NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER) FY18 ANNUAL REPORT

Prepared by

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December 2018

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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 FY18 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):

FY18 Annual Report

Prepared by Lyla Englehorn, CRUSER Associate Director
for Dr. Brian Bingham, CRUSER Director

NAVAL POSTGRADUATE SCHOOL

Released December 2018

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EXECUTIVE SUMMARY

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From Concept Generation to Experimentation…

Since 2011 the Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) has sought to create and nourish a collaborative environment and community of interest for the advancement of unmanned systems 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 directing the continuation of the program at NPS with research funding support from the Office of Naval Research 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 2018 the

CRUSER community of interest includes just over 3,000 members from government, academia and industry.

In 2018 CRUSER has continued to implement the core program activities while also integrating timely new efforts that have direct impact on naval officers through education, research, concept generation and experimentation. The core activities, detailed in this report, include providing seed support for NPS research in unmanned systems, offering a DoD-wide field experimentation program, integrating with the NPS education mission, supporting concept generation and providing a DoD-wide forum for collaboration. In 2018 CRUSER organized a unique series of DoD-wide panel discussions of military, academic and industrial representatives speaking directly to naval leadership about emerging opportunities and challenges in robotics and autonomous systems. In response to the call to increase DoD engagement with industry, CRUSER has supporting initial work on the new Sea Land Air Military Research (SLAMR) facility through a series of design events organized around how industry and the DoD might collaborate on a unique experimental facility.

This Annual Report provides a summary of the many activities executed during CRUSER's eighth 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.

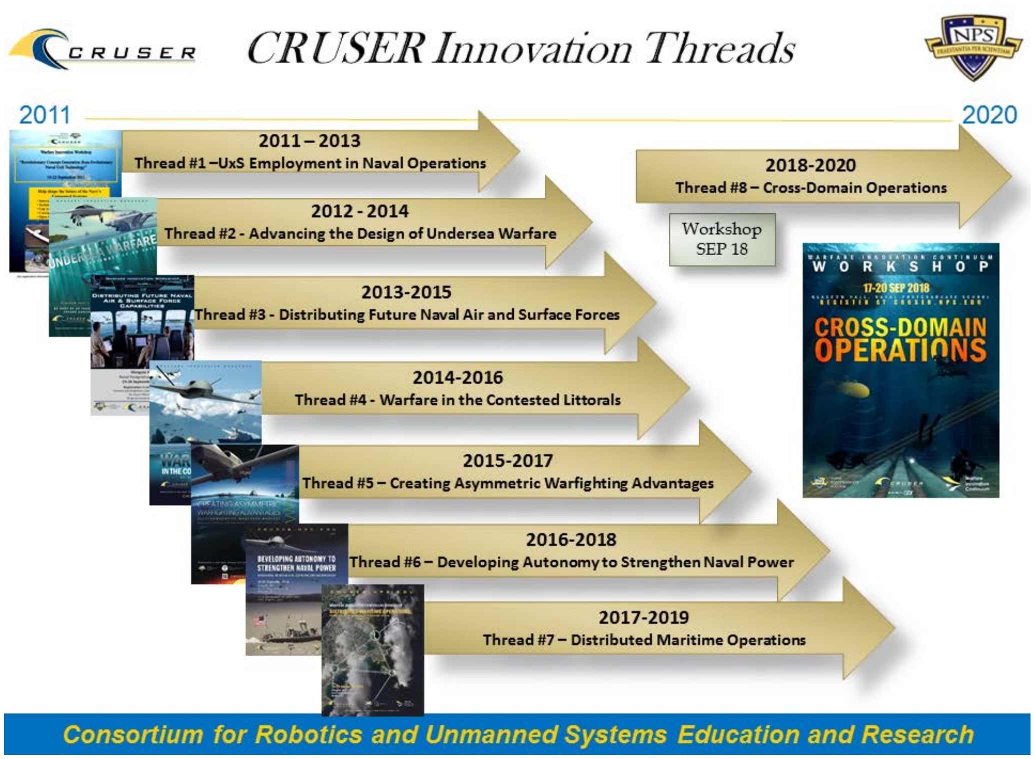

Figure 1. CRUSER program innovation threads as of September 2018

Major concept generation activities (FY11 through FY18) 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, and is included in the full compliment of programs in the NPS Field Experimentation (FX) portfolio. These programs include the Joint Interagency Field Experimentation (JIFX)[1] program, the Advanced Robotics Systems Engineering Lab (ARSENL), the Multi-Thread Experiment (MTX),[2] and the development of the Sea/Land/Air Military Research (SLAMR) facility. In addition, CRUSER collaborates with and supports other related campus research centers such as the Center for Autonomous Vehicle Research (CAVR)[3] and the Center for Network Innovation and Experimentation (CENETIX).[4] 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 supports the full NPS institutional effort to build and maintain 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 relationships with external organizations to include 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), and many warfare centers and systems commands throughout the naval enterprise.

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[1]Joint Interagency Field Experimentation (JIFX) website: https://my.nps.edu/web/fx

[2] Matt Schehl (2018) "NPS Research Team Explores the Boundaries of Unmanned Systems Through MTX" *NPS Public Affairs Office*, posted 11 June 2018 at https://my.nps.edu/-/nps-research-team-explores-the-boundaries-of-unmanned-systems-through-mtx

[3] Center for Autonomous Vehicle Research (CAVR) website: https://my.nps.edu/web/cavr

[4] Center for Network Innovation and Experimentation (CENETIX) website: https://my.nps.edu/web/cenetix

The Director guides the activities of CRUSER to ensure 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 the CRUSER Advisory Group (CAG). In FY18 the NPS CAG included:

- Dean of Research Dr. Jeff Paduan
- Operations Research Professor of Practice CAPT Jeff Kline USN (ret)
- Undersea Research Chair RADM Jerry Ellis USN (ret),
- Mine Warfare Chair RADM Rick Williams USN (ret),
- Surface Warfare Chair CAPT Chuck Good USN
- Air Warfare Chair CAPT Ed "Tick" McCabe USN
- Senior Marine Officer Col Todd Lyons USMC
- Senior Army Officer COL Lamar Adams USA
- Senior Air Force Officer COL Tim Sands USAF
- Senior Navy Officer CAPT Brian Morgan USN
- Senior Intel Officer CAPT Christopher Bone USN

This committee ensures that the Fleet and its operations remain a primary consideration in CRUSER activities to include the selection of activities supported by CRUSER.

II. PRIORITIES

To support the four primary tenets of CRUSER – concept generation, education, research, experimentation, and outreach – various activities and research initiatives will occur, ranging from unmanned systems innovation symposia and technical symposia to experimentation and research projects. CRUSER executed just under $4M in the FY18 cycle, and anticipates funding at the same level for FY19. Activities for each year are briefed to the Advisory Board and require approval from the sponsor.

Primary objectives in FY18 were to continue to provide:

- funding support for seed research projects
- 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 is granted to projects led by NPS faculty members across over 15 academic departments to explore many diverse aspects of unmanned systems (*see Figure 2*).

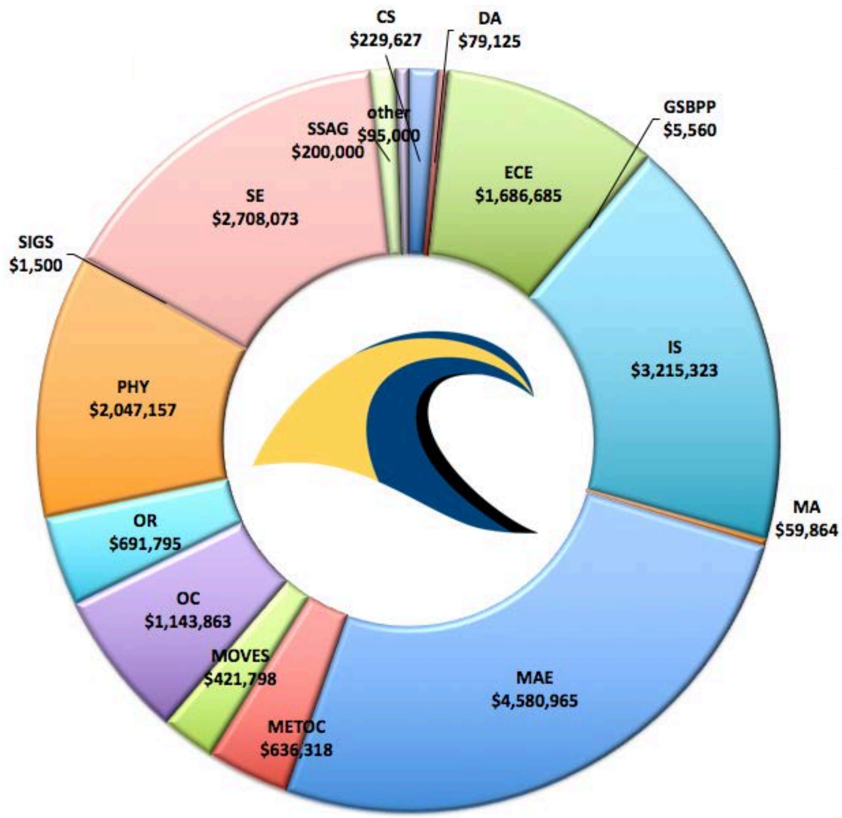

Figure 2. CRUSER seed funding by NPS department, FY12-19.

In late July 2017, CRUSER made its sixth call for proposals to seed research topics. The stated funding period was 1 October 2017 through 30 September 2018, and the funding levels were set at $75,000 to $150,000 per topic.

At the beginning of September 2017 CRUSER received 47 proposals totaling just over $6 million. All were reviewed for CRUSER seed funding. The CRUSER advisory committee selected 16 projects, and granted $2.17 million in total to support robotics and autonomy related research in FY18 (*see Table 1*). Research summaries for each supported project are included in this section of the report. These summaries report on the status of the individual project as of 30 September 2018 and include the technical point of contact for further inquiry.

Table 1. FY18 CRUSER funded projects (*alphabetical by initial lead researcher last name*)

	Principal Investigators(s)	Project Title
1	Dr. Brian Bingham Dr. Preetha Thulasiraman	ROS 2: Cyber Security and Network Robustness for Robotics

2	Dr. Dan Boger and Scott Miller	Manned Unmanned Teaming (MUM-T) for Marine Fire Teams
3	Prof. Alex Bordetsky	Short-Living Nodes and Links for Littoral Mesh Networking
4	Dr. Dwayne Davis Dr. Kevin Jones CDR Kathleen Giles USN	Aerial Swarm Behavior Development in Support of USMC Training
5	Dr. Doug Horner	Adaptive Submodularity for Mixed-Initiative UxV Network Control Systems
6	Dr. Kevin Jones Dr. Dwayne Davis	Swarm Future Platforms
7	Prof. Gamani Karunasiri Dr. Fabio Alves	Bio-inspired MEMS acoustic sensor for robotic autonomous systems applications
8	Dr. Mollie McGuire	The Decision to Rely on Automation Under Stress: The Debut Experimentation Effort for the Human Cognition and Automation Lab
9	Aurelio Monarrez Dr. Sean Kragelund	Cooperative Autonomous ScanEagle
10	Dr. Jim Newman	Development of Autonomous, Optimized Capabilities for MC3
11	Dr. Mara Orescanin	Simultaneous visual and IR UAV imaging of littoral systems for AI driven change detection
12	Dr. Phillip Pace and Dr. Ric Romero	Network Enabled Digital Swarm Image Synthesis (NEDSIS) Phase 2
13	Dr. Susan Sanchez and Dr. Tom Lucas	Data Farming Explorations of the Tactics and Benefits of Unmanned Systems and Unmanned-Manned Teaming
14	Dr. Kevin Smith and Dr. Vlad Dobrokhodov	Acoustic Vector Sensing from Novel Autonomous Systems Using Light-Weight, Low-Power Data Acquisition Systems

15	Dr. Preetha Thulasiriaman	Study of Cybersecurity Requirements for the Military Robot Operating System (ROS-M) using ROS 2.0 on Unmanned Aerial Networks
16	Dr. Oleg Yakimenko	Mission Planning in Support of SAR Operations Involving Heterogeneous UxSs

1. ROS 2: Cyber Security and Network Robustness for Robotics

The current robotics operations system (ROS 1) is a ubiquitous tool for rapidly developing new technology, but for Naval applications the lack of guaranteed security and susceptibility to intermittent communications (e.g., acoustic communications) prevents the rapid transition of many of these emerging technologies to fleet, increasing both transition time and cost. The development of ROS 2 will include cyber security and network communication robustness as a foundational part of the design, rather than as an addition to an existing software framework. Collaborating with the Open Source Robotics Foundation (OSRF) at this early stage of development of ROS 2 (*see Figure 3*) will ensure that Naval interests are represented in the design and allow NPS students and researchers to provide guidance into the creation of this exciting new tool.

Figure 3. Key use cases for ROS 2: embedded systems, DoD products, and multi-robot systems.

This new effort supported direct interaction between NPS and OSRF. During this year we were able to establish the collaboration and have NPS thesis students work directly with software developers at OSRF in Mountain View. Because of the lag associated with financially supporting this external collaboration, much of the work still lies ahead. We anticipate working with OSRF to establish two testbeds for examining cyber vulnerabilities: one within a network simulation environment and one with robotic test hardware (small wheeled robots) here at NPS. These testbeds will support future thesis research in this important area of study.

The research team members included Dr. Brian Bingham, Associate Professor, Mechanical and Aerospace Engineering; and Dr. Preetha Thulasiraman, Associate Professor, Electrical and Computer Engineering. This work also supported the thesis research for LCDR Jose Fernandez, graduating in June 2019.

POC: Dr. Brian Bingham (bbingham@nps.edu)

2. Manned Unmanned Teaming (MUM-T) for Marine Fire Teams

Since 2014, NPS Information Science Department researchers have assisted the Marine Corps Warfighting Laboratory (MCWL) with their UTACC project. MCWL could not fund the research in 2018, so CRUSER stepped in. Eight USMC students produced four theses, two of which earned NPS Outstanding Thesis designation. The team explored potential follow up research, funded under the FY19 Naval Research Program. In the thesis, titled "Assessing UTACC Cognitive Load",[5] the authors analyzed the strengths and weaknesses of human and machine cognition (*see Table 2*). Done properly, teaming humans and machines can improve the cognitive performance of the team. Teaming humans and machines together is not without risks, however. Humans must be able to trust their machine teammates if the machine agent is to successfully contribute to the team's cognitive performance. Currently, there are significant barriers to achieving this trust objective, such as the machine's inability to explain how it arrived at an answer or recommendation the way a human can and the machine's lack of mutual concern and shared sense of vulnerability, which also makes it inherently less trustworthy.

[5] LCOL Alan Clarke USMC, 2018

Table 2. Considerations a leader would make to manage that cognitive load, whether operating with or without unmanned systems.

Machine Agent Cognitive Impact	Task Cognitive Factors	Human Agent Cognitive Impact
Requires proper prior training of Machine Agent	Knowledge-based	Cognitive abilities suitable depending on prior experience & training
Impacts cognitive load/ cognitive capabilities not well suited	Stochastic	Requires judgment/contributes to cognitive load
Requires more advanced algorithms/ more powerful computing capabilities	High cognitive complexity	Contributes to cognitive load
Does not lead to cognitive fatigue	Persistent and enduring task	Leads to cognitive fatigue
No impact to cognitive load	High temporal pressure	Contributes to cognitive load
No impact to cognitive load	Significant negative consequences	Contributes to cognitive load
Machine can fuse information and present to human for consumption	Numerous sources of information	Can only process information perceived with organic sensors
	Task Environment Cognitive Factors	
Requires more advanced algorithms/ more powerful computing capabilities	Highly Dynamic	Requires agent to allocate dedicated cognitive resources task
No impact to cognitive load	High risk of injury or death	Contributes to cognitive load
No impact to cognitive load	Consistent moderate noise with random occasions of loud noise	Contribute to cognitive load
Cognitive capabilities reduced if outside of operating limits	Environmental concerns such as temperature, lighting, dust, and humidity not controlled	Contributes to cognitive load
May impact cognitive load depending on requirements	Concurrent cognitive tasks	Cognitive resources must be allocated among cognitive tasks

Another potential risk to teaming humans and machines lies in the interface design. Poorly designed, non-intuitive interfaces risk overloading the human agent, resulting in cognitive overload through mere team coordination alone. The authors subsequently analyzed how cognitive performance can impact task performance through poor Situational Assessment (SA) and decision-making. Next, the authors synthesized the literature, analysis of human and machine cognitive abilities and the analysis of team coordination and risks, to propose two new tools that assist users in identifying and analyzing the relevant task and environmental cognitive factors to determine the team composition that optimizes the cognitive performance of a task. The second thesis, "UTACC Human Machine Communication and Awareness",[6] concluded that the need to change the ways by which the USMC fights has been identified by key leadership through their public statements and organizational documents such as the Marine Corps Operating Concept.[7] The requirement is described in the Marine Operating Concept when it argues for us to "streamline our ability to evaluate and acquire advanced technologies to ensure

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[6] Major John Fout USMC, 2018

[7] USMC, 2016

we gain advantages from innovations faster than our competitors and adversaries".[8] This change will not be easily implemented due to the bureaucratic nature of the military. It is important to note though, the easiest way to implement change is through minimizing the disturbance to the organization. This is achieved by utilizing the doctrine that is already in place and accepted: MCTL 2.0.

Research team members included Dr Dan Boger, Scot Miller, Christian Fitzpatrick, Dr Don Brutzman, LCOL Alan Clarke USMC, Major Dan Knudsen USMC, Major John Fout USMC, Major John Ploski USMC, Capt Steve Krajewski USMC, Capt Kent Comstock USMC, Capt Lorenso Trevino USMC, and Major Steve Harvey USMC. This research was affiliated with the Marine Corps Warfighting Lab Florida Institute for Human Machine Cognition, and the SECNAV Naval Innovation Advisory Council.

The groundwork for UTACC implementation is in place and needs only be modified. The proposed changes to the Marine Corps Task List 2.0 utilizes the foundation for evaluation and accounts for man-machine integration. This allows for the easiest method in which to incorporate machines for use in future conflict. Thesis three, "Analysis of Emerging and Current Subsystem Technologies in Support of UTACC Capabilities",[9] analyzed emerging sub systems and recommended several for immediate consideration, in order of precedence, for potential investment:

a. Combine Planck Aerosystems, WiBotic, Sentient and Edgybees Into a System-of-Systems

Several subsystems that can be combined into one system-of-systems to provide a robust, persistent vehicle-mounted, mobile local security option. This combination would result in a quadcopter capable of providing persistent 360-degree surveillance for a vehicle-mounted combat patrol. Adding WiBotic's PowerPad wireless charging technology provides the capability of wireless charging once the quadcopter returns to the host vehicle, negating the requirement to exit the vehicle and change batteries. Multiple systems can be used to continue to provide surveillance while other systems are recharging. The addition of Sentient's Kestrel Land MTI and Edgybees digital map overlay adds computer vision and augmented reality features to the video feed received from the quadcopter running Planck Aerosystems' Shearwater™ software. Sentient's Kestrel Land MTI allows the operator to immediately identify moving objects on the video feed while Edgybees' digital map overlay increases the situation awareness with the augmented reality features of street names, route names, and waypoints added to the same video feed. Finally, Edgybees' digital map overlay allows the operator to add a pin drop to the map for locations that need further investigation if the patrol is unable to stop to investigate.

[8] USMC, 2016c, p. 5

[9] Major Steve Harvey USMC, 2018

b. *Integrate Alta Devices' AnyLightTM Panels into the RQ-20 Puma and RQ-11 Raven*

The researchers recommend integrating the Alta Devices AnyLight^{TM} lightweight, flexible solar power battery recharging panels with the RQ-20 Puma and RQ-11 Raven. Doing so may increase the flight duration of either UAV by up to 257%, providing longer mission durations and increased mission flexibility.

c. *Utilization of Department 13's MESMER® System for Forward Operating Bases and Patrol Bases*

Department 13's MESMER® system provides a robust capability for Forward Operating Base (FOB) CUAS security. With its omni-directional antennas capable of mitigating multiple UAVs simultaneously, MESMER® offers protection against swarms of commercial drones. Being able to whitelist known friendly UAVs allows MESMER® to mitigate blacklisted UASs using a variety of mitigation methods. Given the stationary nature of FOBs, coupled with the difficult-to-find nature of small UAVs and emerging adversary tactics, techniques, and procedures, MESMER® offers much needed force protection measures while adhering to the defense-in-depth tenet of force protection. The final thesis, "UTACC Robot Quick Wins",[10] recommended Switchblade (*see Figure 4*) and AR4 Light Ray as the two most capable platforms for targeting of adversaries.

Figure 4. This is an example of one of the unmanned systems that Comstock and Krajewski recommended MCWL try. Other researchers got to see Switchblade used in support of MCWL platoon operations at the Muscatatuck Training Center in Indiana in November 2018.

The Switchblade has the capability to locate and engage targets while operating BLOS. The AR4 Light Ray's small size and ability to intelligently detect human targets at long ranges help it

[10] Capt Kent Comstock USMC, 2018

stand out as a top performer in the targeting mission. The authors identified the Skyranger R80 and the Hivemind NOVA as the two most capable platforms for local security. The Hivemind NOVA's small size and intelligent capabilities make it well positioned to conduct local security missions. The Skyranger R80's unique abilities to operate from a vehicle and interchange with other UAVs while in flight also make it well positioned to conduct local security missions. Research was well received by MCWL. We continue this year by building a virtual environment for manned-unmanned teaming and related C2 concepts.

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

3. Short-Living Nodes and Links for Littoral Mesh Networking

The purpose of this study has been to investigate whether current technology is able to support a clandestine directional MANET that would enable dismounted teams to minimize risk of detection by enemy forces while conducting operations in an electromagnetically contested littoral environment. Correspondingly, the primary focus for research team was to conduct feasibility and constraint analysis related to prospects of implementing novel miniature steerable directional antenna systems, which could be integrated with portable and UGV deployed ATAK mesh networks in support of special operations forces. The research started with a thorough review of emerging directional antenna systems, protocols, and applications that could be used together to minimize the probability of detection of clandestine ground forces using a MANET. It transitioned to prototyping of man-portable and UGV/USV portable short-living link units and a series of limited field experiments with them. The prototyping included an original design including several 3D printed prototype gimbal-based antenna units to enable proof-of-concept student experimentation.

Figure 5. 3D Printed man-wearable miniature steerable directional antenna prototype.

Research questions designed for this study looked to maximize the use of existing protocols and technology and to provide future researchers with a summary of prior work and with recommendations concerning beneficial features of the protocols, applications and antennas considered during the course of the research. Question I: *What protocols can support a MANET during clandestine operations?* This question was investigated by examining the feasibility of existing protocols to manage electromagnetic transmission through the use of the OSI model, supported by software applications that allow an operator to control signal broadcasts and to obtain information and specify routes in a way that minimizes the threat to dismounted forces. Then, the features of the protocols that were most advantageous were discussed and hypothetically combined into one clandestine MANET protocol, which was examined in the context of an operational scenario. Question II: *Can existing antenna technology support dismounted force's use of directional MANET during clandestine operations?* To answer the second question, we developed a novel proof-of-concept prototype by using 3D printing and conducting limited field trials (*see Figure 5*). Question III: *Can miniature steerable directional antennas extend the range of aerial links from a UUV surface node? What is their potential utility in USV/UGV relay nodes?*

To answer these questions we designed and tested a proof-of-concept prototype (*see Figure 6*) of a miniature steerable directional antenna used onboard a small UGV to expand the mesh network to a multi-domain clandestine mesh networking environment.

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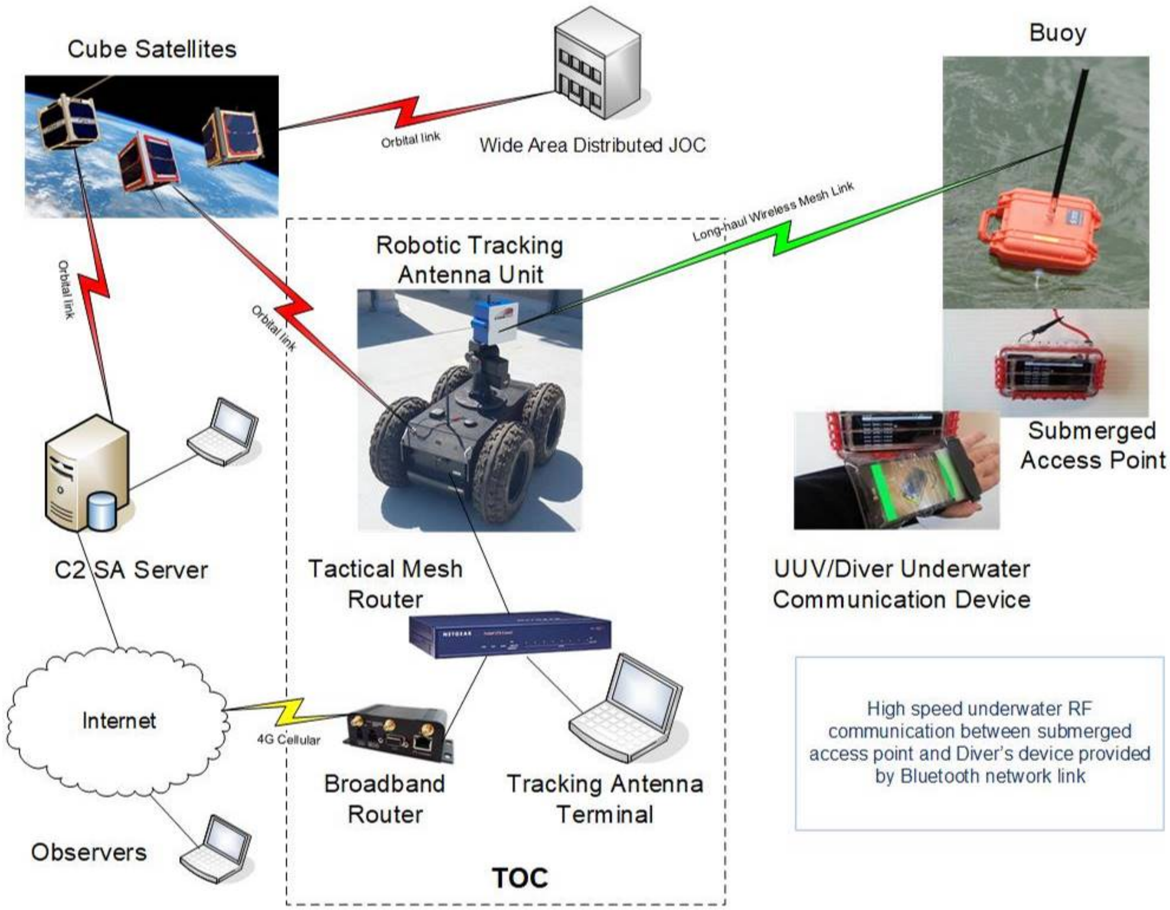

Figure 6. UGV based steerable directional antenna unit enables short-living multi-domain mesh network.

After being unable to find a suitable portable directional antenna system, we developed a prototype to test the feasibility of such a system. Our prototype antenna system was inexpensive, small, light, and able to fulfill our basic requirements, but we felt that it would not likely be the best fit for an operational application. Even with some reinforcing of the gimbal's components and wiring, the system would likely overheat from constant stabilization or fail as a result of the complex timing and calibrations. The gimbal design could provide a short-term, quick and inexpensive means to test MANET protocols that require the use of directional antennas until a more field-capable system is designed. For operational use, instead of employing a mechanically steered antenna, an electronically steered antenna could improve the reliability, availability and maintainability over a gimbal or pan-and-tilt system. Reliability would be improved because an electronically steered antenna is likely to perform without the failures seen in mechanical systems (e.g., overheating, stabilization vibrations). An electronically steered antenna would also be an improvement in that it could respond more quickly to direction changes and could receive information without prior coordination or assistance. Maintainability would be improved because with no moving parts, less maintenance would be required. Therefore, more beneficial than ruggedizing the gimbal components, we suggest that additional work should be placed on controlling an electronically steered antenna's side and back lobes.

The primary goal for UGV based directional link unit prototype part of the experimentation was to explore feasibility and constraints of extending a UUV/diver self-forming mesh to surface and ground nodes. Central to the experiment was to explore the significance of introducing steerable directional antennas to enable mesh links from a surface buoy (and potentially USV platforms) to mobile Ground Station land nodes.

In order to accomplish the task, a working prototype of Maritime-Land-Orbit networking was developed. The overall networking diagram is shown at Figure 5. A limited objective field experiment with UGV-based short-living steerable directional links was conducted in August, 2018 in conjunction with an NPS JIFX event. It proved the feasibility and good potential of our approach. In the experiment, the main objective was to capture a SAAB radar image from the U.S. east coast and immediately transfer it to a UUV/diver underwater communication device via an orbital network cluster. The high speed RF 2.4 GHz underwater network comprised a UUV/diver underwater communication device and a submerged access point. The access point and communication device were linked via Bluetooth. The tactical operations center (TOC) utilized a tracking antenna unit to maintain directional link to the remote buoy at a range of several miles. The tracking antenna unit prototype was developed by CENETIX based on an RMP400 Segway robotic platform. The TOC provided an orbital link to allow a remote operator to download images to the submerged device. In the experiment, an image taken on the U.S. east coast by the SAAB radar was transferred via a simulated orbital link to the command and control (C2) SA Server. In order to maximize the range to the surface buoy from the satellite ground station, we used a UGV-based directional steerable relay to the buoy site. It proved to be efficient, stretching the ground-to-buoy mesh link to 5-7 miles neighbor-to-neighbor distance on-the-move. A specially developed software listener running on the SA Server captured the image and forwarded it to the Tracking Antenna Unit in the field of operation. The Tracking Antenna Unit routed it to the buoy via local mesh network link. Due to the good quality of steerable the short-living link an underwater communication device also developed by CENETIX, successfully received the radar image.

MANET protocols are widely tested by military and academic institutions. It is difficult to provide a comprehensive review of the protocols, as naming conventions and consolidation of the protocols are not consistent. Though we did not cover every possible protocol that could be used to reduce detection of transmitted signals and we did not discuss the many variations of each, we demonstrated the availability of certain relevant features. While all of our recommended protocols have been tested to varying degrees, none have been implemented together. We feel that their combined strengths would result in a protocol that could reduce network detectability and increase the survivability of small ground force units; however, the combined delay of transmission will likely result in performance inferior to that originally achieved by the individual protocols as a result of the increased calculations and data packet size. Conclusion Overall, our studies of short-living man-wearable and UGV portable steerable directional links demonstrated a good potential of developing clandestine mesh networking solutions based on such an approach. As applied in conjunction with short-living node usage, which was the focus of CENETIX studies for CRUSER in 2017, it provided a promising solution for clandestine mesh networking in electromagnetically contested environments. The level of SA sharing across the ATAK type network reached the level of exchanging radar type images, ATAK COP alerts and asset tracking.

This Naval Postgraduate School, Center for Network Innovation and Experimentation (CENETIX) research team included Dr. Alex Bordetsky,PI, Professor IS, CENETIX Director; Mr. Eugene Bourakov, Senior Researcher, CENETIX and Information Sciences; COL Steve Mullins (ret), Information Sciences PhD Candidate, HICSS Doctorate Fellow; Information Sciences NWOT curriculum students LT Ryan Clapper USN, LCDR Beverley Crawford USN, LT Inna Stukova USN, and MAJ Justin Murphy USMC.

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

4. Aerial Swarm Behavior Development in Support of USMC Training

In response to increasing threats from adversary unmanned aerial vehicles (UAV), the Marine Corps Air Ground Combat Center (MCAGCC) has begun incorporating both friendly and adversary UAVs into Integrated Training Exercises (ITX) and other events. Exercise employment of these systems is manpower intensive (i.e., one vehicle, one operator), and therefore limited. Over the course of this project, the NPS Advanced Robotic Systems Engineering Laboratory (ARSENL) was able to leverage its previous success in the development of UAV swarm capabilities to implement adversarial behaviors for use in a real-world training environment and incorporating these capabilities into ITXs conducted at 29 Palms, CA.

This work was conducted along four specific lines of effort: 1) incorporation of existing ARSENL platforms and capabilities into ITX, 2) development of more easily operated fixed-wing swarm platforms with air-to-ground capabilities, 3) development of quadrotor swarm platforms with air-to-ground capabilities, and 4) development of fixed-wing and quadrotor swarm behaviors that realistically emulate observed and potential adversarial capabilities.

Existing ARSENL Zephyr II fixed-wing UAVs were utilized to support two ITXs and custody of 15 platforms was transferred to MCAGCC to facilitate ongoing utilization. ITX utilization included simulation of adversary aerial surveillance and air-to-ground attack (without ordnance drop). MCAGCC feedback and observed logistical difficulties in operating Zephyr platforms in an "expeditionary" environment necessitated increased focus on the development of a more easily operated fixed- wing platform.

The COTS Penguin airframe has been used as a research platform at NPS for several years. The aircraft is very easy for beginners and novices to fly and can be launched by hand, making it an ideal platform for MCAGCC use. Development efforts to adapt the Penguin to MCAGCC requirements included the incorporation of the ARSENL autonomy package, addition of a carriage and release mechanism for external stores, and several airframe modifications to improve performance and reduce weight.

Figure 7. Autonomously controlled "ordnance" release from the Penguin UAV.

The Penguin air-to-ground capability was of particular MCAGCC interest. Modification consisted of a simple wing-mounted 3D-printed part capable of holding two Nerf Pocket Aero Flyers (approximates 40mm ordnance) with a single 4g servo to release one or both (*see Figure 7*). Overall configuration allows for the carriage of four expendable stores. On-UAV ARSENL software was updated to allow for autonomous or command deployment.

Figure 8. CAD Depiction of the ACS-7 Mosquito Hawk quadrotor with two releasable stores.

Initial flights of NPS-developed ACS-7 Mosquito Hawk quadrotor prototypes (*see Figure 8*) were conducted during ITX18-2 for flight characterization and parameter tuning. A 3D-printed carriage and release mechanism similar to the one developed for the Penguin was incorporated into the Mosquito Hawk design. In addition to flight testing, the Mosquito Hawks were used to conduct on-call ground attacks (not fully autonomous) in support of USMC training. Update of autopilot firmware to incorporate ARSENL messaging and failsafe requirements and incorporation of ARSENL swarm capabilities was conducted over the remainder of the year with the platform being declared “swarm capable” in September (final pre-deployment tests are scheduled for November 2018).

At the request of MCAGCC, swarm behavior-development in support of this project focused primarily on the development of ground-attack attack behaviors that realistically emulate what Marines have observed or are likely to encounter in theater. Existing ARSENL formation flight, distributed autonomy, and consensus-based decision making capabilities were leveraged in the development of three distinct coordinated swarm behaviors. The "wave attack" behavior requires all swarm vehicles to fly in formation along a planned ingress path to simultaneously attack a single target. The "delayed attack" behavior requires swarm vehicles to determine an attack sequence and fly individually planned paths to attack a single target with a specified temporal spacing between each attack. Finally, the "overwatch attack" behavior requires the swarm to elect a single vehicle to take up a surveillance position over the intended target with the rest of the swarm conducting a wave attack (after the surveillance vehicle is in position). Ground-attack behaviors were successfully incorporated into ITX events with the Zephyr II, and final testing of the behaviors on the Penguin and Mosquito Hawk platforms to include actual release of simulated ordnance was conducted in August and September respectively.

The research team members included Dr. Duane Davis, Dr. Kevin Jones (Co-PI), CDR Katy Giles USN, and Marianna Jones. This research is affiliated with DARPA, SPAWAR Systems Center Atlantic (SSC-LANT), Marine Corps Air Ground Combat Center (MCAGCC), and the Marine Corps Tactical Training Exercise Control Group (TTECG).

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5. Adaptive Submodularity for Mixed-Initiative UxV Network Control Systems

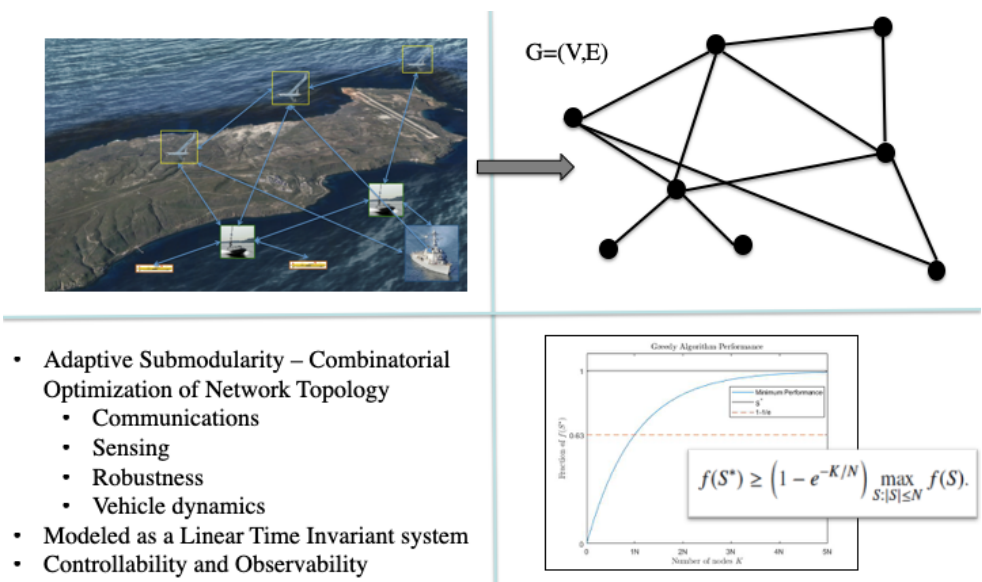

Figure 9. Adaptive submodularity for UxV network control system.

The goal of the research was to develop a methodology to control a Network Control System (NCS) composed of heterogeneous nodes (*see Figure 9*). The NCS consisted of unmanned and manned assets, whereby each node has vehicle dynamics, communications and sensing capabilities and constraints. Given potentially competing objectives between multiple virtual leaders and tasks, a framework was developed for controlling the network nodes as a single system. Metrics were also developed for ensuring adequate performance in terms of controllability, observability, and robustness of a Linear Time Invariant (LTI) system. The metrics were incorporated into an optimization function that was shown to be submodular. This property allows us to use the greedy algorithm to solve a combinatorial optimization in polynomial time. This enables the generation of near-optimal formations that are used to dynamically re-position agents relative to the uncontrolled manned platforms represented as virtual leaders.

Figure 10. Final day group picture of MTX 2017 participants at San Clemente Island (SCI).

In November of 2017, the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) at the Naval Postgraduate School (NPS) conducted a Multi- Thread Experiment (MTX) on San Clemente Island (SCI), CA (*see Figure 10*). The MTX provided a realistic multi-domain scenario to test and increase the autonomy of collaborative unmanned systems. The NCS at the MTX consists of aerial, surface, and undersea assets. These unmanned vehicles and a Navy Destroyer (DDG) operate in support of a Naval Special Warfare (NSW) unit conducting a mission to land on SCI and act on a target. The ScanEagle Unmanned Aerial Vehicle (UAV) provided Intelligence, Surveillance and Reconnaissance (ISR) support with the capability of transmitting live video footage through the network. The SeaFox, a speed-boat sized Unmanned Surface Vehicle (USV) provided transportation and limited ISR capabilities with surface search RADAR. The REMUS 100 Unmanned Underwater Vehicle (UUV) was used to map the seafloor with SONAR during Intelligence Preparation of the Battlefield (IPB) before the NSW unit lands on SCI. The NCS was modeled as a graph of nodes and links. The unmanned vehicles, NSW unit, target, and support ship (DDG) comprise the nodes of this graph. These nodes were connected by links which represent the sensing and communication relations between these nodes. A high-level controller, rather than design a control that specifies exact rudder angles or shaft speeds was developed for the UxV NCS. This controller acts as a secondary controller on top of the primary controller onboard the individual agents. This controller positions mobile nodes to maintain the ability to communicate and sense the target and any other threats. Results of the research: 1). Validated the use of adaptive submodularity as an appropriate near real-time, near-optimal approach for a high-level UxV NCS. 2) Developed a novel LTI control architecture based on a multiple virtual leaders for distributed network control. 3) Compared and contrasted graph robustness measures for including robustness as an important system optimization parameter.

This research was affiliated with the NPS Center for Autonomous Vehicle Research (CAVR), and the project team included Dr. Douglas Horner, Dr. Sean Kragelund, ENS Noah Wachlin USN, and ENS Ben Keegan USN. A video summary of the project is available on the NPS video portal and on the CRUSER YouTube channel.[11]

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6. Swarm Future Platforms

The NPS ARSENL research team has been at the leading edge of Swarm research internationally, in particular for swarm-versus-swarm and counter-swarm tactics, but the current fleet of Gen2 aircraft are dwindling due to attrition and property transfer to the Academies and other collaboration partners. Further, the existing hardware is approaching technological obsolescence. This project was intended to bring to completion the Gen3 direct replacement design to the existing Gen2 fleet, and build out small flocks of several new airframes, both fixed-wing and multi-rotor, to satisfy current and projected future research goals.

The prototype Gen3 airframe (*see Figure 11*) completed a successful functional check-flight (FCF) in August of 2018. A few minor modifications are being made, primarily to further improve the few human handling issues that became apparent after repeated field deployments, and a small fleet will be built out this fall.

[11] NPS video portal link: http://web.nps.edu/Video/Portal/Video.aspx?enc=fQYhjE1oV0Z5nE1Y5oX6u9IQTPIvhLNS

CRUSER YouTube channel link: https://youtu.be/o2mTAzyZdPo?list=PLUeG2W-NLlozTeWNuAFWb0qIdcs9JJznZ

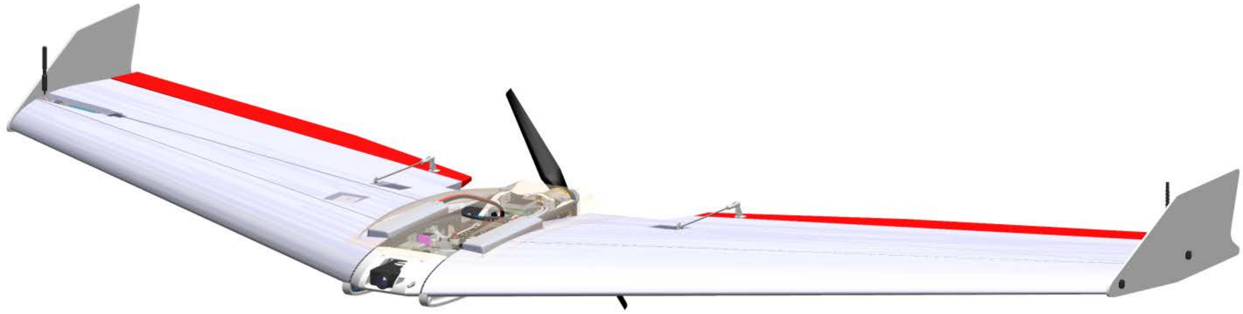

Figure 11. Gen3 Zephyr airframe.

A new, conventionally-tailed fixed-wing aircraft, the Penguin, was designed and assembled and completed a successful FCF in March of 2018. The Penguin design is a reasonable facsimile to the deployed AV Raven airframe - hand-launchable, and with similar flight characteristics and endurance, but the Penguin carries the same swarm avionics as the rest of the ARSENL fleet. The Penguin is also capable of releasing stores from under the wings, allowing it to perform remote, precision delivery or simulated attack experiments. Due to the autonomous hand-launch capability and low-speed landings, the Penguin is suitable for flights in areas without a runway, launching from rugged terrain or a building top, and recovering on unimproved roads, parking areas or grass fields. Flight characteristics for the Penguin make it a better option for pilots with less fixed-wing experience, due to the slower speed and natural stability of the airframe. We are slowly building out a fleet of Penguins, for future ARSENL work, and potential use by other CRUSER research groups.

Figure 12. ASC-7 Mosquito Hawk UAS.

Lastly, a new multi-rotor airframe was added to the fleet, the ASC-7 Mosquito Hawk (*see Figure 12*). The Mosquito Hawk was designed to take advantage of recent technological advances in the race-drone industry, utilizing a super rugged CNC-cut Carbon fiber frame as well as high efficiency motors and electronics from the race-drone market. The Mosquito Hawk is quite small, with a 290mm motor-to-motor span, seven-inch propellers, and a flight weight of under

600g. Under autopilot control, it can fly as fast as any of the ARSENL fixed-wing airframes (nominal cruise speed is about 35knots), and switching to first person viewpoint (FPV) pilot control, speeds of over 60 knots are possible, or even faster with different battery options. The Mosquito Hawk carries the same swarm avionics as the rest of the ARSENL fleet, as well as a similar store-release mechanism as that utilized on the Penguin. The Mosquito Hawk completed a successful FCF in September 2018. Work still needs to be done to perfect the camera payload integration and investigate the flight endurance. Endurance is expected to be over 20 minutes with the camera payload installed and stores attached, and close to 30 minutes with the camera payload and stores removed. The Mosquito Hawk is by far the easiest swarm asset to operate, with launch-to-landing autonomous flight, and assisted flight modes to aid novice pilots.

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7. Bio-inspired MEMS acoustic sensor for robotic autonomous systems applications

When compared with the electromagnetic counterparts, acoustic sensors have many advantages in detecting drones that include non-line-of-sight, passive, low-cost, and low power, weight, and size. Acoustic sensors are the primary sensors employed in most unattended ground sensor systems because they can provide detection, direction finding, classification, tracking, and accurate cueing of other high-resolution sensors. The ability to equip RAS with acoustic sensors that can effectively provide awareness, identification and localization of the acoustic sources on the soundscape could allow immediate countermeasures towards threats or cooperative operation with partner platforms. These capabilities, obtained by miniature sensors with minimal impact on the internal signal processing and computational resources and power budget could signify a tremendous source of operational asymmetry. In order to develop miniature acoustic sensors capable of detecting locating and potentially identifying RAS we sought inspiration in Nature. There are insects such as the parasitic fly Ormia Ochracea that have developed unique approach to direction finding. The female of this species seeks out chirping crickets to lay their eggs on, and do so with an accuracy of less than two degrees. The biomimetic version of the fly's ear drums can be manufactured using microelectromechanical (MEMS) technology and potentially employed in the localization of autonomous vehicles/systems.

The objective of this research project was to continue the development of bio-inspired MEMS directional acoustic sensors to operate in FRIEND robotic autonomous systems (RAS) or other unmanned platforms (UP), for localization and identification of acoustic signatures of other FRIEND RAS or UP (for cooperative tasks) or FOE RAS or UP (for awareness and countermeasures).

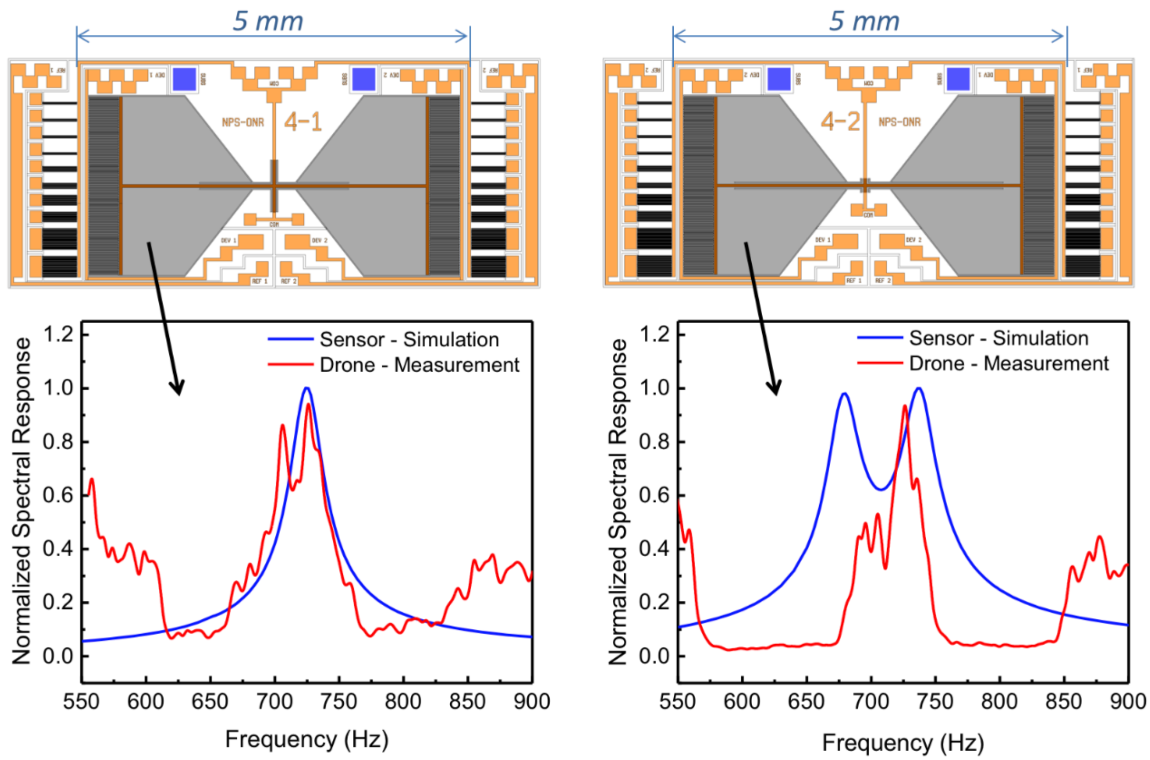

Figure 13. Simulated response of the designed sensors compared with acoustic signature of drones between 550 and 900 Hz. The matched response of the sensor increases the signal-to noise ratio, which will allow for efficient detection.

With current FY18 CURSER funding, we have been working on collecting acoustic signatures of UASs, specifically, small flying UASs and analyzing them in order to design sensors optimized for those acoustic sources (*see Figure 13*). Several drones' acoustic signatures were recorded using research grade reference microphones and appropriate instrumentation. This task was performed in open field (JFIX exercises) and in the NPS anechoic chamber. Several flight regimes and loads were used to record data from 10 different small flying UASs. The spectral responses were analyzed and found very interesting features. Each drone presents some unique spectral lines due to configuration, load, flight regime, etc. However, some acoustic spectral features were perennial for all drones, all flight regimes and all loads.

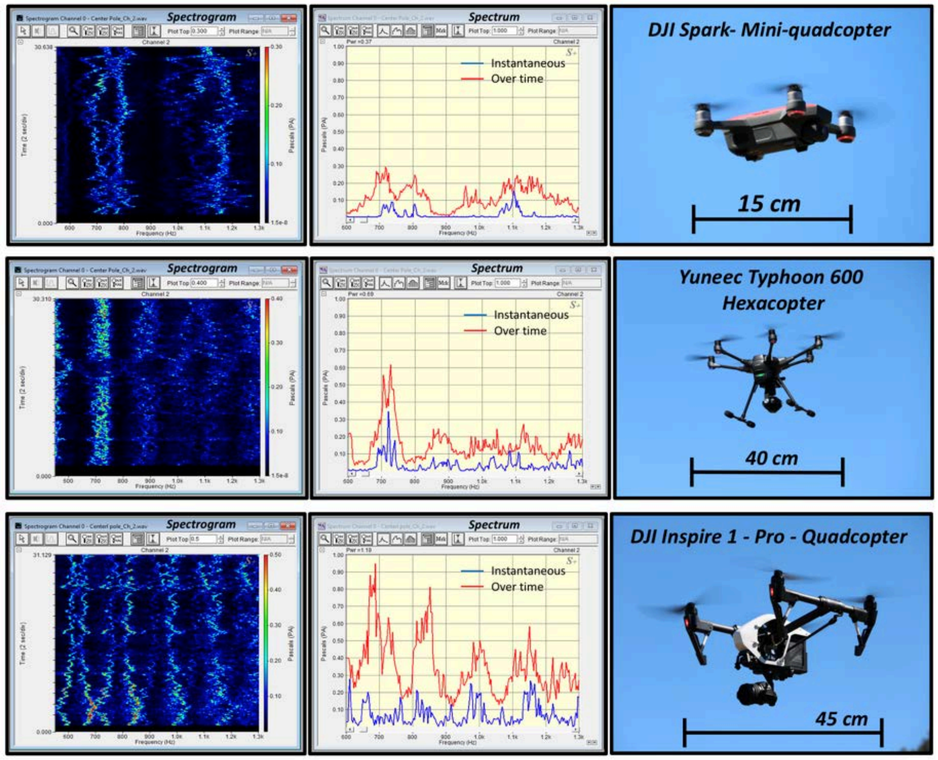

Figure 14. Acoustic signature of small flying UASs. Left column shows the spectrograms, central column shows the spectra and the right column shows the picture of the drone, highlighting the size and number of rotors. Notice (*central column*) that all drones exhibit a peak at around 700 Hz.

Based on the common spectral features observed in the measurements, two MEMS sensors were designed to resonate around 700 Hz (*see Figure 14*) and be insensitive everywhere else. Special features were added such as long bridges, straight capacitive comb fingers, narrow gaps between fingers and an imbedded capacitive network to allow adjusting the reference to the electronic readout. Three configurations were designed. Two single resonance around 700 Hz and one double resonance, also, around 700 Hz to account on any variation due to flight regime or load. The sensors were sent to MEMSCAP foundry service for fabrication and will be ready for testing in late October 2018, which we plan to do in the JIFX 19-1 and 19-2 campaigns.

Progress was also made in the electronic readout where several configurations were studied to optimize sensitivity and directionality. Synchronous demodulation seems to be the technique that enhances sensitivity. A dedicated circuit will be designed and characterized as the research progresses.

Finally, a parallel effort is also underway to develop in house capability to fabricate sensor prototypes using the NPS microfabrication facilities. The reason for that is to reduce the restrictions imposed by the design rules of commercial foundries, which limits the performance of the sensors. The first NPS-produced MEMS directional acoustic sensors are expected to be ready for testing before December of this year (FY18).

The research team included Gamani Karunasiri, Fabio Alves, Renato Rabelo, and LT Todd Coursey USN

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8. The Decision to Rely on Automation Under Stress: The Debut Experimentation Effort for the Human Cognition and Automation Lab

This funded project had two main objectives. The first was initial experimentation in a multi-experiment study investigating the effect of stress on reliance decisions in human-autonomy teaming. Experiment 1 was the included experiment in this proposal, and is the first of a three-experiment study focused on how the decision to rely on autonomy is affected by various factors such as stress and reliability. The second objective was to establish an interdisciplinary human-autonomy teaming lab in the NPS Information Sciences Department.

The experimentation and subsequent lab development went hand in hand, as the proposal funded the equipment necessary to conduct the experiment, and the equipment and space allocated for experimentation will become the human-autonomy teaming lab. The human-autonomy teaming lab has already supported two thesis students' research activities. The first student was a mechanical engineering student, and conducted a study on trust in human-autonomy teams, differentiating between competency-based and integrity-based trust. The second student was an operations research student conducting a study sponsored in part by the Coast Guard assessing the ability to work with machinery that may be difficult due to balance issues one faces on a moving vessel. In addition to the line of studies planned for the lab, and detailed in the proposal, planned studies that the lab will support in human-autonomy will include a four year collaboration effort examining decision support systems in maritime operations. The establishment of the human-autonomy lab is an ongoing effort, and has already proved to be an asset in less than a year.

Experiment 1 is ready to start recruiting participants. All IRB requirements have been completed, and the study has been approved. This experiment has been accepted, and will be presented at the Hawaii International Conferences on System Sciences in the (HICSS) in the *Collaboration with Automation: Machines as Teammates* minitrack in January, 2019. A brief overview of the experiment is detailed below.

Experiment: Stress and human-autonomy teaming

The effect of stress in human-autonomy teaming is an area of research that has largely been overlooked. Previous studies examining the effect of stress in this area have only looked at the effects of time pressure[12] and distracting noise.[13] While both time pressure and noise do induce

[12] e.g., Rice & Keller, 2009

some stress, they both introduce confounds that make any claims about the effect of stress dubious as best. Time pressure is confounded with quite literally, shortened time; and noise stress is confounded with distraction. Therefore, better stress manipulations are needed to adequately assess how stress affects impact human-autonomy teaming. Additionally, measurements of cortisol and heart-rate variability (HRV), common methods for measuring stress[14] are needed to (a) ensure stress manipulations were successful, and (b) examine what level of stress was achieved in the study. Stress can have differing effects depending on the level of stress and type of task,[15] and therefore for generalization purposes it is important to examine the level of stress achieved in by the manipulations.

From a global perspective, the effect of stress on human-autonomy teaming needs more research. However, the specific focus of the proposed study is to examine the effect of stress on the decision to rely on autonomy. Stress limits executive resources that are needed for higher order executive functions, such as working memory and attention allocation,[16] resources that are needed to make rational and informed decisions.

Deciding whether or not to rely on autonomy is fundamental in human-autonomy teams. Misuse and disuse of autonomy can be the result of too much or too little reliance.[17] Because the decision to rely on autonomy can greatly affect the success of a human-autonomy team, and because these decisions require executive resources that can be depleted due to stress, the proposed study aims to explore the effect of stress on the decision to rely on autonomy under varying levels of autonomy reliability. Reliability is taken into account in the current study because it is one of the largest factors that influences the decision to rely on autonomy.[18]

Overview. While the experimental scope of the first proposal is focused on Experiment 1, it is important to view how Experiment 1 fits in with the larger experimental campaign. The overall study is a three experiment study with the aim to investigate the effect of stress on the decision to rely on autonomy under varying levels of autonomy reliability. All experiments will manipulate stress and reliability as independent variables. In brief:

a) Experiment 1 will be a 2 (stress) x 2 (reliability) repeated measures design with stress manipulated between subjects and reliability manipulate within subjects.
b) Experiment 2 will be a 2 (stress) x 2 (reliability) x 2 (reported system confidence) repeated measures design with stress manipulation between subjects and reliability and reported systems confidence manipulated within subjects
c) Experiment 3 will be either a replication of Experiment 1 or Experiment 2 depending on whether reported system confidence has an effect in the previous experiment.

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[13] e.g., Peters, 1994; Sauer et al., 2011

[14] e.g., Michels et al., 2013; O’Donnell et al., 2015; Shields, Sazma, & Yonelinas, 2016

[15] Dickerson & Kemeny, 2004; Shields et al., 2016

[16] Kogler et al., 2015; Shields et al., 2016

[17] Parasuraman & Riley, 1997

[18] Lee & See, 2004

Experiment 3 will extend the findings of Experiment 1 and 2 by a replication in design, but with a humanoid robot instead of a desktop computer.

Stress. In all studies, stress will be manipulated between subjects, so that the participants will be randomly assigned to either a high- or low-stress condition. According to a meta-analysis on the effectiveness of acute stress laboratory manipulations, the largest stress response is induced by uncontrollable, social-evaluative stressors.[19] The most common of these is the Trier Social Stress Task (TSST).[20] The TSST will be used in all experiments to induce stress, and involves two phases: (a) an anticipatory phase, and (b) a test phase. In brief, the participants: (a) are told that they will have to deliver a speech to a panel, and are given five minutes to prepare their speech (anticipatory phase); and (b) are then required to deliver their speech to a stoic panel for five minutes, and then told to perform mental math for five minutes in front of the same panel. This stress technique induces stress through social-evaluative threat, and uncontrollability. A previous study by the PI for this research indicated that there may be a differences in tolerance to stress manipulation between the population of study participants at NPS, mostly mid-career military officers, and the general population. Understanding this difference also contributes to the research goals of the envisioned human-autonomy teaming lab. The pilot study for Experiment 1 will include reviewing potential modifications of the TSST to ensure effective stress manipulation for the NPS population.

There are many processes that activate in response to stress as the body tries to counteract and recover from the deviation of homeostasis brought about by a physical or psychological event (i.e., stress).[21] One of the responses to stress is activation of the hypothalamic-pituitary-adrenal (HPA) axis that produces cortisol.[22] Cortisol can be measured through saliva collection, and is often used to as an objective measure of stress.[23] While cortisol is the best measure of stress, its onset is approximately 20 minutes after the stressor onset,[24] and therefore it does not capture moment to moment variations in stress. However, HRV is another measure commonly used to assess stress[25] and is capable of tracking moment-to-moment changes. Therefore, cortisol and HRV will be collected throughout experimentation as reliable measures of stress.

Decision to rely on autonomy. The main dependent variable in the study is the decision to rely on autonomy. Participants will be repeatedly exposed to a task where they have to choose a response, after they make their response will then receive a suggestion from autonomy. Reliance on autonomy in times where the autonomy advice differs from their own is the behavioral measure of interest. However, this study seeks to look beyond simple reliance to the decision

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[19] Dickerson & Kemeny, 2004

[20] Kirschbaum, Pirke, & Hellhammer, 1993

[21] Kogler et al., 2015

[22] Kogler et al., 2015c

[23] Smyth et al., 2013

[24] Smyth et al.

[25] e.g., Michels et al., 2013; O’Donnell et al., 2015

process. Does stress cause the decision maker to make decisions using a heuristic-based decision approach due to lack of cognitive resources? And if so, does this heuristic-based approach lead to increased autonomy bias overall or does it depend on the reliability of the autonomy? While there is support for stress leading to more heuristic-based decision making[26] more research is needed on stress and decision making in general. This makes it difficult to directly apply this research to decision regarding autonomy reliance. Additionally, while reliability is a major factor in deciding whether or not to rely on autonomy, stress may disrupt the ability to integrate new information about the autonomy's reliability. There is evidence that stress disrupts learning and the ability to incorporate new information in decision making.[27] Therefore, it remains an interesting question whether learned reliability under stress influences the decision to rely on autonomy or if the reliability estimate at the beginning is kept constant.

Inferences into decision making processes can be achieved by looking at reaction times (time it takes to make a decision), eye-tracking, and pupil dilation.[28] These measures will be used to understand the decision making processes in autonomy reliance under stress.

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[26] e.g., Margittai et al., 2016

[27] Porcelli & Delgado, 2017

[28] e.g., Guazzini et al., 2015

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9. Cooperative Autonomous ScanEagle

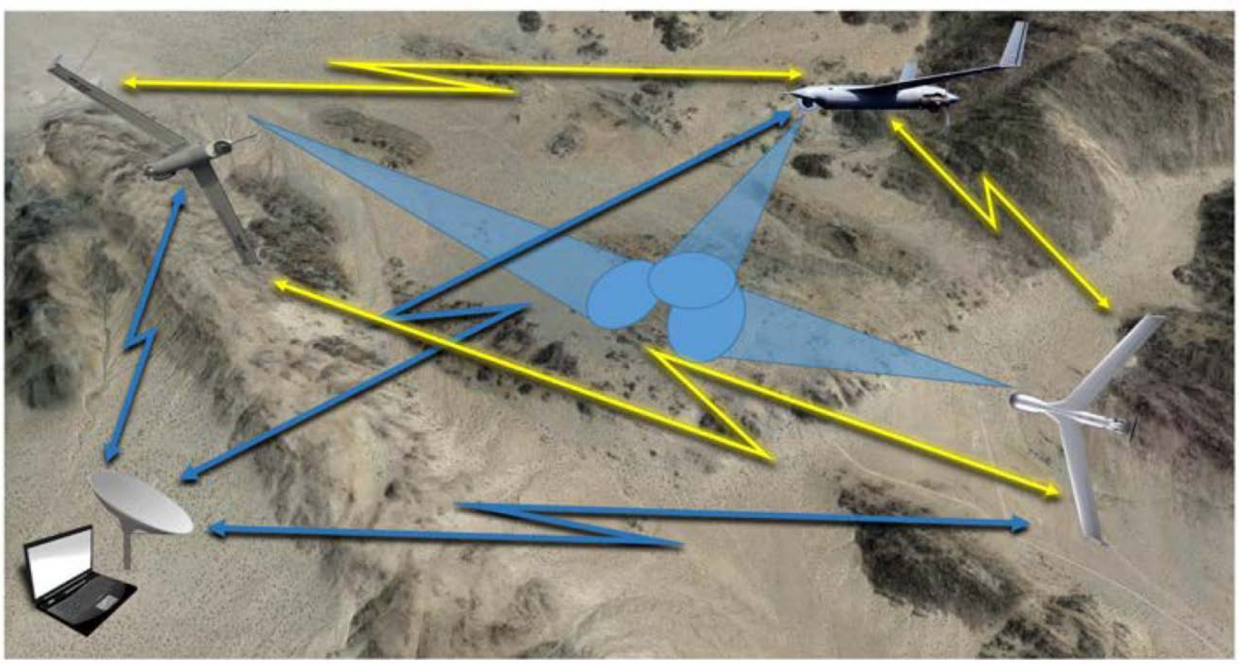

Figure 15. Cooperative behaviors of the ScanEagle UAV.

This approach addressed the challenges associated with the technology gap that exists between current state of unmanned remotely operated tools and the capability of robotic systems to support the warfighter in a fully autonomous mode. Remotely operated platforms are used routinely, but most still require manned attention for most of the mission. Fully autonomous systems capable of dynamic and agile interaction with warfighters remain unavailable. This work specifically focused on reducing the cognitive load on the operator by enabling autonomous and cooperative behavior of the ScanEagle UAV (*see Figure 15*). This research consisted of a partnership between NPS, Space and Naval System Command (SPAWAR) System Center (SSC) Pacific and Naval Air Warfare Center Weapons Division (NAWCWD) China Lake. It leveraged expertise and merged capabilities developed by each organization. In 2014, NPS demonstrated the initial capability to autonomously task a ScanEagle from an onboard computer, referred to as the secondary controller. In 2015, SSC Pacific developed an integration package for ScanEagle payloads that has since been adopted by the Naval Special Warfare (NSW) Multi-mission Tactical Unmanned Aerial System (MTUAS) program as a baseline capability for all advanced payloads in their portfolio. This integration manages and distributes power, data, and signals for payloads. One component of this integration kit is a small embedded computer module offering onboard computing capabilities developed by NAWCWD China Lake. We have successfully explored autonomous behavior of a single ScanEagle UAV. For this, an Information Operations (IO) payload was installed on the aircraft and autonomously redirected itself as necessary to refine the IO solution. Upon achieving a satisfactory solution, the payload redirected the aircraft to an optimal route to provide and maintain full motion video (FMV) coverage of the target. This was accomplished by the secondary controller autonomously slewing the onboard camera to maintain the SPOI on a fixed wireless mesh node. In addition, further refinement of the secondary controller was performed due to lack in vehicle dynamics in the additional algorithm. Extensive flight testing was conducted to tune the turn rate controller for optimizing the vehicle trajectories. The additional tuning and flight testing has produced a robust turn rate controller for the ScanEagle.

The research team included Dr. Sean Kragelund and Dr. Doug Horner, and the research was affiliated with Space and Naval System Command (SPAWAR) System Center (SSC) Pacific and Naval Air Warfare Center Weapons Division (NAWCWD) China Lake.

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10. Development of Autonomous, Optimized Capabilities for MC3

The "Development of Autonomous Capabilities for MC3" project is intended to: 1) Develop autonomous, optimized satellite commanding and data exfiltration capability and incorporate into baseline pass scheduling for implementation at each ground station. Of particular interest is to develop intelligent, script-based commanding and intelligent, response-based-on-downlinked-data feedback to the commanding script. 2) Develop a specification of standardized commands and data formats to simplify new satellite automation for generic satellite tasking, i.e., to perform basic satellite functions, or housekeeping tasks. 3) Develop applications ("apps") that can be used to retrieve and view status and data from any location using a computer or mobile device. Rationale for the need for this capability includes the following: 1) The number of very small satellites is rapidly proliferating. 2) The "many satellite, few ground station" problem is becoming more important. 3) The rapid increase in demand drives the need for autonomous, optimized commanding of the ground stations, as well as the capability to view ground station status and data from any location.

As the project has proceeded, progress includes the capability to use script-based commanding for the PropCube satellites. The PropCube satellites are 1U CubeSats able to collect GPS measurements and turn on and off UHF and S-band beacons in support of ionospheric propagation studies. There are currently three PropCubes in orbit being operated by the NPS Space Systems Small Satellite Laboratory. These satellites were delivered with no automated commanding capability, but are expected to be used for some beacon operations supporting NRL ionospheric science. The script-based commanding, incorporating feedback where possible, has already dramatically improved our capability to uplink commands and download data files. The PropCube Command and Data Handling (C&DH) is particularly challenging as the downlink data rates and efficiency are very low, while the uplink data rate and efficiency is relatively high. This low efficiency data downlink highlights the need for satellite autonomy and makes it important to use efficient scripts and downlinked telemetry as efficiently as possible to avoid unnecessary downlink repetition.

As part of improving the real time commanding efficiency, current efforts include LT Gilley's thesis (June 2019) on decryption of partial packets in the satellite downlink for real time telemetry analysis, currently unavailable except for post-pass processing. This improved level of feedback will immediately further increase the efficiency and capability of the script-based commanding, reducing unnecessary repetition of downlinked telemetry. As part of the spiral development of this software, the next steps for this project include the test implementation of a more advanced autonomous commanding capability. The next step is to take a language such as Python and develop satellite objects that can be based on standardized sets of commands. Embedding the satellite into the language will permit the use of the entire range of programming structures for the satellite. In addition, by standardizing the sets of commands, different satellites can be controlled using the same software. The details of the satellite will be embedded behind the object definition of that specific satellite. At the same time, the automation of the ground stations themselves, actually considering the remote ground stations as similar to satellites, is now understood to be a very similar problem and integral to the satellite automation itself. In particular, as the number of ground stations increases, it becomes important to apply the same principles of autonomy and ground station telemetry as with the satellites themselves.

The research team included Dr. Jim Newman, Jim Horning, Noah Weitz, and Mike Bailey. This research was associated with DoD Space.

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11. Simultaneous visual and IR UAV imaging of littoral systems for AI driven change detection

Bar built estuaries, also known as ephemeral rivers, are common features to coastlines where precipitation is marked by large seasonal variability and the coast is subject to high wave energy. During dry months (typically summer), the buildup of sediment at the river mouth closes of any circulation between the back lagoon/river and the coastal ocean. When precipitation increases, water from the back lagoon/river rises and eventually breaches the beach, thereby creating a direct connection between the river and coastal ocean.[29] During this transition, morphological change is rapid and dramatic. Here, in order to automatically detect change at Carmel River State Beach, an ephemeral river, machine learning algorithms were implemented for image classification using deep neural networks. Classification of heterogeneous environments, such as landscapes, is challenging. Common classification algorithms involve image segmentation where pixel-level class identification is used to create homogeneous classes that span an entire image.[30] Here, deep neural networks are trained using transfer learning methods on a single-label dataset including eight classes of coastal landforms.

Remarkable progress in image classification tasks was made due to the availability of the large annotated datasets (e.g. ImageNet) and the advances made with deep learning methods with Convolutional Neural Networks (CNN). However, obtaining large annotated datasets in heterogeneous landscapes, in this case coastal landforms, remains a challenge. Transfer learning is an effective method for employing benefits of deep learning methods with CNN's on small, annotated datasets. In transfer learning low lever features are transferred from pre-trained CNN's on very large datasets like ImageNet to a large CNN model (VGG19) trained on the small dataset without extensive overfitting monitored via validation dataset.

The transfer learning approach used here is to take a pre-trained network on ImageNet and copy it without the top classification layers to the target network. The target network on top of the transferred layers has two fully connected layers with relu as activation functions and 50% dropout that are randomly initialized. This network configuration is then trained toward the target task. The choice is made to backpropagate errors from the target task into the mid layers of the base (copied) features to fine-tune them to the target task while the very bottom transferred feature layers are left frozen, meaning that they do not change during training on the target task. If the target dataset is small and the number of parameters is large, fine-tuning may result in overfitting which is monitored via validation dataset.

The target network is developed using Keras with Tensorflow backend. Amazon AWS EC2 with GPU instances are used for training and inference. The best result is achieved on VGG19 architecture with five bottom frozen layers and the rest of the layers including classification layers on the top of the network trainable.

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[29] Kraus et al. 2002; Rich and Keller 2013

[30] Buscombe and Ritchie 2018

Performance of classification task is summarized with confusion matrix which presents counts of all testing instances based on their actual class and the class predicted by the model. All entries on the diagonal of the confusion matrix represent correct predictions by the model, accounting for an average accuracy of 94% (*see Figure 16*).

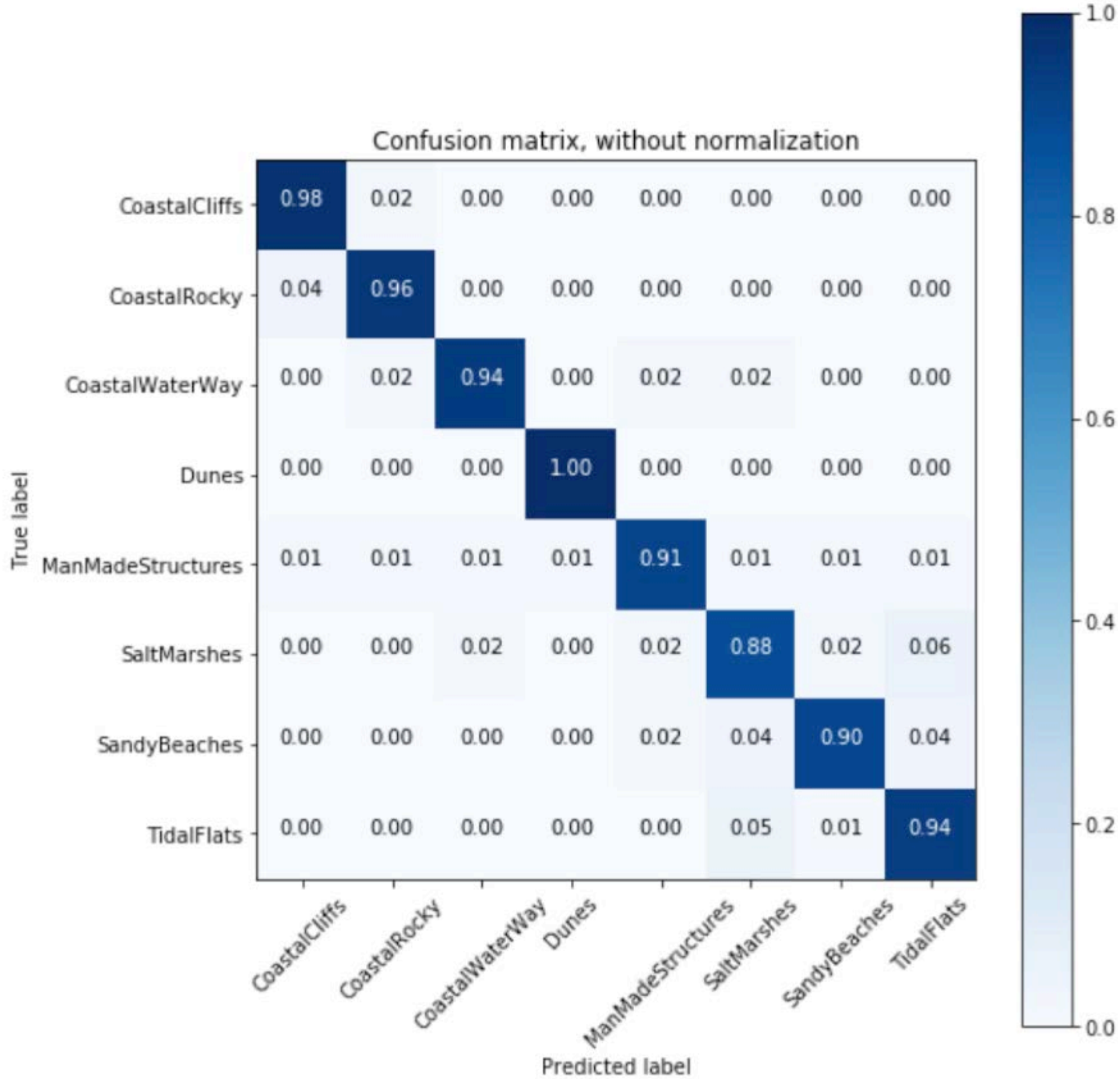

Figure 16. Confusion matrix showing model performance for over 750 test images, where the true label is (vertical axis) is compared with the model predicted label (horizontal axis).

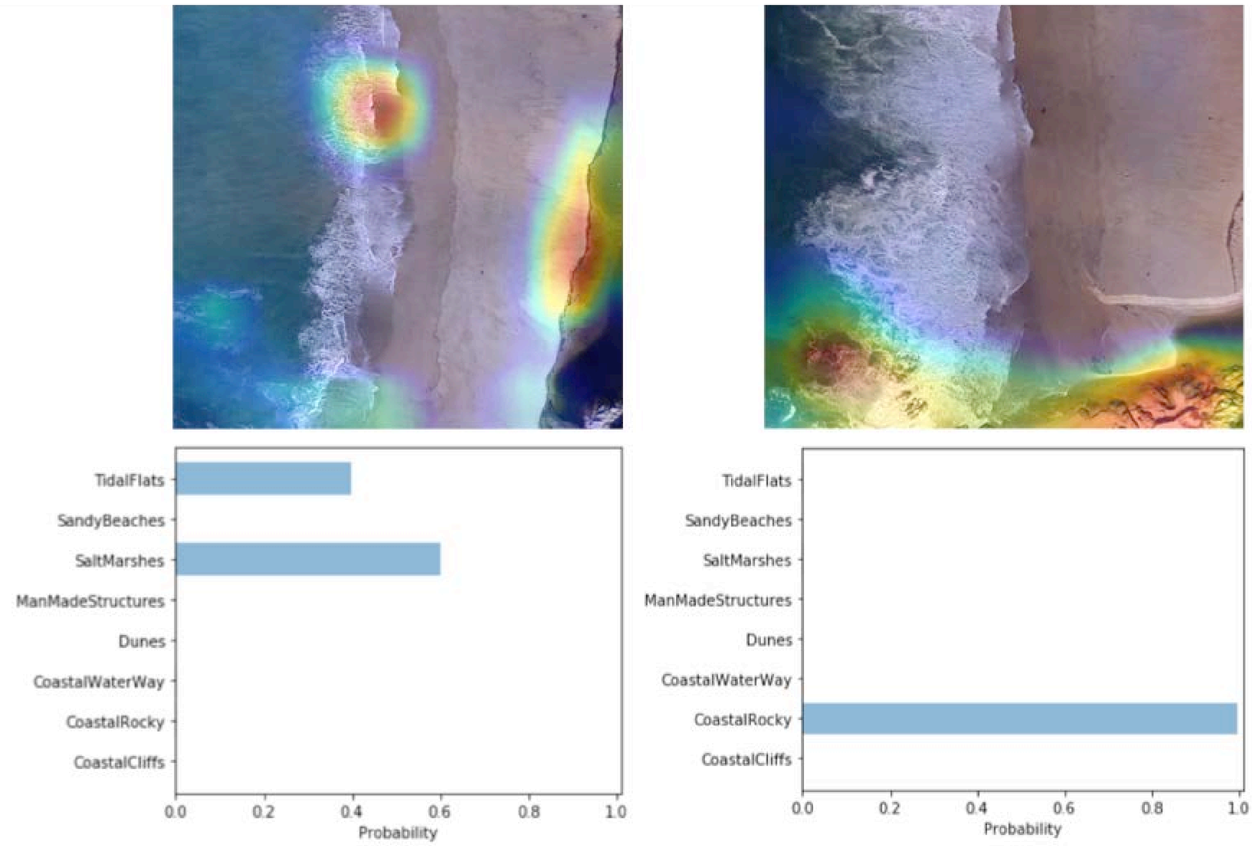

Figure 17. Class activation map and probability classification for Carmel River State Beach on December 6 (left) and January 23 (right). Color warmth indicates degree of confidence in label classification for dominant label shown below.

Change detection algorithms are being developed to use this CNN model to predict a change in landscape at a given location. For example, Figure 16 shows the model predictions for the same area of Carmel River State Beach, which were created using Structure-from-Motion but taken on December 6, 2017 prior to beach breaching (left) and January 23, 2018 after beach breaching (right) (*see Figure 17*). During the breach event, rocky outcrops were exposed in the bottom part of the image, and the back lagoon/marsh drained. Therefore a change in class prediction from Salt Marsh to Coastal Rocky is appropriate for these images.

This project will collaborate with another ONR-funded project to engage high school students in STEM research projects, which will happen this winter at Carmel River State Beach.

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12. Network Enabled Digital Swarm Image Synthesis (NEDSIS) Phase 2

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. We have developed a finite impulse response (FIR) architecture of complex range bin processors to be hosted within a DRFM (digital RF memory) on a FPGA (Field Programmable Gate Array) or System-on-a-Chip (SoC) to modulate an intercepted and sampled imaging radar waveform. We have shown this "digital image synthesizer" (DIS) architecture to be capable of synthesizing multiple, large, false targets against high range resolution, profiling radar (such as synthetic aperture radar (SAR) and inverse SAR) providing a superior RF decoy capability in all types of weather. For the image synthesizer to provide a false-targeting, seduction and deception capability successfully, it must correctly synthesize the temporal lengthening and amplitude modulation caused by the many recessed and reflective surfaces of the target and must also be distributed and networked to generate the realistic multi-faceted Doppler profile for each surface. Figure 18 shows the network-enabled DRFM concept being developed.[31] In this manner, the return signature being broadcast back to the emitter(s), is coherently derived and is disbursed in both range and angle adding to the target's realism.

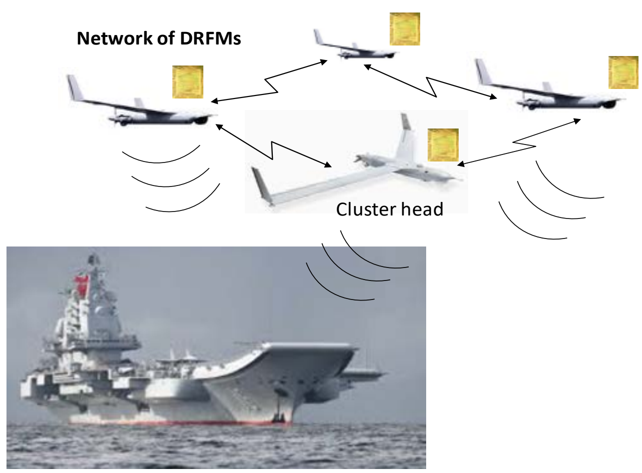


Figure 18. Network-enabled digital swarm image synthesis (NEDSIS) concept showing the objective to deceive the threat that the swarm is much larger.[32]

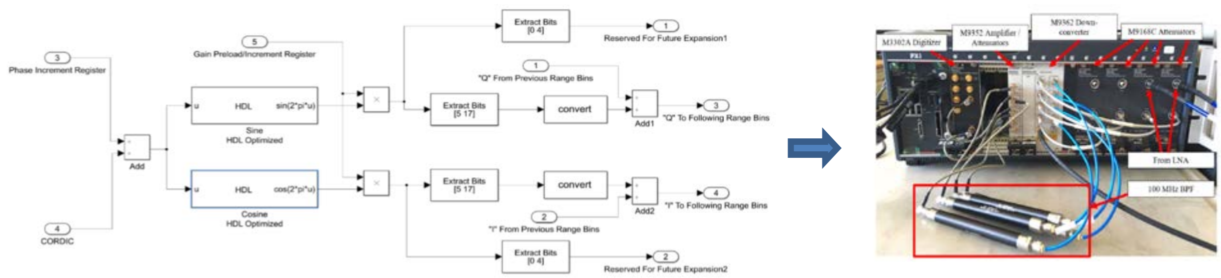
An example of an HDL (hardware description language) model for the complex range bin processor being built in Simulink for porting into the Keysight FPGA DRFM board is shown in

[31] The latency/coherency impact of the network is being explored in another effort.

[32] The network-enabled coherent EW allows angle deception as well as range.

Figure 19.[33] This led to porting the entire DIS MATLAB code that was previously written to a scalable Simulink model that allowed up to 32 range bins. As a proof of concept, the code was ported to a Zynq706 board for verification. Ongoing work with this board involves utilizing the System on the Chip (SOC) capability. Also, MATLAB System Generator and HDL blocks were used in Simulink to generate the FPGA target specific HDL code. Currently, LT. Schroyer is working to synthesize the Simulink model into non-target specific Vivado IPs such that they can be downloaded to the Keysight FPGA.[34] This would be the final piece for a full up analog false target generation output from an analog input signal.

In addition to the hardware/firmware effort, a cooperative agreement was signed with L3T (Greenville, TX), for Maj. Jarrod Larson, USMC to conduct a series of experimental field tests to derive false target coefficients.[35] The tests are to take place at the Yuma Proving Grounds, AZ. However, lining up funding to coincide with the exact date has proved to be a challenge.



(a) (b)

Figure 19. DRFM showing (a) Hardware Description Language (HDL) model of a complex range bin processor and (b) the Keysight DRFM hardware chassis boards.[36]

The tests will last 1-week and involve two air targets (King aircraft, Huey H-1 helicopter) flying towards two surface-to-air acquisition (SAA) missile radar systems in order to collect and digitize the aircraft backscatter. Figure 20 shows an example for one of the test patterns to be flown. In addition, Rohde & Schwartz is lending Maj. Larson the measurement and recording equipment for the test. With the results of the test, we can develop realistic false target *gain*, *phase* and *extent* coefficients for the range bin modulators.[37] This represents a first step in the development of a coefficient database generation concept.

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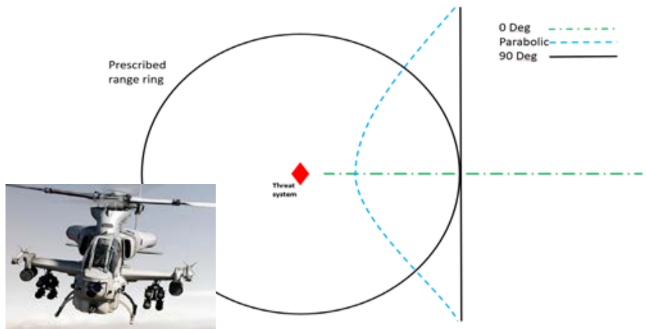
[33] Capt. Hawken Grubbs, USMC, "Field Programmable Gate Array High Capacity Technology For Radar And Counter-Radar DRFM Signal Processing," MS Information Warfare Systems Engineering MS(IW)SE, June 15, 2018.

[34] LT. Richard Schroyer, USN, "FM Pulsed Imaging Radar Manipulation Using FPGAs," MSEE 27 expected Sept 2019.

[35] Maj. Jarrod P. Larson, USMC, "Deriving DRFM False Target Coefficients from Experimental Tests (U)," MSEE (Secret), expected Sept. 27. 2019

[36] Grubbs (*see note 34 for full citation*)

[37] Larson *(see note 36 for full citation*)



H-1 Flight Profile Summary				
Test Run	Range (*System Max)	Altitude (Ft AGL)	Angle (Relative)	Speed (KIAS)
1	1/3	1500	Parabolic	70
2	1/3	3000	Parabolic	70
3	2/3	1500	0	70
4	2/3	1500	Parabolic	70
5	2/3	1500	90	70
6	2/3	3000	0	70
7	2/3	3000	Parabolic	70
8	2/3	3000	90	70

Figure 20. Huey H-1 flight profile for Yuma Proving Grounds flight test in Q4/2018.[38]

The research team included Professor Ric Romero, Professor Phillip Pace, Maj. Jarrod Larson USMC, LT Richard Schroyer USN, Mr. Max Hainz, (ESEP, Germany), Mr. Sascha Mischorr (ESEP, Germany), and Dr. Susan Wilson and Dr. Frank Boyle of L3T. This research was associated with Rohde & Schwartz.

POC: Dr. Phil Pace (pepace@nps.edu)

13. Data Farming Explorations of the Tactics and Benefits of Unmanned Systems and Unmanned-Manned Teaming

Simulation models are integral to modern scientific research, national defense, industry and manufacturing, and public policy debates. These models tend to be extremely complicated, often with large numbers of factors and many sources of uncertainty, but recent breakthroughs help analysts deal with this complexity. Data farming is a descriptive metaphor that captures the notion of generating data purposefully in order to maximize the information "yield" from simulation models. Large-scale designed experiments let us grow the simulation output efficiently and effectively. We can explore massive input spaces, uncover interesting features of complex simulation response surfaces, and explicitly identify cause-and-effect relationships. NPS's SEED Center for Data Farming supports the design and analysis of large-scale simulation experiments to help make modeling and simulation more effective for decision makers.

[38] Schroyer *(see note 35 for full citation)*

This research used data farming approaches for four situations of interest to the Navy and Marine Corps involving unmanned systems. Four NPS master's students were involved: three in operations research (LT John Tanalega, USN; LT Devon Cobbs, USN; and Capt Nathan Gulosh, USMC), and one in undersea warfare (LT Preston Tilus, USN).

Multiple challenges exist in how to take distributed lethality (DL) from an aspirational concept to an at sea capability. Tanalega (2018) and Tilus (2018) sought to advance the Navy's ability to use closed-form constructive simulation to allow us to examine thousands of simulated battles varying scores of factors (e.g., combatants, formations, tactics, threats, environments, and more). The modeling environment is the agent-based Orchestrated Simulation for Modeling (OSM) together with Littoral Combat Ship Integrated Toolkit for Mission Engineering Using Simulations (LITMUS). OSM/LITMUS is currently under development at Navy Surface Warfare Center Dahlgren Division (NSWCDD). Their experiments provide tentative tactical insights regarding saturation levels, the efficient allocation of missiles, and identifying bottlenecks in the kill chain

Tanalega (2018) explored potential uses of unmanned surface vessels in a Surface Action group (SAG) versus SAG scenario. Of particular interest was the long range, high endurance Medium Displacement Unmanned Surface Vessel (MDUSV). When coupled with the Towed Airborne Life of Naval Systems (TALONS), a parasail-mounted sensor platform, the MDUSV can extend the visual and radar horizon of surface forces. Tanalega simulated over 30,000 battles in LITMUS where he varied sensor ranges, force dispersions, formations, whether or not MDUSVs are employed and armed, and more. His findings include: (i) the addition of MDUSV to a surface force triples the probability that the force is first-to-fires; (ii) an 81% first-to-fire probability can be achieved when the passive sensor range is at least 36 nautical miles, which can be accomplished with a 1050-ft tether height; and (iii) MDUSVs are most valuable as scouts, and arming them has minimal impact on first-to-fire probability.

Tilus (2018) used OSM/LITMUS to explore the benefits of unmanned-manned teaming in a tactical anti-submarine warfare (ASW) scenario. He conducted nearly 100,000 simulated ASW missions to quantify the benefit of integrating a P-8 Poseidon with an MDUSV. The LITMUS results indicate that teaming yields a 30% improvement in the probability of kill over that of the MDUSV alone. He also found a 10% decrease in conditional mean time to kill the submarine (given the submarine is killed) when the P-8 and MDUSV work in tandem, compared to time required when the P-8 operates alone. Tilus also identified enhancements necessary for OSM/LITMUS to model more complex scenarios. These were shared with NSWCCD for continued model development.

Gulosh (2018) used an agent-based modeling platform called MANA to investigate the employment of intelligence, surveillance, and reconnaissance (ISR) drone swarms to enhance ground combat operations. He examined two different types of swarm coordination: hierarchical and emergent. In hierarchical coordination, swarm elements are controlled by squad-level agents, who are in turn controlled by higher-level controllers. With emergent coordination, the coordination arises naturally as individual drones react to one another. Of interest was finding out what swarm operational thresholds and tactics best improve combat performance in support of an infantry company, in a scenario modeling significant actions during Operation Enduring Freedom in 2011. Gulosh's results show that ISR sensor coverage can vary greatly depending on the swarm control strategy used (*see Figure 21*). Consequently, warfighters must know which control strategy best suits a particular mission in order to win the fight on future battlefields.

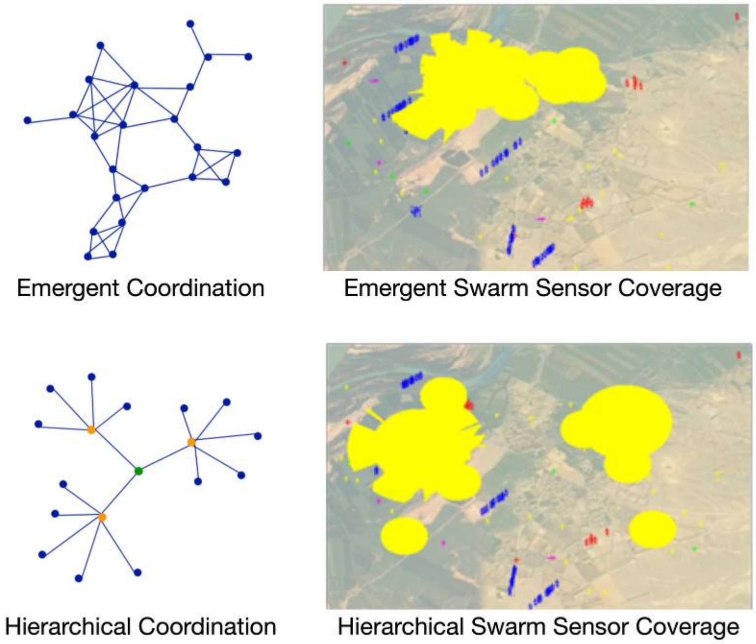


Figure 21. Swarm control strategies and line-of-sight coverage for ISR drone swarms.[39]

Cobbs (2018) conducted a proof-of-concept study to demonstrate a methodology for exploring the impact of changing selected command and control (C2) thresholds on subsequent battle outcomes. His study involved a classified scenario, supplied by the Office of the Chief of Naval Operations, Assessment Division (OPNAV N81) instantiated in the Synthetic Theater Operations Research Model (STORM) campaign analysis platform. The success of this proof-of-concept provides opportunities for similar studies in the future where control thresholds for unmanned systems or other new technologies are examined. Commanders may be more willing to put unmanned platforms at risk than manned platforms, which in turn may open up opportunities for leveraging these new technologies in major naval campaigns.

In addition to the studies above, we continue to advance the data farming methodologies that facilitate rapid scenario generation and rapid exploration of new concepts for unmanned systems. An adaptive sequential experiment collects simulation runs in small batches at a time, and the estimated underlying response is automatically updated as new data become available. A simplified one-dimensional example appears below (*see Figure 22*).

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[39] Adapted from Gulosh (2018)

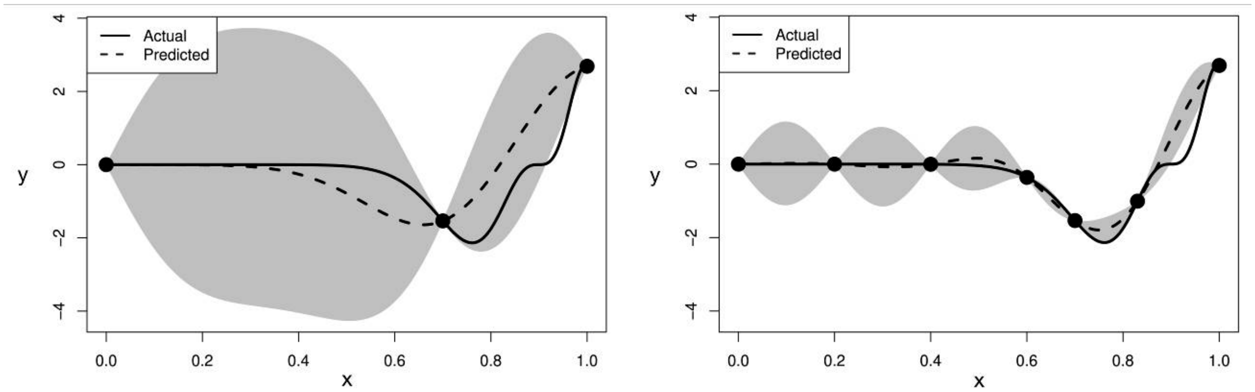

Figure 22. Predicted values converge to actual values, and uncertainty (gray regions) decreases, as the sequential experiment progresses.[40]

The batch-sequential nature of the procedure takes advantage of parallel computing on the cloud or computing clusters. Overall, this approach is desirable for decision makers seeking to quickly identify and understand tradeoffs, such as involved in determining appropriate mixes of manned and unmanned assets, cost-benefit tradeoffs associated with unmanned system capabilities, and more.

Associated with the Navy Surface Warfare Center Dahlgren Division and Northwestern University, this research team included Dr. Susan Sanchez, Dr. Thomas W. Lucas, Mary L. McDonald, and Stephen C. Upton. There were four NPS theses associated with this research, and two were recognized in the MORS/Tisdale Thesis competition – one finalist and one winner.

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14. Acoustic Vector Sensing from Novel Autonomous Systems Using Light-Weight, Low-Power Data Acquisition Systems

Acoustic vector sensors have previously been successfully deployed in operational arrays by the Navy and integrated onto autonomous underwater vehicles at NPS. This work expanded upon previous efforts in order to investigate novel platforms, such as drifting buoys deploying tethered vector sensors, or mobile platforms such as the AquaQuad that feature a combination of sensing and mobility on demand. Due to energy demands and endurance requirements, such sensors and DAQ systems will necessarily need to be lightweight and low-power. In addition, by studying the utility of high-speed communications between independent, distributed sensor nodes in an ad hoc network, the potential for coherent/semi-coherent processing across multiple acoustic vector sensors from distinct platforms can be investigated. In this study, light-weight, low-power DAQ boards were designed with the goal of providing real-time data processing capabilities for the

[40] Adapted from Erickson et al. (2018).

AquaQuad or similar, novel autonomous systems for use by the Navy, as well as coherent processing between nodes for enhanced detection and localization capabilities.

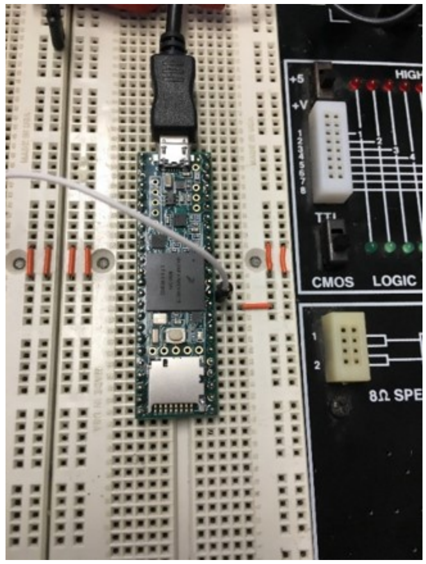

Figure 23. The Teensy data acquisition system being tested.

In FY18, a new lightweight, low-power DAQ was developed based on the Teensy MCU architecture *(see Figure 23*). The effectiveness of this new system is currently being evaluated. The integration of Bullet M Radio 2.4 GHz Ethernet successfully enabled live streaming of sensor data to a comms center. A low-loss cable and connector, allowing tethered sensor deployments to 100 m, was also developed. Various issues with the sensors were also resolved through identification of internal coupling and development of orientation calibration routines. Post-test analysis confirmed the ability of two separate systems to provide bearing information that leads to accurate track estimation (*see Figure 24*). Data continues to be processed and future tests have been identified in FY19.

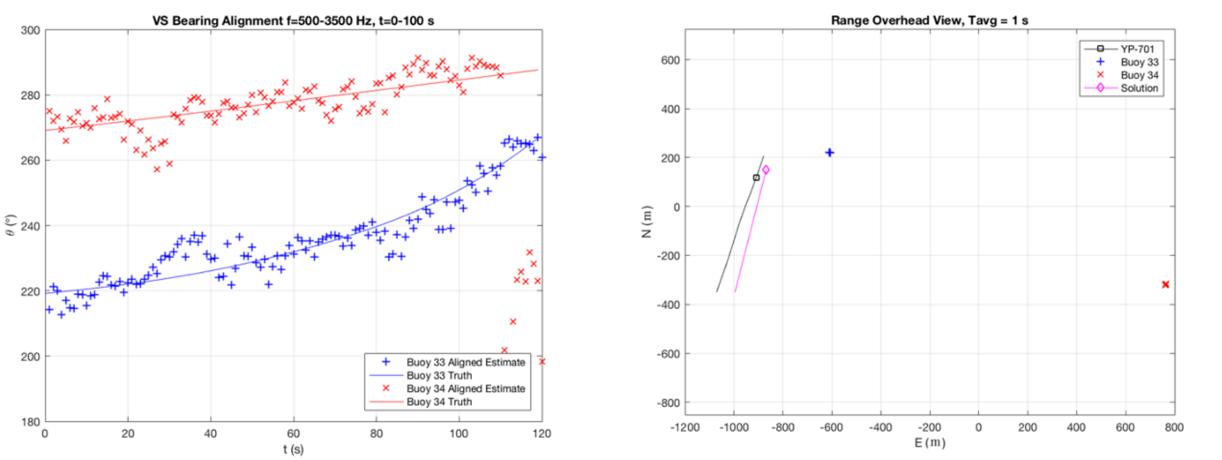

Figure 24. Bearing estimates from two, independent drifting buoy vector sensor systems (*left*), and target motion analysis solution of surface craft based on N-bearings approach (*right*).

Research team members included Research Associate Professor Vlad Dobrokhodov, Dr. Paul Leary, LT Steven Seda, LT Ben Carpenter, Dr. Mark Paulus (NUWC-KPT), Ted Cyr (NUWC-KPT), and Thomas Deal (NUWC-NPT). The research was affiliated with NUWC Division Keyport and NUWC Division Newport.

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15. Study of Cybersecurity Requirements for the Military Robot Operating System (ROS-M) using ROS 2.0 on Unmanned Aerial Networks

One of the understudied areas of UAV security is the sensitivity of the Robot Operating System (ROS) to external threats. ROS is an open source, robust, general-purpose platform that is used for robotics programming. ROS 1.0 was designed without any network or cyber security features mainly because it was designed for research purposes. As such, ROS 2.0 was developed with significant security features built into the system itself. The emphasis for ROS 2.0 is on the middleware, which is built on the Data Distribution Service (DDS) standard. DDS is an open standard for developing real-time mission-critical distributed systems. This research focuses on the viability of ROS 2.0 to safeguard communications between a UAV and a ground control station (GCS). We test ROS 2.0's ability to mitigate certain specific communications threats including message spoofing and rogue nodes. We use the underlying security processes available in DDS including authentication, access control and encryption. The overall objective of this work is to provide the first step in the formal verification and validation process of ROS 2 middleware security such that it can be transitioned to Navy mission-critical applications.

Figure 25. UAV1 communications architecture that illustrates the experimental setup

Our experiments were performed on a Mac Book Pro laptop with an Intel Core i7-3615QM Processor running Ubuntu 16.04 LTS. The PX4 Multi Vehicle Simulation was utilized in setting up the experiments. Within this simulation setup, ROS 1.0 Kinetic is used with PX4 autopilot and the Gazebo 9 simulator (*see Figure 25*). The simulated drones, which in our simulation included three instances (i.e., three UAVs), are visualized in Gazebo. We used three quadrotor iris drones. Our simulation utilized a MAVROS MAVLink node in order to establish communication with PX4. QGroundControl v3.3.1 served as our GCS software. Through QGroundControl, the drone instances are armed, flightpath parameters are entered and the flightpath is executed. The Gazebo drone simulation generated sensor data, including motor and actuator values, from its simulated world, which is then transmitted to PX4. PX4 communicates with ROS and the GCS to send drone telemetry information as well as receive commands. Figure 5 depicts the MAVLink communications structure for the first UAV instance. Through the experiments, we tested the simulations against attempts to manipulate established MAVROS service nodes including the command arming, command landing and command takeoff nodes. A ROS 1.0 ROS 2.0 bridge is created so that the ROS 2.0 security features can be enabled in our drone simulation system. Our simulation setup required that we incorporate a bridge between ROS 2.0 and ROS 1.0, as the most recent version of ROS 2.0 (ROS 2.0 Ardent) does not support Gazebo. The bridge acts as a ROS 1 node as well as a ROS 2 node at the same time and can therefore subscribe to messages in one ROS version and publish them into the other ROS version. A series of simulations under three different conditions was conducted to demonstrate the strength of ROS 2.0 in the face of specific threat vectors. In order to establish a baseline for the simulations, a definitive flightpath was loaded into each of the three simulated UAVs. The flightpath was derived to mirror a reconnaissance mission over a defined route. The route was determined based on the geographic features provided by the QGroundControl software. The UAVs executed this given flightpath under three specific conditions: Condition 1) The simulation is run with ROS 1.0. ; Condition 2) The simulation is run with the ROS 1.0 ROS 2.0 Bridge devoid of any security features; and Condition 3) The simulation is run with the ROS 1.0 ROS 2.0 Bridge with security features enabled.

We ran the simulation through ten individual trials for each of the given conditions. Our simulation baseline trials were conducted without any malicious activity. The baseline results are shown in Table 3. Time was recorded from the moment the first UAV began its ascent to the moment the third UAV landed safely on the ground.

Table 3. Simulation Baseline Results (top) and Drone Disabling Simulation Results (bottom)

Simulation Run Times (min:sec): Baseline Results											
Conditions	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	~Avg
ROS 1.0	2:30	2:20	2:31	2:17	2:28	2:44	2:39	2:27	2:24	2:40	2:30
ROS 1.0/ROS2.0 Bridge	2:33	2:32	2:23	2:19	2:30	2:31	2:47	2:41	2:27	2:42	2:32
Security Enabled ROS 1.0/ROS 2.0 Bridge	2:33	2:31	2:28	2:35	2:30	2:40	2:28	2:26	2:45	2:44	2:34
Time to Disable Drone (min:sec)											
Conditions	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	~Avg
ROS 1.0											
UAV1	0:40	0:41	0:42	0:40	0:41	0:42	0:42	0:40	0:42	0:41	0:41.1
UAV2	0:41	0:41	0:42	0:41	0:41	0:41	0:42	0:41	0:40	0:42	0:41.2
UAV3	0:42	0:42	0:40	0:41	0:42	0:40	0:41	0:40	0:41	0:42	0:41.1
ROS 1.0/ROS2.0 Bridge											
UAV1	0:44	0:42	0:43	0:42	0:43	0:42	0:42	0:45	0:44	0:45	0:43.2
UAV2	0:42	0:42	0:43	0:44	0:45	0:43	0:41	0:44	0:43	0:45	0:43.2
UAV3	0:44	0:42	0:43	0:44	0:45	0:43	0:41	0:44	0:43	0:44	0:43.3
Security Enabled ROS 1.0/ROS 2.0 Bridge											
UAV1	2:54	3:02	2:48	3:01	3:09	2:47	3:06	3:04	3:02	2:53	2:59
UAV2	2:55	3:01	2:47	3:03	3:10	2:46	3:07	3:05	3:03	2:54	2:59
UAV3	2:52	3:03	2:49	3:02	3:11	2:48	3:08	3:05	3:05	2:55	3:00

The first set of experiments focused on the MAVROS command arming service. A rogue node accesses MAVROS and directs it to shut down the targeted drone. This action caused the drone to instantly shutoff its engines and resulted in the drone crashing to the ground. UAV1, UAV2 and UAV3 represent the targeted nodes/drones. The timing results for this experiment are also provided in Table 3. There is an additional 16% increase in flight time latency when compared to the baseline.

The next set of trials involved a message spoofing attack in which a malicious node takes control of a UAV, forcing it to land at a prescribed location. The last set of trials also involved a message spoofing attack where a malicious node takes control of a UAV and forces it to gain altitude to a prescribed location. Due to space, the results for these experiments are not shown in this report. However, we noticed a 17.5% and 17% increase in latency, respectively.

We see from examination of the simulation results under the third condition, where security was enabled, that ROS 2 proved to be effective at mitigating each attack vector. Given these observations, we have shown that ROS 2.0 DDS works well in mitigating basic attacks. However, the effectiveness of this setup is inhibited by a significant latency overhead. It is our belief that implementation of the bridge was the prime factor in increasing the delay in flight time. As ROS 2.0 develops, the need for the bridged approach may no longer be required. Much of the work discussed here is part of Maj. Sergio Sandoval's thesis, NPS MSEE student. Many of the results not shown here can be found in his thesis.

In our future work we plan to continue to test and evaluate ROS 2 security for small networked UAV systems as well as assess the impact of ROS 2 on network performance including overhead and scalability when communications are intermittent.

Research team members included Maj. Sergio Sandoval, MSEE 2018, NPS LCDR Jose Fernandez, ECE Master's Student Dr. Brian Bingham, MAE; and this research was affiliated with Open Source Robotics Foundations (OSRF)

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

16. Mission Planning in Support of SAR Operations Involving Heterogeneous UxSs

The objective of this research was to develop and validate a framework for planning and executing a generic search and rescue (SAR) type mission that exploits advantages of utilizing multiple heterogeneous unmanned vehicles (UxVs). The system to identify and provide initial supplies to victims of natural disasters or catastrophic accidents must be able to locate victim(s) / person in distress (PID) that may be hard to see or buried in debris. The system should also provide rescue operators with intelligence of the area and the location of safe ingress/egress routes. It is also desired that the system be able to provide some initial supplies or communication equipment to PID to allow rescuers to determine the victims' state.

As a result of a conceptual design stage it was determined that it is a combination of the ground and aerial assets that would be the most beneficial to accomplish a typical SAR mission. As such, the prototype design involved a system-of-systems task-oriented approach to pool the resources and capabilities of multiple components together to create a new more complex system offering advanced functionality and performance (*see Figure 26a*).

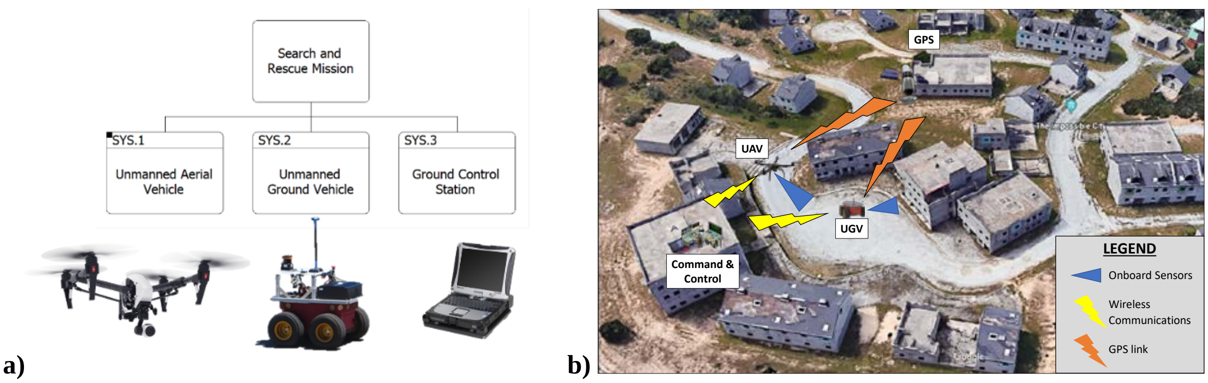


Figure 26. System-of-systems configuration (a), and Operational Viewpoint-1 (OV-1) diagram (b).

While unmanned aerial vehicle(s) (UAV) and unmanned ground vehicle(s) (UGV) are supposed to be able to (pre)process the sensor inputs onboard, the complexity of the mission still assumes the presence of human operator(s) in the loop. As such, the concept of operations assumes the command and control (C2) suite (*see Figure 27a*) serving as the main base of operations. Information from the heterogeneous unmanned assets is sent to the C2 suite and is analyzed by operators. The UAV serves as the main information-gathering platform and is envisioned to be sent out first for an area exploration mission. It would also be responsible for mapping the terrain, locating PID and determining possible routes for the UGV to get to PID. If necessary, UAV could also serve as a communication relay.

The UGV serves as the main PID assistance platform. The UGV is responsible for delivering supplies, to include radio, first aid kit etc., as needed by PID. The UGV would use the nominal route provided by UAV but could alter it based on information provided by its own onboard sensors. Once on target, UGV would provide live video feed for visual confirmation of PID and could relay any request from PID to the rescue personnel (via UAV).

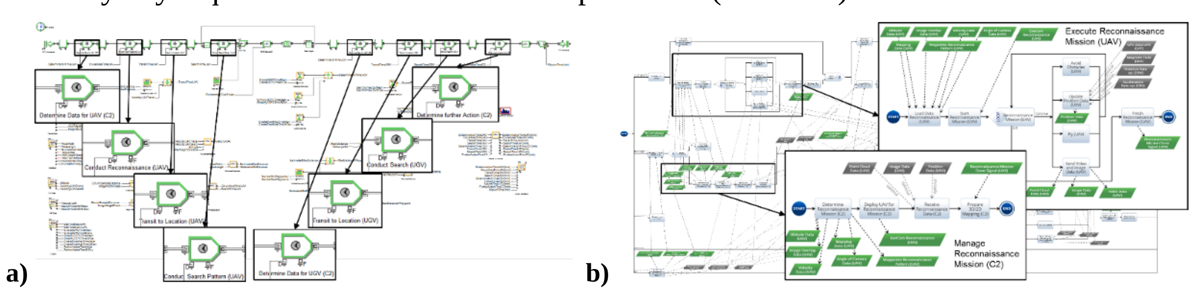


Figure 27. DoDAF OV-6c (SAR mission) (a) and OV-5b (Operational activity model) (b).

Figure 26b visualizes an example of a typical area where the SAR mission would be conducted, and in fact, that was an area, known as the Military Operations in Urban Terrain test site (MOUT) at Impossible City, CA, where the field-testing of the developed prototype was executed.

The entire mission was first analyzed within the Department of Defense Architecture Framework (DoDAF) to visualize infrastructure for specific stakeholders concerns through viewpoints organized by various views (*see Figures 28 and 29*). It was then modeled (*see Figure 30*) using the ExtendSim simulation environment convenient to model discrete event, continuous, agent-based, and discrete rate processes.

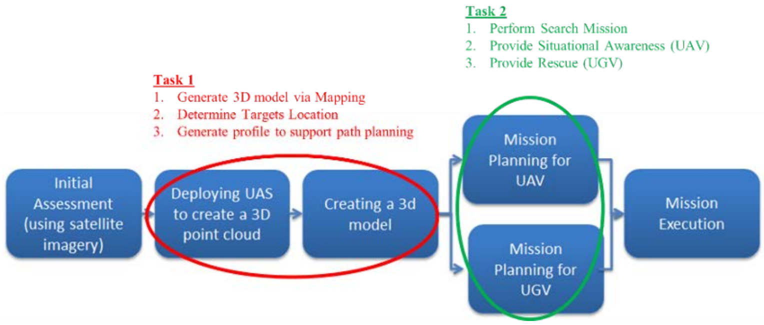


Figure 28. SAR mission planning sequence.

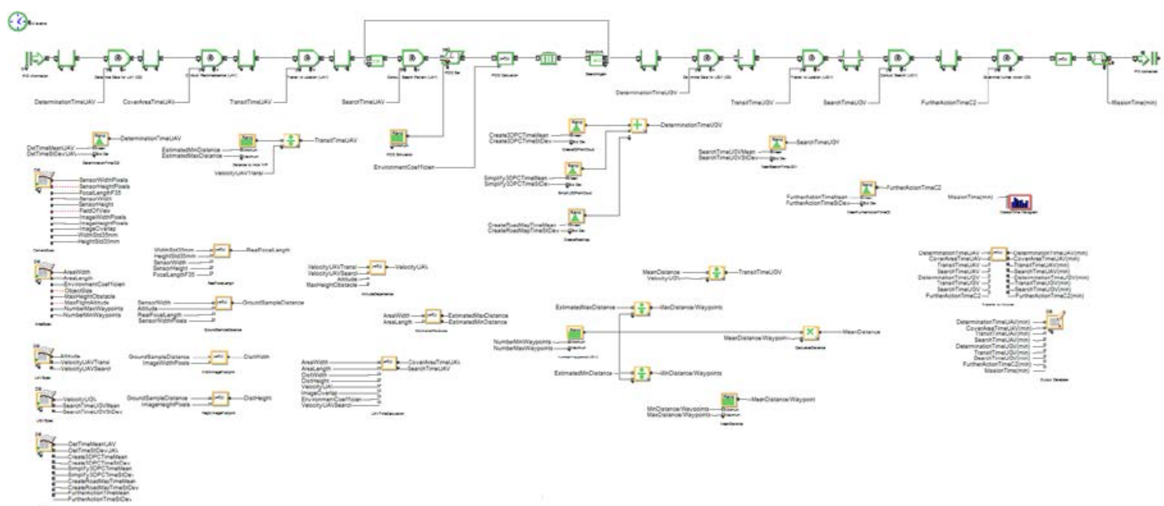


Figure 29. The ExtendSim model of a SAR mission involving heterogeneous UxVs.

Next, the entire system was prototyped using the Da Jiang Innovation (DJI) Inspire 1 UAV and Adept Technology Pioneer 3-AT UGV. Utilizing these systems in the SAR mission involved some hardware modification (*see Figure 31*) and a lot of code writing. Specifically, UGV was equipped with the Electrical Optical (EO) camera, LiDAR, GPS receiver, microphone, and computer running on the Linux Ubuntu 14.04 operating system and employing the ROS packages to generate the necessary commands. The Inspire 1 allowed making use of modular hardware packaging and programmable feature to meet the SAR mission requirements. Software wise, the DJI Inspire 1 comes with software development kit (SDK) that enables developer to tap into drone's hardware and software.

a) b)

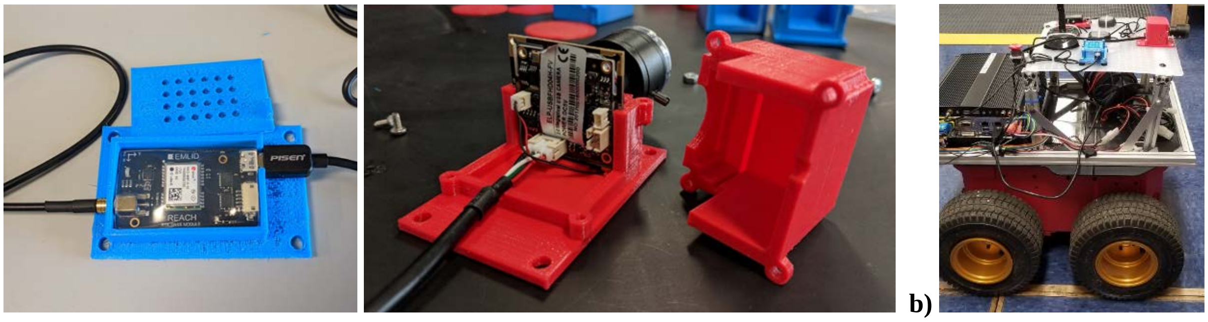


Figure 30. 3D printing / prototyping (a), and the developed ground platform (b).

Figure 31 shows examples of acquiring and preprocessing visual data on the intended area of operations (AoO) by UAV. Two dimensional (2-D) data (*see Figure 31a*) are used for scene recognition and laying out a road network. Multiple 2-D images are used to create a 3-D point cloud, which then is reduced to a usable AoA 3-D model. Figure 31b shows examples of a positive PID identification. Figure 8 visualizes an example of how the road network data were used by UGV to get from the AoO entry point to the close vicinity of PID. Figure 33 demonstrates the final stage when UGV arrives at PID location and UAV that automatically follows UGV confirms it.

a) b)

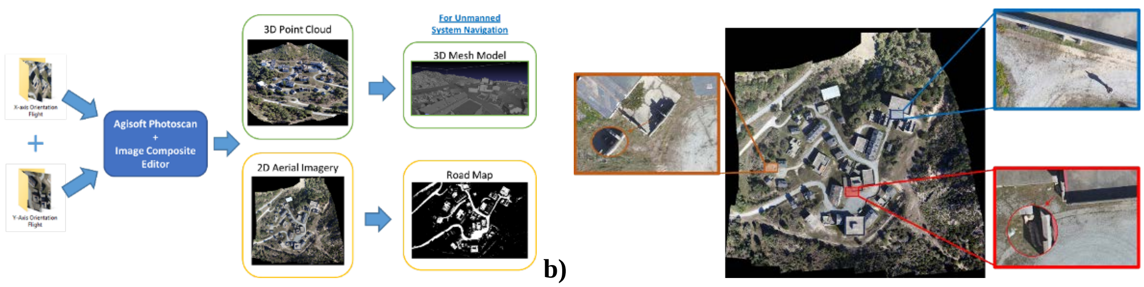


Figure 31. 2-D and 3-D mapping (a), and PID search identification (b).

a) b)

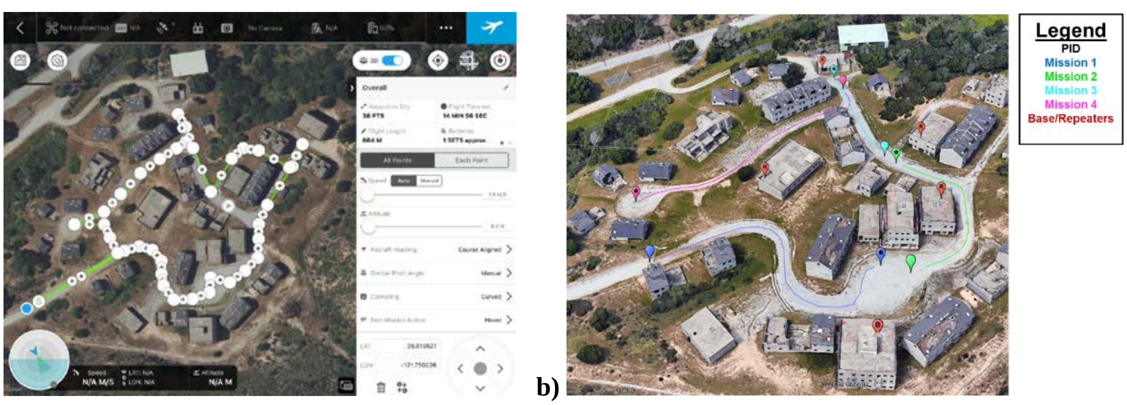
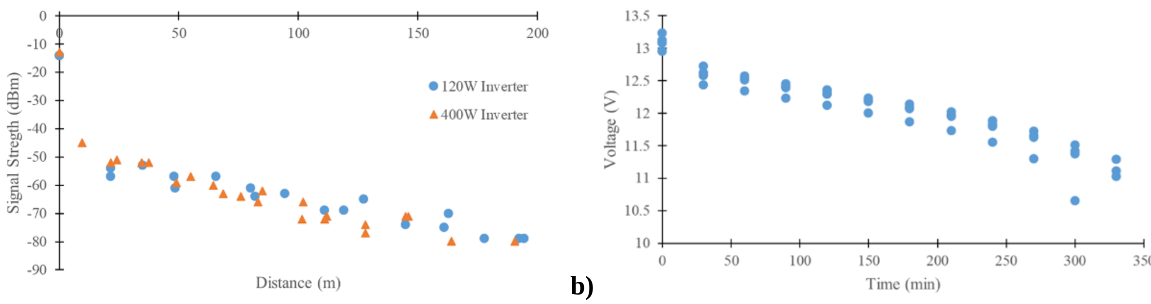


Figure 32. UGV path optimization (a), and recordings of multiple executed missions (b).

Figure 33. PID identification.

Research effort also included several supplemental studies on C[2] link strength (*see Figure 34a*) and endurance (*see Figure 34b*), which was crucial in the real-world urban environment of MOUT.



a) b)

Figure 34. Communication strength (a), and battery endurance (b) testing.

In total, ten Systems Engineering (SE) students, and four research assistants were involved in this research: LT Mario Granata, LT Rob Hall, CPT Todd Howe, LT Daniel Michnewich, LT Wyatt Middleton, CPT Rondolf Moreno, LT Joshua Ramseur, LT Travis Turner, Wei Shun Teo, Stefan Wangert, Jeremy Metcalf, Rushen Dal, Albert Jordan. Two students contributed with their MS theses.

The SE students involved in this research overcame quite a few challenges: the necessity to learn a new programing language (Python) and two operating systems (LINUX and ROS), wireless networking, 3-D printing, basics of inertial navigation and controls, image processing, and data fusion (neither of these subjects are studied within the core Systems Engineering or curricula). They gained an experience in code writing, hardware integration, UGV support logistics and UAV operations.

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

B. FIELD 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 is 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)[41] 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 FY18 JIFX experimentation are reported separately.

2. MTX

Planned in FY17, a maritime NPS-FX Multi-Thread Experiment (MTX) was executed in FY18 on San Clement Island, California 31 October through 15 November 2017.[42] 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,

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[41] JIFX website at https://my.nps.edu/web/fx

[42] MTX video overview on YouTube at https://youtu.be/o2mTAzyZdPo

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.

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 27 PROJECT:** "**Distributed Maritime Operations and Unmanned Systems Tactical Employment Development: Counter-Targeting, Decoys, EMW, and Man-Unmanned Tactics"** Design a cost effective and resilient unmanned and manned system of systems capable of contributing to the Distributed Maritime Operations concept in the 2030-2035 timeframe. Focus your design's contributions on counter-targeting, decoys, deception, electromagnetic warfare and the manned-unmanned tactics associated with them to achieve desired effects in supporting tactical offensive operations in the air, surface, undersea and cyber domains. Consider employment requirements, power requirements, operating areas, bandwidth and connectivity, interoperability, sensor data processing, transfer and accessibility, logistics, forward arming and refueling (FARPS) basing support in forward areas or from CONUS bases. Where possible, include joint contributions in the systems of systems. Generate system requirements for platforms, sensors, and communications in a challenging EM and contested environment. Develop alternative architectures for platforms, sensors, active decoy packages, manning, communication and network connectivity, and their operational employment concepts. Address the costs and effectiveness of your alternatives in mission areas like at-sea strike and electromagnetic maneuver warfare. **POC:** Professor Jeff Kline (jekline@nps.edu)

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. Isaac Kaminer (kaminer@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 Raymond Gamache (rmgamach@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)

2. 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 provided a venue for recognized experts to advise naval leadership as to what they believe the most important challenge will be for the naval enterprise over the next ten years. During a candid discussion, panelists each have an opportunity to offer their respective opinions as to where the Department of the Navy should focus their efforts in the development of robotics and autonomy. 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 35*).

Figure 35. CRUSER Continuing Education Panel "Just One Thing", 19 September 2017.

The second in the planned three "*Just One Thing*" panel series was held in the Pentagon Conference Center on 24 May 2018. Approximately 50 government attendees filled the room to listen to and engage with Drs. Peter W. Singer[43] of the New America Foundation, David Mindell[44] of the Massachusetts Institute of Technology, and Lydia Kostopoulos[45] of Sapien 21 (*see Figure 36*). The panel, moderated by Dr. Raymond Buettner (*see Figure 36, right*), were asked "*What is the one 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?"* Out of that robust discussion, the three "big ideas" for consideration were:

1) ***Do not be afraid of autonomous systems***. Truly autonomous systems, i.e. with free will, can never be built, so we need to engage in building systems with a range of autonomy scalable to the desired application. The NPS MTX effort is an example of the kind of autonomy employment that enable this constrained autonomy.

2) ***The country is at a crossroads with regard to the form our Navy will take and we either will adapt our force structure or be left behind***. An example of a radical idea is the leasing of a large number of small missile combatants based on commercial yacht designs on a rotating basis so the fleet is continuously updated at lower cost while achieving enhanced lethality.

3) ***To keep up with human and organizational challenges created by rapidly emerging technologies, such as autonomous systems, the SECNAV should adopt a "shareholder view" of the force.*** Shareholders would have access to social media tools for a full and vibrant discussion of issues affecting them and an ongoing opportunity to raise issues. The same tools will allow leadership to identify the most important issues from the shareholder's perspective. Top issues would be addressed annually in a virtual shareholder's meeting.

43 Peter Warren Singer (biography): https://www.pwsinger.com/biography/

44 David Mindell (biography): https://www.humatics.com/people/david-mindell/

45 Lydia Kostopoulos (biography): http://smallwarsjournal.com/author/lydia-kostopoulos

Figure 36. "Just One Thing" panel in the Pentagon Conference Center, 24 May 2018. Pictured from left to right Dr. Peter Singer, Dr. Lydia Kostopoulos, Dr. David Mindell, and Dr. Raymond Buettner (*moderator*).

The final panel in the planned three discussion series will be scheduled concurrent with TechCon 2019 in mid-April 2019, and a final report of recommendations will be shared with appropriate leadership before the end of FY19.

3. CRUSER Seminars

In FY18 CRUSER presented two CRUSER Seminars, formerly CRUSER Colloquiums, on the NPS campus for the community of interest. Although this report is only intended to cover FY18, this section also includes details for the initial FY19 CRUSER Seminar as it occurred so early in the new fiscal year.

To start FY18, on 2 October 2017 CRUSER hosted a talk by Dr. Bob Iannucchi from Carnegie Mellon University Silicon Valley, a Distinguished Service Professor in the Department of Electrical and Computer Engineering and Director of the CyLab Mobility Research Center. He presented his talk titled *Wireless Networking Reimagined* in which he detailed his team's longstanding relationship with NPS Field Experimentation, and the findings and status of ongoing work his team is completing with support of the NPS FX team out at Camp Roberts.

> Biography: As the Director of the CyLab Mobility Research Center, Bob Iannucci is known for leading both software and systems research in scalable and mobile computing. Previously, he served as Chief Technology Officer of Nokia and Head of Nokia Research

Center (NRC). Bob spearheaded the effort to transform NRC into an Open Innovation center, creating “lablets” at MIT, Stanford, Tshinghua University, the University of Cambridge, and École Polytechnique Fédérale de Lausanne (EPFL). Under his leadership, NRC’s previously established labs and the new lablets delivered fundamental contributions to the worldwide Long Term Evolution for 3G (LTE) standard. He also helped create and promulgate what is now the MIPI UniPro interface for high-speed, in-phone interconnectivity, and created and commercialized Bluetooth Low Energy – extending wireless connectivity to coin-cell-powered sensors and other devices. Pertinent new technology initiatives of interest to the CRUSER community include TrafficWorks (using mobile phones to crowd source traffic patterns), part of the Mobile Millennium Project, Point and Find (Augmented Reality using the mobile phone’s camera for image recognition and “zero click” search.[46] Dr. Iannucchi has led engineering teams at startup companies focused on virtualized networking and computational fluid dynamics, creating systems that offered order-of-magnitude improvements over alternatives. He also served as Director of Digital Equipment Corporation’s Cambridge Research Laboratory (CRL) and became VP of Research for Compaq. CRL created some of the earliest multimedia indexing technologies, and these became part of Alta Vista. In addition, the CRL team together with Dan Siewiorek, Asim Smailagic and others at CMU created MoCCA — a mobile communication and computing architecture — that prefigured and anticipated (by more than a decade) much of what has become today’s smartphone technology. MoCCA won the IDEA Gold award for its innovative approach to facilitating real-time interaction within teams. The industrial design prototype is now part of the permanent design collection at the Smithsonian Institution. Bob was a founder of Exa Corporation, and led the engineering team that created and delivered Digital Physics (a term he coined and that Exa holds as a registered trademark) fluid flow simulation CAD tools. Exa went public in 2012. Bob spent the earliest days of his career at IBM studying and developing scalable computing systems and was one of the designers of the highly successful IBM 4341 and 4381 processors.

Bob remains active as a hands-on systems builder. His most recent iPhone app for radio direction finding is in use in over 70 countries, and he is actively engaged in building WiFi-based “internet of things” devices and the cloud services behind them. He serves as an advisor to companies developing new technologies for wireless networking. Bob earned his Ph.D. from MIT in 1988, and his dissertation was on the hybridization of dataflow and traditional von Neumann architectures, offering advantages over both. He has served on a number of scientific and engineering advisory boards and was on the program committees for the 3rd and 4th International Symposia on Wearable Computing. Bob also served as a member of the selection committee for the Millennium Technology Prize in 2008.

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[46] identified by MIT Technology Review as one of the TR10 Breakthrough Technologies), and the Morph Concept (opening new directions for using nanotechnology to significantly improve mobile phone functionality and usability)

On 27 February 2018, Mr. Brett Vaughn, senior staff member from the office of the Deputy Chief of Naval Operations for Information Warfare, shared his work mapping efforts in artificial intelligence (AI) across the Naval Research Enterprise.[47] His discussion covered the complex journey the Navy must embark on to realize the full potential of AI, including the challenges this poses and the conditions needed to overcome them. Vaughn covered the differences between an exponential organization, an organization that has achieved a 10-fold growth capacity via the application of exponential technology, and a linear organization. He cited companies like Google, Apple and Netflix as examples of exponential organizations that use exponential technologies to achieve an advantage over their competitors, while the Navy better fits the definition of a linear organization. Vaughn stressed that the Navy is a leader in the science and technology portion of AI and in its development, but he also noted that what the service lacked is in its application. It is time for the AI being developed in the lab to be pushed out into the field and tested in real world scenarios, he said. “What makes you guys so important on this journey is that if you look at the Navy, most of the work done involving AI is in the realm of research and lab work,” Vaughn continued. “A lot of those advances in some areas today are driven by industry and commercial partners, and through the efforts of groups like CRUSER, which builds connections between industry and academia, we can have these connections that are absolutely vital to apply that technology.”

To start FY19 on Monday 22 October 2018, Dr. Kristi Morgansen, University of Washington Interim Chair Professor and Associate Chair for Academics – Adjunct in Electrical Computer Engineering – presented her talk *Empirical Methods at the Boundary of Model-Based and Learned Integrated Sensing and Actuation* for the CRUSER community.

> *Abstract:* A fundamental element of effective operation of autonomous systems is the need for appropriate sensing and processing of measurements to enable desired system actions. Model-based methods provide a clear framework for careful proof of system capabilities but suffer from mathematical complexity and lack of scaling as probabilistic structure is incorporated. Conversely, learning methods provide viable results in probabilistic and stochastic structures, but they are not generally amenable to rigorous proof of performance. A key point about learning systems is that the results are based on use of a set of training data, and those results effectively lie in the convex hull of the training data. This presentation will focus on use of model-based nonlinear empirical observability criteria to assess and improving and bounding performance of learning pose (position and orientation) of rigid bodies from computer vision. A particular question to be addressed is what sensing data should be captured to best improve the existing training data. The particular tools to be leveraged here focus on the use of empirical observability gramian techniques being developed for nonlinear systems where sensing and actuation are coupled in such a way that the separation principle of linear methods does not hold. These ideas will be discussed relative to both engineering applications in the form of

[47] Summary of this talk adapted from NPS Intranet coverage “CRUSER Examines the Navy's Future With Artificial Intelligence” by MC2 Patrick Dionne http://www.nps.edu/web/guest/-/cruser-examines-the-navy-s-future-with-artificial-intelligence

motion planning for range and bearing only navigation in autonomous vehicles, vortex position and strength estimation from pressure measurements on airfoils, and effective strain sensor placement on insect wings for inertial measurements.

Biography: Kristi Morgansen received a BS and a MS in Mechanical Engineering from Boston University, respectively in 1993 and 1994, an S.M. in Applied Mathematics in 1996 from Harvard University and a PhD in Engineering Sciences in 1999 from Harvard University. Until joining the University of Washington, she was first a postdoctoral scholar then a senior research fellow in Control and Dynamical Systems at the California Institute of Technology. She joined the William E. Boeing Department of Aeronautics and Astronautics in the summer of 2002 as an assistant professor. She is currently a full professor and Interim Chair of the department. Professor Morgansen's research interests focus on nonlinear systems where sensing and actuation are integrated, stability in switched systems with delay, and incorporation of operational constraints such as communication delays in control of multi-vehicle systems. Applications include both traditional autonomous vehicle systems such as fixed-wing aircraft and underwater gliders as well as novel systems such as bio-inspired underwater propulsion, bio-inspired agile flight, human decision making, and neural engineering. The results of this work have been demonstrated in estimation and path planning in unmanned aerial vehicles with limited sensing, vorticity sensing and sensor placement on fixed wing aircraft, landing maneuvers in fruit flies, joint optimization of control and sensing in dynamical systems, and deconfliction and obstacle avoidance in autonomous systems and in biological systems including fish, insects, birds, and bats. (https://www.aa.washington.edu/people/faculty/morgansen)

4. 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 4*) lists students mentored in FY18 (2017 DEC, 2018 MAR, 2018 JUN, and 2018 SEP).

Table 4. FY18 CRUSER mentored NPS student theses (*alphabetical by author*)

AUTHOR(s)	TITLE	DATE (year-mo)	URL
LT Ryan Clapper USN	*DIRECTIONAL NETWORKING SOLUTIONS FOR A CLANDESTINE MANET*	2018 MAR	*Controlled access*
LT Tiffany Clark USN	*INTEGRITY-BASED TRUST VIOLATIONS WITHIN HUMAN-MACHINE TEAMING*	2018 JUN	http://hdl.handle.net/10945/59637
LT Alan J. Clarke USN and Maj Daniel Knudsen III USMC	*EXAMINATION OF COGNITIVE LOAD IN THE HUMAN-MACHINE TEAMING CONTEXT (NPS Outstanding Thesis 2018)*	2018 JUN	http://hdl.handle.net/10945/59638

Capt K. Comstock USMC and Capt S. Krajewski USMC	*UNMANNED TACTICAL CONTROL AND COLLABORATION (UTACC) QUICK-WIN ROBOT ANALYSIS*	2018 SEP	http://hdl.handle.net/10945/60380
Maj John M. Fout USMC and Maj James M. Ploski USMC	*UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION HUMAN MACHINE COMMUNICATION AND SITUATIONAL AWARENESS DEVELOPMENT*	2018 JUN	http://hdl.handle.net/10945/59661
Capt Hawken Grubbs USMC	*FIELD PROGRAMMABLE GATE ARRAY HIGH CAPACITY TECHNOLOGY FOR RADAR AND COUNTER-RADAR DRFM SIGNAL PROCESSING (NPS Outstanding Thesis 2018)*	2018 JUN	http://hdl.handle.net/10945/59670
Maj Nathan J. Gulosh USMC	*EMPLOYMENT OF INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE DRONE SWARMS TO ENHANCE GROUND COMBAT OPERATIONS (NPS Outstanding Thesis 2018)*	2018 JUN	http://hdl.handle.net/10945/59672
LT Calvin S. Hargadine USN	*MOBILE ROBOT NAVIGATION AND OBSTACLE AVOIDANCE IN UNSTRUCTURED OUTDOOR ENVIRONMENTS*	2017 DEC	http://hdl.handle.net/10945/56937
Maj S. Harvey UMC and Capt Trevino USMC	*ANALYSIS OF EMERGING AND CURRENT SUBSYSTEM TECHNOLOGIES IN SUPPORT OF WARFIGHTING CAPABILITIES (NPS Outstanding Thesis 2018)*	2018 SEP	http://hdl.handle.net/10945/60410
Maj Andrew Heitpas USMC	*STIGMERGIC CONTROL OF DUAL-DIRECTION COMMUNICATION FERRY NODES FOR DENIED COMMUNICATIONS ENVIRONMENTS (NPS Outstanding Thesis 2018)*	2018 JUN	http://hdl.handle.net/10945/59685
ENS Ben Keegan USN	*UAV POSITION OPTIMIZATION FOR WIRELESS COMMUNICATIONS*	2018 JUN	http://hdl.handle.net/10945/59695
Capt Justin L. King USMC	*CONCEPT OF OPERATIONS FOR USING COMPUTER VISION CAPABILITIES ON TACTICAL AIRCRAFT (NPS Outstanding Thesis 2018)*	2018 JUN	http://hdl.handle.net/10945/59698
Major Wee Leong Lee, Singapore Air Force	*ASSESSMENT OF FOREIGN OBJECT DEBRIS MANAGEMENT USING GROUP 1 UNMANNED AERIAL SYSTEMS (NPS Outstanding Thesis 2018)*	2018 SEP	http://hdl.handle.net/10945/60426
LT Wyatt T. Middleton USN	*VALIDATION OF ARCHITECTURE MODELS FOR COORDINATION OF UNMANNED AIR AND GROUND VEHICLES VIA EXPERIMENTATION*	2018 JUN	http://hdl.handle.net/10945/59555

Giovanni Minelli	*RESOURCE-CONSTRAINED AUTONOMOUS OPERATIONS OF SATELLITE CONSTELLATIONS AND GROUND STATION NETWORKS (doctoral dissertation)*	2018 SEP	http://hdl.handle.net/10945/60435
Maj John Park USMC	*GROUP 3 UNMANNED AIRCRAFT SYSTEMS MAINTENANCE CHALLENGES WITHIN THE NAVAL AVIATION ENTERPRISE*	2017 DEC	http://hdl.handle.net/10945/56779
Major Yi Kai Qiu, Republic of Singapore Air Force	*PROPAGATION ENVIRONMENT ASSESSMENT USING UAV ELECTROMAGNETIC SENSORS*	2018 MAR	http://hdl.handle.net/10945/58353
LCDR John J. Renquist USN	*AN INDEPENDENT ASSESSMENT OF THE ENERGY ENHANCEMENTS TO THE SYNTHETIC THEATER OPERATIONS RESEARCH MODEL (STORM)*	2018 SEP	http://hdl.handle.net/10945/60453
Maj. Sergio Sandoval	*CYBER SECURITY TESTING OF THE ROBOT OPERATING SYSTEM IN UNMANNED AERIAL SYSTEMS*	2018 SEP	http://hdl.handle.net/10945/60458
LT Joseph A. Schnieders USN	*COMPARISON STUDY OF LOW-LEVEL CONTROLLER TECHNIQUES FOR UNMANNED SURFACE VESSELS*	2018 JUN	http://hdl.handle.net/10945/59581
LT J. Tanalega USN	*ANALYZING UNMANNED SURFACE TACTICS WITH THE LIGHTWEIGHT INTERSTITIALS TOOLKIT FOR MISSION ENGINEERING USING SIMULATION (LITMUS)*	2018 MAR	Controlled release
Wei Shun Teo, DSO National Laboratories Singapore	*ADVANCING COTS UAV CAPABILITY TO PROVIDE VISION-BASED SA/ISR DATA (NPS Outstanding Thesis 2018)*	2018 SEP	http://hdl.handle.net/10945/60353
Major Boon Hong Aaron Teow, Singapore Army	*ASSESSING THE EFFECTIVENESS OF A COMBAT UGV SWARM IN URBAN OPERATIONS (NPS Outstanding Thesis 2018)*	2018 SEP	http://hdl.handle.net/10945/60354
LT Preston T. Tilus USN	*ASSESSING ORCHESTRATED SIMULATION THROUGH MODELING TO QUANTIFY THE BENEFITS OF UNMANNED-MANNED TEAMING IN A TACTICAL ASW SCENARIO*	2018 MAR	http://hdl.handle.net/10945/58270
LT Travis M. Turner USN	*ANALYZING UUV HULL CROSS-SECTIONS FOR MINIMIZING WAVE LOADS WHEN OPERATING NEAR SURFACE*	2018 JUN	http://hdl.handle.net/10945/59606
Chief A. Tyerman, Maple Valley Fire & Life Safety	*USING UNMANNED AERIAL VEHICLES FOR AUTOMATED EXTERNAL DEFIBRILLATOR DELIVERY IN THE SEATTLE KING COUNTY REGION FOLLOWING OUT-OF-HOSPITAL*	2018 SEP	http://hdl.handle.net/10945/60360

	CARDIAC ARREST		
Lieutenant Leander J. C. van Schriek, Royal Netherlands Navy	*EVALUATING EFFECTIVENESS OF DIRECTIONAL ACOUSTIC MODEMS INTEGRATED ONTO AUTONOMOUS PLATFORMS (NPS Outstanding Thesis 2018)*	2018 JUN	http://hdl.handle.net/10945/59609
ENS Noah Wachlin USN	*ROBUST TIME-VARYING FORMATION CONTROL WITH ADAPTIVE SUBMODULARITY*	2018 JUN	http://hdl.handle.net/10945/59612
LT Alexander G. Williams USN	*FEASIBILITY OF AN EXTENDED-DURATION AERIAL PLATFORM USING AUTONOMOUS MULTI-ROTOR VEHICLE SWAPPING AND BATTERY MANAGEMENT*	2017 DEC	http://hdl.handle.net/10945/56847
Maj Costantinos Zagaris USAF	*AUTONOMOUS SPACECRAFT RENDEZVOUS WITH A TUMBLING OBJECT: APPLIED REACHABILITY ANALYSIS AND GUIDANCE AND CONTROL STRATEGIES (doctoral dissertation)*	2018 SEP	http://hdl.handle.net/10945/60364
SE Capstone Cohort JUN2018	*DISTRIBUTED MARITIME OPERATIONS AND UNMANNED SYSTEMS TACTICAL EMPLOYMENT*	2018 JUN	http://hdl.handle.net/10945/59587
SE Capstone Cohort DEC2017(1)	*INVESTIGATION OF REQUIREMENTS AND CAPABILITIES OF NEXT-GENERATION MINE WARFARE UNMANNED UNDERWATER VEHICLES*	2017 DEC	http://hdl.handle.net/10945/56878
SE Capstone Cohort DEC2017(2)	*COST, SCHEDULE, AND PERFORMANCE ELEMENTS FOR COMPARISON OF HYDRODYNAMIC MODELS OF NEAR-SURFACE UNMANNED UNDERWATER VEHICLE OPERATIONS*	2017 DEC	http://hdl.handle.net/10945/56859
LT Todd Coursey USN	*DIRECTIONAL SOUND SENSING OF UAV'S USING A MEMS SENSOR*	*2018 DEC*	*Controlled release*
LCDR Dave Herrmann USN	*MORPHODYNAMIC CLASSIFICATION OF COASTAL REGIONS USING MACHINE LEARNING THROUGH DIGITAL IMAGERY COLLECTION*	*2018 DEC*	*URL to be assigned once archived*
Hopchak, M. S.	*AUTONOMOUS DECISION AND INDEPENDENT CUING IN SWARM ROBOTICS*	*2018 DEC*	*URL to be assigned once archived*
Riarh Parminder CANADA	*A STUDY OF MEMS ACOUSTIC DIRECTIONAL SENSORS*	*2018 DEC*	*URL to be assigned once archived*
ANTICIPATED:			
LT Devon Cobbs USN	*DETERMINING THE ROBUSTNESS OF THE SYNTHETIC THEATER OPERATIONS*	*Anticipated*	

	RESEARCH MODEL'S (STORM) COMMAND AND CONTROL THRESHOLDS		
LCDR Beverly Crawford and LT Inna Stukova	*SELF-MOVING BACKBONE FOR LITTORAL MESH NETWORKS*	*Anticipated 2019*	
LT Joseph Gilley USN	*RECONSTRUCTION OF SATELLITE ENCRYPTION AND DATA TRANSFER TO IMPROVE DATA RECEPTION*	*Anticipated 2019 JUN*	
Maj. Jarrod P. Larson, USMC	*DERIVING DRFM FALSE TARGET COEFFICIENTS FROM EXPERIMENTAL TESTS*	*Anticipated 2019 SEP*	*(SECRET)*
LT Ash Mielke USN	*VISUAL AND IR AI CLASSIFICATION OF LITTORAL SYSTEMS*	*Anticipated 2019 DEC*	
MAJ Justin Murphy USMC	*BIOLOGICALLY INSPIRED SHORT-LIVING NODES FOR TACTICAL NETWORKS*	*Anticipated 2019*	
LT Richard Schroyer USN	*FM PULSED IMAGING RADAR MANIPULATION USING FPGAS*	*Anticipated 2019 SEP*	
LT Steven Seda	*(TITLE TBD)*	*Anticipated 2019 JUN*	

CRUSER supported 39 NPS student trips in FY18 to further their thesis work (*see Table 5*). NPS students were then required to give a trip report at a monthly NPS CRUSER meeting to further socialize their work. Additional student trips were funded out of individual project funds.

Table 5. CRUSER supported student travel, FY18 (*in chronological order*)

STUDENT	DESTINATION	DATE	PURPOSE
AUDETTE, M., Capt, USN	Denver CO	12 OCT 2017	Denver Maker Faire to compete in Sparkfun AV Competition and attend workshops
WILLIAMS, A., LCDR USN	Camp Roberts, CA	16-18 NOV 2017	Camp Roberts - multi-rotor testing for thesis & research
TEO WEI SHUN	Camp Roberts, CA	16-18 NOV 2017	Camp Roberts - multi-rotor testing for thesis & research
D'AMBROSIO, A. LCDR USN	San Diego CA	4-8 DEC 2017	Attend PMS-408 program management review

FORD, E., LCDR, USN	San Diego CA	4-8 DEC 2017	Attend PMS-408 program management review
BROWN, P., LCDR, USN	San Diego CA	4-8 DEC 2017	Attend PMS-408 program management review
FORD, Eli, LCDR, USN	Destin, FL	28 JAN - 02 FEB 2018	Attend ONR Unmanned Systems Technology Program Review
HARVEY, S., MAJ, USMC	March AFB, CA	4 - 6 FEB 2018	Attending presentation/demonstration of an emerging technology for thesis review
TREVINO, L. Maj, USMC	March Air Reserve Base, CA	4 - 6 FEB 2018	Meeting with EdgyBees Ltd to conduct a demonstration and product evaluation
BURTON, David MAJ, USMC	Quantico VA	6 -15 FEB 2018	Interviewing personnel from DC I, IWID, MCIOC, II MEF CE
ENGEBRAATEN, SONDRE	Camp Roberts CA	19 FEB 2018	Camp Roberts - multi-rotor testing for dissertation & research
FOUT, JOHN, Capt. USMC	Camp Pendleton CA	22 -23 FEB 2018	Meeting with a number of subject matter experts (SMEs) in the field of human-machine teaming.
PLOSKI, J, Maj. USMC	Camp Pendleton CA	22 - 23 FEB 2018	Meeting with a number of subject matter experts (SMEs) in the field of human-machine teaming
ENGEBRAATEN, SONDRE	Camp Roberts CA	25 FEB 2018	Camp Roberts - multi-rotor testing for dissertation & research
CRAWFORD, B, LT, USN	Camp Roberts CA	25-28 FEB 2018	Supporting field tests at Camp Roberts using the Scan Eagle UAV for Network Control System (NCS) testing and data collection.
STUKOVA, I. LT, USN	Camp Roberts CA	25-28 FEB 2018	Supporting field tests at Camp Roberts using the Scan Eagle UAV for Network Control System (NCS) testing and data collection.
KEEGAN, B. ENS, USN	Camp Roberts CA	26-28 FEB	Collection of data on the SNR between wireless ground nodes through testing with Wave Relay

		2018	MPU5 radios and a Scan Eagle UAV
WACHLIN, N, Capt. USN	Camp Roberts CA	26-28 FEB 2018	Supporting field tests at Camp Roberts using the Scan Eagle UAV for Network Control System (NCS) testing and data collection
BURTON, David MAJ, USMC	Camp Pendleton CA	27 FEB - 3 MAR 2018	Interviewing personnel from I MEF and reviewing/analyzing their MEFEX
SANDOVAL, SERGIO Maj. USMC	Mountain View CA	7 MAR 2018	Thesis work collaboration with the developers of ROS (Robot Operating System) OSRF (Open Source Robotics Foundation)
ENGEBRAATEN, SONDRE	Camp Roberts CA	28 MAR 2018	Camp Roberts - multi-rotor testing for dissertation & research
HANLON, NED, Ensign, USN	Colorado Springs CO	15 - 18 APR 2018	Present a paper at the 34th Space Symposium in Colorado Springs, CO
KEEGAN, B. ENS, USN	Yuma Proving Grounds, AZ	17-20 APR 2018	Thesis Research - Data collection and field testing
WACHLIN, N, Capt. USN	Yuma Proving Grounds, AZ	17-20 APR 2018	Supporting field tests in Yuma, AZ using the Scan Eagle UAV for Network Control System (NCS) testing and data collection
FERNANDEZ, JOSE, LCDR, USN	Warren MI	23-27 APR 2018	Attend the TARDEC Industry Days to observe the current status of ROS-M project and hear discussion of future work, high interest in security
LEE, WEE LEONG, MAJ, Singapore	Camp Roberts, CA	27 APR 2018	To conduct field testing for thesis research in COTS quadrotor UAV
LEE, WEE LEONG, MAJ, Singapore		29 APR 2018	
TEO,WEI SHUN, DoD, Foreign Affiliate Civilian	Kansas City, MO	29 APR - 6 MAY 2018	Meeting with researchers in University of Missouri and works on the integration of the software algorithm for Manifold Hardware
COMSTOCK, K, Capt., USMC	Denver CO	30 APR – 4 MAY	AUVSI Expo - Denver, CO

		2018	
HARVEY, S., MAJ, USMC	Denver CO	30 APR – 4 MAY 2018	AUVSI Expo - Denver, CO
KRAJEWSKI, S. Capt. USMC	Denver CO	30 APR – 4 MAY 2018	AUVSI Expo - Denver, CO
TREVINO, L, Capt. USMC	Denver CO	30 APR – 4 MAY 2018	AUVSI Expo - Denver, CO
HAHN, ANDREW, LT, USN	Berkeley CA	11 MAY 2018	TechCrunch Robotics Sessions
MALIA, JOSH, LT USN	Berkeley CA	11 MAY 2018	TechCrunch Robotics Sessions
SHIVASHANKAR, Santhosh, LCDR USN	Washington, D.C.	23 - 25 MAY 2018	Attended Panel Discussion on CRUSER at the Pentagon
MALIA, JOSH, LT USN	San Diego, CA	6 JUN 2018	Attending meeting to discuss a proposed Operator Decision Aid for use on surface ships for navigation
LEE, WEE LEONG, MAJ, Singapore	Camp Roberts, CA	12 JUL 2018	To conduct field testing for thesis research in COTS quadrotor UAV
TEOW BOON HONG, AARON, CPT Singapore	Hong Kong	14 -18 SEP 2018	Presenting a paper and attending a conference on unmanned vehicles
LEE, WEE LEONG, MAJ, Singapore		19 SEP 2018	

D. CONCEPT GENERATION

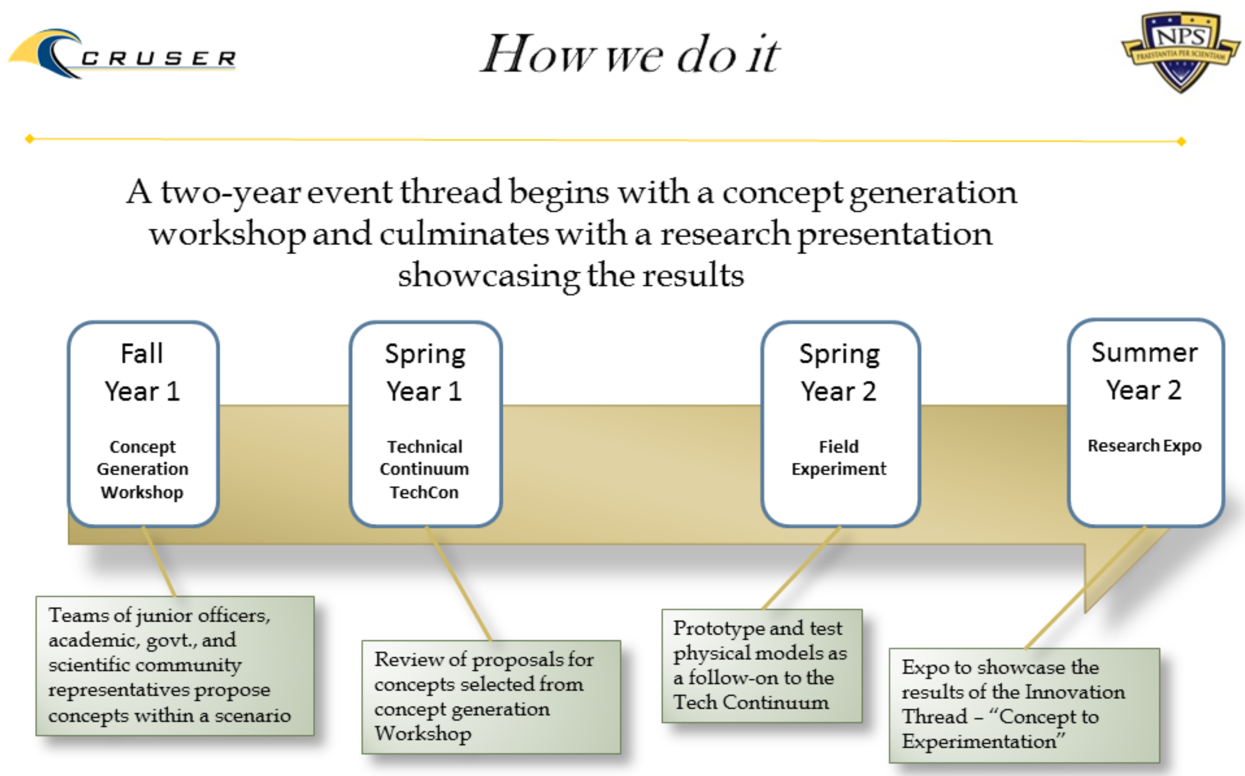

Figure 37. CRUSER innovation thread structure.

The CRUSER concept generation work initiates each new programmatic innovation thread (*see Figure 40*) and at the time of this FY18 annual report we have just launched our eighth innovation thread, *Cross-Domain 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 2018

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
11) Cross-Domain Operations, September 2018

Our most recent workshop, *Cross-Domain Operations*, was held 17-20 September 2018 on the NPS campus. This workshop included nearly 100 participants representing a wide variety of stakeholder groups.

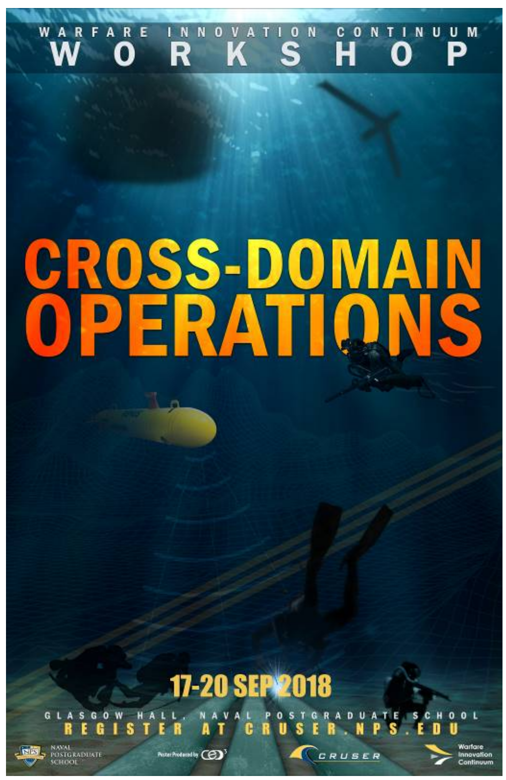

Figure 38. September 2018 Warfare Innovation Continuum (WIC) Workshop, "Cross-Domain Operations."

This Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) sponsored Warfare Innovation Continuum (WIC) workshop was held 17-20 September 2018 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 2018 workshop, *Cross-Domain 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 emerging technologies enhance cross-domain operations?* With embedded facilitators, five teams had three days to meet that challenge, and presented their best concepts on the final morning of the workshop.

Workshop participants were recruited from across the full CRUSER community of interest to include NPS, DoD commands, academia and industry. A concerted effort was made to solicit representatives from all naval warfare domains, as well as from the full range of armed services on campus.

Figure 39. September 2018 Warfare Innovation Continuum (WIC) workshop participants.

This September 2018 WIC workshop included just over 80 active participants, observers and guests – the full participant pool representing nearly 30 different organizations. Half of the workshop participants were NPS students drawn from over a dozen curricula across the NPS campus. For this workshop, the final roster also included participants from The Johns Hopkins University Applied Physics Lab (JHU/APL), the Naval War College (NWC), Battelle, L3 Technologies, and Lockheed Martin. Fleet commands included OPNAV N2N6FX, Naval Air Systems Command (NAVAIR), Naval Undersea Warfare Center (NUWC) Newport, 12th Flying Training Wing, Space and Naval Warfare Systems Command (SPAWAR) Systems Center (SSC) Pacific, Naval Surface Warfare Center Panama City Division (NSWC PCD), U.S. Fleet Forces (USFF), the Office of Naval Research (ONR), the Royal Australian Navy (RAN), and the New Zealand Defence Force.

The six concept generation teams were organized to maximize diversity of participant experience. Team workrooms provided individual workspaces while maintaining the ability of team members and facilitators to share many ideas at several stages in concept development. All participants were encouraged to leverage their individual expertise and experience, regardless of their team assignments.

A group networking event was scheduled on the first night to enhance group dynamics, and prepare individuals to work efficiently in an intensive team environment. Senior members of CRUSER, NPS leadership and academic community, as well as visiting subject matter experts were invited to attend any and all of the workshop that fit their interest and schedule. All were encouraged to attend the final concept presentations on Thursday morning.

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 2018 WIC Workshop report, but in summary these concepts include:

- ***Counter UxS:*** this topic area includes concepts to counter attacks by adversary autonomous assets (real and virtual) in multiple domains envisioned in a future contested region. Examples of specific concepts within this topic area include *Algorithm Capture* and *Weaponized Autonomous Sensor Persistence (WASP) – many smaller unmanned systems (UxS) blocking and/or attacking another UxS.*

- ***Cross-Domain Connectivity:*** this topic area includes concepts to establish robust and resilient communication networks between autonomous manned and robotic assets operating across multiple domains simultaneously in a future contested environment assuming degraded or denied communications. Examples of specific concepts within this topic area include *Underwater Disaggregated Architecture* and *C3PO for Machines – a universal translator*.

- ***Human-Autonomy Teaming:*** this topic area includes concepts to integrate manned and unmanned assets working as an integrated force in a future battlespace. Examples of specific concepts within this topic area include *Virtual Battlefield Sim* and *Third Eye – a human worn augmented data collector*.

- ***Autonomy for Deception:*** this topic area includes concepts employing autonomy to spoof, decoy, or otherwise deceive future adversary forces, human and robotic. Examples of specific concepts within this topic area include *Trash Camo, Bio Buoys* and the *Submarine Investigation, Revelation, and Exploitation Network (SIREN) - many UxS elements mimicking a high value unit*.

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 FY19 and FY20 Call for Proposals. Technical members of the CRUSER community of interest will present proposals at a technical continuum gathering such as TechCon 2019 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 2019 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 2020.

2. Technology Continuum (TechCon) 2018

Figure 40. CRUSER Technical Continuum (TechCon), April 2018

NPS CRUSER held its sixth annual Technical Continuum (TechCon) on 17 and 18 April 2018. This event was for NPS students and faculty interested in education, experimentation and research related to employing unmanned systems in operational environments. TechCon 2018 was intended to further concepts developed during the September 2017 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.

TechCon presentations are archived and available through the NPS Dudley Knox Library at https://calhoun.nps.edu/handle/10945/53346.

3. Rapid Prototyping in the RoboDojo

The RoboDojo is an NPS maker lab where all curricula can get hands-on experience with basic robotic systems and advanced prototyping and fabrication methods. We offer short workshops, equipment, tools, and user communities for all NPS students, faculty, and staff. The RoboDojo users are interested in new technologies of interest and older technologies that continue to have operational application. Our lab is closely aligned with the Marine Maker community, OPNAV N415 Additive Manufacturing, Navy Fab Labs, and many other educational, government, and private maker labs.

In FY18 the RoboDojo hosted workshops on a variety of topics taught by NPS students, faculty, staff, ONR reservists, and visiting specialists (*see Table 6*).

Table 6. Workshops hosted in the RoboDojo in FY18.

Programming & Software	Arduino Basics Object Oriented Programming in Arduino Arduinos in Action RetroPi Intro to Raspberry Pi Raspberry Pi Basics: Building an alarm system Intro to Linux Linux Routers and Firewalls Introduction to ROS (Robot Operating System) Open BCI: Brain Computer Interfaces VR After Dark Augmented Reality Emergent Algorithms Intro to Cyber Capture the Flag Introduction to Software Defined Radios Docker and Github R Shiny
UAS	Blue Force/Red Force use of Unmanned Aerial Systems Drone Simulators: RealFlight Drone Flying on Softball Field Drone Building Inductrix Drones

Prototyping	CNC Milling CNC Routing with X-Carve Introduction to CAD functions in Fusion 360 Solidworks Build a 3D printer Surface Mount Soldering Introduction to 3D Printing Designing for the Laser Cutter/Engraver Rapid Prototyping of Manned and Unmanned Systems Vinyl Cutting Designing a Custom Circuit with KiCAD Learn to Solder Build a Versa Wing Intro to Digital Design for 3D Printing Metal 3D Printing

The RoboDojo also hosted both the Linux Users Group and the Solidworks Users Group throughout FY18, hosted a "Combat Robots" event in October 2017 and again in October 2018, and was a key participant in "Discover NPS Day" in December 2017 and again in October 2018. In FY18 the RoboDojo supported two Systems Engineering (SE) classes, two Computer Science (CS) classes, and three classes for the Defense Analysis (DA) Department. One of the DA classes was an independent study addressing use of Additive Manufacturing to support Information Operations. Many guests to campus also visited the RoboDojo. Guests in FY18 included:

- SSC Pacific
- LtGen Dana USMC, DC for I&L
- MajGen Mullen USMC
- Carnegie Mellon
- Georgia Tech Research Institute (GTRI)
- Marine Corps Warfighting Lab (MCWL)
- Naval War College
- DIUx

E. OUTREACH AND RELATIONSHIPS

1. Community of Interest

CRUSER continued to grow its membership throughout FY18. 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 41*). 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 the CRUSER web presence and member interaction with military, academic and industry personnel during field experimentation, workshops, educational forums and CRUSER monthly meetings. FY15 brought the community over the 2,000-member mark, and CRUSER membership surpassed 3,000 members in March 2016 and has remained at that level since.

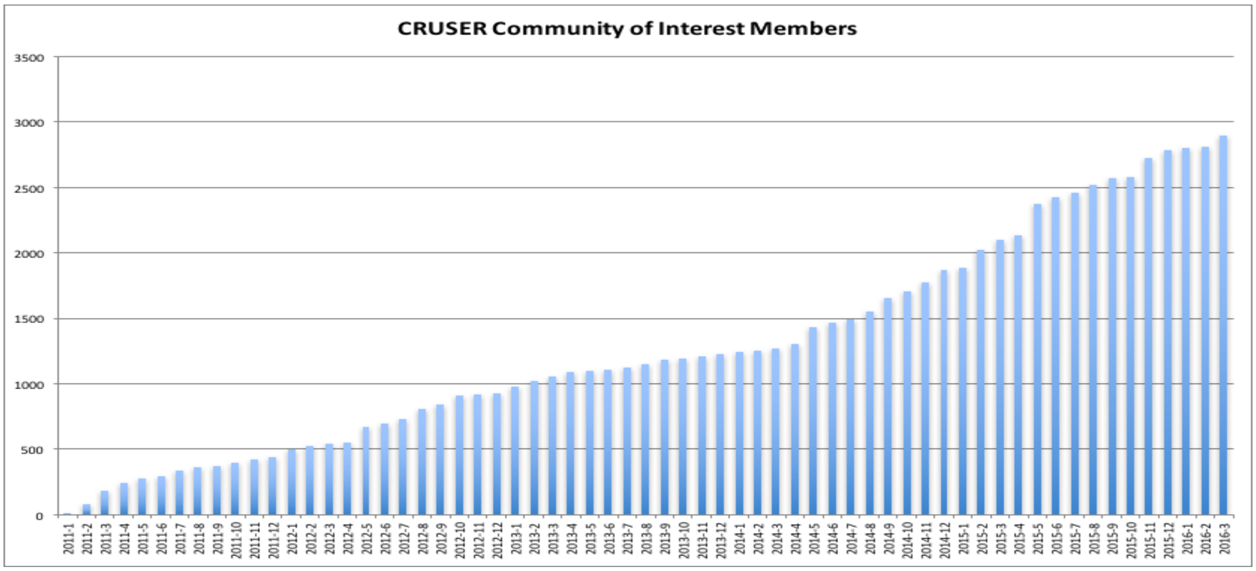

Figure 41. CRUSER community of interest growth from January 2011 to March 2016.

Beyond NPS campus members, the CRUSER community of interest (CoI) includes major stakeholders from across the DoD, industry and academia (*see Figure 42*). As of 30 September 2018, industry members made up 44% of the total CRUSER CoI, with the U.S. Navy and U.S. Marine Corps as the next largest group represented at nearly 20%.

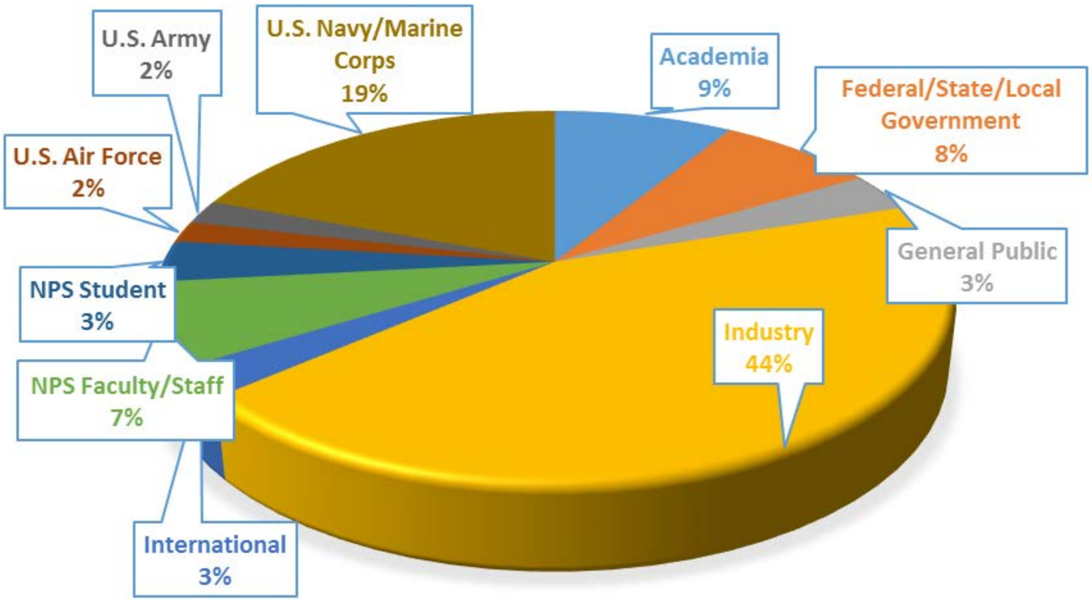

Figure 42. CRUSER community of interest breadth of membership as of 30 September 2018.

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.[48] 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 FY18 there were eleven NPS CRUSER monthly meetings featuring 16 presentations (*see Table 7*).

Table 7. FY18 NPS CRUSER Monthly Meeting presentations.

Date	Presentation(s)
OCT 2017	*No meeting in lieu of CRUSER Seminar by Dr. Bob Iannucchi*
NOV 2017	*LCDR Alexander Williams USN, NPS - Forward-Deployed Aerial ISR System*
DEC 2017	*No meeting*

[48] **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

JAN 2018	*Gerald Scott, NPS - Field Experimentation 18-2* *Michael McCarrin, NPS - Enhancing Object Recognition in LIDAR Point-Cloud Data* *Jessica Reichers, NAWCWD - Autonomous Research Arena (AuRa) Human-Machine Interface*
FEB 2018	*CDR Katy Giles, USN - Mission-based Architecture for Swarm Composability* *Dr. Ray Buettner and Ashley Hobson, NPS - Sea, Land, and Air Military Research (SLAMR) Facility*
MAR 2018	*Dr. Doug Horner, Dr. Alex Bordetsky, Dr. Sean Kragelund and Aurelio Monarrez- Multi-Thread Experiment (MTX)*
APR 2018	*Dr. Alex Bordetsky, NPS, Director of CENETIX – Integrating and operating the Multi-Thread Experiment (MTX) Maritime, Land and Air Network*
MAY 2018	*Sondre Engebraten – Test and Evaluation of Decentralized Controller for a Multi-Function Drone Swarm* *CPT Todd Howe USMC – Planning and Prototyping a SAR Mission with UxVs*
JUN 2018	*LT Andy Schnieders USN: Comparison Study of Low-Level Controller Techniques for Unmanned Surface Vessels* *LT Tiffany Clark USN: Integrity-Based Trust Violations within Human-Machine Teaming*
JUL 2018	*Dr. Ray Buettner and NPS CRUSER Staff: Cybersecurity for UxV Systems*
AUG 2018	*Dr. Brian Bingham: Welcome and CRUSER FY19 Call for Proposals Discussion* *Boon Hong Aaron Teow: Assessing Effectiveness of Using Combat UGV Swarm in Urban Operations* *Wee Leong Lee: Feasibility Assessment of sUAS-based FOD Detection System*
SEP 2018	*No meeting due in lieu of WIC Workshop 17-20 SEP 2018*

Monthly meeting details are available on the CRUSER website (cruser.nps.edu).[49]

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

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 FY18 are included in the following table (*see Table 8*):

Table 8. FY18 CRUSER program briefings and presentations

DATE	ORGANIZATION
OCT 2017	CDR Mike Brasseur USN, Sea Combat Division – N5 Naval Surface and Mine Warfighting Development Center CAPT Ron Toland USN, Commanding Officer – Fleet Anti-Submarine Warfare Training Center (FLEASWTRACEN)
NOV 2017	
DEC 2017	
JAN 2018	BrGen William J. Bowers USMC, Commanding General, Education Command President – Marine Corps University BGen C.F. Wortman USMC, CG – Marine Corps Warfighting Lab CAPT Mel Yokoyama USN, Commanding Officer – SPAWAR Systems Center (SSC) Pacific Admiral Michael Mullen, Seventeenth Chairman – Joint Chiefs of Staff US Army (AMRDEC, CERDEC), Navy (PMA 209), and UK delegates, Collaborative Open Systems Architecture (COSA) Project workshop
FEB 2018	Mr. Glenn Fogg, Deputy Director – ASD Experimentation & Prototyping
MAR 2018	SES Mr. Robert L. Woods, Principal Deputy Assistant Secretary – Manpower & Reserve Affairs
APR 2018	LtGen Michael G. Dana USMC, Deputy Commandant – USMC Installations & Logistics Ambassador Pham Quang Vinh, Ambassador Extraordinary and

	Plenipotentiary – The Socialist Republic of Vietnam to the U.S.
MAY 2018	MajGen Robert A. Karmazin, Director – J7 Joint Special Operations Forces Development USSOCOM MajGen David "Stretch" Coffman USMC, Director – Expeditionary Warfare (N85) RADM John P. Neagley USN, Program Executive Officer – Unmanned and Small Combatants
JUN 2018	CAPT Chris “Bruno” Brunett USN, Defense Innovation Board Fellow – U.S. Fleet Forces Command
JUL 2018	Dr. Christopher Ekstrom, Deputy Oceanographer and Navigator of the Navy – OPNAV N2N6EB Professor John Jackson, E.A. Sperry Chair of Unmanned and Robotic Systems – Naval War College Dr Jung-Hoon Chung, Director Defense Technology R&D Center; Dr. Yun-Ho Shin, Senior Researcher; and Dr. Jin Seop Soon, Dept of System Dynamics – Korea Institute of Machinery & Materials (KIMM) NASA Ames Unmanned Aircraft System (UAS) Traffic Management (UTM) Project Team – NASA Ames Research Center, CA
AUG 2018	Dr. Kristen Collar, National Security Analyst; and CAPT Phil Perdue USN (ret) – JHU/APL CAPT Cavanaugh USN – COMSUBRON 11 Dr. Wes Cooper – SMWDC Dr. Alan Van Nevel, Director of Research, and Head, S&T Dept – Naval Air Warfare Center Weapons Division (NAWCWD) Dr. John Waterson, Principal Program Manager For Maritime – DARPA STO
SEP 2018	Dr. J. D. Wilson, Assistant Deputy Commandant for Information (ADCI) – Headquarters Marine Corps Col Robert C. Fulford USMC, Director of the Expeditionary Warfare School – Marine Corps University

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. NPS FX related programs incorporate participation by other reserve units as well, and will continue to welcome reservists from all units that we are able to accommodate.

ONR-RC continued to provide operational support to many CRUSER activities, programs, and events in FY18. Collaboration between CRUSER researchers at the Naval Postgraduate School (NPS) and ONR-RC began five 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. 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 FY18 24 reservists supported CRUSER programs (*see Table 9)*.

Table 9. Reservist support for CRUSER programs in FY18.

Month	**Number of Officers**	**Project (s)**
MAR 2018	5	JIFX 18-2
APR 2018	4	JIFX, TechCon 2018
MAY 2018	2	RoboDojo, Mine Warfare Symposium
JUN 2018	3	JIFX 18-3
AUG 2018	7	JIFX 18-4, ARSENL, RoboDojo
SEP 2018	3	WIC Workshop 2018, RoboDojo
TOTAL:	**24**	

III. CONCLUSION

FY18 was the first year of CRUSER's extended mandate of operation. Thanks to all those who have contributed to program success, CRUSER has been granted another five years of program life with promised annual funding by (Acting) Secretary of the Navy Sean Stackley in a memorandum signed in March 2017.

A. PROPOSED FY19 ACTIVITIES

FY19 will see the completion of the seventh innovation thread and the start of the eighth. In support of the SECNAVs mission for CRUSER to, *"shape generations of naval officers through education, research, concept generation and experimentation in maritime applications of robotics, automation and unmanned systems"*, the following deliverables are planned:

- CRUSER will support faculty and student research involving projects associated with robotics and autonomous systems.
- CRUSER will host field experimentation opportunities throughout FY19 for students and research staff in collaboration with the Joint Interagency Field Experimentation (JIFX) program at NPS.
- CRUSER will continue to fund NPS student travel to participate in research and experimentation dealing with all aspects of unmanned systems.
- CRUSER will continue to support the integration of robotics and unmanned systems issues into appropriate courses and educational materials that will enable the Navy and Marine Corps officers afloat to become familiar with the challenges associated with the development and operational employment of these systems.
- CRUSER will host an eighth NPS CRUSER Technical Continuum (TechCon) to present and discuss technologies and innovations under development at NPS and by members of the community of interest, with emphasis on the concepts generated by previous Warfare Innovation Workshops (April 2019).
- CRUSER will sponsor a Warfare Innovation Workshop to kick-off its eighth innovation thread (September 2019).
- CRUSER will continue to grow the community of interest (including DoD, industry and academic members) and host monthly community-wide meetings.
- CRUSER will continue to sponsor and participate in STEM outreach events relevant to robotics education.

- CRUSER will continue to sponsor summer research internships for service academy students to work in laboratories across NPS.

In addition to these ongoing activities, CRUSER is initiating the following new activities to increase our capacity to engage with the robotics and autonomous systems industries:

- CRUSER will expand industry membership in the community of interest, which currently includes roughly 1,400 industry members, through participation the innovation thread events: Warfare Innovation Workshop, TechCon, JIFX experimentation, etc.

- CRUSER will engage industry through a vetted request for information (RFI) process to jointly develop the implementation and operation plans for the Sea Land and Maritime Robotics (SLAMR) facility.

- CRUSER will maintain and moderate a website for sharing UxS cyber assessments across the DoD.

In accordance with all applicable rules and regulations, NPS will continue to execute MIPRs, grants, cooperative agreements, contracts and purchases as necessary to complete the activities described above.

B. LONG TERM PLANS

In FY19 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. CRUSER will continue to support the development of robotics and autonomy across the greater Naval enterprise, the DoD, and all global partners.

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 FY18 report:

Bordetsky, A., & Bourakov, E. (2006). Network on target: Remotely configured adaptive tactical networks. Retrieved from https://calhoun.nps.edu/handle/10945/35934

Bordetsky, A., Glose, C., Mullins, S. and Bourakov, E. (2018). "Machine Learning of Semi-Autonomous Intelligent Mesh Networks Operation Expertise" *HICSS 52 Proceedings*, Hawaii

Bordetsky, A., Bourakov, E., and Kline, T (2017), "Networks That Don't Exist: Mesh Networks of Short Appearance Nodes" *NetSci-X*, Tel-Aviv, Israel

Comstock, K. and Krajewski, S. "Interdependence: Putting robots in the rifle squad", *Marine Corps Gazette*. Accepted for publication, anticipated publication early 2019.

Erickson, C. B., B. E. Ankenman, M. Plumlee, and S. M. Sanchez (2018). "Gradient based criteria for sequential design." *Proceedings of the 2018 Winter Simulation Conference*, eds. M. Rabe, A. A. Jason, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson. Piscataway, NJ: IEEE, forthcoming early 2019.

Erickson, C., B. E. Ankenman, and S. M. Sanchez (2018). "Data from fitting Gaussian process models to various data sets using eight Gaussian process software packages." *Data in Brief*, 18(June), 684-687.

Horner, D. and ENS Noah Wachlin USN (2018) "Robust Time-Varying Formation Control with Adaptive Submodularity"

Horner, D. and ENS Ben Keegan USN "UAV Position Optimization for Wireless Communications"

Orescanin, M.M. and D. Herrmann, M. Orescanin (2018). "Deep Neural Network Classification of Littoral Systems for Change Detection", *American Geophysical Union Fall Meeting*, 13 December 2018, Washington DC. Last accessed 26 December 2018 at https://agu.confex.com/agu/fm18/meetingapp.cgi/Paper/399930

Orescanin, M.M. and D. Herrmann, M. Orescanin (2019). "Deep Neural Network Classification of Heterogeneous Littoral Systems", *Nature Geosciences,* anticipated publication early 2019

Sandoval, Sergio Maj. USMC (2018) "Communications Authentication Protocols for Unmanned Aerial Systems Running the Military Robot Operating System" *CRUSER TechCon 2018*, 12 April 2018.

S. Sandoval and P. Thulasiraman (2018) "Cyber Security Testing of the Robot Operating System 2 in Unmanned Aerial Systems," *IEEE CCNC First Workshop on Unmanned Aerial Vehicle Communications and Networks,* anticipated 2019

Tilus, P. (2018). "Team the P-8 and the Sea Hunter for ASW." *Proceedings Magazine*, Vol. 144/9/1,387. U.S. Naval Institute

Included in FY17 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

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

APPENDIX B: CUMULATIVE THESES AND STUDENT PROJECTS SUPPORTED

This list includes thesis and projects from FY11 forward. Unclassified NPS theses are available through the NPS Dudley Knox Library and DTIC. This list is alphabetized by student last name, and separated by year of completion (*chronologically backward by fiscal year*).

AUTHOR(s)	TITLE	DATE	URL
FY18			
LT Ryan Clapper USN	DIRECTIONAL NETWORKING SOLUTIONS FOR A CLANDESTINE MANET	2018 MAR	Controlled access
LT Tiffany Clark USN	INTEGRITY-BASED TRUST VIOLATIONS WITHIN HUMAN-MACHINE TEAMING	2018 JUN	http://hdl.handle.net/10945/59637
LT Alan J. Clarke USN and Maj Daniel Knudsen III USMC	EXAMINATION OF COGNITIVE LOAD IN THE HUMAN-MACHINE TEAMING CONTEXT (NPS Outstanding Thesis 2018)	2018 JUN	http://hdl.handle.net/10945/59638
Capt K. Comstock USMC and Capt S. Krajewski USMC	UNMANNED TACTICAL CONTROL AND COLLABORATION (UTACC) QUICK-WIN ROBOT ANALYSIS	2018 SEP	http://hdl.handle.net/10945/60380
Maj John M. Fout USMC and Maj James M. Ploski USMC	UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION HUMAN MACHINE COMMUNICATION AND SITUATIONAL AWARENESS DEVELOPMENT	2018 JUN	http://hdl.handle.net/10945/59661
Capt Hawken Grubbs USMC	FIELD PROGRAMMABLE GATE ARRAY HIGH CAPACITY TECHNOLOGY FOR RADAR AND COUNTER-RADAR DRFM SIGNAL PROCESSING (NPS Outstanding Thesis 2018)	2018 JUN	http://hdl.handle.net/10945/59670
Maj Nathan J. Gulosh USMC	EMPLOYMENT OF INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE DRONE SWARMS TO ENHANCE GROUND COMBAT OPERATIONS (NPS Outstanding Thesis 2018)	2018 JUN	http://hdl.handle.net/10945/59672
LT Calvin S. Hargadine USN	MOBILE ROBOT NAVIGATION AND OBSTACLE AVOIDANCE IN UNSTRUCTURED OUTDOOR ENVIRONMENTS	2017 DEC	http://hdl.handle.net/10945/56937
Maj S. Harvey UMC and Capt Trevino USMC	ANALYSIS OF EMERGING AND CURRENT SUBSYSTEM TECHNOLOGIES IN SUPPORT OF WARFIGHTING CAPABILITIES (NPS Outstanding Thesis 2018)	2018 SEP	http://hdl.handle.net/10945/60410
Maj Andrew Heitpas USMC	STIGMERGIC CONTROL OF DUAL-DIRECTION COMMUNICATION FERRY NODES FOR DENIED COMMUNICATIONS	2018 JUN	http://hdl.handle.net/10945/59685

	ENVIRONMENTS (NPS Outstanding Thesis 2018)		
ENS Ben Keegan USN	UAV POSITION OPTIMIZATION FOR WIRELESS COMMUNICATIONS	2018 JUN	http://hdl.handle.net/10945/59695
Capt Justin L. King USMC	CONCEPT OF OPERATIONS FOR USING COMPUTER VISION CAPABILITIES ON TACTICAL AIRCRAFT (NPS Outstanding Thesis 2018)	2018 JUN	http://hdl.handle.net/10945/59698
Major Wee Leong Lee, Singapore Air Force	ASSESSMENT OF FOREIGN OBJECT DEBRIS MANAGEMENT USING GROUP 1 UNMANNED AERIAL SYSTEMS (NPS Outstanding Thesis 2018)	2018 SEP	http://hdl.handle.net/10945/60426
LT Wyatt T. Middleton USN	VALIDATION OF ARCHITECTURE MODELS FOR COORDINATION OF UNMANNED AIR AND GROUND VEHICLES VIA EXPERIMENTATION	2018 JUN	http://hdl.handle.net/10945/59555
Giovanni Minelli	RESOURCE-CONSTRAINED AUTONOMOUS OPERATIONS OF SATELLITE CONSTELLATIONS AND GROUND STATION NETWORKS (doctoral dissertation)	2018 SEP	http://hdl.handle.net/10945/60435
Maj John Park USMC	GROUP 3 UNMANNED AIRCRAFT SYSTEMS MAINTENANCE CHALLENGES WITHIN THE NAVAL AVIATION ENTERPRISE	2017 DEC	http://hdl.handle.net/10945/56779
Major Yi Kai Qiu, Republic of Singapore Air Force	PROPAGATION ENVIRONMENT ASSESSMENT USING UAV ELECTROMAGNETIC SENSORS	2018 MAR	http://hdl.handle.net/10945/58353
LCDR John J. Renquist USN	AN INDEPENDENT ASSESSMENT OF THE ENERGY ENHANCEMENTS TO THE SYNTHETIC THEATER OPERATIONS RESEARCH MODEL (STORM)	2018 SEP	http://hdl.handle.net/10945/60453
Maj. Sergio Sandoval	CYBER SECURITY TESTING OF THE ROBOT OPERATING SYSTEM IN UNMANNED AERIAL SYSTEMS	2018 SEP	http://hdl.handle.net/10945/60458
LT Joseph A. Schnieders USN	COMPARISON STUDY OF LOW-LEVEL CONTROLLER TECHNIQUES FOR UNMANNED SURFACE VESSELS	2018 JUN	http://hdl.handle.net/10945/59581
LT J. Tanalega USN	ANALYZING UNMANNED SURFACE TACTICS WITH THE LIGHTWEIGHT INTERSTITIALS TOOLKIT FOR MISSION ENGINEERING USING SIMULATION (LITMUS)	2018 MAR	Controlled release
Wei Shun Teo, DSO National Laboratories Singapore	ADVANCING COTS UAV CAPABILITY TO PROVIDE VISION-BASED SA/ISR DATA (NPS Outstanding Thesis 2018)	2018 SEP	http://hdl.handle.net/10945/60353
Major Boon Hong Aaron Teow, Singapore Army	ASSESSING THE EFFECTIVENESS OF A COMBAT UGV SWARM IN URBAN OPERATIONS (NPS Outstanding Thesis	2018 SEP	http://hdl.handle.net/10945/60354

	2018)		
LT Preston T. Tilus USN	ASSESSING ORCHESTRATED SIMULATION THROUGH MODELING TO QUANTIFY THE BENEFITS OF UNMANNED-MANNED TEAMING IN A TACTICAL ASW SCENARIO	2018 MAR	http://hdl.handle.net/10945/58270
LT Travis M. Turner USN	ANALYZING UUV HULL CROSS-SECTIONS FOR MINIMIZING WAVE LOADS WHEN OPERATING NEAR SURFACE	2018 JUN	http://hdl.handle.net/10945/59606
Chief A. Tyerman, Maple Valley Fire & Life Safety	USING UNMANNED AERIAL VEHICLES FOR AUTOMATED EXTERNAL DEFIBRILLATOR DELIVERY IN THE SEATTLE KING COUNTY REGION FOLLOWING OUT-OF-HOSPITAL CARDIAC ARREST	2018 SEP	http://hdl.handle.net/10945/60360
Lieutenant Leander J. C. van Schriek, Royal Netherlands Navy	EVALUATING EFFECTIVENESS OF DIRECTIONAL ACOUSTIC MODEMS INTEGRATED ONTO AUTONOMOUS PLATFORMS (NPS Outstanding Thesis 2018)	2018 JUN	http://hdl.handle.net/10945/59609
ENS Noah Wachlin USN	ROBUST TIME-VARYING FORMATION CONTROL WITH ADAPTIVE SUBMODULARITY	2018 JUN	http://hdl.handle.net/10945/59612
LT Alexander G. Williams USN	FEASIBILITY OF AN EXTENDED-DURATION AERIAL PLATFORM USING AUTONOMOUS MULTI-ROTOR VEHICLE SWAPPING AND BATTERY MANAGEMENT	2017 DEC	http://hdl.handle.net/10945/56847
Maj Costantinos Zagaris USAF	AUTONOMOUS SPACECRAFT RENDEZVOUS WITH A TUMBLING OBJECT: APPLIED REACHABILITY ANALYSIS AND GUIDANCE AND CONTROL STRATEGIES (doctoral dissertation)	2018 SEP	http://hdl.handle.net/10945/60364
SE Capstone Cohort JUN2018	DISTRIBUTED MARITIME OPERATIONS AND UNMANNED SYSTEMS TACTICAL EMPLOYMENT	2018 JUN	http://hdl.handle.net/10945/59587
SE Capstone Cohort DEC2017(1)	INVESTIGATION OF REQUIREMENTS AND CAPABILITIES OF NEXT-GENERATION MINE WARFARE UNMANNED UNDERWATER VEHICLES	2017 DEC	http://hdl.handle.net/10945/56878
SE Capstone Cohort DEC2017(2)	COST, SCHEDULE, AND PERFORMANCE ELEMENTS FOR COMPARISON OF HYDRODYNAMIC MODELS OF NEAR-SURFACE UNMANNED UNDERWATER VEHICLE OPERATIONS	2017 DEC	http://hdl.handle.net/10945/56859
LT Todd Coursey USN	DIRECTIONAL SOUND SENSING OF UAV'S USING A MEMS SENSOR	2018 DEC	Controlled release

LCDR Dave Herrmann USN	MORPHODYNAMIC CLASSIFICATION OF COASTAL REGIONS USING MACHINE LEARNING THROUGH DIGITAL IMAGERY COLLECTION	2018 DEC	URL to be assigned once archived
Hopchak, M. S.	AUTONOMOUS DECISION AND INDEPENDENT CUING IN SWARM ROBOTICS	2018 DEC	URL to be assigned once archived
Riarh Parminder CANADA	A STUDY OF MEMS ACOUSTIC DIRECTIONAL SENSORS	2018 DEC	URL to be assigned once archived
FY17			
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
Lieutanant 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

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APPENDIX C: COMMUNITY

This is a representative listing of the CRUSER community of interest at the conclusion of FY18. It is not meant to be inclusive, but is included to demonstrate depth and breadth of interest.

ACADEMIA

AFIT
AFJROTC Jefferson High School
Alaska Center for Unmanned Aircraft Systems Integration
American University
APLUW
Applied Physics Laboratory
Argonne National Laboratory
Arizona State University
ASU Research Enterprise
Australian Defence Force Academy
AUV IIT Bombay
AUVSI Foundation
Bangalore Robotics
Ben-Gurion University of the Negev
Berkley
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 University
Chapman University
Chosun University
Clover Park Technical College
Community College of Baltimore County
Cornell University AUV
CSULB
CSULB HHS
CSUMB
C-UAS, BYU
Daniel H. Wagner Associates
Delft University of Technology
Doolittle Institute
Drexel University
Eindhoven University of Technology
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
The Johns Hopkins University (JHU)
Johns Hopkins University Applied Physics Laboratory (JHU/APL)
Kasetart University
Kennesaw State University
KSU
Ludwig Maximilians Univeristat
Macquarie University
Marine Advanced Technology Education (MATE) Center
Maritime State University
MATE
MBARI
McGill University
Memorial University of Newfoundland
Mississippi State University
MIT
MIT Lincoln Lab
MIT Lincoln Laboratory
Monterey Bay Aquarium Research Institute
MPC
National Defense University
Naval Air Warfare Center
Naval War College
Naval War College - Monterey
Netherlands Defence Academy
New Mexico State University
NJIT
NMSU
North Carolina Central University
North Carolina State University
North Carolina State University (ITRE)

Northwestern Polytechmical University
Northwestern University
Notre Dame
NWC
OK State
Old Dominion University
Oregon Institute of Technology
OSU
RPI
Saint Louis University
San Diego Christian College
San Diego City College
San Diego State University
SDSU/Faster Logic LLC
South Dakota School of Mines and Technology
Southwestern College
SSAG
St. Georges College
St. Mary's University
Stanford
SUNY Stony Brook
Teach for America
Technion
Texas A&M
The Ohio State University
Thomas Jefferson High School for Science and Technology
TUM
U South Florida
U.S. Naval Academy
UC Davis
UCF
UCSF
UF
UFL
UK National Oceanography Centre
University of Alaska at Fairbanks
University of Hawaii
University of Michigan
University of Oklahoma
University of Texas
University of Colorado - Boulder
University at Buffalo
University of Alabama
University of Alabama in Huntsville
University of Alaska, Fairbanks
University of California Davis
University of California, Merced
University of Dayton Research Institute
University of Hawaii
University of Hawaii - Hilo
University of Idaho
University of Iowa
University of Maryland
University of Maryland UAS Test Site
University of Memphis
University of Michigan
University of Minnesota - Twin Cities
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 at Arlington Research Institute (UTARI)
UNLV
Unmanned Vehicle University
US CG Aux
USC
USF
USRA
Utah State
Utah State Space Dynamics Lab
UXV University
Virginia Tech
Virginia Tech
Wake Forest University
Wichita State University

Federal/State/Local Government:

Aeronautics Research Directorate
Allied Command Transformation
Ames Research Center
AOPA (Aircraft Owners & Pilots Association
Argonne National Laboratory
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 Las Vegas
Cleveland VA Medical Center
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
Department of Justice
Department of the Interior
Department of State
DHS ICE
DHS/OPS
DIA
DMDC
DoD OIG
DOT Office of Inspector General
DTRA
DTRA/CXTT
Eldorado Sheriff's Office
Elk Grove PD
FAA
FAA Western-Pacific Region
FEMA
Fremont PD
Fremont PD/CPOA
GEMA/HS
GWU
HHS/ASPR
Houston police
HQ NORAD/USNORTHCOM
HQ TRADOC
Irvine PD
Jet Propulsion Laboratory (JPL)
Joint Staff J-7
Joint Staff Remote/Unmanned Futures Office
Joint Vulnerability Assess. Branch
Lawrence Livermore National Lab
Lawrence Livermore National Laboratory
Lawrence Livermore Natl Lab
Marin County Sheriff
Marin Sheriff
Marina Police Department (Retired)
Monterey Co Sheriff
Mountain View PD
NASA
NASA JPL
NASA Langley Research Center
NASA, CSUMB
NASA, Langley Research Center
NASA-JSC
National Air Security Ops Center -CBP
National Defense University
National Geospatial-Intelligence Agency
National Guard Bureau
National Transportation Safety Board
NAVAIR
NAVAIR (NAWCWD)
Naval Oceanographic Office
Naval Research Laboratory
Naval Sea Systems Command
Naval Undersea Warfare Center Division Newport
NAVSEA
NAWCAD
NDU
NEMA
Nevada Institute for Autonomous Systems
NOAA
NPS
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
PMW 750
Riverside DA Office
RS Special Research Access
Sac Co Sheriff
Sacramento Office of Emergency Services
Sacramento Sheriff
San Diego Sheriffs 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 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. House of Representatives

United States Secret Service
Unmanned Underwater Systems Section - part of the Directorate of Naval Combat Systems
US Army ERDC
US Central Command
US Coast Guard
US Marshall
US Navy
US Secret Service
US Special Operations Command
USCG R, D, T&E
USCG Research & Development Center
USEUCOM
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
AAI Corporation
Aatonomy
Abbott Laboratories
Abbott Technologies
ACADEMI
Accelerated Developmnet & Support Corp
Access Spectrum
ACE Applied Composites Engineering
ACSEAC
ACSS (Aviation Comm & Surv. Systems), LLC
ACT
Action Drone
ADS Inc
ADSYS Controls Inc
Advanced Acoustic Concepts
Advatech Pacific
AEgis Technologies
Aerial MOB
Aero UAVs
AeroEd Group
Aerofex Corp
Aerojet
Aerojet Rocketdyne
Aeroprobe Corp
Aeropsace Corp
Aerospace & Def INO Parts
Aerospace Analytics
Aerospace/defense Professional
AeroTargets International
Aerovel Corp
AeroVironment
Affordable Engineering Services
Ag Eagle
AgriSource Data, LLC
Air Concepts Group
Air Law Institute
Air View Consulting
Airbus Defence & Space
Airspeed Equity
Airware
ALAKAI Defense Systems
Alaris Pro
Alaska Aerospace Corporation
ALCO
Alex
Alidade Incorporated
Allen Aerial Imagery, LLC
Alpha Research & Technology, Inc.
Alta Devices
Altair
Altron
Amazon
American Autoclave Co
AMP Research
AMP Research, Inc.
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
Atlas NA

Atlas North America
auratech
Aurora Flight Sciences
Ausley
Autonomous Avionics
Autonomous Surface Vehicles, LLC
AUVAC
AUVSI Foundation
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
Bell Helicopter
BGI Innovative Solutions
Bicallis, LLC
Black & Veatch Special Projects Corp.
Blackbird Technologies
Blackhawk Emergency Management Group
Bluefin Robotics Corporation
BMNT Partners
Boeing
Boomerang Carnets
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
CHHOKAR Law Group
CHI Systems
Chinwag
Cisco
Citadel Defense Co
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
Copperhead Aeronautics
Cornerstone Research Group
Cornet Technology
Corning
Corsair Engineering
CPI
CRYSTAL
Crystal Rugged
CS Draper Laboratory
CSA
CSCI - Computer Systems Center Inc.
CS-Solutions Inc
CT Johnson & Associates
CTJA, LLC
CUBIC
Cutting Edge
Cyber Security & IS IAC (CSIAC)
CyberWorx
CYPHY Works
DARPA
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

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
Draper Lab
Draper Laboratory
Draper Labs
DREAMHAMMER
D-RisQ
Drone AmericA
Drone Aviation Corp
Drone Logger Enterprise
Drone Services Hawaii
DroneBase
Dronecode
DST Control
Duetto Group
Duzuki
E.J Krause & Associates
EC Wise
ECC
Ehang
Elbit Systems
Electric Boat
Electricore
Electro Rent Corporation
Elementary Institute of Science
Ellevision, LLC
Elmo Motion Control
ELTA Systems
Emerging Technology Ventures
Emerging Technology Ventures Inc.
Engility, Inc
Engineered Packaging Solutions
EnrGies
EQC, Inc
ERA
Ernest Brown & Company
Ervin Hill Strategy
ESRI
Esterline Control & Communication Systems
Eutelsat America
Exelis Inc
FABLAB San Diego
Fairchild Imaging
Farm Space Systems LLC
Fathom5
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
Freewave
Frost & Sullivan
Fugro Geoservices Inc.
G2 Solutions
Galois Inc.
GC Ventures
GDEB
GDIT
GE Aviation
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
Gold Star Strategies LLC
Goleta Star LLC
GPH Consulting
Greensea Systems
Griffon Aerospace
Gryphon
Gryphon Sensors
GTRI
GTS Consulting
H.O. JOHNSON RESULTANTS LLC
Hangar Technology
Harris Corp
Harwin
Hawaii Hazards Awareness & Resillience Program
Herley Lancaster
Hoggan Lovells LLP
Honeywell
Hoyt Scientific

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 Umanned Systems
Insights
INSITU
INSITU/AUVSI
Institute for Homeland Security Solutions
Intelligent Automation
InterContinental IP
Intergraph Gov Solutions
Iris Technology
iRobot
ITA International
IXI Technology
JACOBS
Janes Capital Partners
Japan Aerospace Exploration Agency
JHNA
JHU/APL
JOBY Aviation
John Deere
Joint Venture Monterey Bay
Jove Sciences, Inc.
Juniper Unmanned
Just Innovation
Kairos Autonomi
Kaman
Ken Cast
Knife Edge
KNOWMADICS
Kongsberg
Kraken
Kratos Defense
KSI
L-3 Advanced Programs, Inc.
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 Aeronautics Company
Lockheed Martin Co (LMCO)
Lockheed Martin Missile & Fire Cont
Lynntech
Magnet Systems
Makani Power Inc
MAMM 3D Inc.
Management Sciences, Inc
MAPC (Maritime Applied Physics Corp)
Maplebird
Marine Acoustics
Maritime Applied Physics Corporation
Maritime Tactical Systems, Inc. (MARTAC)
MARTAC
Martin UAV
MASI LLC
Materials Systems Inc.
Materion
MBARI
MBDA Incorporated
McBee Strategic
McCauley Prop Systems
McClean Group
McKenna, Long & Aldridge LLP
MCR Critical Thinking Solutions Delivered
MDA Corporation
Medweb
Merlin Global Services
Mesa Technologies
Metal Technology
Metcon Aerospace & Defense
METI
Metis Design
Metron Inc
Micro USA Inc.
Microflown
MicroPilot
Microwave Monolithics Inc
Middle Canyon LLC
MilSource
Miltrans
MINCO
MISTIC INC

Mistral Inc
Mistral Inc.
MIT Enterprise Forum San Diego
MITRE Corporation
Modern Technology Solutions, Inc.
Modus Robotics
Momentum Aviation Group
Monterey County Herald
Moog Inc
Morrison & Foerster LLP
MosaicMill
MSI
MTSI - Modern Technology Solutions
Multi GP
Murtech Inc.
Nano Motion
Nanomotion
NASC
National Science & Technology Corp.
Nautilus
Naval Nuclear Laboratory
NAVPRO Consulting LLC
Near Earth Autonomy
Newport News Shipbuilding
Next Vision Stabilized Systems Ltd
Nexutech, Ltd
Neya Systems LLC
NGC
NGC (Northrop Grumman Corp)
NiederTron Robotics
NLD MOD (Defence Materiel Org
NNS
North Dakota Counter UAS Task Force
Northeastern University
Northrop Grumman Corporation
NorthWind
NUAIR
NUAIR Alliance
NUAIR Alliance Griffiss
NV Drones
NWB Environmental Services
NWUAV Propulsion Systems
Ocean Aero
Ocean Lab
Oceaneering
ODNI
Odyssey Marine Exploration
Ontario Drive & Gear
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
Paragrine Systems
Parsons
Paso Robles Ford
Patuxent Partnership
Paul R Curry & Associates
Pentagon Performance Inc.
People Tec
perceptronics solutions
Perkins COIE
Persistent Systems
PG&E
Phantom Works
Phyiscal Optics Corp
Physical Sciences Inc
Polarity
Pole Zero
Power Correction Systems Inc.
Power Ten Incorporated
Power4Flight LLC
Praxis Aerospace Concepts International
Precision
PREMANCO Ventures
Prescient Edge
Princeton Lightwave
Prioria Embedded Intelligence
Profit Quadro
Progeny Systems
Promia
Propellerheads
Provectus Robotics Solutions
Prox Dynamics
Proxdynamics
q-bot
QinetiQ
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

RD Integration
Red Hat
Red Six Solutions
RedHat
Redwall Technologies
Reference Technologies INC.
Renaissance Strategic Advisors
RFMD
Riegl USA
Riptide Autonomous Solutions
RIX Industries
RJ Vincent Enterprises LLC
RMV Technology Group
ROBOTEAM
Robotic Research
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
Sagetech Corporation
SAIC
Saildrone
SAP
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 Govt 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
Sikorsky Aircraft
Silent Falcon UAS Technologies
Silvus Technologies
Simlat
SIRAB Technologies Inc
SKYEYE GLOBAL
Skylift Global
SNC - Sierra Nevada Corporation
SNC (Sierra Nevada Corporation)
Soar Oregon
Soar Technology
Soar Technology, Inc.
Society of Experimental Test Pilots
Soliton Ocean Services, Inc.
Sonalysts, Inc.
Sonitus Technologies
Space Micro
Sparton
Sparton Corporation
Sparton Defense and Security
Spatial and Spectral Research
Spatial Integrated Systems
Spectrabotics
Spectrum Aeronautical, LLC
Spinner
Spiral Technology, Inc.
SRC, Inc.
SRI
SRI International
SSL
ST Aerospace
Stark Aerospace Inc.
Steinbrecher & Span LLP
STMicroelectronics
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 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 Aerospace Corporation
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
Third Block Group
Tiger Tech Solutions
Tiresias Technologies
TMT ~ spg
Topcon
Torch Technologies
TorcRobotics
Toyon
TP Logic
Trabus
Trans Universal Energy, LLC
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 - USSI
UltraCell
Ultra-EMS
Ultravance Corp
UMS3
Unexploded Ordnance Center of Excellence
United Technologies Research Center
Universal Display Corporation
Unmanned Aero Services
Unmanned Power LLC
Unmanned Systems
Unmanned Systems Institute
Unmanned Systems Research & Consulting LLC
Unmanned Vehicle Systems Consulting, LLC
Unmanned World Wide
US Nuclear Corp.
UTC Aerospace Systems
UTC Aerospace Systemsâ€™ ISR Systems
UxSolutions, Inc
Valkyrie Systems Aerospace
VCT (Vehicle Control Technologies Inc)
Vector CSP
Velocity Cubed Technologies
Veridane
ViaSat
Video Ray LLC
VideoBank
Virtual Agility
Vision Technologies
Vital Alert
VPG Inc
VSTAR Systems Inc.
Vulcan
Wade Trim
Wateridge Insurance Services
WBT Innovation Marketplace
WDL Systems
Whitney, Bradley & Brown Inc. (WBB)

Williams Mullen
Wind River
WINTEC
Wireless SEC Assoc
Woolpert
Wounded Eagle UAS
Wyle
Yamaha Motor Corp. USA
Z Microsystems
ZDSUS
Zepher
Zimmerman Consulting Group
Ziska Unmanned Machines Associates
Zivko Aeronautics
Zodiac Aerospace
Z-Senz
Zugner LLC

International:
4TH Naval Warfare Flotilla
ADD(Agency for Defence Development
Be MoD
British Consulate - General LA*
Business France
Canadian Forces Aerospace Warfare Centre
Canadian Forces Maritime Warfare Centre
C-Astral
Defence Science & Technology Group
Drone X Solution
Dronomy
FFI
FMV
Goleta Star LLC
High Eye BV
Higheye
LIG Nex1, South Korea.
Netzer
Pixiel
Simlat
Swedish Naval Warfare Center
Swedish Navy Warfare Center
UCAL-JAP Systems LTD.

U.S. Air Force:
26th Special Tactics Squadron
412 th Test Wing
412th Test Wing
413th Flt Test Squadron
432 OG
432nd Operational Support Squadron
51st DOA
548th ISR Group
558 FTS
88th T&E Squadron
9th Intelligence Squadron
AFIAA
AFIT
AFRL
AFRL/RYAA
Air Combat Command
Air Education and Training Command
Air Force Institute of Technology
Air Force Research Laboratory (AFRL)
Air National Guard
COMPATRECONWING TWO
HQ NORAD
Joint Counter Low, Slow, Small UAS (JCLU)
Joint Counter Low, Slow, Small Unmanned Aircraft Systems Joint Test
JS J-7, Future Joint Force Development
JS/JIOR
JWAC
MI Air National Guard
NORAD - USNORTHCOM
NPS
PACOM
RETIRED
SOCOM
The Joint Staff
Twenty-Fifth Air Force
US Strategic Command
USAF
USAFA
USSOUTHCOM
USSTRATCOM

U.S. Army:
314 MI BN
526th Intel Squadron
79th IBCT
AMC/RDECOM/AMRDEC
ARL
Army Research Lab
Army Research Lap
Army S&T
Army Science Board
Army Unmanned Aircraft Systems
ATEC
DLI
DoD Unexploded Ordnance Center of Excellence
FCOE
Ft Lewis
I2WD TFE
Ist IO Command
Maneuver Battle Lab
Maneuver Center of Excellence
Maneuver Center of Excellence, Maneuver Battle Lab

Mission Command Center of Excellene
NATO
Night Vision Lab
NORAD-USNORTHCOM (UAS-AI)
Operations Research Department
PEO GCS - RSJPO
RDECOM
Redstone Arsenal
Robotic Systems Joint Project Office
RSJPO
TACOM
TRADOC
TRADOC Analysis Center
Unmanned Systems Team, MBL
US Army
US Army Aero Services Agency
US Army Capabilities Integration Center
US Army Research Laboratory
US Military Academy
USASOC
USMA
USNORTHCOM
UXOCOE

U.S. Navy and Marine Corps:
1st Force Recon Co
1st Intel Br
3rd Marine Aircraft Wing
9th Comm Battalion, I MEF
9th Comm BN
Accelerated Development & Support Corp
Air Test & Evaluation Squadron 30
AOC/NWCCD
Army Research Laboratory
ASN(RDA)
ASN-RDA
Booz Allen Hamilton
C3F
Center for Naval Analyses
CETO
CNA
CNAP N809A - UAS Requirements
CNO Strategic Actions Group
CNRC Region West
COMCARSTRKGRU TWO
COMDESRON 31
Commander, Navy Region Northwest
COMNAVSURFOR
COMPACFLT
COMPACFLT (N9)
COMPATRECONWING ELEVEN
COMPATRECONWING TWO (N7)
COMPHIBRON EIGHT
COMPHIBRON SIX, N1
COMSUBDEVRON FIVE
COMSUBDEVRON TWELVE
COMSUBDEVRON-12
COMSUBDEVRON-5, DET UUV
COMSUBPAC (Code N7C)
COMSUBPAC / CTF 34
COMTACGRU ONE
COMTHIRDFLEET
COMTHIRDFLT
COMUSNAVSOUTH
Crane Division, Naval Surface Warfare Center
Crane Naval Surface Warfare Center
CRIC
CRUSER
CSDS-12
CSDS-5
CSG2
CTF70
CVN 68
DARPA
DASN
DON/AA
DUSN (Policy)
Expeditionary Strike Group Three
Explosive Ordnance Disposal Program Office (PMS 408)
FAA Headquarters
Fleet Readiness Center SouthWest
Fleet Survey team
FNMOC
HELICOPTER SEA COMBAT WING PACIFIC
HQMC
HQMC Installations & Logistics
HSC-3
HSCWINGPAC
HSM Weapons School Pacific
HSM-35
HSM-71
HSM-78
I MEF
Irregular Warfare Technology Office
Joint Integrated Air & Missile Defense Organization (J8)
Joint Integrated Air & Missle Defense Organization
Joint Staff Remote/Unmanned Futures Office
JUAS COE
Littoral Combat Ship Anti-Submarine Warfare Mission Package Detachment 2 (LCS ASW MP DET 2)
MARCORSYSCOM
MARFORPAC Experimentation Center
Marine Corp Warfighting Lab
Marine Corps
Marine Corps University, Quantico, VA

Marine Corps Warfighting Lab
Marine Unmanned Aerial Vehicle Squadron 4
MARSOC
MAWTS-1
MCCDC, CD&I, CDD, FMID
MCIOC
MCWL
Mine Warfare Program Office, PMS 495
MINE WARFARE TRAINING CENTER
MINWARA
N2N6E7
N3N5IW
N8
NAE CTO
NAS Patuxent
NASA-JSC
NAV SPEC WAR COM
NAVAIR
NAVAIR - PMA-266
NAVAIR - UASTD
NAVAIR Code 410
NAVAIRWD
Naval Air Warfare Center Patuxent River
Naval Air Warfare Center Training Systems Division
Naval Air Warfare Center Weapons Division
Naval Air Warfare Center-Aircraft Division
Naval Meteorology and Oceanography Command
NAVAL OCEANOGRAPHIC OFFICE
Naval Oceanography and Mine Warfare Center
Naval Research Laboratory
Naval Surface and Mine Warfighting Development Center
Naval Surface Warfare Center
Naval Surface Warfare Center Carderock Division (NSWCCD)
Naval Surface Warfare Center Dahlgren Division (NSWCDD)
Naval Surface Warfare Center Panama City Division
Naval Surface Warfare Center, Carderock Division
Naval Undersea Warfare Center
Naval Undersea Warfare Center, Division - Keyport
Naval Weapons Center Weapons Division
NAVFAC CIOFP1
NAVFAC HQ
NAVOCEANO
NAVSEA
NAVSEA 05T
NAVSEA Carderock
NAVSEA Naval Surface Warfare Center Dahlgren Div
NAVSEA O5L
NAVSEA Port Hueneme
NAVSEA SEA05L
NAVSEALOGCEN
NAVSPECWARCOM
NAVSPECWARGRU THREE
Navy Expeditionary Combat Command (NECC)
Navy Office of General Counsel
Navy PEO LMW PMS 408
Navy Region Southwest
Navy Special Warfarc Command
Navy TENCAP
Navy, Office of the General Counsel
NAWC
NAWC - AD
NAWC WD
NAWCAD
NAWCAD Lakehurst
NAWCTSD
NAWCWD
NAWC-WD
NBVC Pt. Mugu
NCIS
NCWDG
NECC
NIAC
NMAWC
NMAWC Det Norfolk
NORAD-NORTHCOM
NPS
NR NSW INTEL 17
NRL
NSCW
NSMWDC
NSW (Retired)
NSW Group 11
NSW SPECRECON TWO
NSWC
NSWC Carderock
NSWC Crane
NSWC Dahlgren
NSWC Dahlgren Division
NSWC Dahlgren Division, Directed Energy Warfare Office
NSWC Panama City
NSWC Panama City Division
NSWC PCD
NSWC PHD
NSWC Philadelphia
NSWC Port Hueneme
NSWC/IHDIV
NSWCCD
NSWCCD Det. Puget Sound
NSWCDCD
NSWCDD/W16
NSWCIHEODTD
NSWCPCD
NSWG-10

NUWC
NUWC Keyport
NUWC Keyport Code 222
NUWC Newport
NUWC NPT
NUWC NWPT
NUWCDIVKPT DETPAC Kauai OS//PMRF
NUWCDIVNPT
NWC
NWDC
NWDC/DAWCWD
Office of Naval Intelligence
Office of Naval Intelligence (ONI)
Office of Naval Research
Office of Naval Research - Reserve Component
Office of the SecNav
ONI
ONR
ONR 322
ONR 34
ONR Det 113
ONR Global
ONR P38
ONR Reserves
ONR/NRL 113
ONR/NRL S&T 113
ONR/NRL S&T Det 113
ONRG
ONR-RC
OPNAV
OPNAV N2/N6
OPNAV N2/N6F22
OPNAV N415
OPNAV N51
OPNAV N97
OPNAV N98
OSD
PEO (U&W)
PEO C4I
PEO C4I, PMW 770
PEO IWS
PEO Littoral & Mine Warfare
PEO Littoral Combat Ship
PEO LMW PMS 495
PEO USC
PMA265
PMA268 / DP Associates
PMS485
PMW 750 / PEO C4I
Point Mugu Sea Range, NAVAIR
Puget Sound Naval Shipyard
Retiring
SDS-5 DET UUV
SECNAV
SMWDC
SMWDC HQ
SOAC
SOCAFRICA
SOCOM
SOCS
SPAWAR
SPAWAR - Atlantic
SPAWAR Systems Center Pacific
SPAWARSYS Center
SPAWARSYSCEN - PACIFIC
SPAWARSYSCOM
SPECWARCOM
SSC Atlantic
SSC PAC
SSC Pacific
SSCPAC
Stennis Space Center Fleet Survey Team
Strategic Sealift Officer Program / N-14
SUBDEVRON 12
SUBDEVRON FIVE
SUBDEVRON FIVE, DET UUV
SUBDEVRON TWELVE
SUBFOR
Submarine Development Squadron Five (CSDS-5), Bangor Washington
Submarine Officers Advanced Course
Systems Planning and Analysis, Inc.
TACTRAGRUPAC, San Diego, Ca
Third Fleet
TRITON FIT
U.S. Fourth Fleet/U.S. Navy Southern Command
U.S. Navy/Cyber Vet Solutions, LLC
Unmanned Patrol Squadron ONE NINE
US Naval Test Pilot School
US Navy Reserve
USFF
USFF N72
USFFC
USMC
USMC Installations & Logisitcs
USMC Pentagon
USNA
USNR
USS Chung-Hoon
USS MCCAMPBELL
UXOCOE
UxS Cross Functional Team
VMU-3
VR-55
VX-30
Warfare Analysis & Integration Department

APPENDIX D: CRUSER FY18 CALL FOR PROPOSALS

The FY18 call for proposals was released in mid-July 2017.

CRUSER Call for Proposals FY18

PROPOSALS DUE DATE:	**15 Aug 2017**
Selection Date:	**1 Sep 2017**
Funding Start Date:	**As early as 1 Oct 17**
Funding Expiration Date:	**30 Sept 2018**
Funding Levels:	**up to $150,000**
Proposal Type:	**Single-Year**

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 (RAS) 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 with operationally relevant research and experimentation.

Anticipated Funding Amount: Funding has not yet been received for FY18; 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 projects averaging ~$100k -$150k each.

- *CRUSER funding, outside of the individual proposal, is available for INCONUS travel support for full-time enrolled MS & PhD students only. Travel for Professors and Faculty Associate – Researchers will only be supported by the funded project. Students requiring travel funds will follow the standard CRUSER Student Travel request procedure to be approved for this travel support. Students who do not have prior approval to travel on CRUSER funding will be charged to the project.*

Research Focus Areas: ***"Developing Autonomy to Strengthen Naval Power"*** --originated from the Warfare Innovation Continuum (WIC) Workshop held in Sep 2016. Proposals will be accepted in the following research related topic areas:

a) Littoral Mesh Networking and Remote Sensing: These concepts all employ autonomy to create a mesh network of communications and sensing nodes in a contested urban littoral environment.
b) Innovative Undersea Warfare (USW): These concepts leverage autonomy to clear and secure sea lanes and harbor approaches for landing and resupply in a contested urban littoral environment.
c) Autonomous Unmanned Surface Vehicle (USV) Missions: These concepts employ autonomy to leverage or disable all available assets in a contested urban littoral environment.
d) A2AD Capabilities: Other robotics and unmanned/autonomous concepts of interest that do not fit into the categories above yet leverage unmanned/autonomous systems to create asymmetric advantages in an A2AD environment.
e) Any research topics related to unmanned/autonomous systems will also be considered.

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

Required Documents: Supplemental information (to include templates) can be found on the CRUSER website by navigating to http://my.nps.edu/web/cruser/call-for-proposals and selecting "FY18 Call for Proposals" link. The required documents are listed below:

1. 5-7 page proposal. **Do not** submit via the Research Office.
2. Current Year Research Office Budget form (https://my.nps.edu/web/research). *{List CRUSER as the Sponsor. If selected, Dr. Raymond R. Buettner will sign as Director and route via RSPO. No sub-JONs will be created}.*
3. Quad Chart (use the CRUSER provided template)

Submission Procedures:

- All FY18 proposal packages will be submitted online at: https://survey.nps.edu/136241/lang-en

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 other 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) and the CNO's Sailing Directions (www.navy.mil/cno/cno_sailing_direction_final-lowres.pdf)
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. 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: Dr. 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 across the military, 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.

NPS FX 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 is a retired naval office and holds a Master of Science in Systems Engineering degree from the Naval Postgraduate School as well as a Doctorate degree in Civil and Environmental Engineering from Stanford University. He co-founded CRUSER and, as a former Director, serves as the CRUSER Advisory Committee. He is the Principal Investigator for the Joint Interagency Field Experimentation project.http://faculty.nps.edu/rrbuettn/about.html

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/

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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	NPS 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
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 former Deputy Secretary of Defense the Honorable Robert O. Work.

The CRUSER Director appreciates the continuing support of Secretary of the Navy Richard V. Spencer.

The CRUSER Director acknowledges the efforts of the entire CRUSER Advisory Committee, and specifically the three senior members: Dr. Jeff Paduan, NPS Dean of Research;. retired Navy Rear Admiral Jerry Ellis NPS Chair of Undersea Warfare; retired Navy Rear Admiral Rick Williams, NPS Chair of Mine Warfare.

The CRUSER Director acknowledges the extraordinary work of the past CRUSER Directors, retired Navy Captain and Operations Research Professor of Practice Jeff Kline and Information Sciences Professor Ray Buettner who continue to serve as an essential advisors 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 FY18 annual report summarizes CRUSER activities in its eighth year of operation, and highlights future plans.

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

POC: Dr. Brian Bingham, CRUSER Director

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