47847
LT Loney R. Cason III USN	*Continuous acoustic sensing with an unmanned aerial vehicle system for anti-submarine warfare in a high-threat area*	2015-12	http://hdl.handle.net/10945/47918
LT Ross A. Eldred USN	*Autonomous underwater vehicle architecture synthesis for shipwreck interior exploration*	2015-12	http://hdl.handle.net/10945/47940
LT Robert T. Fauci III USN	*Power management system design for solar-powered UAS*	2015-12	http://hdl.handle.net/10945/47942
LCDR Oscar García Chilean Navy	*Sensors and algorithms for an unmanned surf-zone robot*	2015-12	http://hdl.handle.net/10945/47949
SE Team Mental Focus	*A decision support system for evaluating systems of undersea sensors and weapons*	2015-12	http://hdl.handle.net/10945/47868
SE Team Mine Warfare 2015	*Scenario-based systems engineering application to mine warfare*	2015-12	http://hdl.handle.net/10945/47865
SE Team TECHMAN	*Systems engineering of unmanned DoD systems: following the Joint Capabilities Integration and Development System/Defense Acquisition System process to develop an unmanned ground vehicle system*	2015-12	http://hdl.handle.net/10945/47867

Capt. 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	http://hdl.handle.net/10945/47276
LT Spencer S. Hunt, USN	*Model based systems engineering in the execution of search and rescue operations.*	2015-09	http://hdl.handle.net/10945/47277
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	http://hdl.handle.net/10945/47334
Maj Thomas M. Rice, USMC, Maj Erik A. Keim, USMC and Maj Tom Chhabra, USMC	*Unmanned Tactical Autonomous Control and Collaboration Concept of Operations*	2015-09	http://hdl.handle.net/10945/47319
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 and 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)*	2014-12	http://hdl.handle.net/10945/44659

	missions		
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
LtCol Robert B. Davis, USMC	*Applying Cooperative Localization to Swarm UAVs using an Extended Kalman Filter*	2014-09	http://hdl.handle.net/10945/43900
Joong Yang Lee, Republic of Singapore Air Force	*Expanded Kill Chain Analysis of Manned-Unmanned Teaming for Future Strike Operations*	2014-09	http://hdl.handle.net/10945/43944
Chee Siong Ong, Singapore Defence Science and Technology Agency	*Logistics Supply of the Distributed Air Wing*	2014-09	http://hdl.handle.net/10945/43969
LT Nicole Ramos, USN	*Assessment of Vision-Based Target Detection and Classification Solutions Using an Indoor Aerial Robot*	2014-09	http://hdl.handle.net/10945/43984
JooEon Shim	*Optimal Estimation of Glider's Underwater Trajectory with Depth-dependent Correction using the Regional Navy Coastal Ocean Model with Application to ASW*	2014-09	http://hdl.handle.net/10945/44002

LT Vance Villarreal, USN	*Relationship between the sonic layer depth and mixed layer depth identified from underwater glider with application to ASW*	2014-09	
LT Blake Wanier, USN	*] A Modular Simulation Framework for Assessing Swarm Search Models*	2014-09	
Systems Engineering Analysis Cross-Campus Study (SEA 20B)	*The distributed air wing*	FY14	http://hdl.handle.net/10945/42717
LT Timothy L. Bell, USN	*Sea-Shore interface robotic design*	FY14	http://hdl.handle.net/10945/42580
LCDR Anthony A. Bumatay, USN; LT Grant Graeber, USN	*Achieving information superiority using hastily formed networks and emerging technologies for the Royal Thai Armed Forces counterinsurgency operations in Southern Thailand*	FY14	http://hdl.handle.net/10945/41353
CWO4 Carlos S. Cabello, USA	*Droning on: American strategic myopia toward unmanned aerial systems*	FY14	http://hdl.handle.net/10945/38890
ENS Taylor K. Calibo, USN	*Obstacle detection and avoidance on a mobile robotic platform using active depth sensing*	FY14	http://hdl.handle.net/10945/42591
LT Nahum Camacho, Mexican Navy	*Improving operational effectiveness of Tactical Long Endurance Unmanned Aerial Systems (TALEUAS) by utilizing solar power*	FY14	http://hdl.handle.net/10945/42593
Capt Seamus B. Carey, USMC	*Increasing the endurance and payload capacity of unmanned aerial vehicles with thin-film photovoltaics*	FY14	http://hdl.handle.net/10945/42594
LCDR James M. Cena, USN	*Power transfer efficiency of mutually coupled coils in an aluminum AUV hull*	FY14	http://hdl.handle.net/10945/38895
LCDR David W. Damron, USN	*Tropical cyclone reconnaissance with the Global Hawk: operational thresholds and characteristics of convective systems over the tropical Western North Pacific*	FY14	http://hdl.handle.net/10945/38913
LCDR Randall E. Everly, USN; LT David C. Limmer, USN	*Cost-effectiveness analysis of aerial platforms and suitable communication payloads*	FY14	http://hdl.handle.net/10945/41375
LT Jessica L. Fitzgerald, USN	*Characterization parameters for a three degree of freedom mobile robot*	FY14	http://hdl.handle.net/10945/38929
LT James R. Fritz, USN	*Computer-aided detection of rapid, overt, airborne, reconnaissance data with the capability of removing oceanic noises*	FY14	http://hdl.handle.net/10945/38932
Douglas Horner, NPS	*A data-driven framework for rapid modeling of wireless communication channels (PhD dissertation)*	FY14	http://hdl.handle.net/10945/38947
Maj Courtney David Jones, USMC	*An analysis of the defense acquisition strategy for unmanned systems*	FY14	http://hdl.handle.net/10945/41400

ENS Jacob T. Juriga, USN	*Terrain aided navigation for REMUS autonomous underwater vehicle*	FY14	http://hdl.handle.net/10945/42654
LT Timothy D. Kubisak, USN	*Investigation of acoustic vector sensor data processing in the presence of highly variable bathymetry*	FY14	http://hdl.handle.net/10945/42664
Donald R. Lowe, DON (Civ); Holly B. Story, DOA (Civ); Matthew B. Parsons, DOA (Civ)	*U.S. Army Unmanned Aircraft Systems (UAS) - a historical perspective to identifying and understanding stakeholder relationships*	FY14	http://hdl.handle.net/10945/42678
LCDR Sotirios Margonis, Hellenic Navy	*Preliminary design of an autonomous underwater vehicle using multi-objective optimization*	FY14	http://hdl.handle.net/10945/41415
Jeanie Moore, FEMA Office of External Affairs	*Da Vinci's children take flight: unmanned aircraft systems in the homeland*	FY14	http://hdl.handle.net/10945/41420
MAJ Scott A. Patton, USA	*A comparison of tactical leader decision making between automated and live counterparts in a virtual environment*	FY14	http://hdl.handle.net/10945/42705
LT Brett Robblee, USN	*High Energy Laser Employment in Self Defense Tactics on Naval Platforms [RESTRICTED]*	FY14	restricted
First LT Volkan Sözen, Turkish Army	*Optimal deployment of unmanned aerial vehicles for border surveillance*	FY14	http://hdl.handle.net/10945/42729
LCDR Barcley W. Stamey, USN	*Domestic aerial surveillance and homeland security: should Americans fear the eye in the sky?*	FY14	http://hdl.handle.net/10945/41446
LT Sian E. Stimpert, USN	*Lightening the load of a USMC Rifle Platoon through robotics integration*	FY14	http://hdl.handle.net/10945/42733
Christopher Ironhill, Bryan Otis, Frederick Lancaster, Angel Perez, Diana Ly, and Nam Tran	*Small Tactical Unmanned Aerial System (STUAS) Rapid Integration and fielding process (RAIN)*	FY13 SEP	http://hdl.handle.net/10945/37705
Junwei Choon, Singapore Technologies Aerospace	*Development and validation of a controlled virtual environment for guidance, navigation and control of quadrotor UAV*	FY13 SEP	http://hdl.handle.net/10945/37600
Judson J. Dengler, U.S. Secret Service	*An examination of the collateral psychological and political damage of drone warfare in the FATA region of Pakistan*	FY13 SEP	http://hdl.handle.net/10945/37611
LCDR Georgios Dimitriou, Hellenic Navy	*Integrating Unmanned Aerial Vehicles into surveillance systems in complex maritime environments*	FY13 SEP	http://hdl.handle.net/10945/37613
LT John P. Harrop, USN	*Improving the Army's joint platform allocation tool (JPAT)*	FY13 SEP	http://hdl.handle.net/10945/37635
Captain Joel M. Justice, Los Angeles Police Department	*Active shooters: is law enforcement ready for a Mumbai style attack?*	FY13 SEP	http://hdl.handle.net/10945/37645

Captain Zhifeng Lim, Singapore Armed Forces	*The rise of robots and the implications for military organizations*	FY13 SEP	http://hdl.handle.net/10945/37662
Lieutenant Junior Grade Yavuz Sagir, Turkish Navy	*Dynamic bandwidth provisioning using Markov chain based on RSVP*	FY13 SEP	http://hdl.handle.net/10945/37708
Mariela I. Santiago, NUWC Newport	*Systems engineering and project management for product development: optimizing their working interfaces*	FY13 SEP	http://hdl.handle.net/10945/37709
LCDR Zachariah H. Stiles, USN	*Dynamic towed array models and state estimation for underwater target tracking*	FY13	http://hdl.handle.net/10945/37725
LT Andrew T. Streenan, USN	*Diver relative UUV navigation for joint human-robot operations*	FY13	http://hdl.handle.net/10945/37726
Harn Chin Teo, ST Aerospace Ltd.	*Closing the gap between research and field applications for multi-UAV cooperative missions*	FY13 SEP	http://hdl.handle.net/10945/37730
MAJ James C. Teters,II, USA	*Enhancing entity level knowledge representation and environmental sensing in COMBATXXI using unmanned aircraft systems*	FY13 SEP	http://hdl.handle.net/10945/37732
LT Joshua D. Weiss, USN	*Real-time dynamic model learning and adaptation for underwater vehicles*	FY13 SEP	http://hdl.handle.net/10945/37741
Systems Engineering Analysis Cross-Campus Study (SEA 19A)	*2024 Unmanned undersea warfare concept*	FY13	http://hdl.handle.net/10945/34733
LT Timothy M. Beach, USN	*Mobility modeling and estimation for delay tolerant unmanned ground vehicle networks*	FY13	http://hdl.handle.net/10945/34624
First Lieutenant Begum Y. Ozcan, Turkish Air Force	*Effectiveness of Unmanned Aerial Vehicles in helping secure a border characterized by rough terrain and active terrorists*	FY13	http://hdl.handle.net/10945/34717
Boon Heng Chua, Defence Science and Technology Agency, Singapore	*Integration Of Multiple Unmanned Systems In An Urban Search And Rescue Environment*	FY13	http://hdl.handle.net/10945/32805
LT Mary Doty	*Analysis of Ocean Variability in the South China Sea for Naval Operations*	FY13	
LT James Fritz	*Computer Aided Mine Detection Algorithm for Tactical Unmanned Aerial Vehicle (TUAV)*	FY13	
Captain Uwe Gaertner, German Army	*UAV swarm tactics: an agent-based simulation and Markov process analysis*	FY13	http://hdl.handle.net/10945/34665
Capt Christopher R. Gromadski, USMC	*Extending the endurance of small unmanned aerial vehicles using advanced flexible solar cells*	FY13	http://hdl.handle.net/10945/27836
LT Andrew Hendricksen, USN	*The Optimal Employment and Defense of a Deep Seaweb Acoustic Network for Submarine Communications at Speed And Depth using a Defender-Attacker-*	FY13	

	Defender Model		
LT Kyungnho Kim, USN	*Integrating Coordinated Path Following Algorithms To Mitigate The Loss Of Communication Among Multiple UAVs*	FY13	http://hdl.handle.net/10945/32848
LCDR Paul Kutia	*Intelligence fused Oceanography for ASW using Unmanned Underwater Vehicles (UUV)[SECRET]*	FY13	
LCDR Andrew R. Lucas, USN *(thesis award winner)*	*Digital Semaphore: technical feasibility of QR code optical signaling for fleet communications*	FY13	http://hdl.handle.net/10945/34699
LCDR Eric L. McMullen, USN and MAJ Brian Shane Grass, U.S. Army	*Effects Of UAV Supervisory Control On F-18 Formation Flight Performance In A Simulator Environment*	FY13	http://hdl.handle.net/10945/32870
LT Thai Phung	*Analysis of Bioluminescence and Optical Variability in the Arabian Gulf and Gulf of Oman for Naval Operations[Restricted]*	FY13	
LT Stephen P. Richter, USN *(thesis award winner)*	*Digital semaphore: tactical implications of QR code optical signaling for fleet communications*	FY13	http://hdl.handle.net/10945/34727
LT Marta Savage, USN	*Design and hardware-in-the-loop implementation of optimal canonical maneuvers for an autonomous planetary aerial vehicle*	FY13	http://hdl.handle.net/10945/27898
Robert N. Severinghaus	*Improving UXS network availability with asymmetric polarized mimo*	FY13	http://calhoun.nps.edu/public/handle/10945/34740
LT Eric Shuey, USN and LT Mika Shuey, USN	*Modeling and simulation for a surf zone robot*	FY13	http://hdl.handle.net/10945/27905
LT Timothy S. Stevens, USN	*Analysis of Nondeterministic Search Patterns for Minimization of UAV Counter-Targeting*	FY13	http://hdl.handle.net/10945/32905
Maj Matthew T. Taranto, USAF	*A human factors analysis of USAF remotely piloted aircraft mishaps*	FY13	http://hdl.handle.net/10945/34751
LT James B. Zorn, USCG	*A systems engineering analysis of unmanned maritime systems for U.S. Coast Guard missions*	FY13	http://hdl.handle.net/10945/34766
Systems Engineering Analysis Cross-Campus Study (SEA 18B)	*Tailorable Remote Unmanned Combat Craft (TRUCC)*	FY12	http://hdl.handle.net/10945/15434
LT Brian Acton, USN and LT David Taylor, USN	*Autonomous Dirigible Airships: a Comparative Analysis and Operational Efficiency Evaluation for Logistical Use in Complex Environments*	FY12	http://hdl.handle.net/10945/7299

Maj Jerrod Adams, U.S. Army	*An Interpolation Approach to Optimal Trajectory Planning for Helicopter Unmanned Aerial Vehicles*	FY12	http://hdl.handle.net/10945/7300
Maj Mejdi Ben Ardhaoui, Tunisian Army	*Implementation of Autonomous Navigation And Mapping Using a Laser Line Scanner on a Tactical Unmanned Vehicle*	FY12	http://hdl.handle.net/10945/10728
Mr William P. Barker	*An Analysis of Undersea Glider Architectures and an Assessment of Undersea Glider Integration into Undersea Applications*	FY12	http://hdl.handle.net/10945/17320
ENS Joseph Beach, USN	*Integration of an Acoustic Modem onto a Wave Glider Unmanned Surface Vehicle*	FY12	http://hdl.handle.net/10945/7308
LCDR Chung Wei Chan, Republic of Singaporean Navy	*Investigation of Propagation in Foliage Using Simulation Techniques*	FY12	http://hdl.handle.net/10945/10577
LT Kristie M. Colpo, USN	*Joint Sensing/Sampling Optimization for Surface Drifting Mine Detection with High-Resolution Drift Model*	FY12	http://hdl.handle.net/10945/17345
Capt Martin Conrad, USAF	*Does China Need A "String Of Pearls"?*	FY12	http://hdl.handle.net/10945/17346
Maj Bart Darnell, USAF	*Unmanned Aircraft Systems: A Logical Choice For Homeland Security Support*	FY12	-
Mr. Michael Day	*Multi-Agent Task Negotiation Among UAVs*	FY12	-
Maj Thomas F. Dono, USMC	*Optimized Landing of Autonomous Unmanned Aerial Vehicle Swarms*	FY12	http://calhoun.nps.edu/public/bitstream/handle/10945/7331/?sequence=1
LT Thomas Futch, USN	*An Analysis of the Manpower Impact of Unmanned Aerial Vehicles (UAV's) on Subsurface Platforms*	FY12	http://hdl.handle.net/10945/6795
LCdr Pascal Gagnon, Canada	*Clock Synchronization through Time-Variant Underwater Acoustic Channels*	FY12	http://hdl.handle.net/10945/17368
Capt Riadh Hajri, Tunisian Air Force	*UAV to UAV Target Detection And Pose Estimation*	FY12	http://hdl.handle.net/10945/7351
CDR Kevin L. Heiss, USN	*A Cost-Benefit Analysis Of Fire Scout Vertical Takeoff And Landing Tactical, Unmanned, Aerial Vehicle (VTUAV) Operator Alternatives*	FY12	http://hdl.handle.net/10945/6806
CDR Chas Hewgley, USN	*Autonomous Parafoils: Toward a Moving Target Capability*	FY12	-
Captain Chung-Huan Huang, Taiwan (Republic of China) Army	*Design and Development of Wireless Power Transmission for Unmanned Air Vehicles*	FY12	http://hdl.handle.net/10945/17380
LT Michael A. Hurban, USN	*Adaptive Speed Controller for the Seafox Autonomous Surface Vessel*	FY12	http://hdl.handle.net/10945/6811
LT Levi C. Jones, USN	*Coordination and Control for Multi-Quadrotor UAV Missions*	FY12	http://hdl.handle.net/10945/6816

LT Serkan Kilitci, Turkish Navy and LT Muzaffer Buyruk, Turkish Army	*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*	FY12	http://hdl.handle.net/10945/10633
ENS Rebecca King, USN	*Underwater Acoustic Network As A Deployable Positioning System*	FY12	http://hdl.handle.net/10945/7368
Ramesh Kolar	*Business Case Analysis of Medium Altitude Global ISR Communications (MAGIC) UAV System*	FY12	http://hdl.handle.net/10945/7369
LT Colin G. Larkins, USN	*The EP-3E vs. the BAMS UAS An Operating and Support Cost Comparison*	FY12	http://hdl.handle.net/10945/17395
ENS Michael Martin, USN	*Global Versus Reactive Navigation for Joint UAV-UGV Missions in a Cluttered Environment*	FY12	http://hdl.handle.net/10945/7380
Maj Jose D. Menjivar, USMC	*Bridging Operational and Strategic Communication Architectures Integrating Small Unmanned Aircraft Systems as Airborne Tactical Communication Vertical Nodes*	FY12	http://hdl.handle.net/10945/17418
ENS Christopher Medford, USN	*The Aerodynamics of a Maneuvering UCAV 1303 Aircraft Model and its Control through Leading Edge Curvature Change*	FY12	http://hdl.handle.net/10945/17417
Maj Les Payton, USMC	*Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)*	FY12	http://hdl.handle.net/10945/10667
LT Timothy Rochholz	*Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks*	FY12	http://hdl.handle.net/10945/17448
LT Darren J. Rogers, USN	*GSM Network Employment on a Man-Portable UAS*	FY12	http://hdl.handle.net/10945/17449
LT Dylan Ross, USN and LT Jimmy Harmon, USN	*New Navy Fighting Machine in the South China Sea*	FY12	http://hdl.handle.net/10945/7408
LT Jason Staley, USN and Capt Troy Peterson, USMC	*Business Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF)*	FY12	
Mr Hui Fang Evelyn Tan, Republic of Singapore	*Application Of An Entropic Approach To Assessing Systems Integration*	FY12	http://hdl.handle.net/10945/6877
Systems Engineering Analysis Cross-Campus Study (SEA 17B)	*Advanced Undersea Warfare Systems*	FY11	http://hdl.handle.net/10945/6959
Capt Dino Cooper, USMC	*The Dispersal Of Taggant Agents With Unmanned Aircraft Systems (UAS) In Support Of Tagging, Tracking, Locating, And Identification (TTLI) Operations*	FY11	

LTJG Spyridon Dessalermos, Hellenic Navy (Greece)	*Adaptive Reception for Underwater Communications*	FY11	http://hdl.handle.net/10945/10756
LT Steve Halle, USN and LT Jason Hickle, USN	*The Design and Implementation of a Semi-Autonomous Surf-Zone Robot Using Advanced Sensors and a Common Robot Operating System*	FY11	http://hdl.handle.net/10945/5690
Major Christian Klaus, German Army	*Probabilistic Search on Optimized Graph Topologies*	FY11	http://hdl.handle.net/10945/5569
LT Matthew Larkin, USN	*Brave New Warfare Autonomy in Lethal UAVS*	FY11	http://hdl.handle.net/10945/5781
Lieutenant Mauricio M. Munoz, Chilean Navy	*Agent-based simulation and analysis of a defensive UAV swarm against an enemy UAV swarm*	FY11	http://hdl.handle.net/10945/5700
LT Matthew Pawlenko, USN	*Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV)*	FY11	http://hdl.handle.net/10945/5466
Maj Derek Snyder, USMC	*Design Requirements For Weaponizing Man-portable UAS In Support Of Counter-sniper Operations*	FY11	http://hdl.handle.net/10945/5543
LT Lance J Watkins, USN	*Self-propelled semi-submersibles the next great threat to regional security and stability*	FY11	http://hdl.handle.net/10945/5629

APPENDIX C: COMMUNITY

This is a representative listing of the CRUSER community of interest at the conclusion of FY17. It is not meant to be inclusive, but is included to demonstrate depth and breadth of interest.

ACADEMIA

AFIT
AFJROTC Jefferson High School
Airspeed Equity
Airware
Alakai Defense
Alaska Center for Unmanned Aircraft Systems Integration
Alaska Center for Unmanned Systems Integration
American University
APLUW
Applied Physics Laboratory
Argonne National Laboratory
Arizona State University
Auburn University
Australian Defence Force Academy
AUV IIT Bombay
AUVSI Foundation
Bangalore Robotics
Ben-Gurion University of the Negev
Berkley
C-UAS, BYU
Cal Poly SLO
California Polytechnic Institute
CalWestern School of Law
Carl Hayden High School
Carnegie Mellon University
Carnegie Mellon University Silicon Valley
Case Western Reserve U
Chapman University
Chosun University
Community College of Baltimore County
Cornell University AUV
CSULB
CSULB HHS
CSUMB
Daniel H. Wagner Associates
Doolittle Institute
Drexel
Embry-Riddle Aeronautical University
Embry-Riddle Aeronautical University/ERASU-Prescott
FEUP
FIRST
Florida Atlantic University
Florida Institute for Human Machine Cognition
Francis Parker School
French Air Force Academy
Georgia Institute of Technology
Georgia Tech
Georgia Tech Research Institute (GTRI)
Howard University
Imperial College London
Indian Institute of Science Education and Research-Thiruvananthapuram (IISER-TVM)
Indiana State University
Institute for Religion and Peace
Johns Hopkins University Applied Physics Lab
Kasetart University
Kennesaw State University
KSU
LSTS
Ludwig Maximilians Univeristat
Macquarie University
Marine Advanced Technology Education (MATE) Center
Maritime State University
MBARI
McGill University
Memorial University of Newfoundland
Mississippi State University
MIT
MIT Lincoln Laboratory
MPC
National Defense University
Naval Air Warfare Center
Naval War College
Netherlands Defence Academy/Eindhoven University of Technology /TNO/Delft University of Technology
New Mexico State University
NJIT
NM State
NMSU
North Carolina Central University
North Carolina State University
North Carolina State University (ITRE)
Northwestern

Northwestern Polytechmical University
Northwestern University
Notre Dame
NWC
OK State
Old Dominion University
Oregon Institute of Technology
OSU
PSU/APL
RPI
Saint Louis University
San Diego Christian College
San Diego City College
San Diego State Univ.
SDSU/Faster Logic LLC
Sinclair College
Southwestern College
SSAG
St. Georges College
St. Mary's University
Stanford
SUNY Stony Brook
Teach for America
Technion
Texas A & M Univ. - Corpus Christi
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
UCSF
UF
UFL
UK National Oceanography Cenre
University of Alabama
University of Alaska
University of Alaska, Fairbanks
University of Arizona
University at Buffalo
University of California Davis
University of California, Merced
University of Colorado - Boulder
University of Dayton Research Institute
University of Hawaii
University of Hawaii - Hilo
University of Idaho
University of Iowa
University of Maryland UAS Test Site
University of Memphis
University of Michigan
University of Minnesota - Twin Cities
University of Oklahoma
University of Maryland
University of New Brunswick
University of North Carolina at Charlotte
University of North Dakota
University of Notre Dame
University of Pittsburgh
University of Quebec in Montreal
University of South Carolina
University of South Florida
University of Texas
University of Texas at Arlington Research Institute (UTARI)
UNLV
Unmanned Vehicle Univ
US CG Aux
USC
USF
USRA
Utah State Space Dynamics Lab
Utah State University
UXV University
Virginia Tech
Wichita State University

State/Local/Fed Gov:
Aeronautics Research Directorate
Allied Command Transformation
Ames Research Center
AOPA (Aircraft Owners & Pilots Association
Argonne National Lab
Arl Co Police
Armstrong Flight Research Center
ASDRE
Bakersfield PD
Banning Police Dept
Business Oregon
CA Dept of Insurance Fraud
CA DMV Investigations
Cal EMA
Calexico PD
California Highway Patrol
CBP
CENTCOM
Chicago Fire Dept
CHP
City of Frisco
City of Las Vegas
Cleveland VA Medical Center
Coast Guard Headquarters
CRIC
CS OEM
CSU Fresno Police

DARPA
DARPA, Tactical Technology Office
Defense Innovation Unit Experimental DIUx
Defense Threat Reduction Agency
Department of Defense
Department of Energy
Department of Homeland Security
DHS ICE
DHS/OPS
Department of Justice
Department of the Interior
Dept of Energy
DIA
DMDC
DoD
DoD OIG
DOS
DOT Office of Inspector General
DTRA
DTRA/CXTT
Eldorado Sheriff's Office
Elk Grove PD
FAA
FAA Western-Pacific Region
FEMA
GWU
HHS/ASPR
HQ TRADOC
Irvine PD
Jet Propulsion Laboratory
Joint Staff J-7
Joint Staff Remote/Unmanned Futures Office
Joint Vulnerability Assess. Branch
LA County Sheriff
Lawrence Livermore National Laboratory
Marin County Sheriff
Marin Sheriff
Marina Police Department (Retired)
Monterey Co Sheriff
Mountain View PD
NASA
NASA JPL
NASA-JSC
NASA, CSUMB
NASA Langley Research Center
National Air Security Ops Center -CBP
National Geospatial-Intelligence Agency
National Guard Bureau
National Transportation Safety Board
NAVAIR (NAWCWD)
Naval Oceanographic Office
Naval Research Laboratory
Naval Sea Systems Command
NAVSEA
NAWCAD
NDU
NEMA
Nevada Institute for Autonomous Systems
NOAA
NORAD/USNORTHCOM
NSF
NSWCDD
Oakland PD
Office of Naval Intelligence
Office of Sen. Kirsten E. Gillibrand
Office of the Under Secretary
Oklahoma City Chamber of Commerce
Oklahoma Dept of Commerce
OSD
OSD ASDR&E
OUSD (AT&L)
PACOM
Placer County Sheriff
PMW 750
POST
Sac Co Sheriff
Sacramento Office of Emergency Services
Sacramento PD
Sacramento Sheriff
San Diego Sheriff’s Department
San Leadro PD
San Mateo County Sheriff
San Mateo PD
Sandia National Laboratories
SOCOM
Space and Naval Warfare System Center Pacific
SPAWAR Systems Center
SPAWARSYSCEN PACIFIC
State Dep
State of Alaska (DOT)
State of Oklahoma
State of Utah - Econ. Dev. Office
State of Utah, Governor's Office Economic Development
State of Wisconsin
STRATCOM
Swedish Defence Material Administration
The Aerospace Corporation
Transport Canada Safety & Security
Tulsa Chamber of Commerce
Tustin PD
U.S. Coast Guard Marine Safety Center
United States Secret Service
US Army ERDC
US Central Command
US Coast Guard
US Marshall
US Navy

US Secret Service
US Special Operations Command
USCG
USCG R, D, T&E
USCG Research & Development Center
USG
USNA
USSOCOM
USTRANSCOM
Ventura Co Sheriff
Ventura County Economic Development Association
Ventura PD
Visalia PD
WI DOJ/DCI

INDUSTRY:

0cog Inc.
2d3 Sensing
3D PARS - 3D Printing and Advanced Robotic Solutions
5D Robotics
American Association for the Advancement of Science (AAAS)
AAI Corporation
AAI Corporation/Textron Systems
Aatonomy
Abbott Laboratories
Abbott Technologies
ACADEMI
Access Spectrum
ACE Applied Composites Engineering
ACSEAC
ACSS (Aviation Comm & Surv. Systems), LLC
ACT
Action Drone
ADS Inc
ADSINC
ADSYS Controls Inc
Advanced Acoustic Concepts
Advatech Pacific
AEgis Technologies
Aerial MOB
Aero UAVs
AeroEd Group
Aerofex Corp
Aerojet
Aerojet Rocketdyne
Aeropsace Corp
Aerospace & Def INO Parts
Aerospace Analytics
Aerospace/defense Professional
AeroTargets International
Aerovel Corp
Aerovelco
AeroVironment, Inc.
Affordable Engineering Services
Ag Eagle
AgriSource Data, LLC
Air Concepts Group
Air Law Institute
Air View Consulting
Airbus Defence & Space
ALAKAI Defense Systems
Alaris Pro
Alaska Aerospace Corporation
ALCO
Alex
Alfresco
Alidade Incorporated
Alpha Research & Technology, Inc.
Alta Devices
Altair
Altron
Amazon
American Autoclave Co
AMP Research, Inc.
Andro Computational Solutions
ANT Global Services
Antonelli Law
AOC Inc
Applied Mathematics, Inc.
Applied Physical Sciences Corp.
Applied Research Associates Inc.
Applied Research in Acoustics
Applied Visions, Inc.
APS
Arcturus UAV
ArcXeon LLVC
Argon Corp
Argon ST
Arkwin Industries, INC.
Arnouse Digitall Device Corp
Artemis
ASC (Advanced Scientific Concepts Inc.)
ASI (Aeronautical Systems Inc.)
Assured Information Security
ASV Global
ASYLON
ATC
ATI
Atkinson
Atlas North America
auratech
Aurora Flight Sciences
Ausley
Autonomous Avionics
AUVAC
AUVSI

AUVSI Saguaro Chapter
AUVSI, Squidworks Inc.
Avian
Avineon, Inc.
Axiom Electronics
B. E. Meyers
Bacolini Enterprises
BAE Systems
BAH
Ball Aerospace & Technologies Corp
Barry Aviation
Battelle Memorial Institute
Battlespace, Inc.
BBN Technologies
BecTech
Bell Helicopter Textron, Inc.
BGI Innovative Solutions
Bicallis, LLC
Black & Veatch Special Projects Corp.
Blackbird Technologies
Blackhawk Emergency Management Group
Bluefin Robotics Corporation
BMNT Partners
Boeing
Boomerang Carnets
Riverside DA Office
RS Special Research Access
Booz Allen Hamilton (BAH)
Borchert Consulting and Research AG
Boston Engineering Corporation
Bot Factory
Bramer Group LLC
Broadcast Microwave Services Inc. (BMS)
BRPH
C2i Advanced Technologies
C4ISR & Networks
Cabrillo Technologies
CACI
Calvert Systems
Camber Corp
CANA LLC
CAPCO LLC.
CapSyn (Capital Synergy Partners, INC.)
Carnegie Robotics
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
CETUS
Channel Technologies Group
Charles River Analytics
Charles Stark Draper Laboratory
CHHOKAR Law Group
CHI Systems
Chinwag
Chroma Systems Solutions
Cisco
Clarity Aero
Clear-Com
CLK Executive Decisions
CNA Analysis & Solutions
Cobham plc
CODAN Radio Communication
Coherent Technical Services, Inc.
Colby Systems Corporation
Comphydro Inc
Compsim LLC
Comtech Solutions LLC
Concepts to Capabilities Consulting LLC
Conoco Phillips Company
Consolidated Aircraft Coatings
Copeasctic Engineering
Cornerstone Research Group
Cornet Technology
Corning
Corsair Engineering
CPI
CRYSTAL
Crystal Rugged
CS-Solutions Inc
CSA
CSCI - Computer Systems Center Inc.
CT Johnson & Associates
CTJA, LLC
CUBIC
Cutting Edge
Cyber Security & IS IAC (CSIAC)
CyberWorx
CyPhy Works
D-RisQ
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 Intelligence Inc. (DII)
Digital Adopxion
Digital Harvest
Diversified Business Resources, Inc.
DOER Marine
Domo Tactical Communications
Dove Innovations

DPI UAV Systems
DPSS Lasers
DRA - Defense Research Associates
Dragonfly Pictures
DREAMHAMMER
Drone America
Drone Aviation Corp
Drone Logger Enterprise
Drone Pilots Federation
Drone Services Hawaii
DroneBase
Dronecode
DST Control
Duetto Group
Duzuki
Dynetics
E.J Krause & Associates
EC Wise
ECC
Ehang
Elbit Systems of America
Electricore
Electro Rent Corporation
Elementary Institute of Science
Ellevision, LLC
Elmo Motion Control
ELTA Systems
Emerging Technology Ventures Inc.
Engility, Inc
Engineered Packaging Solutions
EnrGies
EQC, Inc
ERA
Ervin Hill Strategy
ESRI
Esterline Control & Communication Systems
Eutelsat America
Excelis
Exelis Inc
FABLAB San Diego
Fairchild Imaging
Farm Space Systems LLC
Faun Trackway USA
FEI-Zyfer Inc.
Felix Associates
Five Rivers Services, LLC
Flagship Government Relations
FLIR Systems, Inc.
FLYCAM UAV
FLYMOTION Unmanned Systems
FORSCOM Aviation Directorate
FreeFlight Robotics
Freescale
FreeWave Technologies Inc.
Fremont PD
Fremont PD/CPOA
Frisco, TX PD
Frost & Sullivan
Fugro Geoservices Inc.
G2 Solutions
Galois Inc.
GC Ventures
GE Aviation
GEMA/HS
General Atomics
General Atomics Aeronautical Systems
General Atomics Aerospace
General Atomics ASI
General Dynamics
General Dynamics Advanced Information Systems
General Dynamics Electric Boat
General Dynamics Information Technology
General Dynamics Land Systems
General Dynamics Mission Systems
Geospatial San Diego
Germane Systems
GET Engineering
Getac
Gibbs & Cox, Inc.
GL INTERNATIONAL
Global Technical Systems
Go Pro Cases
Go Professional Cases
Gold Star Strategies LLC
Goleta Star LLC
GPH Consulting
Griffon Aerospace
Gryphon
Gryphon Sensors
GTS Consulting
H.O. JOHNSON RESULTANTS LLC
Hangar Technology
Harris Communications
Harwin
Hawaii Hazards Awareness & Resilience Program
Herley Lancaster
Hoggan Lovells LLP
Honeywell
HQ SACT
Hughes
Hydr0 Source LLC
Hydroid
Hyperspectral Imaging Foundation
IBM
IC2S (Innovative C2 Solutions, LLC.)
IDA
iDEA Hub
IEEE ICSC2015

IHI
Ike GPS
Image Insight
Implevation, LLC
IMSAR
Information Processing Systems, Inc
inmarsat
Innoflight
Innovation Center
Innovative Computing & Technology Solutions, LLC
Inova Drone
Inside Unmanned Systems
Insight Global
Insights
Insitu
INSITU/AUVSI
Institute for Homeland Security Solutions
Intelligent Automation
InterContinental IP
Intergraph Government Solutions
Iris Technology
iRobot
ITA International
ITT Exelis
IXI Technology
JACOBS
Janes Capital Partners
Japan Aerospace Exploration Agency
JHNA
JOBY Aviation
John Deere
Joint Ground Robotics Enterprise (OUSD)
Joint Venture Monterey Bay
Jove Sciences, Inc.
Juniper Unmanned
Kairos Autonomi
Kaman
Ken Cast
Kitware
Knife Edge
KNOWMADICS
Kongsberg
Kraken
Kratos Defense
KSI
L-3 Advanced Programs, Inc.
L-3 Cincinnati Electronics
L-3 COM Communications
L-3 Precision Engagement Systems
L3 Technologies
Laser Shot
Latitude Engineering
LDRA
Leidos
Lenny Schway Photography
Leucadia Group
Lightspeed Innovations
Liquid Robotics, Inc.
Llamrai Enterprices
Lockheed Martin
Lockheed Martin Aeronautics Company
Lockheed Martin Missile & Fire Control
Lynntech
Magnet Systems
Makani Power Inc
Make in LA
MAMM 3D Inc.
Management Sciences, Inc
MAPC (Maritime Applied Physics Corp)
Maplebird
Marine Acoustics
Maritime Applied Physics Corporation
Maritime Tactical Systems, Inc. (MARTAC)
MARTAC
MartinUAV
MASI LLC
Materials Systems Inc.
Materion
Mav6, LLC
MBDA Incorporated
McBee Strategic
McCauley Prop Systems
McClean Group
McKenna, Long & Aldridge LLP
McKinsey & Co.
MCR Critical Thinking Solutions Delivered
MDA Corporation
Medweb
Merlin Global Services
Mesa Technologies
Metal Technology
Metcon Aerospace & Defense
METI
Metis Design
Metron Inc
Meyers AeroConsulting
Michael Baker International
Micro USA Inc.
Microflown
MicroPilot
Microwave Monolithics Inc
Mid-Atlantic Aviation Partnership (MAAP)
Middle Canyon LLC
MilSource
Miltrans
MINCO
MISTIC INC
Mistral Inc.

MIT Enterprise Forum San Diego
MITRE Corporation
Modern Technology Solutions, Inc.
Modus Robotics
Momentum Aviation Group
Monitor National Security
Monterey County Herald
Moog Inc
Morrison & Foerster LLP
MosaicMill
MRU Systems
MSI
MTSI (Modern Technology Solutions, Inc.)
Multi GP
Murtech Inc.
Nano Motion
Nanomotion
NASC
National Institute of Aerospace
National Science & Technology Corporation
Nautilus
Naval Nuclear Laboratory
NAVPRO Consulting LLC
NDIA
Near Earth Autonomy
Newport News Shipbuilding
Next Vision Stabilized Systems Ltd
Nexutech, Ltd
Neya Systems LLC
NiederTron Robotics
NLD MOD (Defence Materiel Org
NNS
North Dakota Counter UAS Task Force
Northeastern University
Northrop Grumman Corp.
NorthWind
Novel Engineering
NUAIR Alliance, Inc.
NV Drones
NWB Environmental Services
NWUAV Propulsion Systems
Ocean Aero
Ocean Lab
Ocean Wings UAS, Inc.
Oceaneering Technologies
ODNI
Odyssey Marine Exploration
Ontario Drive & Gear
OPNAV Safety Liaison
Optical Cable Corp
Oracle
Orca Maritime, Inc.
Orion Systems
ORYX
Oxford Technical Solutions
P11 Consulting
Pacific Science & Engineering Group
Pacific Synergistics International (PSI)
Pappas Associates
Paradigm
Paragrine Systems
Parsons
Paso Robles Ford
Patuxent Partnership
Paul R Curry & Associates
Pentagon Performance Inc.
People Tec
Perceptronics Solutions
Perforce
Perkins COIE
Persistent Systems
PG&E
Phantom Works
Physical Optics Corp
Physical Sciences Inc
Pixia
PMS505
Polarity
Pole Zero
Power Correction Systems Inc.
Power Ten Incorporated
Power4Flight LLC
Praxis Aerospace Concepts International
Precision
PREMANCO Ventures
Prescient Edge
Precision
Princeton Lightwave
Prioria Embedded Intelligence
Profit Quadro
Progeny Systems
Promia
Propellerheads
Provectus Robotics Solutions
Prox Dynamics
q-bot
QinetiQ North America
QUALCOMM
Quanterion Solutions Incorporated
Quartus Engineering
Quatro Composites
R Lynch Enterprises
R-3 Consulting
R3SSG
Rajant
Ramona Research
Rand Corporation
Randiance Technologies

Range Networks
Rapid Imaging Software
Raytheon Company
Raytheon Company - Integrated Defense Systems
Raytheon Missile Systems
RD Integration
Red Hat
Red Six Solutions
Redwall Technologies
Reference Technologies INC.
Renaissance Strategic Advisors
RFMD
Riegl USA
Riptide Autonomous Solutions
RIX Industries
RJ Vincent Enterprises LLC
RMV Technology Group
ROBOTEAM
Robotics Research
Rockwell Collins
Rocky Mountain Institute
Rogue Tactical LLC
Rolls Royce
Roving Blue
RT Logic
RTI
Rumpf Associates International
Rupprecht Law
SAAB
Saab Defense and Security USA
SAGE Solutions Group, Inc
SAIC
Saildrone
SAP National Security Systems
SAP NS2
SAS Institute
Scale Matrix
SCD.USA Infrared
Scientific Applications & Research Associates
Scientific Research Corporation
Scorpion Aerosystems Inc.
Scoutsman Unmanned LLC
Sculpture Networks Inc.
SDG&E
Sea Phantom International, Inc
SeaBotix
Seamatica Aerospace Limited
Seapower Magazine
SebastianConran/associates
SEKAI
Selex Galileo Inc.
Semantic Computing Foundation
Sematica Aerospace Limited
Senseta Inc
Sensintel
sensonor
Sensurion Aerospace
Sentinel Robotic Solutions (SRS)
SES Government Solutions
SETA / ONR
Seven Seals
Shadow (Robot Company)
Shephard Media
Shoof Technologies
Show Pro Industries
Sierra Nevada Corp
SIFT (Smart Info Flow Technologies)
Signal
Signal Monitoring Solutions
Signature Science
Sikorsky
Silent Falcon UAS Technologies
Silvus Technologies
Simlat
SIRAB Technologies Inc
SKYEYE GLOBAL
Skylift Global
Smith Currie & Hancock
SNC - Sierra Nevada Corporation
Soar Oregon
Soar Technology, Inc.
Society of Experimental Test Pilots
Soliton Ocean Services, Inc.
Sonalyst, Inc
Sonitus Technologies
SPA
Space Micro
Sparton Corporation
Sparton Defense and Security
Spatial and Spectral Research
Spatial Integrated Systems
Spectrabotics
Spectrum Aeronautical, LLC
Spinner
Spiral Technology, Inc.
SRC, Inc.
SRI International
SSL
ST Aerospace
Stark Aerospace Inc.
Steinbrecher & Span LLP
Straight Up Imaging
Strategic Analysis Enterprises
Strategic Defense Solutions, LLC
Stratom
Stryke Industries
Sunhillo Performance Technologies
Sutton James

SwRI (Southwest Research Institute)
Sypris Electronics
Systems Planning & Analysis, Inc
SYZYGYX Incorporated
Tactical Air Support, Inc.
Tarsier Technologies
TaSM (Technology and Supply Management) LLC
TCG
Tech Associates, LLC
Tech Incubation
Tech Source
Technology Training Corporation
TechSource
TECOM
Teledyne
Teledyne - SeaBotix
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.
The Boeing Company
The Clearing
The Jackson Group
The Maritime Alliance
The MITRE Corporation
The Pilot Group
The Radar Revolution
The Ranger Group
The Spectrum Group
The Steelman Group, Inc.
Third Block Group
Tiger Tech Solutions
Tiresias Technologies
TMT ~ spg
Topcon
Torch Technologies
TorcRobotics
Toyon
TP Logic
Trabus
Transportation Power Inc.
Travelers United
Trimble Navigation Ltd
TRIMECH Solutions
Twin Oaks Computing
UAS Colorado
UAS Today
UASolutions Group
UASUSA
UAV Factory
UAV LLC.
UAV Pro
UAV Solutions
UAV Vision
UAVNZ
Ultimate Satellite Solutions (UltiSat)
Ultra Electronics
Ultra Electronics - USSI
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
US Nuclear Corp
USI
UTC Aerospace Systems (ISR Systems)
UxSolutions Inc
Valkyrie Systems Aerospace
Van Scoyoc Associates
VCT (Vehicle Control Technologies Inc)
VDC Research
Vector CSP
Vehicle Control Technologies, Inc.
Velocity Cubed Technologies
Velodyne Acoustics
Veridane
ViaSat
Video Ray LLC
VideoBank
VideoRay
Virtual Agility
Vision Technologies
Vital Alert
VPG Inc
VSTAR Systems Inc.
Vulcan
Wade Trim
Wateridge Insurance Services
WBB
WBT Innovation Marketplace

WDL Systems
Whitney, Bradley & Brown Inc.
Williams Mullen
Wind River
WINTEC
Wireless SEC Assoc
Woolpert
Wounded Eagle UAS
Wyle
Yamaha Motor Corp. USA
Z Microsystems
Z-Senz
ZDSUS
Zepher
Zimmerman Consulting Group
Zivko Aeronautics
Zodiac Aerospace
Zugner LLC

International:

Agency for Defence Development (ADD)
Australian Army
Australian Navy
Be MoD
Brazilian Navy
British Consulate - General LA*
Business France
C-Astral
Canadian Forces Aerospace Warfare Centre
Civilian
Defence Science & Technology Group
Drone X Solution
Dronomy
Egyptian Naval Forces
FFI
FMV
German Navy
Goleta Star LLC
High Eye BV
Higheye
Italian Navy
LIG Nex1, South Korea
Mexican Navy
NAWC
NORTHCOM
Pixiel
Royal Australian Navy
Royal Navy
Royal Swedish Navy, 4TH Naval Warfare Flotilla
RSWN
Simlat
Swedish Naval Warfare Center
Tunisian Army
Turkish AF
Turkish Air Force
Turkish Navy
UCAL-JAP Systems LTD.
UK Defence Science and Technology Laboratory
UK Ministry of Defense

APPENDIX D: CRUSER FY17 CALL FOR PROPOSALS

The FY17 call for proposals was released in late July 2016. Proposals selected for funding are summarized in the second chapter of the full FY17 CRUSER Annual Report.

CRUSER
Consortium for Robotics and Unmanned Systems Education and Research

NAVAL POSTGRADUATE SCHOOL

CRUSER Call for Proposals FY17

PROPOSALS DUE DATE:	**15 Aug 2016**
Selection Date:	**1 Sep 2016**
Funding Start Date:	**As early as 1 Oct 16**
Funding Expiration Date:	**30 Sept 2017**
Funding Levels:	**up to $150,000**
Proposal Type:	**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 robotics and unmanned autonomous systems (AS) 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 FY17; 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. We anticipate being able to fund 20-30 projects averaging ~$100k each.

Research Focus Areas: CRUSER Innovation Thread 5-- ***Creating Asymmetric Warfighting Advantages: Electromagnetic Maneuver Warfare***—began at the Sep. 2015 Warfare Innovation Workshop (WIW). Specific research threads identified included:

a) Temporal networks: agile ad hoc networks will create an asymmetric advantage in any future A2AD battlespace. Research that focuses on supporting robotics and unmanned AS with these networks or using them to establish/support these networks would fall into this category.

b) Agile communications: standardized communications between diverse assets in a future battlespace will improve outcomes, and should be designed into technologies in development today. Research that enables robotics and unmanned AS using multi-modal communications or that would create multi-modal capabilities for the naval forces is included in this category.

c) Fleet-spoofing and/or military deception (MILDEC): using small, expendable unmanned systems and retired assets, these concepts all endeavor to confuse our adversary and cause enemy forces to commit assets and weapons to counter an imaginary fleet.

d) Alternative PNT: robust means for positioning, navigation, and timing (PNT) will be essential in a future battlespace, and could be accomplished using an array of sensors deployed on a variety of diverse assets.

e) Other robotics and unmanned AS concepts of interest that do not fit into the categories above yet leverage either small, expendable unmanned systems or the electromagnetic spectrum to create asymmetric advantages in an A2AD environment such as "Cross-Domain UAVs" and "Bio-Mimicry Comms".

NOTE: Researchers are encouraged to relate proposals to an Innovation Thread Reserch Focus Area. However, proposals for topics related to ANY robotic/unmanned sytems area will be considered.

Classification Level: Unclassified (Preferred) but Classified work will be considered.

Required Documents: -- Select "FY17 Call for Proposals" at http://my.nps.edu/web/cruser/call-for-proposals --

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. Current Year Research Office Budget form - https://my.nps.edu/web/research/proposal-development
4. Quad Chart – template on http://CRUSER.nps.edu

Submission Procedures:

- FY17 CRUSER Proposals and supporting documents should be submitted directly to cruser@nps.edu (Jean Ferreira, CRUSER Operations Manager). *Do not submit through the Research Office. [If selected, PIs will be required to submit a formal NPS research proposal to CRUSER via their Deprt. Chair and Dean.]*

Review and Selection Board: Proposals will be evaluated by a panel of reviewers co-chaired by the Dean of Research and the CRUSER Director.

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
5) New research area (seed money to attract other contributors)
6) Research topics related to ANY robotic and unmanned sytems area may be proposed, though proposals related to any CRUSER innovation thread are preferred. (See website and above focus areas)
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 level of effort approriate for CRUSER).

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
- A Presentation at a montly meeting and at the annual CRUSER TechCon
- A CRUSER News article
- Participation in CRUSER sponsored events
- Contributions to the CRUSER Annual Report
- Providing updated labor plans and budget projections as requested

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APPENDIX E: CRUSER LEADERSHIP 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. Brian Bingham is an Associate Professor in the Mechanical and Aerospace Engineering Department at the Naval Postgraduate School. Dr Bingham received his PhD in mechanical engineering from MIT in 2003. After a brief stint at the Ocean Institute in California, he was appointed to a post-doctoral position at the Woods Hole Oceanographic Institution, Deep Submergence Lab. Dr. Bingham has served as a member of the faculty at the Franklin W. Olin College of Engineering from 2005-2009 and the University of Hawaii at Manoa from 2009-2015. His research is on innovative tools for exploring, understanding and protecting the marine environment. This work includes projects on underwater navigation, autonomous vehicles and sensor integration. http://faculty.nps.edu/vitae/cgi-bin/vita.cgi?p=display_vita&id=1299243456

ASSOCIATE DIRECTOR: Carl Oros, LtCol, USMC (Ret.) is a Faculty Associate - Research and Information Sciences (IS) doctoral student in the Department of Information Sciences. His research and teaching interests include wireless networking, tactical wireless LANs, operator-centric information architectures that support the C2 communication of valuable bits to the lowest tactical level, and biological information. As a Principle Investigator, he has managed several USMC sponsored tactical wireless research projects and has been actively involved in the NPS-USSOCOM Cooperative Field Research Program and the OSD sponsored Joint Interagency Field Experimentation (JIFX) program since 2004. Carl is a retired Marine Corps CH-53E assault support helicopter pilot and holds a Master of Science Degree in Information Technology Management from NPS, a Masters in Military Studies (USMC Command & Staff College), and a BA in Geophysics (Univ. of Chgo). He has been published in the handbook of research on Complex Dynamic Process Management, and the Command & Control Research Program (CCRP) and AFCEA-George Mason University (GMU) Critical Issues in C4 symposia. His current research is focused on the biological aspects of information. http://faculty.nps.edu/vitae/cgi-bin/vita.cgi?p=display_vita&id=1138032442

ASSOCIATE DIRECTOR: 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 is a member of the NPS Design Thinking community. 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 EMERTIUS/SENIOR ADVISORY COMMITTEE MEMBER: Jeff 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

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LIST OF ACRONYMS AND ABBREVIATIONS

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

AUV	Autonomous underwater vehicle
C2	Command and control
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
ISR	Intelligence, surveillance, and reconnaissance
JCA	Joint campaign analysis
JIFX	Joint Interagency Field Experimentation
LDUUV	large displacement UUV
MDA	Maritime domain awareness
MIO	Maritime threat detection and interdiction operations
MTX	NPS multi-thread experiment
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
ONR	Office of Naval Research
RAS	robotic and autonomous systems
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
SOF	U.S. Special Operations Forces
TDA	Tactical decision aid
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
UUV	Unmanned undersea vehicle
UxS	Unmanned system
WIC	Warfare Innovation Continuum

ACKNOWLEDGMENTS

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

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 appreciates the continuing support of the Acting Under Secretary of the Navy, Mr. Sean Stackley.

The CRUSER Director acknowledges the efforts of the CRUSER Advisory Board: retired Navy Rear Admiral Jerry Ellis NPS Chair of Undersea Warfare; retired Navy Rear Admiral Rick Williams, NPS Chair of Mine Warfare; Dr. Jeff Paduan, NPS Dean of Research.

The CRUSER Director acknowledges the extraordinary work of the first CRUSER Director, retired Navy Captain Jeff Kline who continues to serve as an essential advisor to the program.

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 FY17 annual report summarizes CRUSER activities in its seventh 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

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