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Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) 2019 Annual Report

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER) 2019 ANNUAL REPORT

Prepared by

Lyla Englehorn, Faculty Associate – Research

28 February 2020

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Prepared for: Dr. Brian Bingham, CRUSER Director

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14. ABSTRACT
The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems (UxS) education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems (UxS) in military and naval operations. This 2019 annual report summarizes CRUSER activities in its eighth year of operations and highlights future plans.

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

2019 Annual Report

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for Dr. Brian Bingham, CRUSER Director

NAVAL POSTGRADUATE SCHOOL

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EXECUTIVE SUMMARY

From Technical to Ethical…

From Concept Generation to Experimentation…

Since 2011 the Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) has sought to create and nourish a collaborative environment and community of interest for the advancement of unmanned systems 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 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. As of December 2019, the CRUSER community of interest includes just under 3,000 members from government, academia, and industry – from the U.S. and partners around the globe.

In 2019 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 response to the call to increase DoD engagement with industry, CRUSER reframed our annual technical gathering, TechCon 2019, as a series of panel discussions to explore how industry and government might work together better to develop emerging technologies.

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

I. BACKGROUND

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 January 2020

Major concept generation activities (FY11 through FY19) 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 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 complement of programs in the NPS Field Experimentation (FX) portfolio. These programs include the Joint Interagency Field Experimentation (JIFX)[1] program, 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)[2], the Advanced Robotics Systems Engineering Lab (ARSENL) and the Center for Network Innovation and Experimentation (CENETIX).[3] 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

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

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

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

Command (NAVAIR), Naval Sea Systems Command (NAVSEA), and many warfare centers and systems commands throughout the naval enterprise.

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 FY19 the NPS CAG included:

- Dean of Research Dr. Jeff Paduan
- Operations Research Professor of Practice CAPT Jeff Kline USN (ret)
- Information Sciences Associate Professor Dr. Raymond Buettner
- 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 Corps Representative Col Todd Lyons USMC thru July 2019, replaced by Col Randy Pugh USMC in September 2019
- 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 primary tenets of CRUSER – concept generation, education, research, experimentation, and outreach – activities and research initiatives ranging from unmanned systems innovation symposia and technical symposia to experimentation and research projects. CRUSER executed just under $4M in the FY19 cycle and anticipates funding at the same level for FY20. Activities for each year are briefed to the Advisory Group and require approval from the sponsor.

Primary objectives in 2019 were to continue to provide:

- 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 15 academic departments and schools to explore many diverse aspects of unmanned systems (*see Figure 2*).

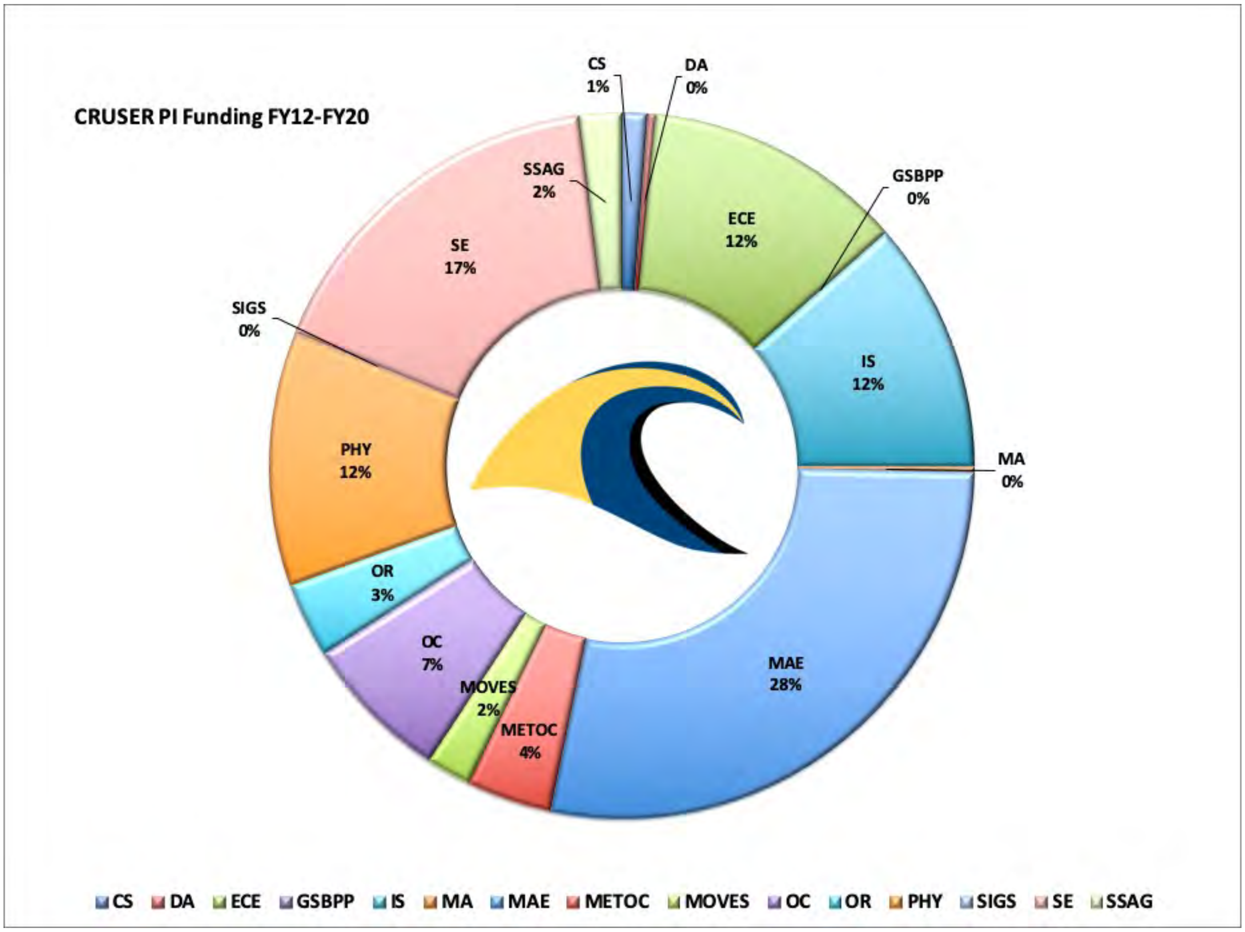

Figure 2. CRUSER seed funding by NPS department, FY12-20. LEGEND: Computer Science (CS), Defense Analysis (DA), Graduate School of Business & Public Policy (GSBPP), Information Sciences (IS), Mathematics (MA), Mechanical & Aeronautical Engineering (MAE), Meteorology (METOC), Modeling & Virtual Environments Simulation (MOVES), Oceanography (OC), Physics (PHY), School of International Graduate Studies (SIGS), System Engineering (SE), and Space Systems Academic Group (SSAG).

In late July 2018, CRUSER made its seventh call for proposals to seed research topics. The stated funding period was 1 December 2018 through 31 December 2019, and maximum funding level was $150,000 per topic. At the beginning of September 2018 CRUSER received 47 proposals totaling just over $6.9 million. All were reviewed for CRUSER seed funding. The CRUSER advisory group selected 20 projects and granted $2.56 million in total to support robotics and autonomy related research in FY19 (*see Table 1*). An additional $322,000 was distributed to campus labs for equipment, and for faculty development activities. Research summaries for each supported project are included in this section of the report. These summaries report findings of the individual project as of 31 December 2019 and include the technical point of contact for further inquiry.

Table 1. FY19 CRUSER funded projects (*alphabetical by lead researcher's last name*)

	Principal Investigators(s)	**Project Title**
1	Prof. Gamani Karunasiri, Prof. Fabio Alves	Bio-inspired MEMS Acoustic Senor for Small Flying UAS Localization
2	Dr. Curt Blais	Unmanned Systems Interoperability Standardization: U.S. Navy and international community activities
3	Prof. Alex Bordetsky	Short-Term Self-Moving Maritime-Land Mesh Networks
4	Prof. John Dillard	A Sourcing Strategy for Scaling Unmanned Mine Countermeasure Capabilities
5	Prof. Vlad Dobrokhodov, Prof. Kevin Jones, Dr. Paul Leary	Enable Real-Time Access to Underwater Acoustic and Beam-Forming Data on a Hybrid Aqua-Quad Vehicle
6	Prof. David Garren, Prof. Phil Pace	Dynamic Automatic Calibration of Coherent Radar UAV Swarm Arrays
7	Prof. Doug Horner, Prof. Sean Kragelund	Distributed Adaptive Submodularity for Mixed-Initiative UxV Networked Control Systems
8	Prof. Kevin Jones, Prof. Vlad Dobrokhodov, Dr. Paul Leary	Environmental Hardening and At-Sea Testing of the Aqua-Quad Hybrid Platform
9	Prof. John Joseph, Prof. Doug Horner, Prof. Kevin Smith	Long-Endurance Wide-Area Maritime Surveillance System
10	Prof. Isaac Kaminer, Prof. Claire Walton	Multi-Domain Super Swarm: Robust Tactics for Engaging an Attacking Large-Scale Swarm
11	Prof. Emil Kartalov	3D-Printable Artificial Muscles for UUV Propulsion

12	Prof. Joseph Klamo, Prof. Young Kwon	Identification of Wave Environments that Degrade the Performance of AUVs Operating Near-Surface
13	Prof. Mollie McGuire	The Effect of Stress on the Decision to Rely on Automation: an investigation into transparency and anthropomorphism on decision making with autonomy under stress
14	Prof. Jim Newman, Mr. Gio Minelli	Development of Autonomous, Optimized Capabilities for MC3
15	Prof. Marcello Romano	Dynamics and Control of an Autonomous "Tugboat-Spacecraft" to Maneuver a Passive Resident Space Object
16	Professor Timothy Sands	Deterministic Artificial Intelligence for Surmounting Battle Damage
17	Prof. Kevin Smith, Prof. Vlad Dobrokhodov	Acoustic Target Motion Analysis from Novel Autonomous Systems Using Light-Weight, Low-Power Data Acquisition Systems
18	Prof. Preetha Thulasiraman	Cybersecurity Evaluation and Testing of the ROS 2 Architecture for Networked UAV Systems
19	Prof. Douglas Van Bossuyt, Dr. Brian Mesmer (UAH), Dr. Kristin Weger (UAH)	Autonomous Systems Adoption Challenges and Requirements Management Solution
20	Prof. Oleg Yakimenko	Air Superiority via Decentralized Swarming Tactics and Autonomous Pursuit

1. Bio-inspired MEMS Acoustic Senor for Small Flying UAS Localization (Karunasiri /Alves)

The objective of this research project is to continue the development of bio-inspired MEMS directional acoustic sensors for localization of small flying UAS. The proposed investigation will focus in exploring suitable electronic readouts/demodulation schemes for co-located sensor assemblies, as well as, appropriate network topologies for distributed sensors to be deployed in swarming UAS.

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. They are equally effective against continuous sound sources such as generated by helicopters, tanks, SUV's, generators and other tactical vehicles, and transient events from indirect and direct fire such as mortars, rockets, artillery, and snipers. Recently, the skyrocketing small flying unmanned aerial systems (sUAS) technology has pushed the sensor field towards the characteristics that match the spectrum of sound sensors. The ability to 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 2 degrees. The two eardrums of the fly are separated by a mere 0.5 mm yet it homes in on the cricket chirping with a 7 cm wavelength, using an ITD of at most 2.5 μs and negligible ILD. The two eardrums of the fly are mechanically coupled and have two natural resonant frequencies. In the first mode the ears move out of phase with each other in a pure rocking mode due to the minute pressure difference between the two eardrums. The second mode has the eardrums moving in phase, resulting in a pure bending mode about the tympanal bridge. The bending mode is a result of the sum of the forces on the eardrums. These modes, caused by the mechanical link between eardrums, give the *ormia ochracea* high sensitivity to the direction of the sound.

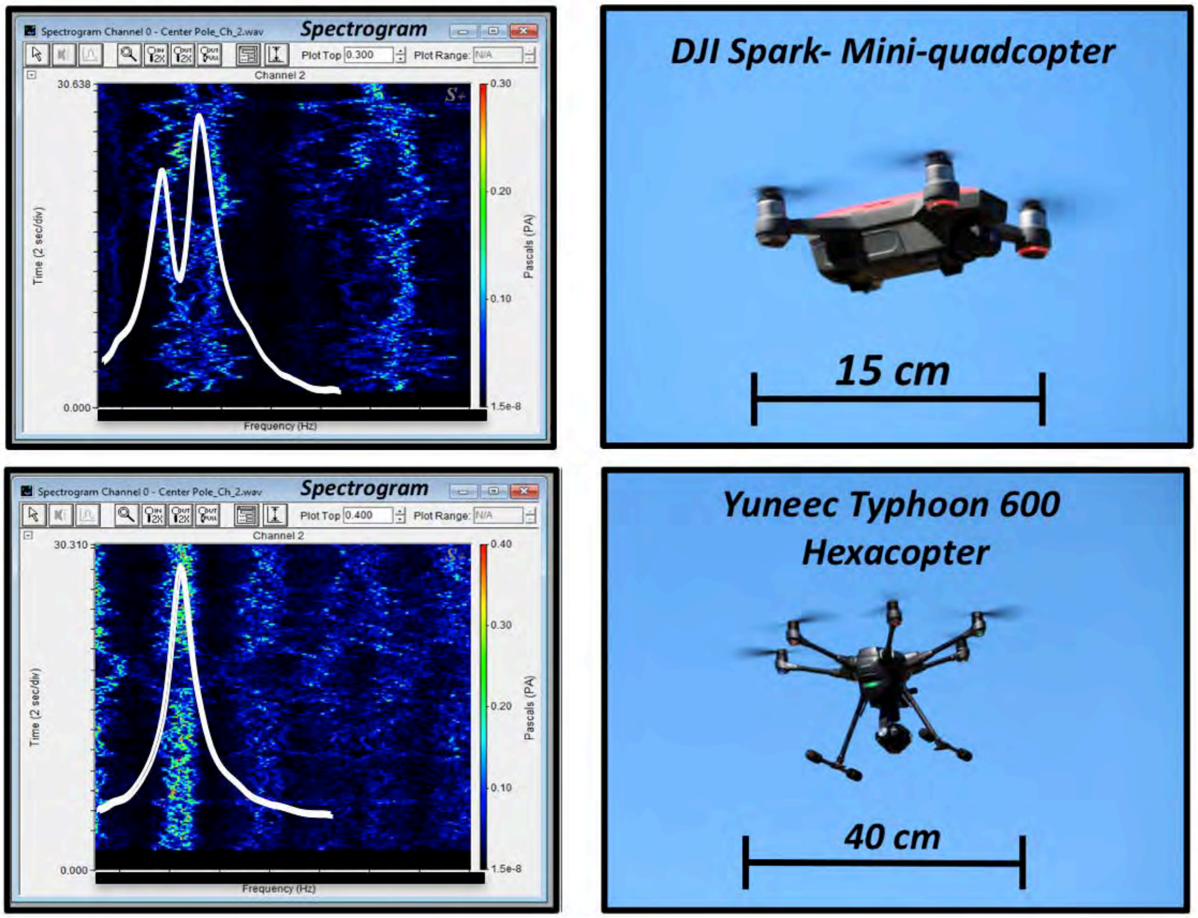

Figure 3. Acoustic signature of small flying UASs. Left column shows the spectrograms in a certain region of the spectrum with the MEMS sensors response superimposed (white solid lines). The right column shows the picture of the UASs highlighting the size and number of rotors.

The motivation for this research is for localization and identification of sound sources with sensors much smaller than the wavelength they detect and without the need of complex array arrangements, making MEMS Ormia-based detectors very attractive.

Under current CRUSER funding, we have worked on designing sensors optimized for small flying UAS acoustic signatures. Two sets of sensors have been designed, fabricated and characterized in an anechoic environment. Figure 3 shows the acoustic spectrogram of two small UAS with the measured response of the sensors superimposed (white solid line). As it can be observed, there is a good match between the sources' strongest spectral lines and the sensors response. It is important to highlight that for most small UASs with different loads and flying regimes, the predominant spectral lines found to coincide.

The MEMS sensors were tested in NPS anechoic chamber with hovering drone as a sound source. It was found that detection voltage range greater than research grade broad-band commercial microphones can be achieved with excellent directional sensitivity as shown in Figure 4.

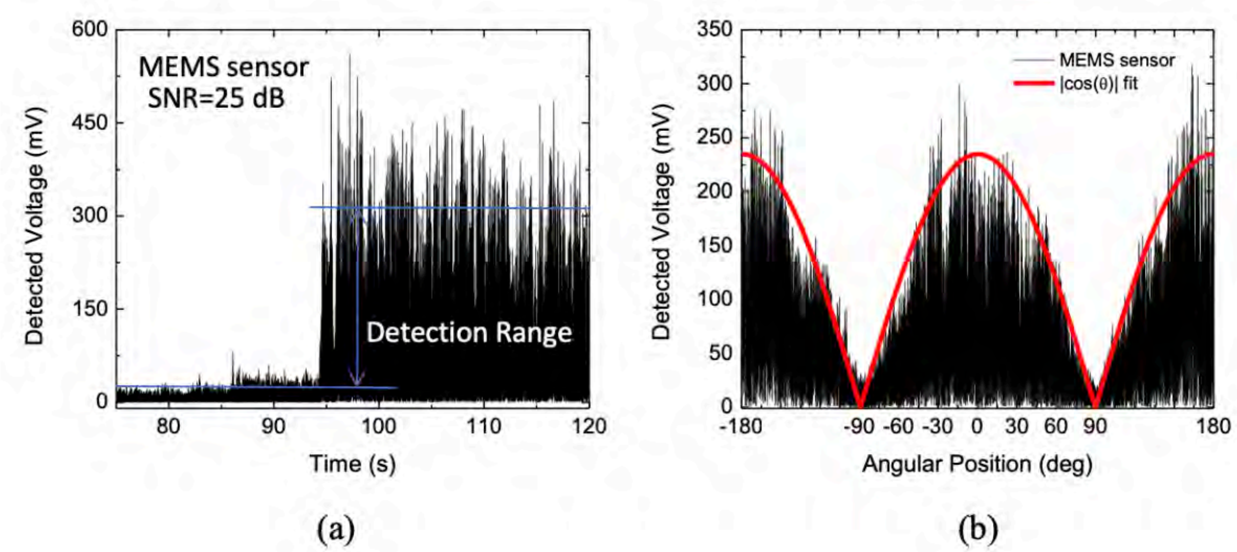

Figure 4. Detection range (a) and directionality (b) measurements of the MEMS acoustic sensor designed for small UAS localization, measured in an anechoic chamber.

In order to remove the ambiguity around normal incidence (*see Figure 4(b)*) and network more than one sensor for localization, an intelligent electronic readout (including microprocessor, GPS and wireless link) was integrated to a pair of two-sensor assemblies. Preliminary tests were performed in an anechoic environment as well as on the baseball field at NPS. The results showed that the localization of acoustic sources (simulated using a digital sound file and a speaker system) are achievable with low percentage of false alarms. False locations were found concentrated in one specific region of the field and are most likely due to reflections from nearby buildings. This can be filtered out with well-known algorithms.

In parallel, new electronic readout circuit using charge-to-voltage conversion has been designed make the system robust for field testing and preliminary laboratory tests show encouraging results. Previously, this has been accomplished using the universal capacitive readout MS3110, which is prone to static variations of the comb finger capacitors, which imposes significant restrictions to field operation. We have developed a charge amplifier circuit was developed to independently measure the displacements of the wings under sound excitation. The ability to simultaneously read these displacements is needed to determine the bearing of sound using a single MEMS sensor, in contrast to previously reported works that needed either a calibrated microphone or a second MEMS sensor to determine the incident sound pressure level. Measurements showed that both the phase difference and amplitude difference of oscillating wings were strongly dependent on the incident angle of sound. We have designed printed circuit boards to accommodate the new readout circuitry and optimize them maximize the signal to noise ratio.

In future work, digitization and communication (networking) circuits must be added as well as synchronous demodulation can be introduced to allow direct measurement of signals below the noise level.

This NPS research team included Dr. Fabio Alves, Associate Professor of Physics, PI, Dr. Gamani Karunasiri, Distinguished Professor of Physics, and NRC Postdoc Dr. Renato Rabelo, and four NPS students.[4] This project generated two publications[5] (*included in Appendix A*) for the research team, two NPS theses[6] (*included in Appendix B*), and one patent.[7]

Funding from CRUSER was instrumental to place the project in a more advanced stage, specially by assuring the project participants could attend all field experimentation events. A continuation of this support in upcoming years would allow to involve more students and intensify the field tests/exercises activities, which are crucial for the development of the system in discussion. Development of MEMS miniature acoustic sensors for gunshot and aerial drone localization, Sponsored by ONR, Code 32 is a follow-on project that grew from the NPS CRUSER seed funding.

POC: Dr. Fabio Alves (fdalves@nps.edu)

2. Unmanned Systems Interoperability Standardization: US Navy and International Community Activities (Blais)

The United States Navy, in parallel with the other services and many civilian and military organizations, is researching, developing, and deploying unmanned systems (UMS) at a rapid pace. The advancements have occurred so quickly, with great promise for revolutionizing warfighting, that the organizations largely have ignored fundamental principles of systems engineering, such as ensuring interoperability across systems to achieve even greater warfighting capabilities. Only more recently has interoperability gained attention as a continuing requirement for unmanned systems (UMS) operating with other UMS, as well as with Command and Control (C2) systems, and Modeling and Simulation (M&S) systems (Blais 2016). Unfortunately, in an effort to correct the shortcoming, there are now multiple standardization activities occurring today that will provide critical capabilities in ensuring future systems are "fully interoperable," as specified in the Department of Navy (DON) Unmanned Systems Goals. The various activities include USN-centric Program Executive Office (Unmanned and Weapons) (PEO(U&W)) Naval

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[4] Capt John Mutton USMC, LT Austin Fleming USN, LT Brian Gureck USN, and LT Jaemin Yang of the South Korean Navy

[5] Rabelo et. al. (2019)

[6] Fleming (DEC 2019) and Mutton (JUN 2019)

[7] Karunasiri, G and Alves, F., Direction finding system using MEMS sound sensors, US Patent No. US9,843,858 B1, Dec. 12, 2017.

Interoperability Profile (NIOP) efforts across several topic teams, such as Tracks and C2, as well as international and coalition-partner standardization activities in the Simulation Interoperability Standards Organization (SISO) C2 System to Simulation System Interoperation (C2SIM) Product Development Group (PDG) (SISO 2017). Although these are significant and important activities, the overall warfighting enterprise, both US and Coalition, still lacks a cohesive, systematic, overarching mandate and effort to unify how systems are directed and how systems interact in operational settings.

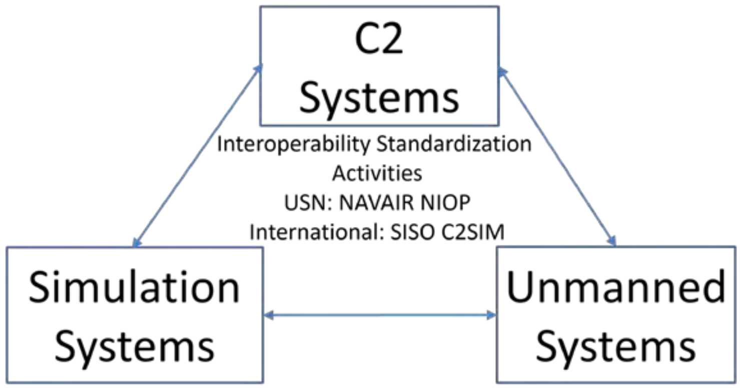

Figure 5. Naval and international standardization activities for CRUSER engagement.

The purpose of this project was to investigate ongoing UMS interoperability efforts by engaging in the activities central to the US Navy; namely, the NIOP efforts and the international C2SIM standardization effort (Figure 5). In doing so, new initiatives have been identified that deserve continued participation by CRUSER researchers. For example, the Navy has a new Unmanned Maritime Autonomy Architecture (UMAA) with significant focus on maximizing interoperability through adherence to specified interfaces and architecture elements across the UMS fleet and for common C2 (Unmanned Maritime Systems 2018). It remains to be seen if the new approaches will adopt the NIOP work that has already been underway for the past several years. The research foundation for improved interoperability across systems is semantic interoperability through web-based standards (i.e., the Semantic Web) (Blais 2018).

This project supported attendance to the 2018 Semantic Web Conference in Monterey, California, and the Web Ontology Language (OWL) / Protégé Ontology Editing Tool training at Stanford University in order to provide information to the CRUSER community through event report deliverables. In addition to furthering investigation of semantic technologies, the project engaged in two key areas of interoperability standardization introduced above; namely, PEO(U&W) efforts to develop the Naval Interoperability Profiles and SISO development of an international standard for interoperability across C2 systems, simulation systems, and unmanned systems (C2SIM). The following paragraphs describe these activities in greater detail; however, it is noted that much of the current work and resulting artifacts in the Navy is marked "For Official Use Only" (FOUO), Distribution Statement D (Distribution authorized to Department of Defense and U.S. DoD contractors only: Critical Technology). To keep this report summary open for unlimited distribution, the description does not provide specifics on the format or content of the Navy's emerging standards. For the NIOP effort, the project supported participation in various topic team meetings to provide technical reviews of developed documentation and interface formats (e.g., Extensible Markup Language (XML) schemas).

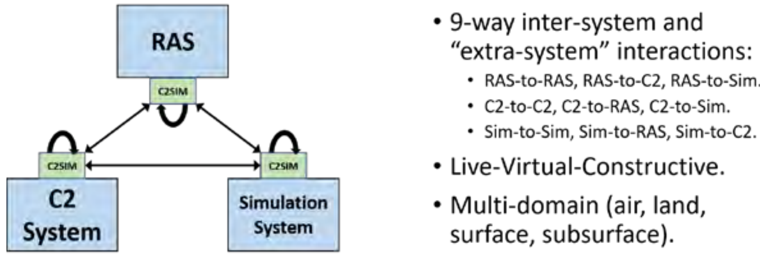

Figure 6. C2SIM concept for interoperation across C2 systems, simulation systems, and robotic and autonomous systems (RAS).

The project Principal Investigator (PI) had specific current knowledge in areas of semantic interoperability and track data interchange (Blais 2018) that enabled direct contributions to the Tracks topic team, responsible for specifying how UMS systems will exchange track information with C2 systems and other UMS systems, and the C2 topic team, responsible for specifying interactions for the control of UMS systems. The C2 NIOP is based on other current UMS control methods, but it will be necessary for the Navy to ensure that the approach stays closely aligned rather than diverging from the other standards. There are other topic teams working on standards for such areas as imagery, networking, and communication. Under the level of funding for the project, the Principal Investigator was not able to invest as much time in these other groups but encouraged others at NPS to provide their expertise to these groups. Unfortunately, other NPS researchers were not able to participate. Going forward, NPS in general, and the CRUSER community in particular, can be a critical source of technical expertise to assist in the development of these standards.

NPS has a long history of participation in the development of international standards for interoperability across C2 systems, M&S systems, and robotics and autonomous systems (RAS), such as the Military Scenario Definition Language (MSDL) standardized by SISO in 2008 (SISO 2008) and the Coalition Battle Management Language (C-BML) standardized in SISO in 2013 (SISO 2013). NATO and NATO member nations have been active participants in the past C-BML standard development and are now involved in C2SIM standardization efforts. C2SIM (replacing the existing C-BML and MSDL standards) is the only international standard addressing information interchange across all these systems and providing a coalition solution for the USN (Figure 6). The project made significant contributions to the C2SIM effort by providing expertise in ontology development (OWL), Extensible Markup Language (XML), and XML Stylesheet Language Transformations (XSLT), applying techniques from Blais (2018) to assist development of the C2SIM core ontology standard and domain extensions (Blais et al. 2019). The PI assisted NATO researchers in a UMS extension to the core ontology for experimentation in NATO in the Spring of 2019 and identified UMS use cases to serve as a basis for conceptualization and specification of a UMS extension to the C2SIM core ontology (Blais 2019) (Figure 7). Moreover, the project supported development of a paper to the SISO community arguing for the use of formal semantic techniques in all standardization efforts (Blais, Reece, and Singapogu 2019). From an international perspective, and especially in light of the importance of Coalition operations, it is encouraging to find that Navy interoperability standards are considering carefully respective NATO Standard Agreement (STANAG) documents. Aligning interoperability standards across Coalition partners will enable greater capabilities in future UMS operations. Furthermore, aligning with the emerging international C2SIM standard—which has significant NATO involvement—will enable interactions across C2 systems and simulation systems necessary for UMS testing, development and evaluation of new tactics, techniques, and procedures (TTPs), training, and mission planning, rehearsal, and execution.

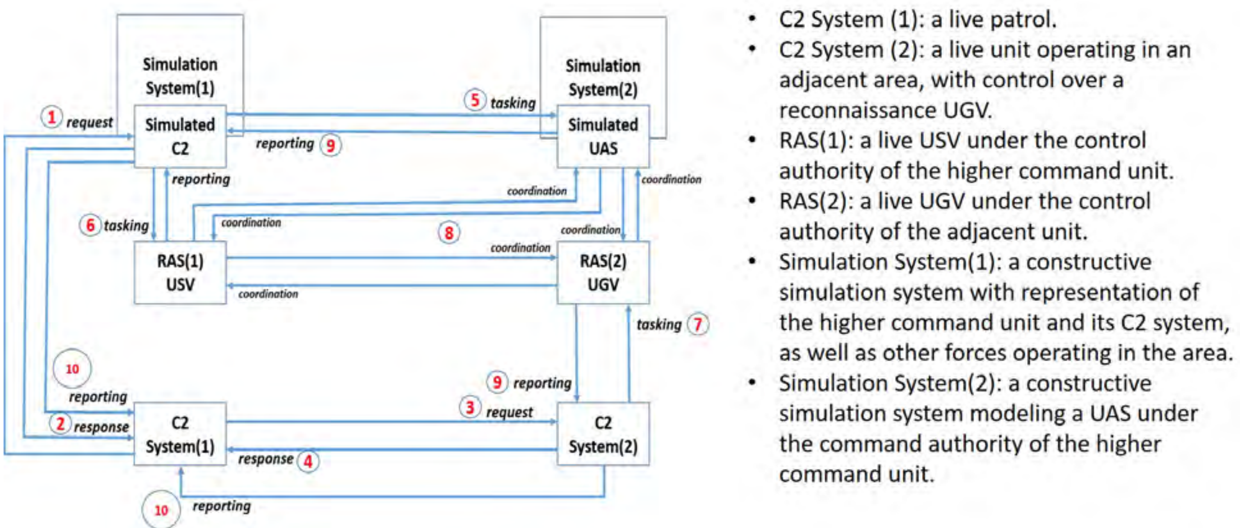

Figure 7. Proposed use case for C2SIM interoperability test/experimentation.

From the investigations and activities of this project, the following actions are recommended:

- **CRUSER must stay engaged in these interoperability efforts**, both within the Navy and in the international community. Through field experimentation and supported faculty/student research projects, CRUSER can be a vital force in contributing to, evaluating, and testing emerging Naval and international interoperability standards. It is essential that CRUSER contribute to unification of efforts rather than independently perpetuating divergence of efforts.

- **NPS must stay engaged in Naval UMS interoperability standardization efforts** to influence unification of the approaches. As an independent agent of change, NPS is in a unique position to advise and consult across different organizations, even at the joint and multi-service levels. There is growing interest in multi-domain operations that will require even greater focus on interoperability standards. The community is struggling to deal with parochial interests at a time when cross-domain, cross-organizational interests are growing in importance.

The community cannot attain the necessary coordination by continuing down separate paths but must work together. NPS can play an important role in encouraging and creating this collaboration. Continuing involvement in these activities will demonstrate NPS and CRUSER commitment to Naval and Coalition UMS interoperability standardization, while directly benefitting NPS education and research with state-of-the-art interoperability standardization products and technical lessons learned.

This research project was a direct application of concepts and technical techniques from the NPS dissertation by the project PI titled "Rich Semantic Track (RST) Ontology: Unified Semantics and Pragmatics for Track Data Interchange," October 2018.

This NPS research drew upon much prior work[8] and was completed in affiliation with George Mason University, NATO Modeling and Simulation Group, Simulation Interoperability Standards Organization, FKIE Germany, AirBus, Raytheon Missile Systems, Defense Modeling and Simulation Coordination Office, NAVAIR PEO(U&W). The NPS course *MV4503 Simulation Interoperability Practicum* benefited from this project work, and this project contributed to the initiation of a cooperative research and development agreement (CRADA) between NPS and Raytheon Missile Systems and generated four presentations at the Simulation Innovation Workshop in February 2019. This research project was a direct application of concepts and technical techniques from the NPS dissertation by the project PI titled "Rich

[8] Other references cited in the project summary: References (in addition to project-generated products): Blais, Curtis L. 2016. Unmanned Systems Interoperability Standards. NPS-MV-16-001. Monterey, CA: Naval Postgraduate School. Blais, Curtis L. 2018. Rich Semantic Track (RST) Ontology: Unified Semantics and Pragmatics for Track Data Interchange. Dissertation. Monterey, CA: Naval Postgraduate School. September. Simulation Interoperability Standards Organization (SISO). 2008. Standard for: Military Scenario Definition Language. SISO-STD-007-2008, Version 1.0. October 14. Simulation Interoperability Standards Organization (SISO). 2013. Standard for: Coalition Battle Management Language. SISO-STD-011-2014, Version 1.0. October 31. Simulation Interoperability Standards Organization (SISO). 2017. Product Nomination for Command and Control Systems to Simulation Systems Interoperation. SISO-PN-010-2018, revision 1.1. October 27. Unmanned Maritime Systems (PMS 406) 2018. Unmanned Maritime Autonomy Architecture (UMAA) Architecture Design Description (ADD). December 20.

Semantic Track (RST) Ontology: Unified Semantics and Pragmatics for Track Data Interchange," October 2018.[9]

POC: Dr. Curt Blais (clblais@nps.edu)

3. Short-Term Self-Moving Maritime-Land Mesh Networks (Bordetsky)

The purpose of this research is to identify the best-suited architectural requirements for the construction, deployment, and operations of autonomous short-lived networks using unmanned assets. The most vital assets to the DoD are the human lives and as such, this research was focused on tackling the task of removing the need for humans to be in close proximity of hazardous environments during the network configuration phase of communications establishment (*see Figure 8*).

Figure 8. Self-moving maritime-land mesh networks.

[9] Presentation: "Toward Semantic Interoperability across Command and Control Systems, Simulation Systems, and Unmanned Systems," Defense Modeling and Simulation Coordination Office Workshop on "Modeling and Simulation in Support of Autonomy," Alexandria, VA, 21 November 2019. Presentation: "Summary of DMSCO Workshop on Modeling and Simulation in Support of Autonomy," Raytheon Missile Systems Technical Interchange, Naval Postgraduate School, Monterey, CA, 10 December 2019. Presentation: "Rich Semantic Track (RST) Ontology: Unified Semantics and Pragmatics for Track Data Interchange," Raytheon Missile Systems Technical Interchange, Tucson, AZ, 28 October 2019. Presentation: "Project Status Report: Unmanned Systems Interoperability Standardization: US Navy and International Community Activities," CRUSER Monthly Seminar, Naval Postgraduate School, Monterey, CA, 1 April 2019.

Survivability of communications in austere environments is a key concern as the U.S. develops and deploys autonomous systems. The Navy must communicate but needs to exploit the potential of self-organizing networks of elusive unmanned systems to conduct cyber-physical maneuver in the maritime-land combat clutter to survive in the future operating environment. This project addressed significant key warfighting needs to:

1) Introduce robust system of unmanned vehicles that can act in the role of humans in network deployment duties, while allowing human operators to direct, observe, and maintain situational awareness from a safe distance.

2) Gain an asymmetric warfighting advantage through hard-to-detect networks.

3) Increase survivability during C2 communications.

4) Reduce detectable footprint of USN/USMC/USSOF tactical communications to counter near-peer communications direction-finding capabilities.

5) Enable real-time collaborative mission planning and execution with seamless and continuous situational awareness in contested or denied.

This project worked to enable a maritime-land mesh network of short-living nodes and links while integrating UxV in a multi-domain environment. The team integrated miniature directional antennas with littoral mesh nodes, and the elusive networking capability they bring, while minimizing tactical operator interactions with directional antennas. With the goal of designing the knowledge base foundations for managing short-living nodes and short-living links autonomies, the team identified the best-suited architectural requirements for the construction, deployment, and operations of autonomous short-lived networks using unmanned assets and the architectural requirements for a network backbone infrastructure that could be deployed and operated using a long-distance control link by using miniature directional antenna units in the maritime-land mesh networking testbed.

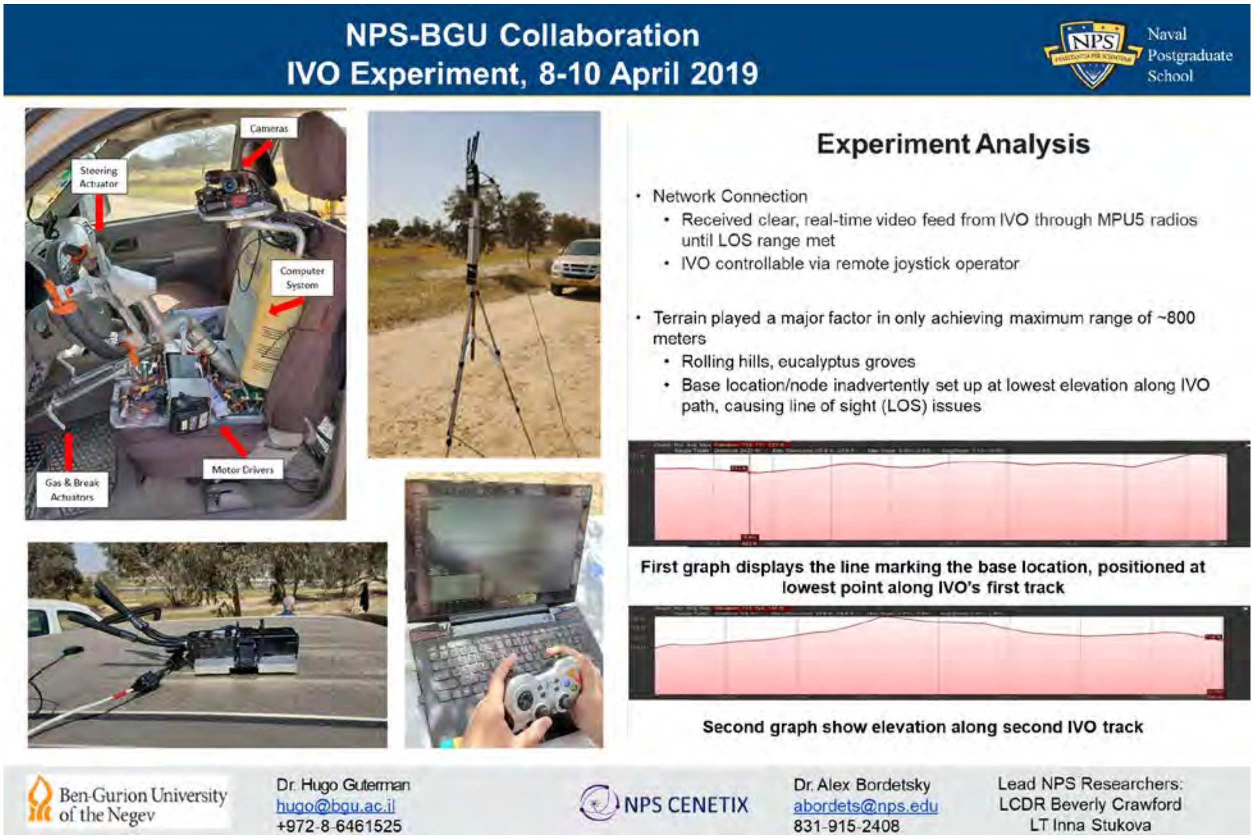

Figure 9. Field experiment with self-moving mesh backbone based on self-driving cars.

The research team studied current unmanned systems technologies that could carry on networking nodes, position them in the right locations, and adjust their positions as needed. Figure 9 illustrates the successful field experiment with deploying the self-moving tactical network backbone by means of self-driving vehicles. The team then examined different types of communication links and protocols to determine which will provide the most reliable and secure communications. Additional testing was done based on long range communications to determine which technology solution could best extend network control link ranges. We've also evaluated the options for choosing the functions best suited to be carried onboard unmanned systems to provide situation awareness self-moving network operation.

This research was a project of the NPS Center for Network Innovation and Experimentation (CENETIX). The detailed description of project results is in the thesis report "Short-Term Self-Forming Tactical Networks in Austere Environments" written by two lead students, LCDR Beverly Crawford USN and LT Inna Stukova USN. Beyond the two thesis students, this team was led by Dr. Alex Bordetsky (Principal Investigator) and included Senior Researcher Eugene Bourakov and PhD Candidate Steve Mullins. NPS students MAJ Justin Murphy and CPT John Azbill were also part of this team, and this project benefited three NPS courses: *Tactical and Wireless Networks (IS 4505), Network Operation Centers (IS 4926),* and *Large-Scale Systems Design and Experimentation (1S 4730).* This work generated a 2019 USN-ISR Naval Science, Technology and Capabilities Steering Group (NSTCSG) workshop presentation and has led to a follow-on OSD CWMD experiment.

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

4. Scaling Unmanned Mine Countermeasure Capabilities Sustainment: Issues and Solutions (Dillard)

Within the Naval Sea Systems Command, PMS 408 is the program management office for expeditionary missions, including Mine Counter-measure Unmanned Underwater Vessels as emergent capabilities. It is faced with many typical and atypical challenges in a rapidly growing acquisition effort. Vehicular and sensor component MCM UUV technologies continue to evolve at a rapid pace, with potential for multiple system configurations to sustain after initial deployment. The best sustainment strategy over the life cycle of these systems is not obvious, while current capacity is provided by a single vendor. The PMS 408 office requested a review of the xMCM UUV sustainment strategy, specifically to address within our study: the logistical sustainment impacts and challenges while expanding; the most critical aspects of transition from legacy capability support to expanded and "next increment" capability logistics needs; and the main risk areas and opportunities to mitigate them.

Figure 10. Mk 18 Mod 2 Kingfish configuration (*courtesy AUVAC*).[10]

Eight discrete findings emerged as areas of potential near-term sustainment risk for consideration by the program office. These were in the areas of: managing "vendor lock" risk via modularity and interface controls, especially in the mission payload area; managing the transition to in-sourcing (organic support) as products mature; maintaining contractor logistical support for early UUV configurations being appropriate in the near-term; ensuring time will allow for FAR-based

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10 https://auvac.org/configurations/view/225-Home%20-%20Hydroid

contracts if OTAs will not be allowed/used for production; ensuring pier-side spaces/facilities are available for growth and potentially multi-configurations; launch/recovery vessel configuration (*see Figure 10*) for compatibility; ambiguous cybersecurity requirements/solutions vs. compliance timelines and resources available; and UUV manpower rating/certification and accessions pipeline into the xMCM force. The resource strategy for logistics support of new systems requires decision-makers to select contracted, blended, or organic support, or a combination thereof. Tools that facilitate inclusion of varied logistics requirements and understanding the impacts thereof for program success might be useful going forward. The authors' extant Logistics Support Resource Strategy Map was also provided for helping program support management consider the broad range of logistics support resource strategy issues as the next iteration of Life Cycle Support Planning evolves.

Beyond Principal Investigator (PI) John Dillard, this research team also included David N. Ford.

POC: Dr. John Dillard (jtdillar@nps.edu)

5. Enable Real-Time Access to Underwater Acoustic and Beam-Forming Data on a Hybrid Aqua-Quad Vehicle (Dobrokhodov/Jones/Leary)

The focus of the FY19 project was on developing a communication channel between the underwater sensing and the surface computing units of the Aqua-Quad (AQ) hybrid vehicle. This effort continued the evolutionary design of a number of "distributed" subsystems within the AQ. When enabled, the real-time acoustic data from depth can be used at the surface level for higher-level data processing (signal detection, classification, tracking, etc.) or can be communicated over the long-distances for mission-relevant decision making. The development consisted of multiple iterations of the hardware and software designs followed by a sequence of verification steps that assessed the key tradeoffs of power loss over the length of the tether, the tether weight vs its buoyancy, the data loss vs communication frequency and the carried power/voltage; see the conceptual mapping of the design and the criteria spaces below (*see Figure 11*). The effort built a prototype distributed system capable of carrying a bidirectional signal (data and commands) on the top of the power line; conceptually, the technique is known as a "1-wire serial communication". The system consists of the power and signals injection board at the surface, the power and signal selecting circuit at the depth, which are connected by a slender and low volume flexible communication tether (two lines, AWG 26-28). The surface board interfaces the power management system and the main CPU of the AQ, while the bottom circuit is connected to the acoustic vector sensor and the signal processing board at the depth. The surface and the sensor level components of the 1-wire communication system rely on the computing power of 2 identical ARM Cortex-M4 Teensy microcontrollers which utilize the low-level RS485 half-duplex communication mechanism. Installed at the surface and the depth levels, they implement the embedded software that emulates the full-duplex communication achieved by the half-duplex 1-wire communication protocol.

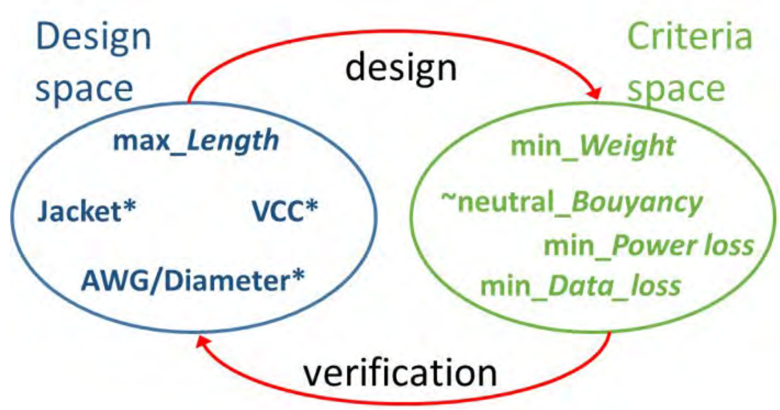

Figure 11. Mapping of the Design and Criteria spaces in the search of optimal (*) design.

The challenge solved by this design is in enabling the half-duplex communication over the long wire while satisfying the weight and power loss limitations of the submerged sensory subsystem. The “power selection” board at depth extends the functionality of the “1-wire” standard by supplying the constant voltage (rather than the “power on contact” that is typical of “1-wire”) to the microcontroller-sensor bundle. The verification phase built a number of tests that addressed various tradeoffs and performance metrics of the system (*see Figure 11*). The initial “Teensy to Teensy” (T2T) test developed the communication protocol and implemented the RX-TX communication scheme for both microcontrollers. The test objective was to assess the quality of the developed hardware, tune the power injection-selection filters, and to verify the baseline capability of the serial data transmitting. A simple counter test (increment from 0 to 255 with 1-second hold, then back to 0) implemented this step. The test confirmed the fundamental constraints of the 1-wire approach; RS485 bus protocol is sensitive to repeated digital data values which electrically look the same as a DC voltage offset and consequently get filtered. It also confirmed the need for proper message identification and encoding algorithms. At the following step, the Manchester encoding algorithm achieved the 100% loss-less 2Mbaud data communication over 150ft long tether (*see Figure 12*); more details of this phase can be found in a separate report. As a result, the protocol develops a message that carries the key sensory information along with the identifying Header/Tail and the CRC checksum. The following communication test started with the transmission of simulated VS-301 data (both analog and digital) which were processed onboard Teensy (“at depth”) in real-time by a number of the previously developed data acquisition and beam-forming algorithms; see the reports of FY17-18 efforts. The “bottom-to-surface” test with simulated data focused on the evaluation of the noise floor in the long communication lines and its impact on the robustness of the beam-forming solution. It was practically confirmed that the communication channel is fully functional and that it exhibits a well-expected dependency of noise in comm line to the length of the tether: the longer the comm line is the higher the noise level, specific details can be found in a separate report.

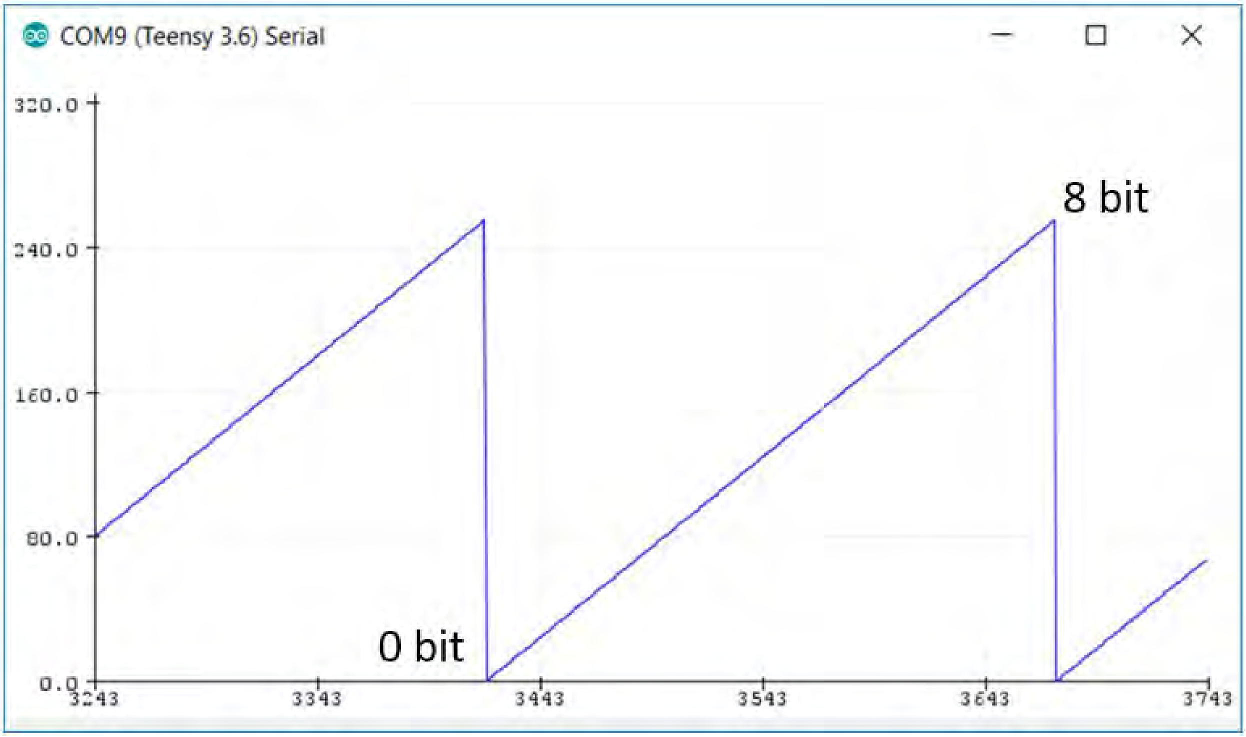

Figure 12. Loss-less communication achieved with Manchester encoding.

The final test utilized the output of a real vector sensor with the goal of confirming the influence of the ADC resolution to the sensitivity of the acoustic channel. To quantify the significance of the ADC resolution, the experiment used as a reference a higher-grade ADC system – a commercial-grade 24-bit ADC board NI9234 from National Instruments. The comparative result identified the resolution deficiency of the 16-bit ADC of Teensy board; effectively, only 14 bits are representative of a signal. As a result, two approaches are identified as potential solutions for the problem. First – pre-amplification of the acoustic signal within the relevant level. Second – integration of higher-grade ADC circuit to enable concurrent sampling of relevant acoustic data at 24-bit resolution. In conclusion, the development steps achieved the desired functionality of the communication channel. The simplicity of the 1-wire communication hardware with software encoding augmentation enables full-duplex communication of utility data and commands over the half-duplex RS485 channel. The most significant tradeoff discovered is in the length of the communication tether that adversely affects the noise level in the channel. An additional design constraint was discovered by analyzing the lack of "sensitivity" of the 16-bit ADC. Two additional directions are under development to help eliminating this constraint. In-depth details of the development can be obtained by requesting the distribution-D reports.

In addition to Principal Investigator (PI) Dr. Vlad Dobrokhodov, the members of this research team included Dr. Kevin Jones, Dr. Paul Leary, Dr. Mark Paulus. This work was completed in affiliation with the Department of Mechanical and Aerospace Engineering and the Department of Physics at NPS in Monterey, and the Undersea Test Range and Fleet Readiness Center in

Keyport, WA. This project resulted two publications (*listed in Appendix A*) and benefited the NPS course *PC4015 Advanced Applied Physics Laboratory*.

POC: Dr. Vlad Dobrokhodov (vndobrok@nps.edu)

6. Dynamic Automatic Calibration of Coherent Radar UAV Swarm Arrays (Garren/Pace)

UAVs are expected to play a critical role in future DOD missions. These platforms can provide multiple capabilities, such as reconnaissance and weapons delivery, without the risk to blue-force personnel. Such UAVs can be configured with multiple sensor payloads, including optical, infrared, and radar-based collection systems. Radar provides a particular advantage as a payload, since such sensors operate in all weather conditions, day or night. Various DOD concepts of operation (CONOPS) involve the use of a large number of UAVs to accomplish mission goals. For example, it is possible that a UAV swarm can operate as a large dynamic coherent active radar array in order to manipulate the wavefronts sensed by adversarial surface-based receivers. Appropriate manipulation of such wavefronts could cause inaccurate tracks of the individual UAVs as estimated by adversary surface systems using monopulse techniques. However, such a capability requires an ability to maintain accurate estimates of the relative locations of the individual swarm UAVs to within a small fraction of the central radar wavelength. The fundamental problem is that the instantaneous position of a given UAV is typically changing continuously, at least on the spatial scales of the central radar wavelength. These errors arise from the locally varying atmospheric turbulence, which is well known in the field of fluid dynamics to exhibit statistical fluctuations on all spatial scale lengths. Any atmospheric turbulence effects that perturb a given UAV's position by more than a half of a centimeter can have profoundly deleterious effects upon a UAV swarm functioning as a coherent radar array. Thus, it is critical to compensate for these errors dynamically as the individual UAV radars are perturbed by the atmosphere turbulence throughout the mission.

This research project generated a relatively low-cost solution to the coherent swarm array calibration problem by proposing a solution that uses a radar system on each UAV. In this paradigm, a multi-function radar system serves the requirements of surveillance, reconnaissance, communication, electronic warfare, and automatic self-calibration. Typical coherent radar arrays on airborne platforms (e.g., EA-18G Growler AN/ALQ-99 tactical jamming system) can be accurately calibrated during the fabrication and testing processes alone. However, for a swarm of UAVs that are each perturbed independently by atmospheric turbulence, new radar calibration methods must be developed. This project has demonstrated the feasibility of the automatic calibration of a swarm of radar UAVs. The developed solution does not require any surface fiducial points in the field, as such fiducials do not exist for many naval CONOPs. The required measurements for the algorithmic solution are based upon estimates of the radar ranges between pairs of the UAVs. This technique initially applies Newton-Raphson methods, wherein lower accuracy GPS estimates are used as initial conditions for the iterations. This strategy applies

Newton-Raphson techniques for using the measurements of the range distances between the UAVs to yield successively improved UAV position estimates with each iteration of the mathematical processing. GPS receiver measurements provide the initial seed from which subsequent iterations give more accurate UAV position estimates than that of the initial GPS measurements. The foundations of this iterative Newton-Raphson processing are sound mathematically and have been demonstrated to yield significant improvements in UAV position estimates for simulated swarms of up to hundreds of UAVs. For all cases examined, the root-mean-squared (RMS) radar position errors become less than 1/100 of the corresponding GPS estimates.

The examples below consider cases of random placement of the true UAV radar phase centers at some particular instant in time. Next, random GPS position errors characterized by a 1-sigma value of 1 meter in each of the three spatial dimensions were added to the true UAV positions. Next, simulated radar range measurements were generated between the pairs of UAVs, with 1-sigma random errors of 0.001 meters that were added to the true range values. Finally, the initial GPS estimates of the UAV positions, as characterized by 1-meter 1-sigma errors in each spatial dimension, and the measured range values with the 0.001-meter 1-sigma errors are injected into an iterative Newton-Raphson algorithm implementation which uses a mathematical pseudo-inverse since there can be more range measurements than unknown UAV position parameters.

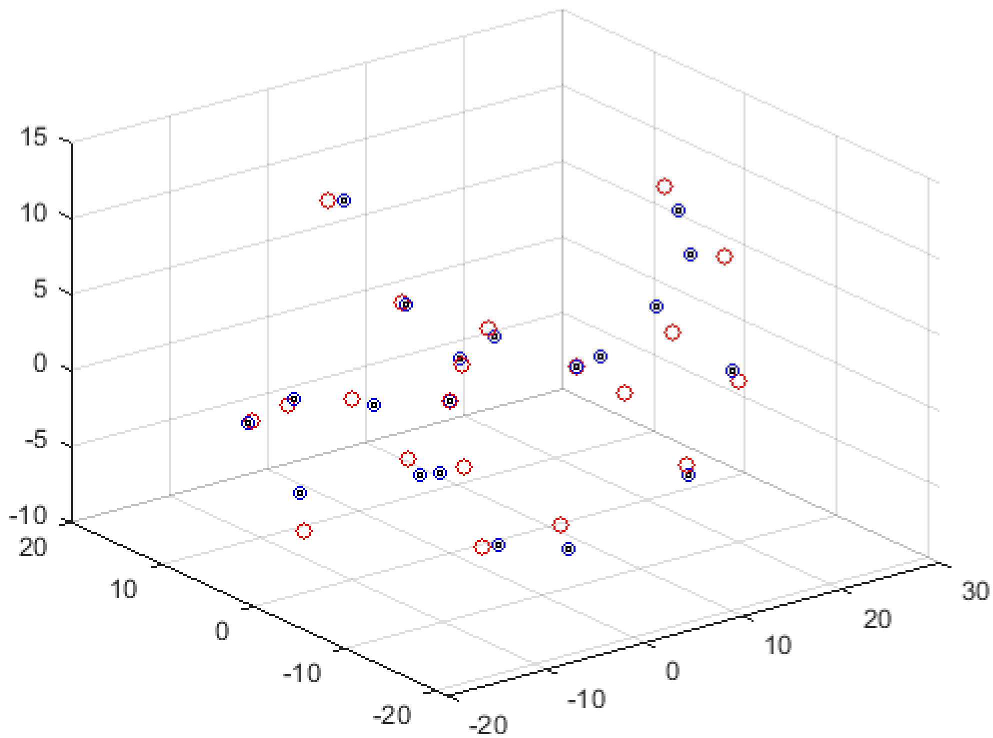

Figure 13. Simulated swarm array of 20 UAVs, with the large red circles denoting the initial GPS estimates, the medium-sized blue circles giving the Newton-Raphson estimates, and the small black circles showing the true UAV positions.

The scenario examined herein pertain to the random placement of 20 UAVs. The GPS 1-sigma errors of 1-meter in each spatial dimension and the 0.001-meter range errors were simulated relative to the true UAV positions. This algorithm converges quickly with regard to iteration number. Figure 13 gives the positions of the initial GPS-estimated positions of the UAV radar phase centers as large red circles. The Newton-Raphson estimates are shown as medium-sized blue circles, and the true UAV positions that are denoted as small black circles. The case of 20 UAVs is shown in the left panel, and the 200-UAV scenario is on the right. These plots indicate that the Newton-Raphson estimates almost overlay exactly with the true values at this scale, whereas the positional offset of the initial GPS estimates relative to truth is obvious for most of the UAVs. These plots provide insight into the value that this self-tightening swarm calibration methodology that can be result from accurate range estimates between the UAV radar phase centers. The proposed analysis offers to use these initially promising results in order to investigate the details of a viable methodology for calibrating a swarm of UAVs based upon radar range estimates between pairs of UAVs. This project has included an examination of the transmission and reception beam patterns that can be obtained for the case of a radar UAV swarm that is well calibrated using the techniques described above. Figure 14 examines the case of forming a coherent radar beam by using a swarm of 20 UAVs, each operating at a center frequency of 5 MHz. The resulting beam pattern includes the effects of the residual self-calibration error, after the Newton-Raphson method is used to remove the majority of the initial GPS estimates. Even with the presence of residual position errors, a very sharp beam can be formed for both radar transmission and reception. Range estimates between UAVs can be obtained through radio-frequency range estimation. One way to estimate this is by transmitting a known sequence for which a receiver listens. A matched filter is known to be able to detect optimally the transmitted sequence. The range between the transmitter and receiver can be estimated by the time of flight of the sequence. Moreover, in a line-of-sight environment, this design can be built into the normal data communications structure by inserting the sequence as a preamble to each transmitted frame.

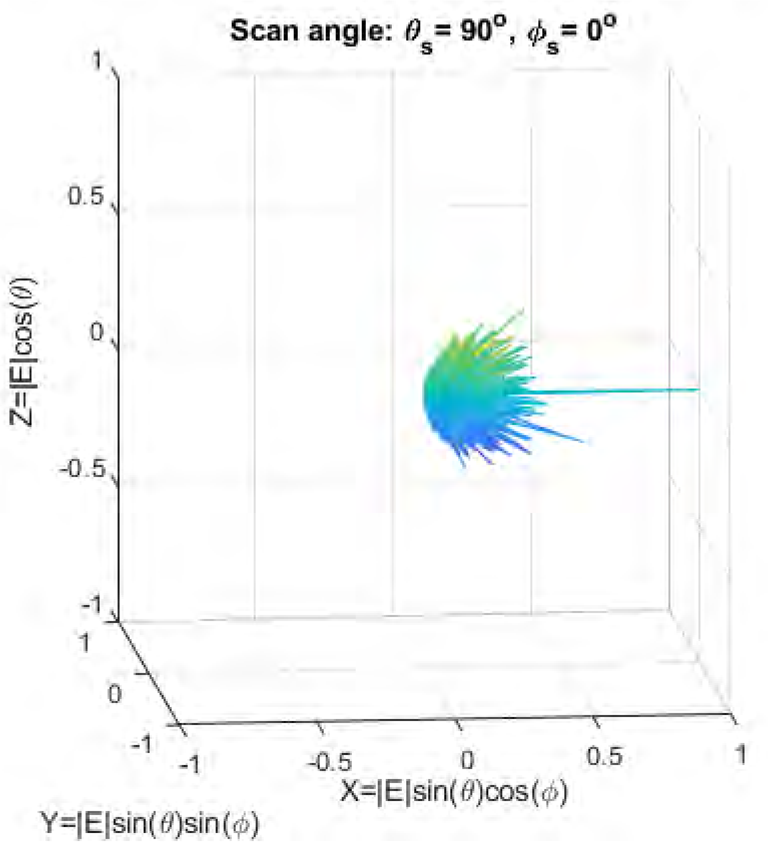

Figure 14. Array beam pattern for a transmission beam which is pointed 3 degrees above the horizontal.

If all UAVs are given designated times to transmit (i.e., the transmit time is known) and all platforms can be adequately synchronized, then accurate range estimates can be simultaneously obtained during normal communication. The natural question that follows is: “what sequence can be used that maximizes the aforementioned scheme’s effectiveness?” Two candidates are Gold sequences and Zadoff-Chu sequences. Both sets of sequences are used to affect similar functionality in cellular networks. Gold sequences have very good cross-correlation properties and marginal autocorrelation properties. This means that if two Gold sequences are transmitted on the same resource simultaneously, they will not interfere with each other. On the other hand, finding the exact time instance when the sequence arrives at the receiver (autocorrelation) is less robust. Conversely, Zadoff-Chu sequences have very good autocorrelation properties, but marginal cross-correlation properties. This means that there are virtually no sidelobes in the autocorrelation sequence, but Zadoff-Chu sequences that are sent at the same time may interfere with each other. This cross-correlation vulnerability can be overcome by assigning the same ZC sequence to all transmitters, but circularly shifting each one differently. By doing this each circularly shifted sequence will (relative to the same sequence not circularly shifted by the same amount) have perfect cross-correlation properties. For these reasons, we submit that ZC sequences are a natural choice to use as frame preambles for range estimation. Using this method, error in distance estimates, have been reported as low as a millimeter for certain signal-to-noise ratios. In summary, the functionality of a coherent radar array requires that these independent UAV ephemeris fluctuations to be estimated accurately so that resulting calibration errors can be removed. In this project, advanced signal processing methods have been applied to correct for the atmospherically induced and dynamically changing positions of the radar phase centers on each of the UAVs in the swarm. Thus, this capability will enable a myriad of DoD radar missions to be performed by swarms of UAVs.

The research team members were NPS Professor Phillip Pace, NPS Professor David Jenn, NPS Assistant Professor John Roth, and LT Richard Schoyer USN who used this project for his Masters thesis.[11] This research project has resulted in approximately 20 new lecture slides that were added within the course EC3700 Joint Network-Enabled Warfare I. These new lecture slides covered the Newton-Raphson techniques used to calibrate a swarm of radar UAVs. In addition, it is expected that this research can provide new course material for other radar courses, including EC4610 Radar Systems and Joint Network-Enabled Warfare II.

POC: Dr. David Garren (dagarren@nps.edu)

7. Distributed Adaptive Submodularity for Mixed-Initiative UxV Networked Control Systems (Horner/Kragelund)

A heterogeneous collection of unmanned systems can dramatically improve naval expeditionary warfare by providing autonomous intelligence, surveillance and reconnaissance (ISR) support to sea and land operations to improve mission effectiveness. To control the group as a single networked system, a Network Control System (NCS), requires considerations of communications, sensing, vehicle dynamics and situational awareness for optimal positioning and movement of the vehicles. This research seeks a distributed, computationally efficient solution to this multi-variable optimization problem. Our approach is the use of a technique called adaptive submodularity. Using the set property known as submodularity, it reduces the

[11] LT Richard Schoyer, USN, “FM Pulsed Imaging Radar Manipulation using FPGAS,” MSEE, June 2019. Recipient of Naval Information Warfare Systems Command Award in Electronic Systems Engineering.

complexity associated with the optimization from NP-Hard to polynomial time. This permits a solution in seconds rather than hours that can be then used by a near real-time system. There are performance bounds that ensures that it is a near-optimal solution.

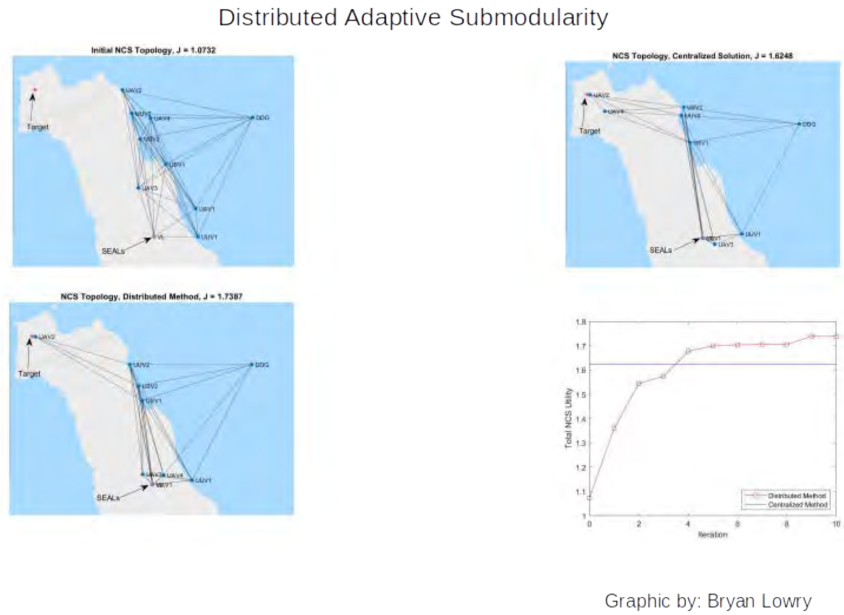

Figure 15. Comparison between the centralized and distributed adaptivity submodularity solutions. The cost function (J) shows a higher value for the optimization in the distributed implementation.

In this research we have extended previous research by moving from a centralized approach to a distributed approach. A centralized approach calculates the submodular optimization from a central location and transmits the solution to all the mobile unmanned systems. This has the obvious major limitation if that node was no longer able to do this, the system fails. A distributed approach has the benefit of not being dependent on a single node and being more robust for combat environments. A downside of the distributed approach is the added communication requirements to reach a consensus among all UxVs. The research was able to show the following:

1) An initial implementation for adaptive submodularity.

2) A comparison of the centralized and distributed submodularity approaches.

3) A demonstration of a distributed UxV submodularity algorithm that combined aerial, surface and underwater vehicles to support a Naval Special Warfare mission scenario.

Adding adaptivity to submodularity seeks to us AI techniques to generate near optimal solution with incomplete information. With this research we have begun to implement a technique known a distributed Monte Carlo Tree Search (MCTS). A configure space is the possible solutions that exist for the multi-objective optimization. It is defined as the power set given the possible locations for all of the vehicles. This is a daunting optimization challenge. MCTS looks for promising solutions through a sequence of four steps – selection, expansion, simulation and backpropagation. a randomized search of the configuration space. The Monte Carlo simulation generates reward functions through rollouts which are many instantiations of possible motions of the NCS over the mission profile. These rewards are backpropagated through the tree to determine the next moves. A second research objective was to compare and contrast centralized and distributed approaches. Our initial finds show that frequently distributed solutions converge to better solutions than centralized solutions. One possible reason is that in the centralized approach, each single UxV position is selected based on the best (greedy) selection. This can limit evaluations of the communications since the network is initially incomplete. Conversely, with a distributed approach, evaluations are conducted based on local evaluations of all optimal (greedy) movements – hence the communication component of the optimization is more fully realized.

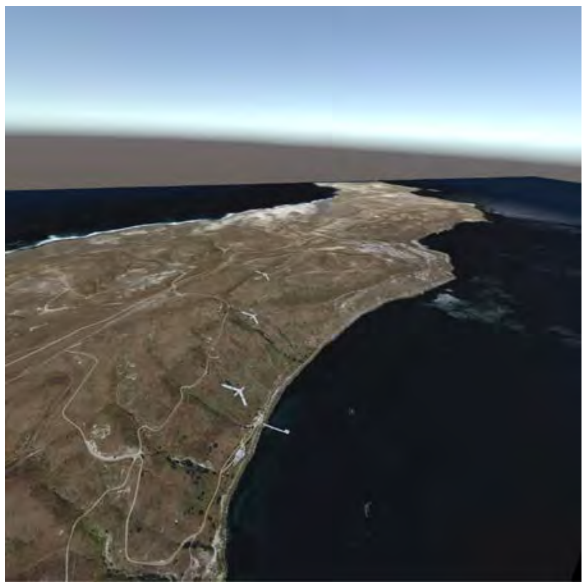

Figure 16. This is an image capture of a Virtual Reality environment of San Clemente Island with the deployment of the UxV Network Control System (NCS). It is a hybrid system that is intended to show a combination of simulation and real vehicles in order to test algorithms in a cost-effective manner.

Finally, this work is an outgrowth of the Multi-Thread Experiment (MTX) [12] conducted in 2017-18. Testing was conducted at San Clement Island (SCI) combining aerial, surface and underwater vehicles (*see Figure 16*). The expeditionary mission objective combined NAVSPECWAR SEALs with a COMTHIRDFLT DDG for a direct-action mission located in the northern part of SCI. The research has demonstrated the viability and improvement of using a distributed submodularity approach as a replacement of the centralized approach. Work has begun to take this from a simulation environment and put it onboard the UxV NCS. To fully test

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[12] See video overview of the MTX project at https://web.nps.edu/Video/Portal/Video.aspx?enc=fQYhjE1oV0Z5nE1Y5oX6u9IQTPIvhLNS

this capability (with hundreds of UxVs) would be cost prohibitive. Instead, we have begun development of a hybrid system. It combines simulated and deployed UxVs within a Virtual Environment. One strength of the approach is the ability for a mission manager to evaluate the AI solutions and manipulate the UxV positions to gain better understand into the optimization process.

The NPS research team consisted of Dr. Douglas Horner, Dr. Geoffrey Xie, Dr. Ruriko Yoshida, Dr. Sean Kragelund, and Lee Van Houtte; and NPS students Maj Ryan Keller USMC, LT Bryan Lowry USN, and LT Darren Kurt USN. This project is a collaboration between the NPS Center for Autonomous Vehicle Research (CAVR) and the NPS Undersea Warfare Group. This project generated two NPS theses, two conference presentations, and benefited the NPS course *Introduction to Unmanned Systems* (*ME3720*).

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

8. Environmental Hardening and At-Sea Testing of the Aqua-Quad Hybrid Platform (Jones/Dobrokhodov/Leary)

Developments this year were focused on the environmental hardening of the Aqua-Quad platform. Not surprisingly, this has turned out to be one of the most challenging aspects of the project. Early prototypes were designed primarily to gain systems integration experience and preliminary flight data, with only rudimentary efforts directed at environmentally hardening of the device. For rapid prototyping, as well as cost and weight concerns, additive manufacturing has been used extensively, but many printed parts turn out to be somewhat transparent to water, particularly at any significant depth. Techniques were developed to print parts that can withstand depths we are likely to experience on a device which is designed to float. Experiments demonstrated that joining these parts permanently with glue easily maintained the water resistance to any depth that the plastic parts could withstand; however, a much more challenging task was to allow for temporary seals using O-rings and bolted joints.

Figure 17. Lower shell of the printed pressure vessel with embedded, printed O-ring seat and O-ring. 3D printed Poly-carbonate with suitable design and printer settings results in water impermeable parts.

Using a combination of printed shells with printed O-ring seats bonded in place, we have been able to withstand depths on the order of 50cm for short periods, and depths on the order of 20cm for extended periods. An example lower pressure-vessel shell printed in transparent Poly-carbonate, with an installed printed O-ring seat (red), and an O-ring in place is shown in Figure 17. We are still pursuing other O-ring seal configurations that may provide better long-term non-permanent seals, but since the ultimate goal is to deploy the device just once in its lifespan, bonded joints are considered to be adequate. The shell components are cheap enough to produce that destroying a shell to gain access to or recycle the internal equipment might be considered acceptable. The incorporation of the new pressure vessel design required rather significant modifications to the airframe, primarily to implement a pressure-vessel with very few breaches through the enclosure. In the new airframe (*see Figure 18*) all electronics and batteries are contained inside the central 3-piece pressure vessel. The motor support structure is elastically mounted to the pressure vessel to aid in isolation of vibrations in flight. Only five water-tight connections penetrate the pressure-vessel, for power going to the four motors and power coming from the solar array. These are commercially available connectors suitable for depths up to about 10m.

Figure 18. Aqua-Quad prototype models. Rear right: previous generation with solar array mock-up installed. Rear left: current generation with printed pressure vessel and isolated propulsion frame (no array). Front: half size, race-based prototype for low-cost testing of array aerodynamics.

We also managed to get some autonomous flight data this year, flying the previous generation airframe at The Impossible City in Fort Ord. We used the newly developed, instrumented, power distribution board to monitor energy flow. Power required for flight was logged and matched theoretical estimates pretty closely; however, the flight model did not include the lower part of the pressure vessel or the solar array. We experienced an anomaly during those flights involving yaw-authority. It is common for large, long endurance multi-copters to have rather weak yaw authority due to the efficiency of the propellers (yaw authority is enhanced by increased propeller drag). In flight this resulted in motor saturation when the autopilot commanded high yaw accelerations. Motor saturation causes loss of stability in a quad-copter, as stability is actuated by controlling motor speeds. When two motors are at full throttle and two motors are at zero throttle in order to facilitate yaw, there is no throttle margin left to actuate pitch and roll. The model had to be rescued via manual control. To alleviate this, the newer frame design has the motor axes rotated slightly such that there is a small thrust component in the direction needed to aid in yaw authority. We have not flown the new model yet with this modification but expect to go through a few iterations to optimize the cant angle. This is essentially trading some lift efficiency in order to gain yaw authority. Another option under consideration is to essentially eliminate yaw maneuvers almost entirely. None of the payloads currently under consideration for Aqua-Quad require particular headings of the airframe, so in practice yaw maneuvers are not actually required.

Most recently, to aid in the evaluation of the solar-array support structure with regard to flight stability and performance; a half-scale model of the Aqua-Quad was fabricated using racing-drone parts/techniques. This ruggedized platform allows for extremely cheap, rapid testing of various array layouts, with essentially no risk to expensive equipment. Testing of this model will provide critical data for two student theses that are just getting under way. The students intend to develop a quasi-time-accurate mission planning simulator, with one focusing on energy harvesting and storage, and the other focusing on energy requirements for flight. A critical trade-space for the Aqua-Quad design includes the size and shape of the array, and the amount of power it can produce. The aerodynamic characteristics of the array in the presence of the quad propulsion are quite challenging to predict or simulate, so we will depend on a more heuristic approach using the sub-scale model and data logged in flight. This data will provide empirical coefficients or curves to improve the simulator.

This NPS research team representing the NPS Department of Mechanical and Aerospace Engineering, the NPS Center for Autonomous Vehicle Research (CAVR), and the NPS Advanced Robotics Systems Engineering Laboratory (ARSENL) was led by Dr. Kevin Jones and included Dr. Vlad Dobrokhodov and Dr. Paul Leary. This work has generated one conference presentation and paper (*included in Appendix A*), has two new NPS thesis students[13] on the team, and has benefitted one NPS course (*ME3201*). The team has also been awarded a patent for this work.[14]

POC: Dr. Kevin Jones (kdjones@nps.edu)

9. Long-Endurance Wide-Area Maritime Surveillance System (Joseph/Horner/Smith)

A long-endurance, integrated multi-glider acoustic and oceanographic sensing system can provide critical information about the maritime battlespace in near real time. Figure 19 shows a conceptual diagram of how the system could be deployed leveraging the strengths of unmanned and remotely piloted undersea and surface gliders. Major advantages of a system include:

(a) multi-month endurance that keeps sensors on-scene for extended periods

(b) system scalability that allows sizing the deployed system with respect to mission requirements

(c) use of a distributed network that is able to adjust to partial system failures and has organic backup capability

(d) use of proven platforms for reliable independent operations requiring little support

(e) ability to reconfigure on the fly to adjust to dynamic environments or changes in operational needs

(f) remotely piloted and semi-autonomous operations requiring minimal operator oversight

[13] Sean Yang and Gabriel Lim, anticipated graduation in September 2020

[14] K.D.Jones and V.N.Dobrokhodov, "Hybrid Mobile Buoy for Persistent Surface and Underwater Exploration," application filed in April 2014, awarded April 2016.

(g) on-demand cross-domain gateway to pass critical information in a timely manner

(h) real time in-situ sensing through the water column and near-surface atmosphere for accurate battlespace environment assessment,

(i) onboard computing capability for compiling information and modeling and

(j) continuous acoustic sensing at optimal depths.

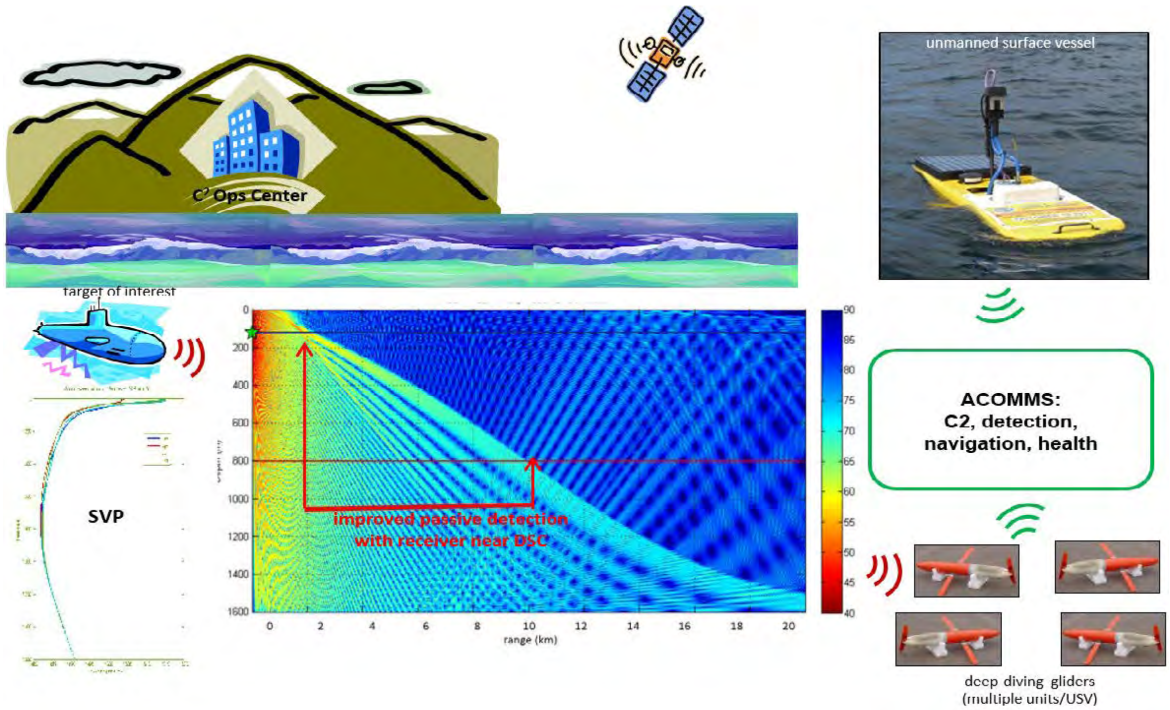

Figure 19. Conceptual diagram of how the observing and surveillance system can be deployed.

This project continued development of the system that will provide directional sensing capability using a GTI M20-601 (*see Figure 20*) when fully installed on the undersea glider. The sensor will be suspended from the glider while the glider is in a drift mode at depth to optimize the sensor performance. Algorithms for data processing are in development leveraging similar work in signal process of other GTI particle motion sensors used on campus. Communications between the undersea and surface gliders continue testing as essential navigation information, command and control messages and processed data must be exchanges between undersea and surface components to be successful.

Figure 20. GTI M20-601 2D particle motion sensor that will provide directional and pressure amplitude information from undersea sound sources.

This NPS research team was led by Professor John Joseph and included Dr. Doug Horner (NPS ME Department), Dr. Kevin Smith (NPS Physics Department), and Dr. Tetyana Margolina (NPS OC Department). Collaborations with other NPS projects using similar directional acoustic sensor technology and with a Monterey Bay Aquarium Research Institute (MBARI) research effort on adapting undersea gliders to communicate with surface gliders augmented this work. The NPS Tactical Oceanography course (OC4270) benefited from this research project.

POC: Professor John Joseph (jejoseph@nps.edu)

10. Multi-Domain Super Swarm: Robust Tactics for Engaging an Attacking Large-Scale Swarm (Kaminer/Walton)

The goal of this project was to develop robust tactics for countering multi-domain super swarms: large-scale swarms which span multiple environmental, communication, and weapons domains. Our previous research has provided tools for assessing adversarial swarms' internal cooperating strategies, quantifying risk based on swarm and weapons models, and generating optimal defender trajectories. We have developed a simulation-based testbed for experimental validation of these strategies and built a database of adversarial swarming models to test against. Our primary goal has been to develop universal counter UxS strategies for swarm engagement which are effective against a wide variety of swarming tactics. These strategies must provide guarantees against black box swarms—adversarial swarms with unknown internal control algorithms. Figure 21 provides an overview of our previous research (*see Figure 21, yellow*) and how the work accomplished in the 2019 (*see Figure 21, blue*) fits into the overall picture.

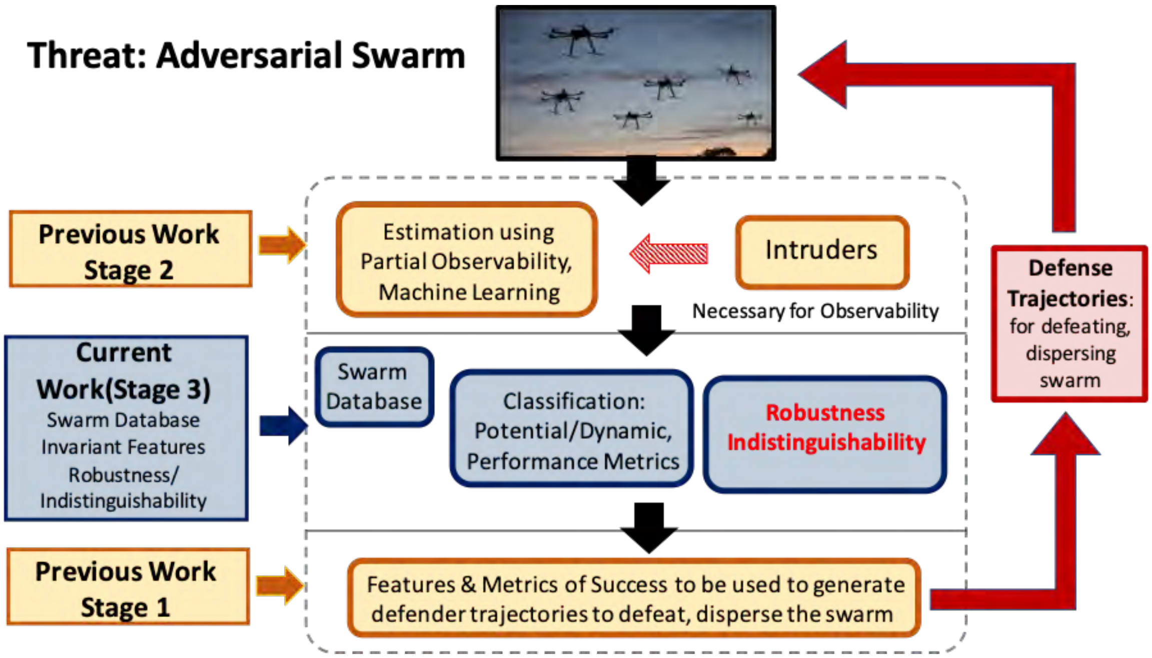

Figure 21. Overview of the overall research project.

Our previous work on observability has provided theoretical and computational tools, as well as strategies in the form of intruder trajectories, for the problem of detecting the internal cooperating strategies of an adversarial swarm by estimating a set of parameters that define a particular swarm cooperating strategy. Our work on herding has provided tools for generating optimal defender trajectories given parameter estimations for adversarial swarm strategies. Our objective this year has been to utilize our developed estimation tools to fill a remaining strategic gap. Ultimately, robust defense strategies need to act without certain knowledge of attacker behavior model. This uncertainty is generated by uncertain model parameters, as tackled last year, but it is also found in the model itself. What is needed is the identification and estimation of features which transcend specific swarm models/features found across all models whose estimation yields decisive strategic insight. We have used the estimation tools developed last year to test the observability and utility of multiple proposed `invariant' metrics, such as reactivity, centrality, and fragility. These metrics were tested on the Swarm Database we developed this year—a database of a variety of different implemented swarming strategies. The results have been discouraging: the proposed `invariant' turned out to be non-unique and thus unobservable. As an alternative, we have employed the optimization tools developed under the SoA's "Maritime Defense and Herding" program together with the estimation tools developed last year to address the problem from a completely different angle, that of the "Black Box Robustness-Indistinguishability" discussed below.

Our accomplishments for this year include:

- **Large-Scale Swarm Database**—We have developed a simulation testbed with a database of a variety of different implemented swarming strategies.

- **Swarm Features for Classification Analysis—**We have used the estimation tools developed last year to test the observability and utility of multiple proposed `invariant' metrics, such as reactivity, centrality, and fragility. These metrics were tested on the Swarm Database. We found that many proposed metrics were non-unique and unobservable, making them unfit as tools for swarm estimation and model learning.

- **Model Free Estimation—**The discovery of many non-unique features suggests commonality in swarm interaction models which can be utilized for robustness. Motivated by the "negative" results found for swarm features, we then applied the estimation tools to a new case: estimation given incorrect swarm model. We found that even without knowledge of the correct model, the estimated incorrect model was sufficient for generating defensive strategies. In fact, these defense strategies were "indistinguishable" in their success at protecting an HVU as the strategies optimized using the correct model.

- **Black Box Robustness-Indistinguishability—**With the above results, we have expanded our reach to look into the robustness and indistinguishability (in terms of defense results) of defense strategies given black box (unknown) swarm models. This includes the case described above, where the correct model is not known in estimation. It also includes limited estimation (wide ranges of possible parameters), mixed swarm strategies, and model switching. We discuss robustness and indistinguishability in more detail below. Our accomplishments for this year include:

- **Large-Scale Swarm Database—**We have developed a simulation testbed with a database of a variety of different implemented swarming strategies.

- **Swarm Features for Classification Analysis—**We have used the estimation tools developed last year to test the observability and utility of multiple proposed `invariant' metrics, such as reactivity, centrality, and fragility. These metrics were tested on the Swarm Database. We found that many proposed metrics were non-unique and unobservable, making them unfit as tools for swarm estimation and model learning.

- **Model Free Estimation—**The discovery of many non-unique features suggests commonality in swarm interaction models which can be utilized for robustness. Motivated by the "negative" results found for swarm features, we then applied the estimation tools to a new case: estimation given incorrect swarm model. We found that even without knowledge of the correct model, the estimated incorrect model was sufficient for generating defensive strategies. In fact, these defense strategies were "indistinguishable" in their success at protecting an HVU as the strategies optimized using the correct model.

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of defense strategies given black box (unknown) swarm models. This includes the case described above, where the correct model is not known in estimation. It also includes limited estimation (wide ranges of possible parameters), mixed swarm strategies, and model switching. We discuss robustness and indistinguishability in more detail below.

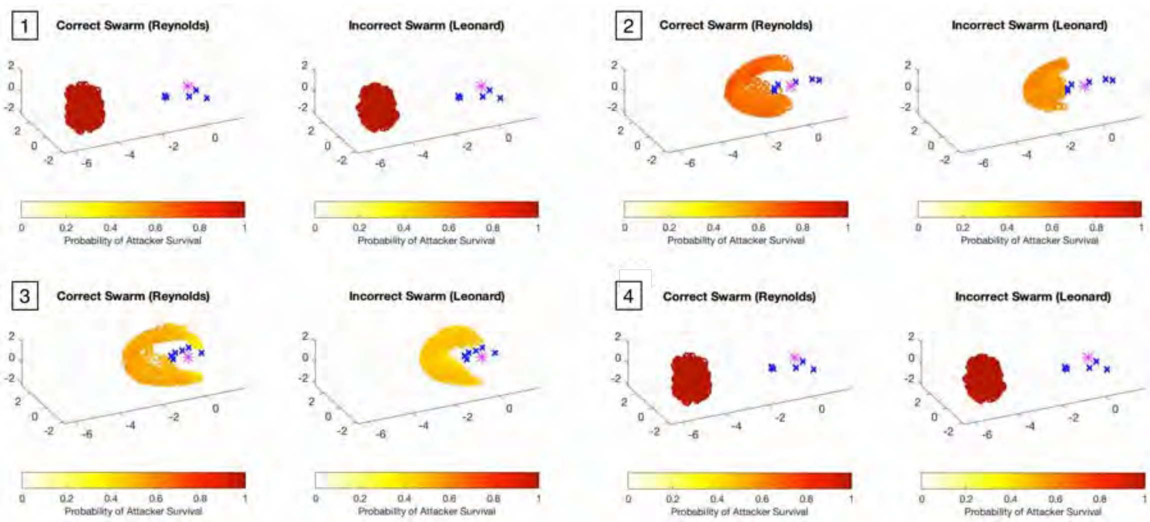

Figure 22. Snapshots of same 5-defender strategy against two different swarm models.

The most exciting results of our 2019 work are the preliminary results demonstrating the potential to develop strategies which are robust against multiple swarming strategies. For instance, Figure 22 shows a 5-defender strategy played out against two different swarm models. The same defender strategy is able to successfully protect the HVU, despite differences in attacker weapons and pursuit-evasion responses. For some models, we find a feature which we currently refer to as "Black Box Robustness-Indistinguishability"—although the swarming tactics are quantifiably different, the outcomes of these two defensive engagements are indistinguishable with respect to success at protecting the HVU. Successful defense against a large-scale swarm attack on any Naval vessel has been identified by the CNO as critical to maintaining US naval superiority. The goal of our ongoing research is to develop fundamental quantitative tools currently lacking for defense against autonomous swarms—and thus to enable the use of informed real-time strategies against large-scale autonomous swarms, for defense and operations. Full a priori knowledge of adversarial swarm strategies is unlikely to be available in engagement. The objective of this project is to provide robustness guarantees on multiple fronts and to develop universal counter UxS strategies for swarm engagement which are effective against a wide variety of swarming algorithms. Our findings this year show that this is both promising and feasible. Using the tools described above, we have shown that even with incorrect and/or partial knowledge of an adversarial swarm's tactics, robust defense tactics can still be generated. These strategies will be resilient against a variety of tactics and capabilities.

This project was completed in affiliation with China Lake Warfare Center, and the NPS research team included Professor Isaac Kaminer, Professor W. Kang, Dr. Claire Walton, and Dr. Sean

Kragelund as well as NPS students LT B. Lowry USN, LT J. Figueroa USN, and LT T. Tsatsanifos of the Greek Navy who is using this project as his thesis work.[15] Two NPS courses (ME4811, ME4821) have benefited from this work, and the ONR project N0001419WX00155, "Fundamental Issues on Observability of Adversarial Swarms" was generated from this work. In addition, the research team is organizing CRUSER-ONR sponsored workshops xSwarm 2020 and counter-Swarming 2020. The goal for xSwarm 2020 and counter-Swarming 2020 is to be an exploratory workshop for discussing the challenges of "black box" swarms or—xSwarms—large groups of agents for which there is a lack of a priori information about the internal control and decision-making mechanisms and only partial information about the system's perceptual and communication capabilities. The goal of the workshop is to bring together researchers across diverse fields to provoke sharing of research, discussion, and brainstorming for the development of new tools for understanding xSwarms. Attendees will have the opportunity to present relevant research, suggest areas of inquiry to the community, and lead or participate in panel discussions.

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

11. 3D Printable Artificial Muscles for Biomimetic Stealthy Propulsion (Kartalov)

Autonomous vehicle applications require locomotion and/or propulsion. In naval settings, unmanned underwater vehicles (UUVs) would greatly benefit from acoustic stealth, increased range, and decreased energy requirements. To meet that need, we proposed artificial synthetic muscles to be 3D printed in soft polymer or resin. The low density of the material would allow most of the sonar beam energy to pass through such a UUV, instead of being reflected by high mismatch in density back to the source. As a result, artificial muscles promise acoustic translucence and consequent increased stealth. Furthermore, the biomimetic nature of the artificial muscles allows for mimetic propulsion that avoids propeller cavitation and thus would make the UUV sound like a biological during movement, further improving stealth. Finally, biomimetic propulsion combined with the electrostatic actuation in the muscles ought to produce an energetically more efficient propulsion, while the decreased mass of the engine would lighten and scale down the overall vehicle. The resulting decreased power consumption ought to increase operational range and duration of deployment between refueling/recharging events. That would improve logistics and help provide the ability of maintaining large fleets or swarms of UUV in operational settings. We have conceptualized the general design of the muscles as based on electrostatic actuation by charging superarrays of microcapacitors. The idea is to use the bulk of the material as the dielectric for the capacitors while the defined microchannels within the bulk would provide plates and wiring by being filled with conducting fluid or gel. Manufacturability is assured by using 3D printing techniques to print the material and define the

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[15] T. Tsatsanifos, LT Greek Navy, "Computationally efficient algorithms for optimal motion planning against large scale swarm attack." Graduation anticipated June 2020

microchannels within it. Various microfluidic techniques are also employed in the design and manufacture of the structures.

COMSOL CASSETTE – STRAIN UNDER VOLTAGE

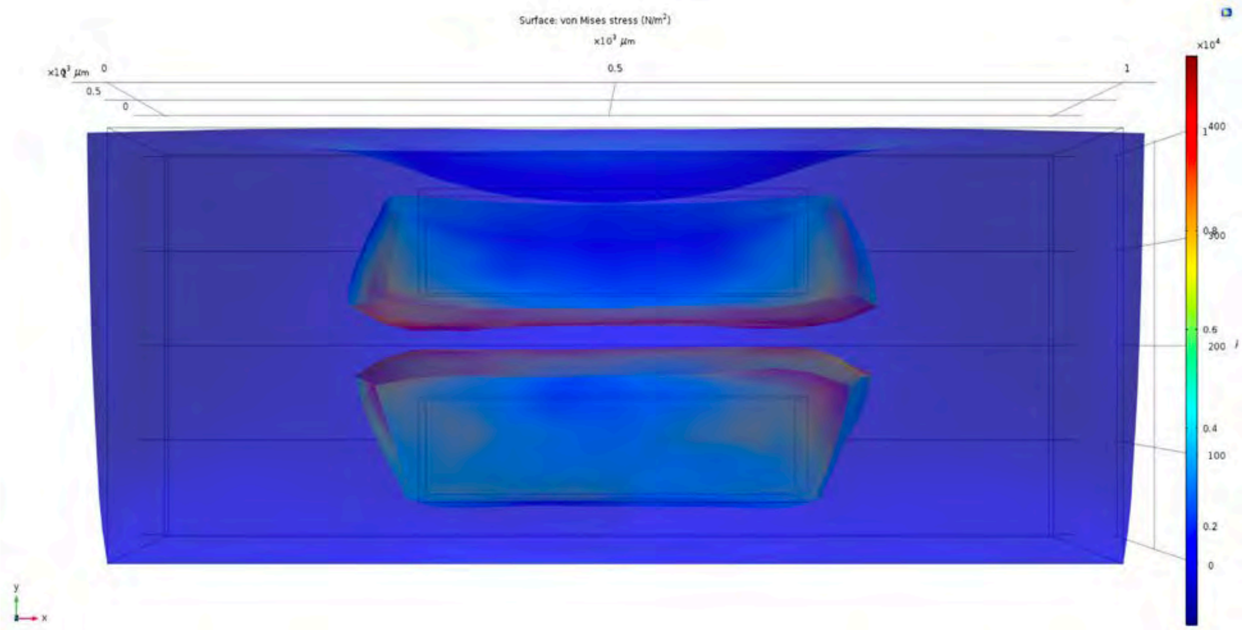

Figure 23. dielectric cassette strained by voltage applied between hollow plates filled with conducting material. COMSOL calculated output force density confirming feasibility of artificial muscles. We parameter-swept to determine optimal side thickness for maximal force density output.

After the initial rough design, we set out to prototype these devices for experimental testing. We quickly discovered though that we did not have a good handle on the best aspect ratios and parametric relations to use in the design, towards maximal generated force output. One direction to take was to begin manufacture and alternate between fabrication and testing. However, we realized that limited time and resources would make this approach rather slow and wasteful, especially as our lack of access to a soft-resin high-resolution 3D printer confined us to fabrication in 2D by lithographic methods for purposes of experimental proof of principle. So, to help either fabrication approach and significantly cut down on prototyping time and expense, instead we chose to work out the design parameters using COMSOL simulations of the basic design architectures. We started out with the smallest core element of the superarrays – a unit cassette featuring a pair of hollow plates defined in bulk dielectric and filled with conducting material. We set the scaling to 100 microns plate separation for a 400x400 micron plate. We fixed one of the walls of the dielectric cassette mechanically and allowed the rest of the structure to deform as a result of the application of high voltage between the plates. The simulations produced output force and output force density (force per unit area) consistent with our back-of-the-envelope calculations, confirming the expectations and showing that the design would work. In biology, muscles have two primary components: muscle fibers and tendons. The muscle fibers are very long cells, which are encapsulated in connective tissues and combine to form muscle fiber bundles. Similarly, the connective tissues combine to form tendons at the ends of the muscle. The muscle fibers tendons connect the muscle to the bones and transfer the force generate by the muscles. In our artificial muscles, the plates attract electrostatically and compress the intervening slabs of dielectric. That compression is partially transferred to the surrounding bulk material, which contracts and transfers the force to the outside world, just like tendons.

ARRAY OF 2 CASSETTES

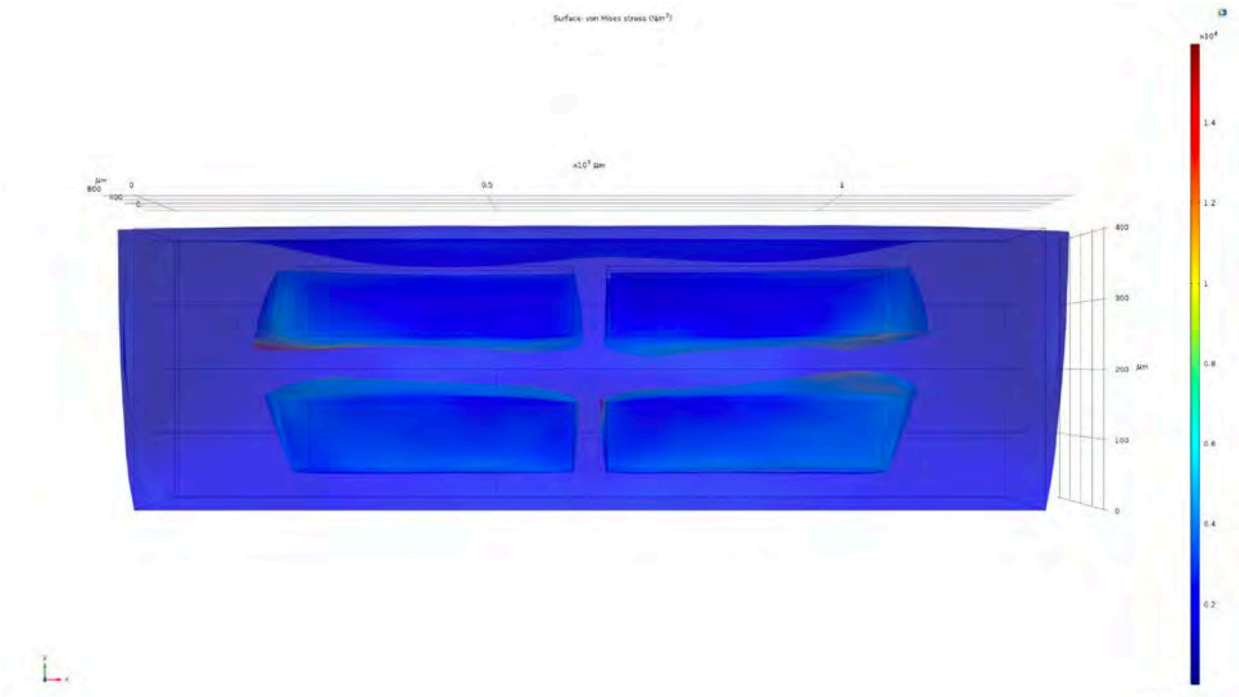

Figure 24. Two cassettes arrayed together are strained under applied voltage. The overall structure responds as expected and deforms according to projections. We are working on arraying sideways as well to show force gain.

In our unit cassette, the side material around the plates functions as the connective tissue that moves the tendons. So, we parameter-swept its thickness from 100 microns to 400 microns in COMSOL while recording the output force and force density. As expected, the output force increased with side thickness but with diminishing returns. As transfer efficiency is increased more force is transferred but eventually all force is transferred as can be and further increase in connective thickness does not help. Furthermore, the plates and connective sides compete for real estate in the cassette, so there is a tradeoff between force generation and force transfer. This suggested the existence of a goldilocks region with optimal distribution between generation and transfer, such that the output force density is maximized. We confirmed this prediction by the parameter sweep in COMSOL. Plotting the results produced a noticeable peak at around 130 microns side thickness for the 400x400 micron plates vertically separated by 100 microns. This is an excellent optimization and empirical discovery that tells us exactly how to design and build these structures for maximal force density output. Furthermore, this optimizes the overall cassette and allows us to use it as a building block to superarray, since the maximized parameter if force density. The next stage of simulations was to put multiple cassettes together and figure out the optimal spacings between them in the plane of their arraying. We built simulations for two cassettes side-by-side and for four cassettes in a 2x2 matrix, both in the plane parallel to the plates. The results are very encouraging and suggest the arraying would work very well. To recap, we determined the optimal settings of several critical architectural parameters for the devices, towards maximization of force output density. We confirmed the devices would work as expected and are arrayable as planned. Thus, the work is a major step forward towards successful and efficient prototyping of artificial muscles. We are organizing the results for publication as a scientific article and as a patent application.

This NPS research team included Dr. Emil Kartalov and Michelangelo Coltelli of the Physics Department. They are preparing a paper on the work and are actively recruiting NPS thesis students. This work has benefited mechanics courses in the Physics Department, and the team has filed a patent application on the original idea through Caltech collaboration. This past year Caltech converted the provisional into a non-provisional. The NPS team is also preparing a new patent application based on the new results from the COMSOL simulations.

POC: Dr. Emil Kartalov (epkartal@nps.edu)

12. Identification of Wave Environments that Degrade the Performance of AUVs Operating Near-Surface (Klamo/Kwon)

Currently, the U.S. Navy uses autonomous underwater vehicles (AUV) for a limited number of deep-water missions such as sonar scanning to detect mines. There exist environmental conditions, specifically strong underwater currents, which can severely degrade the mission performance of the AUV. In the case of strong underwater currents, the AUV typically struggles to maintain its heading. As the U.S. Navy increases its reliance on AUVs to perform more complex missions, AUVs will need to operate near the surface as well. Examples of missions that require near surface operation include intelligence, surveillance, and reconnaissance (ISR) gathering, networked communication with surface and air vehicles, and any near-shore shallow water operations. However, when operating near the surface, certain wave environments will cause wave-induced loads on the AUV that severely limit the vehicle performance, just like strong current do during deep water operations. The degraded performance could involve large speed losses and the inability to maintain a desired depth or heading. Degraded AUV performance during any mission would potentially compromise the ability of the AUV to complete its objectives. For the U.S. Navy to have the ability to utilize a large number of AUVs for a wide range of future missions requires military officers with experience operating AUVs and a strategy for increasing our scientific knowledge on AUV performance.

This research effort addressed both issues. A U.S. Navy military officer gained experience with AUVs by restoring a previously unused vehicle that resides at the Naval Postgraduate School (NPS) to working condition. He is currently demonstrating a potential research project it could support which would highlight a realistic path toward increasing the U.S. Navy's scientific knowledge on AUV performance. The vehicle of interest is the beta-version of the Bluefin Robotics SandShark. This vehicle is a man-portable micro-AUV with a diameter of 4.875 inches and a length of approximately 38 inches. This small size allows it to be operated easily by a single person and potentially to be used in many different water basin facilities at NPS. These characteristics make the vehicle very suitable for use in thesis research by military officers at NPS. The effort to restore the vehicle to an operational state required several issues to be addressed. Due to being stored for an extended time period without a charge, the Lithium-Ion battery needed to be replaced. The old battery and power management board had to be returned to the original manufacturer, AllCell, and a new battery was purchased and the power management board re-installed.

The Department of Navy safety certification process for Lithium-Ion battery use was also completed. A charging cable and vehicle communications cable needed to be custom built as well. The connectors on the vehicle for these cables required that different compatible SubCon connectors be purchased for each cable. A power charging brick and ethernet cable were spliced onto each of the connectors to complete each cable assembly. A research team member successfully charged the battery through the vehicle's power management board and then powered on the vehicle. The battery has been cycled numerous times and he has identified how long the battery can power the vehicle before needing to be recharged. To communicate mission planning with the vehicle requires a laptop running a specific version of the Linux operating system and having a specific QGroundControl project compiled. The communication cable he built connects the laptop to the vehicle to transfer the mission planning information.

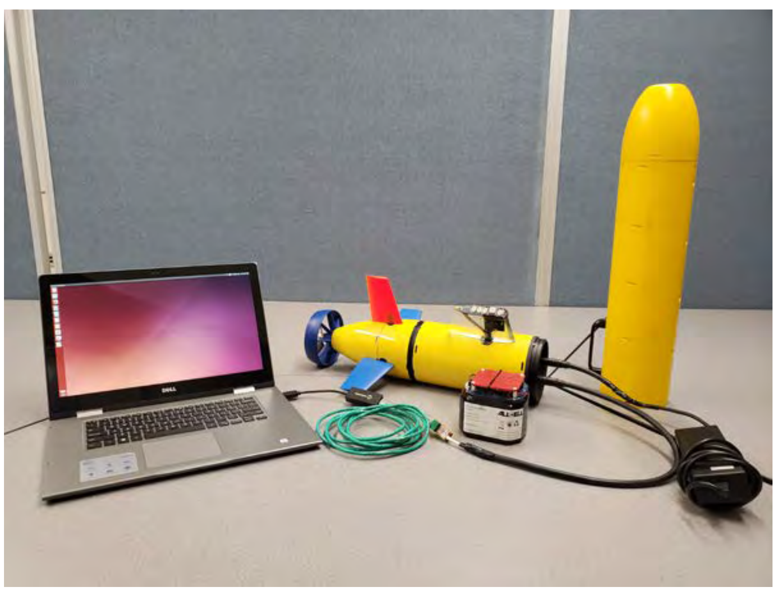

Figure 25. Various components built or modified to operate the previously unused man-portable AUV.

The required installation and project files for QGroundControl were obtained from a research group at the Massachusetts Institute of Technology that had the same beta-version vehicle previously. Figure 25 shows the various components that needed to be built or worked on to get the demonstration vehicle operational. The new Lithium-Ion battery with the red power management board attached is directly in front of the vehicle. The custom-made battery charging cable and vehicle communication cable are shown connected to the bulkhead of the vehicle. The other end of the communication cable is connected to the operator laptop running QGroundControl and creating mission profiles for the vehicle. Currently, he is learning to create different mission profiles for the vehicle and adjust the vehicle's internal settings so that it can operate in a shallow water basin without the presence of a global positioning system (GPS) signal. In the normal designed operating conditions, the vehicle requires a minimum water depth beneath the keel and requires updating of the GPS signal. Neither of these are possible in the enclosed small water basins in most NPS labs used for scientific research. Therefore, demonstrating that the vehicle can be operated in this unique condition is necessary for it to have broad use in military officer's M.S. thesis research involving the scientific exploration of AUV performance. Even though the funding period has ended, the research effort is being continued as his M.S. thesis research project. The planned initial demonstration of the vehicle's potential usefulness will be investigating how wave-induced loads on an underwater vehicle affect vehicle performance. The vehicle mission profile will call for it to advance at a constant speed will holding a constant depth. The performance will be baselined in calm water and then the same mission profile will be run with wave being generated in the small water basin. Any decrease in the ability of the vehicle to maintain speed or hold depth can be attributed to operating near the surface in a seaway. This thesis research will be conducted in winter and spring term of 2020.

The research team included Professor Joseph Klamo, Professor Young Kwon, LT Kristia Suriben USN, and LT Jonathan Marks USN representing the NPS Systems Engineering Department and the NPS Mechanical and Aerospace Engineering Department. This work generated a follow on project "Experimental Assessment of GhostSwimmer Performance in Shallow Water Marine Vegetation", Naval Research Program FY2020 Funded supporting U.S. Fleet Forces Command, and the project funding supported an Oak Ridge Institute for Science and Education (ORISE) Research Participant Program summer intern.

POC: Dr. Joseph Klamo (jklamo@nps.edu)

13. The Effect of Stress on the Decision to Rely on Automation (McGuire)

The current project, funded by CRUSER, examines human reliance on automation in contexts characterized by stress, with and without motivation, and with differing levels of automation reliability. In this project, participants are recruited from NPS, and consist of the student population. At a high-level overview, the experiment consists of several phases. Participants are asked to take a test measuring working memory capacity, then are asked to rest for 10 minutes. The rest period is so that any tension felt during the working memory test does not carry over into the other tasks. Also, the time directly post-rest serves as a baseline for stress. Heart-rate variability, electrodermal activity, and cortisol are sampled right after the rest period. After the rest period, participants are introduced to the reliance task, and go through a short training session with it. After the training, the participants are then put into the stress or non-stress protocol. This lasts for 15 minutes. After the stress or non-stress protocol, participants complete the actual reliance on automation task, and cortisol and physiological stress indicators are sampled throughout. Finally, participants engage in a trust in automation task, before filling out an exit questionnaire and being debriefed. Motivation is induced through performance-based incentives, so participants earn money during the reliance task. Additionally, automation reliability is manipulated within participants, so that participants are playing with an AI partner with either high or low reliability.

This project is supporting a Marine thesis student in the Information Sciences department. The thesis student helped with thinking through the design and is conducting data collection and analyses. Experimentation of this kind also helps with the instruction of research methods. It helps to illustrate the type of experimentation being conducted on campus, and how this research is carried out. This project as well as other experimentation also provide students with thesis opportunities. Currently, I have three laboratory experiments running, and a thesis student running each one of them. Bringing opportunities to get involved in research is invaluable to the students' success at NPS.

Since this project is still in the data collection phase, there is not yet data to report. Data collection should wrap up in the Spring of 2020 and will then be submitted for journal publication. The NPS student will also benefit as they will be included as an author on the submission. In addition to submitting the results for publication, this work will also be submitted in future proposals with the intention to build upon this line of research. One proposal in collaboration with CSUN has already been submitted. This work, even though not yet complete, has opened doors to have conversations with those wishing to collaborate on similar studies.

POC: Dr. Mollie McGuire (mrmcguir@nps.edu)

14. Development of Automated Fault Detection, Diagnosis, and Resolution Capabilities for MC3 (Newman/Minelli)

The Mobile CubeSat Command and Control (MC3) ground station network provides low-cost communications for US government small satellite research and development missions. The modestly-funded network consists of nine ground stations managed by a small team of operators. To maximize performance with limited budgets, the team routinely makes tradeoffs in reliability (low-cost components) and redundancy (single-string systems). To minimize inevitable downtime, the process of automated fault detection, diagnosis, and eventual resolution allows the operators to be more responsive to issues as they arise. These include developing the following:

- Autonomous health and environmental monitoring system for MC3
- Network and device connectivity monitoring with autonomous notification system

- Abstracting satellite data collection for incorporation into autonomous operations

While ground station issues can have many causes, understanding the health of each station and the environment the hardware is exposed to provides insight into the types of failures experienced. Health and environmental monitoring allow for trends to be analyzed in collected telemetry and characterize normal operating behavior of the stations in the MC3 network. Furthermore, introducing automated methods for collecting and analyzing station telemetry can improve the response time for diagnosing encountered issues. Temperature, humidity, power, and network response times serve as sufficient telemetry points to characterize a ground station based on the tasks MC3 performs. A power distribution unit and consumer-off-the-shelf (COTS) environment monitor was purchased to begin collecting the desired telemetry using the ground station located at NPS. Machine learning algorithms were researched to determine how to appropriately determine if a ground station component was functioning normally. NASA's Inductive Monitoring System (IMS) algorithm appears to provide real-time responses to changes in telemetry necessary to address issues as they arise on the MC3 network.

The temperature, humidity, and power telemetry points are measurable using COTS components, but network connectivity required a software solution. While software for network connectivity monitoring exists, such as the suite of products offered by Solarwinds, it was important the software could provide clear visual cues when issues arise for ground station operators and allow for them to manipulate the devices being monitored. The result is a web-based monitoring program referred to as MC3 Status as shown in Figure 26. The software provides a custom interface with the ability to monitor the status of each device connected to the Internet at every ground station. Along with providing clear visual cues for when devices are both functional and nonfunctional, MC3 Status informs operators of changes in the network through email and text messaging. Basic commands were also integrated so operators can perform remote repair tasks including toggling device's power. The interface also allows for new devices and ground stations to be added as hardware is replaced and stations are added to the network. MC3 Status provides autonomous monitoring of networked devices with tools to perform human-in-the-loop repairs through basic commands. While the software provides more information regarding the MC3 network's health than before, integrating a version of the aforementioned IMS algorithm or similar machine learning software can further reduce operator involvement.

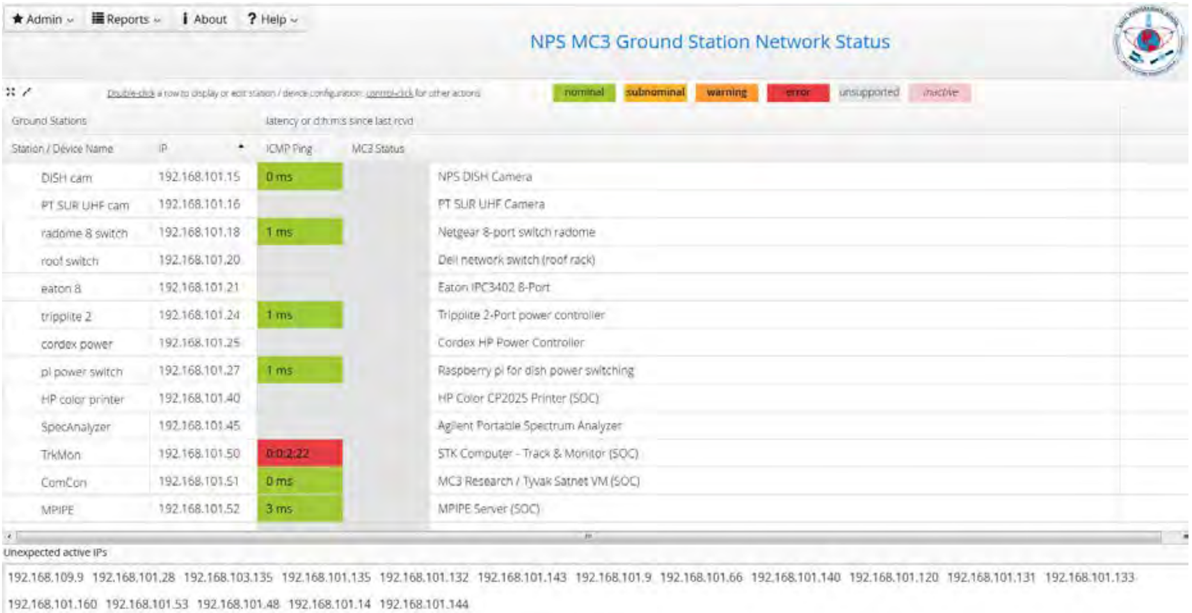

Figure 26. MC3 Status web interface showing the network connectivity status of hardware devices located at the NPS ground station.

While autonomously monitoring and analyzing ground station telemetry is critical, using the ground station network as a satellite operator can also benefit by introducing automation. Most spacecraft have telemetry that use a specific structure designed for that particular mission even though the types of telemetry required are fairly generic. By determining the similarities in data collected across satellites being flown with MC3, data can be abstracted into generic classes to simplify communication and allow for code reuse across multiple satellites. A Python implementation of a generic satellite class was created that allows for state preservation across multiple executions of the software. It also allows for similar data to be collected from unique spacecraft without having to alter the software to account for the unique saved states. Furthermore, this can help standardize satellite operations and make it easy to program the MC3 network to autonomously perform a series of tasks based on common data between each spacecraft. This would allow telemetry and status downlinks to be automatically performed alongside daily operator requests, and ensure all satellites are constantly being communicated with.

Health monitoring, MC3 Status, and satellite class abstraction shift the burden of performing simple yet time consuming tasks on the MC3 network itself. It is recommended to continue expanding on the all three projects with a focus on combining any health and environmental monitoring efforts into the MC3 Status project. Furthermore, improving the data collection and storage component of the aforementioned telemetry points can make it easy to integrate a machine learning algorithm, such as IMS, and determine trends in MC3's telemetry. The addition of more abstracted satellite classes will allow for further testing of the scripting capabilities as new spacecraft are launched in the coming year. A demo of the class structure using a current mission, such as NPSAT-1, would allow other satellites to inherit similar variables and data types without needing to develop brand new software. It is also recommended to abstract elements of spacecraft commanding. Satellite operators could write command scripts reusing similar syntax across multiple spacecraft due to inheritance provided by the abstraction and generic classes.

The research team for this project consisted of Dr. Jim Newman, Dr. Gio Minelli, Jim Horning, Noah Weitz, and Mike Bailey. This research was associated with DoD Space.

POC: Dr. Jim Newman (jhnewman@nps.edu)

15. Dynamics and Control of an Autonomous "Tugboat-Spacecraft" to Maneuver a Passive Resident Space Object (Romano)

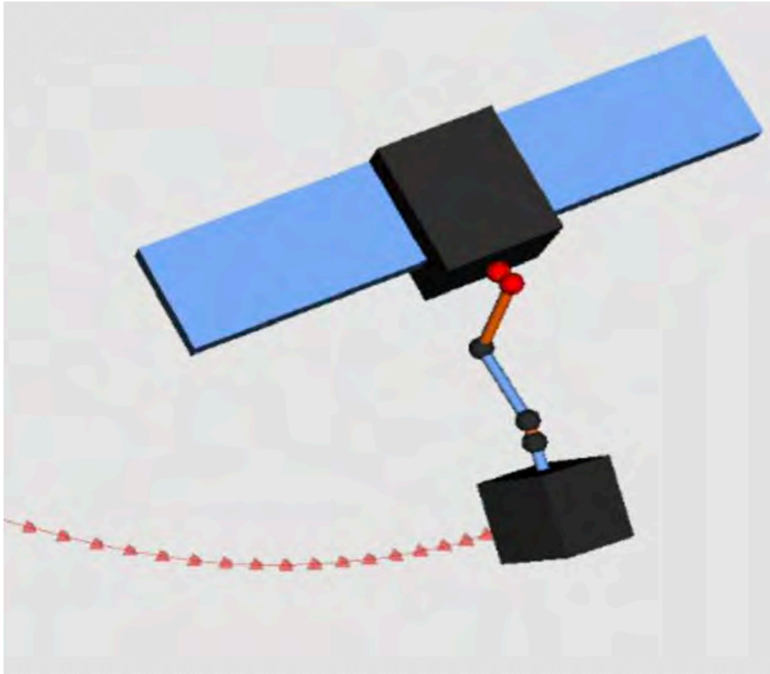

Figure 27. An illustration of a spacecraft equipped with a robotic manipulator, after grasping a resident space object.

This project investigated the feasibility and performed initial detailed studies on the concept of a "Tugboat-Spacecraft", consisting of a small autonomous spacecraft taking over the control of a larger passive Resident Space Object. The Resident Space Object, which might be tumbling, can be for instance a failed spacecraft to be serviced, or an orbiting space debris to be removed from orbit, or other object. The goal of the "tugboat spacecraft" is to control the Resident Space Object as regards its rotation, e.g. to detumble it, and its translation, e.g. to change its orbit. Two main results were obtained during the research:

1) The most important result obtained during the research was an analytical-theoretical result on the minimum-time control of a generic linear time invariant system. This result

can be applied to the problem of moving in a minimum time a spacecraft toward a resident space object in proximity. Notably, the above result is far more reaching than the specific subject of the proposal!

2) A generic algorithm has been developed to determine the optimal rotational maneuver of an arbitrary rigid-body object.

Both of the above results, obtained during the execution of the project, have considerably advanced the available knowledge toward obtaining the goal of maneuvering a Tugboat-Spacecraft toward an orbiting target and then detumble it, in preparation of further manipulation or removal from orbit.

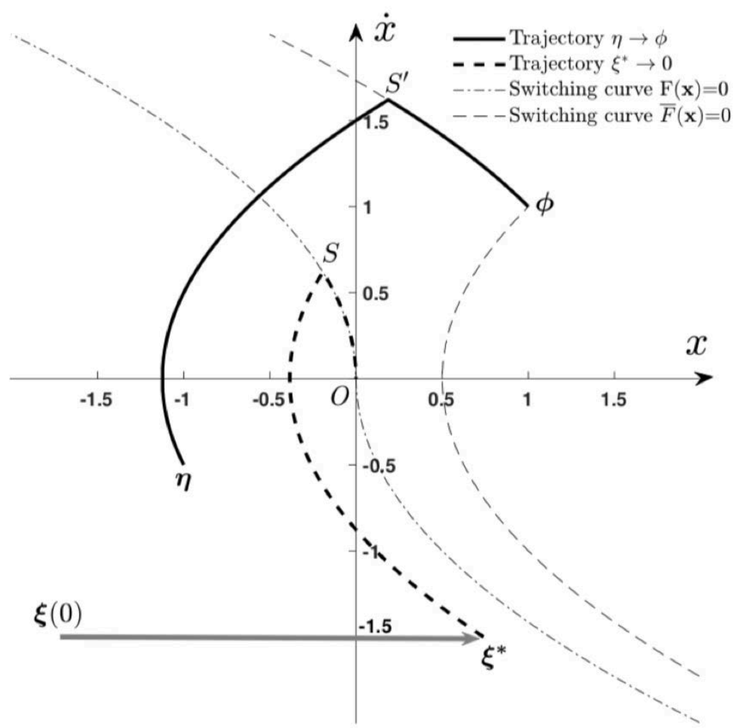

Figure 28. Illustration of the new method found to determine analytically the minimum time control of any Linear System between two ARBITRARY states. The method is valid for any linear system, but this illustration pertains with the example of a double integrator.

This NPS research generated a conference presentation, a paper submitted for publication, the follow-on project *Optimal Maneuvering of two Co-orbiting Spacecraft* sponsored by DoD Space, and one patent application.[16] An NPS student is using the work to support her PhD dissertation[17]

[16] Tavora, B., Park, H., Romano, M., & Yun, X. (n.d.). Equilibrium-Based Force and Torque Control for an Aerial Manipulator to Interact with a Vertical Surface. Robotica, 1-23. doi:10.1017/S0263574719000870

in 2020, and the project benefited three NPS courses: 1) *Robotic Multibody Systems (AE/ME4820)*, 2) *Spacecraft AD&CS (AE3818)*, and 3) *Spacecraft Rotational Mechanics (AE3820)*. Results and methods developed during the project have been included by Dr. Romano's in his teaching and Master/PhD advising.

More information on the project is available at https://my.nps.edu/web/srl/marcelloromano.

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

16. Deterministic Artificial Intelligence for Surmounting Battle Damage (Sands)

This report substantiates the first detailed treatise of deterministic artificial intelligence (D.A.I.) applied to the control of unmanned underwater vehicles. The major premise of D.A.I. is to assert a deterministic self-awareness statement based in either the physics of the underlying problem or system identification to establish governing differential equations. The key distinction between D.A.I. and ubiquitous stochastic methods for artificial intelligence is the adoption of first principles whenever able (in every instance available) prior to resorting to stochastic methods. The term “resorting” is used intentionally to highlight the major weakness of stochastic artificial intelligence lies in the necessity of copious so-called training data to teach the stochastic A.I. algorithms structures that are self-evident in the adoption of physics and differential mathematics. Evocation of first principles as self-awareness statements necessitate full (autonomous) expression of a desired trajectory in terms of displacement, rate, and acceleration. Inspired by the exponential solution of ordinary differential equations and Euler’s expression of exponential solutions in terms of sinusoidal functions, the full expression of the desired trajectory will be formulated using such functions. Deterministic self-awareness statements, using the autonomous expression of desired trajectories are asserted to control underwater vehicles in ideal cases. Subsequently, simple and optimal learning methods are derived to allow the underwater vehicle to correctly respond to disturbances, noise, unmodeled dynamics, and especially mismodeled dynamics. In totality, the proposed methodology automates control and learning merely necessitating very simple user inputs: desired initial and final states, and desired initial and final time. Simulations of the proposed method reveal the generalized (optimal) force or torque required to maneuver without user interaction.

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[17] Optimal Maneuvering of a Spacecraft, Alanna Sharp, PhD Dissertation, to be discussed in 2020.

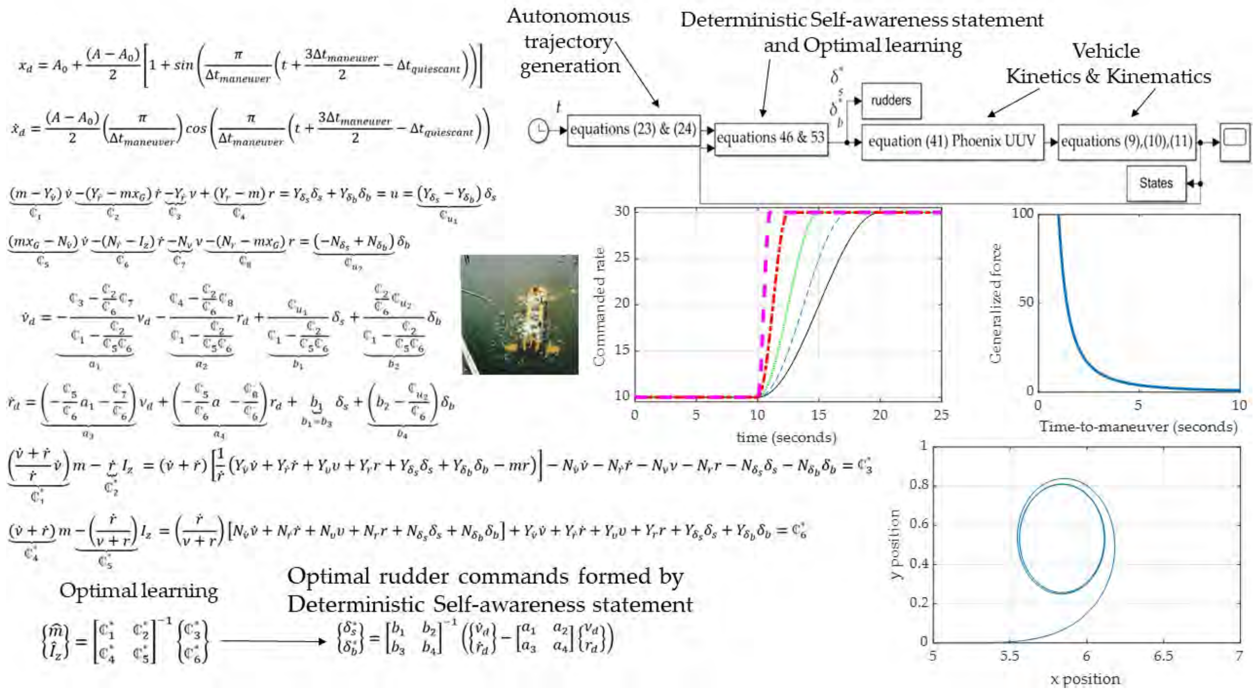

Figure 29. Deterministic Artificial Intelligence Summary chart: left side (top to bottom) is most important equations. Ride side is topology and plotted results.

This NPS research was completed in affiliation with Columbia University and Stanford University, and benefited NPS three NPS courses (AE3815, AE3818, AE3820).

POC: Dr./COL Timothy Sands USAF (tasands@nps.edu)

17. Acoustic Target Motion Analysis from Novel Autonomous Systems Using Light-Weight, Low-Power Data Acquisition Systems (Smith/Dobrokhodov)

During FY19 development work was continued to provide an efficient acoustic beamforming algorithm to run in real time, while simultaneously sampling four analog acoustic channels. One substantial hurdle to processing 4-channel raw data into bearing estimates is the challenge of concurrent sampling of the vector sensor's 4 analog channels at sufficient resolution in real-time, while utilizing the Teensy's 2 built-in ADC modules. This was accomplished by off-loading timing of the triggering of ADC conversion to a Flex Timer Module (FTM) which is clocked directly from the system memory bus, which in turn triggers 2 alternating pairs of Programmable Delay Block (PDB) timers each of which triggers a channel-specific ADC configuration. Also clocked from the FTM is a Direct Memory Access (DMA) module which transfers individual ADC conversion values from the conversion register to a data buffer for processing. At this time, the performance and accuracy of acoustic vector sensor bearing estimates have been measured experimentally, using both synthesized acoustic data with known directional content, as well as experimentally measured data in a controlled laboratory environment. First, synthesized 4-

channel acoustic data with known directional content was created in MATLAB, and loaded into Teensy's SRAM memory to simulate the 4-channel acoustic input. To do this, broadband white noise was generated, filtered to the desired signal frequency, and phase-shifted appropriately for each x,y, and z velocity channel to reflect a given bearing, and written to memory as a constant array. On boot, Teensy ran a single bearing calculation process on this array treating the data as a single sample buffer. To summarize the results simply, we found that, while bearings are calculated for any signal regardless of amplitude (thus are extremely noisy when real signal is largely absent), in frequency bands where signal is present bearing estimates agree with truth exactly. As bearings themselves have no magnitude, the out-of-band fluctuations are expected due to random bit noise. However, a simple frequency-domain signal level detector, which pulls bearings only for frequencies which contain signal above a certain threshold, would allow exact reporting of true bearing. After confirming the accuracy of calculated bearings using synthesized data, a simple experiment was set up in an anechoic environment, using a calibrated sound source and an aerial acoustic vector sensor sampled and processed according to methods outlined in the previous section. The sample buffer used was 1024 samples long and sampled at a rate of 100,000 samples per second. A 1.2 KHz source was placed at known bearings relative to the sensor, and the bearing output from the Teensy processor was streamed via Serial communications for data capture. Again, while bearings are noisy across the spectrum outside of the band of the projected signal, at the true source frequency, filtered calculated bearings match true bearings within 5 degrees.

The NPS research team included Dr. Kevin Smith, Dr. Paul Leary, Dr. Vlad Dobrokhodov, and Dr. Kevin Jones. This project generated a conference paper and presentation[18] and benefited the NPS course *Intermediate Applied Physics Laboratory (PC3014).*

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

18. Cybersecurity Evaluation and Testing of the ROS 2 Architecture for Networked UAV Systems (Thulasiraman)

Our study this year focused on the network performance of the Robot Operating System (ROS) 2 in a lossy, wireless environment, when used in a network of nodes similar to how a group of unmanned assets would operate. Specifically, we evaluated the impact of combining varying Quality of Service (QoS) and security settings in the ROS 2 environment and explored the effect that scaling to multiple nodes has on network performance. This is the first work to comprehensively study ROS 2 network performance using QoS and security classification as a function of scale and message size. Network performance metrics included latency and message drop rate between nodes. Our research uniquely integrates ROS 2 with NS-3 (an open source

[18] Real-time multi-channel acoustic beamforming using a lightweight microcontroller processor," P. Leary, V. Dobrokhodov, K. Smith, K. Jones, Oceans 2019, October, 2019, Seattle, WA

network simulator/emulator), developing a simulation architecture that is effective for rapidly studying ROS 2 network performance.

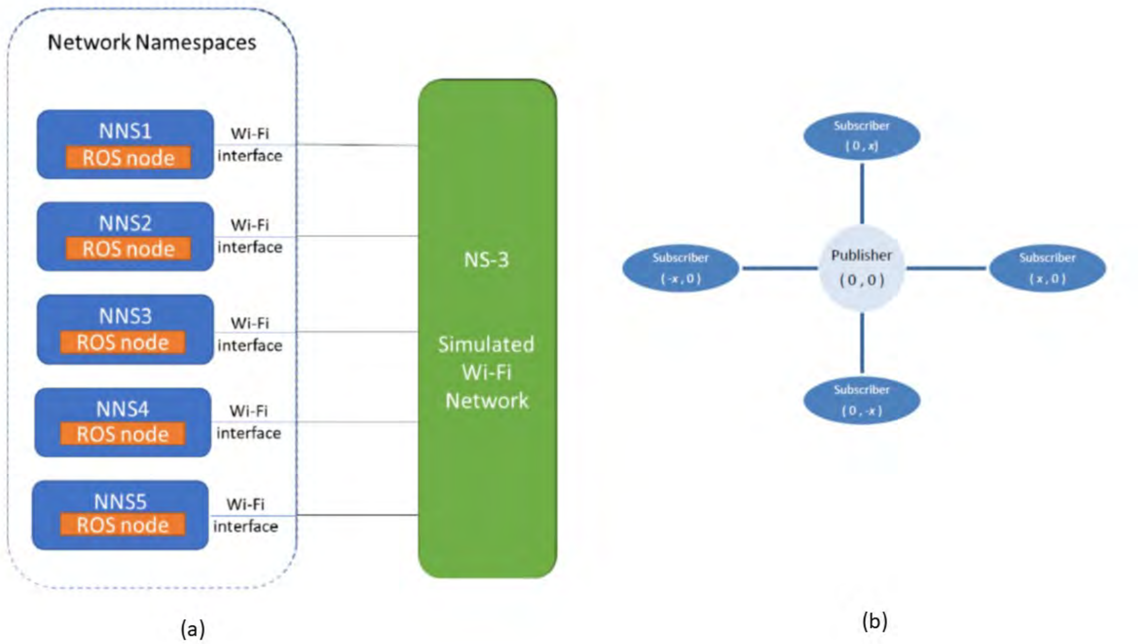

Figure 30. Overview of simulation architecture: (a)Architecture showing simulation of five ROS 2 nodes using network namespaces and NS-3 WiFi; (b) Top down view of the position of Subscriber nodes relative to Publisher node.

Our simulation architecture makes use of network name spaces to virtualize the network stack. For our simulations, a Wi-Fi network interface is created for each individual network namespace. Each ROS 2 node is then executed within its own network namespace, with NS-3 simulating a Wi-Fi network connecting each ROS 2 node. Figure 30(a) depicts how five ROS 2 nodes within their own network namespace communicate with each other via the simulated NS-3 Wi-Fi. In NS-3, nodes are positioned using a 2D Cartesian coordinate system. Using the constant position model, the NS-3 simulator starts with nodes at a distance x from a central node. Figure 30(b) depicts how four ROS 2 subscriber nodes are positioned around the central node, which contains the ROS 2 Publisher node. The simulation is run for two minutes, during which the data for the network performance is collected. After collection of the required data, the simulation is re-started with a new distance. Through multiple iterations of this process, network performance at different distances is measured.

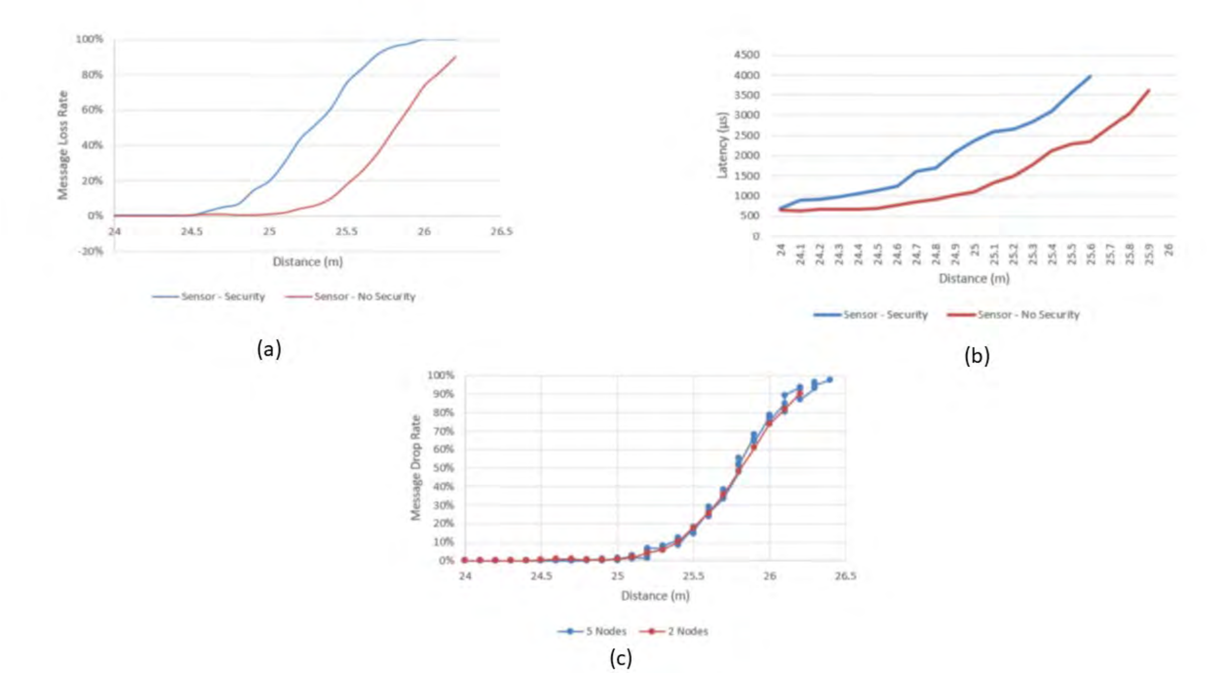

Figure 31. Results for the Sensor profile: (a) message loss rate with security turned on and off; (b) latency of messages for the Sensor profile with security turned on and off; (c) message drop rate comparing two nodes and five nodes with security on.

Our experiments considered three ROS 2 QoS profiles (Default, Sensors, and Parameters), operating with four ROS 2 policies (History, Depth, Reliability and Durability). We varied the values for each of the four policies and ran experiments for each combination when security settings were turned on and when security settings were turned off. Due to space, we show only a subset of results that were obtained. The results presented focus on the Sensors profile. The Sensor profile of ROS 2 is used when sensor data is being collected. For sensor data, in most cases it's more important to receive readings in a timely fashion, rather than ensuring that all of them arrive. That is, developers want the latest samples as soon as they are captured, at the expense of maybe losing some. For that reason, the sensor data profile uses best effort reliability and a smaller queue depth. This profile is the most relevant to UxS operations using ROS 2. Figure 31(a) illustrates the message loss rate for two ROS 2 nodes using the Sensor profile with security on and off. Figure 31(b) shows the latency of the Sensor profile when security is turned on and off. Lastly, Figure 31(c) shows the message drop rate of the sensor profile when the network is scaled to five nodes (with security on) as compared to two nodes. For all three figures, the distance given on the x-axis correlates to when NS-3 Wi-Fi begins to exhibit lossy behavior. More results can be found in associated theses. The simulation results demonstrated that the integration of NS-3 as a simulation platform for ROS 2 is useful and an effective way to rapidly test network performance. The different QoS profiles affect the network performance in distinctive ways. The results from the various simulations demonstrated the trade-offs in network performance when using different QoS profiles. The Sensor profile delivers messages as quickly as possible, with a minimal impact on latency. There was also significant overhead when security settings were turned on. Due to this overhead, we found that enabling ROS 2 security resulted in a higher message drop rate across all QoS profiles. We also found that scaling the network to more nodes resulted in various consequences with the use of different QoS settings. Scaling up to more nodes in a network also resulted in an equivalent increase in the average latency of messages. This work contributes to evaluating and configuring ROS 2 parameters for different unmanned system use cases while providing a simulation framework on which tests can be run.

The NPS research team members were Dr. Preetha Thulasiraman, Dr. Brian Bingham, Mr. Bruce Allen, LCDR Jose Fernandez USN, and Maj. Zhaolin Chen. This project generated two student theses[19] (*included in Appendix B*), and three publications (*included in Appendix A*) – one of which received Second place at IEEE SYSCON 2019 for the "Best Student Paper Award."[20] In addition, the project supported the NPS course *EC4770 Wireless Communications Security* as the research conducted in this project informed the discussion of UxS cyber security in this class.

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

19. Autonomous Systems Adoption Challenges and Requirements Management Solution (Van Bossuyt/Mesmer/Weger)

The research objective was to identify challenges concerning the adoption of autonomous systems in the DoD and acceptance of autonomous systems by warfighters using human factors and engineering approaches. The research is being undertaken in partnership with University of Alabama Huntsville (UAH) to take advantage of several unique capabilities the UAH Industrial & Systems Engineering and Engineering Management Department has which are not replicated at the Naval Postgraduate School (NPS). During AY19, the combined NPS and UAH team worked to provide a subcontract to UAH in order to initiate the work. This took 11 months to complete. The initial project kickoff meeting was held in December 2019 at Huntsville with the NPS PI, NPS project team, UAH PI, and UAH Co-I. Because of the delay in funds transferring to UAH, the UAH portion of the work is now underway and scheduled to be completed by June 2020. One benefit of the delay that was encountered is that the project team and CRUSER now have a better understanding of how to navigate the NPS external grant process. This will benefit future CRUSER projects to enable collaboration with other institutions when other institutions have specific capabilities not available at NPS. Upon successful completion of the research, actionable information for systems engineers in the requirements phase of the systems engineering (SE) process will be delivered in the form of a technical report and accompanying toolset. It is important to the DOD that the acquiring/constructing organization and the

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[19] J. Fernandez, "Quality of Service and Cybersecurity Communication Protocol Analysis for the Robot Operating System 2," MSEE, June 2019; Z. Chen, "Performance Analysis of ROS 2 Networks Using Variable Quality of Service and Security Constraints for Autonomous Systems," MSEE, September 2019.

[20] S. Sandoval and P. Thulasiraman, "Cyber Security Assessment of the Robot Operating System 2 for Aerial Networks," IEEE International Systems Conference (SYSCON), April 2019

warfighter accept autonomous systems because successful adoption of autonomous systems can make the warfighter more effective, reduce potential risks to the warfighter, and potentially reduce mission costs. While a warfighter may be ordered to use a specific autonomous system, it is desirable for the warfighter to want to use the system of their own accord. This work will gather evidence from questionnaires and interviews on the preferences and beliefs held by stakeholders pre- and post-autonomous systems adoption. The primary stakeholders of this study are DOD engineers, DOD contractor engineers, and warfighters that fall into the defense acquisition phases of "Engineering and Manufacturing" and "Production and Deployment". The evidence will be analyzed using qualitative content analysis and quantitative descriptive statistics to identify challenges to autonomy adoptions. Preliminary examinations will show how challenges in adoption could be explored using the evidence with systems and design engineering approaches of risk analysis, value modeling, game theory, and emergent system behaviors. Systems engineers will be able to use this information to better inform and manage requirements specific to adoption of autonomous systems.

This project was completed in affiliation with UAH faculty members Bryan Mesmer, Kristin Weger and several UAH graduate students. The NPS research team included Dr. Doug Van Bossuyt, Rob Semmens (NPS Systems Engineering Department) and NPS Systems Engineering student LT Ben Rathwell USN. This project work benefited NPS courses *SE4150 System Architecture* and *SE3302 System Suitability*.

POC: Dr. Douglas Van Bossuyt (douglas.vanbossuyt@nps.edu)

20. Air Superiority via Decentralized Swarming Tactics and Autonomous Pursuit (Yakimenko)

The recent advances in low-cost sUAS have enabled tremendous opportunities in a variety of missions. The current sUAS platforms have ultra-high definition video capability, moderate payload capacity, and beyond line of sight command and control capability in surprisingly small and affordable packages. However, with the low-cost yet capable aircraft platforms that are readily available worldwide, such systems have been utilized by hostile personnel in both foreign and domestic locations. The small size and rapid development capabilities present a particularly difficult challenge when attempting to counter such vehicles. One of the most important limitations of any ground-based system is that the small size of incoming sUAS results in a very low detection range, regardless of physical principle behind the detection paradigm. In order to circumvent this without spreading ground infrastructure outwards, one of the ideas is to have a forward-deployment capability so that a fleet of anti-sUAS drones could be deployed against the incoming multi-object threat to intercept it at far frontiers. As such, the goal of this research was to investigate different aspects of counter-UAS missions executed by a swarm of anti-UAS drones. This effort included design, building, testing, and evaluating an advanced UAS swarm capability to automatically detect, localize, block, split and pursuit multiple incoming threats.

The previous research efforts resulted in designing and building a fleet of small multi-rotor UAS based of 3DR Solo platforms enhanced with extra payload enabling network-based decentralized swarm control. Several DJI M100-based developmental platforms were built to evaluate visual detection and tracking algorithms. These platforms were used in this research effort to develop, test, verify, and demonstrate novel algorithms contributing to air superiority against the foe UAS swarm. This project involved students from several curriculums and intended to do several related feasibility studies on applicability of a variety of technologies that would be involved. That included developing counter-UAS mission architecture (from the systems engineering perspective), assessing capabilities of detecting sUAS using currently installed electro-optical (EO) as well as perspective acoustic sensors, developing group (swarm) tactics for the initial phase of engagement followed by one-on-one terminal engagement, developing a virtual environment to fully test the developed algorithms in computer simulations. Even though the currently available sUAS have a major endurance limitation precluding from using them even if all enabling technologies were developed, future research in the area of possible alternatives to the current lithium polymer batteries, might change it. Towards this end, one of the students was also looking at the hydrogen fuel cell batteries. Obviously, for swarms to truly achieve their full potential, control must be decentralized. This does not mean that there can be no interaction with a centralized controller, but each agent should be able to operate independently, at least to some degree, of any centralized control structure. In the terms of a two-loop control architecture it is a matter of minimizing the operators input to the outer-loop controller and relying on own state feedback data from other agents and results of sensing the operational environment. While a single ground control station may be used to control multiple UAS, it does not fully address the issue of scaling a multi-robot or swarm system. Specifically, to further increase scalability, this research looked at developing behavioral swarm primitives. Each primitive provides a slightly different swarm behavior that would allow an operator to adapt a swarm to the desired behavior by choosing an appropriate controller.

Figure 32. Twenty UAS in two groups with the goal of engaging each other.

In this research, a defending swarm employed an implicitly collaborating behavior, which assumed that all participants in the swarm were actively seeking to participate in the swarm, and all agents were acting and reacting in a similar way to themselves (which is different from swarms with competing agents). The challenge of coordinating a sUAS swarm to establish a communication network was tackled by using a mesh network allowing to expand the range of operations and exchange the larger data packets. We successfully collaborated with the Rajant Radio Corp. and were able to fly a swarm of 20 drones (*see Figure 32*). The developed technology has now been transferred to DARPA to be used in their OFFSET project. This hardware architecture allowed implementing advanced swarming behaviors (control laws).[21] Having a variety of the aforementioned primitive behaviors available to support multiple missions within the same cascaded architecture, the swarm will be able to pursue either the simple objectives like block, split, attack, disperse, surprise, and decoy, or more complex objectives, e.g. also dictating to maintain certain formation to assure the best delusion of precision in finding and tracking an enemy agent. In terms of an individual or group pursuit to destroy an evading enemy agent, this research explored a variety of strategies relied on the relative angle to the target being the only sensory information (which would come from onboard EO sensor). With such minimal information, the pure proportional navigation (PPN) would be the only choice. Several modifications of PPN, including two- and three-dimensional trajectory-shaping guidance algorithms, were developed and studied in this research.[22] They proved to be extremely computationally efficient technique for pursuing sUAS without the need for costly localization estimation thus making it possible to implement onboard of a sUAS in real time. Similarly, the evading algorithms were developed for the foe side. All developed algorithms were first tested in virtual simulations conducted in the Gazebo modeling environment. To this end, a full-fledge parameter identification problem for a 3DR Solo drone was posted and resolved by using fight data collected in the preliminary trials (Gazebo offers the ability to accurately and efficiently simulate populations of robots in complex outdoor environments). Several test campaigns were conducted to evaluate key elements of the developed techniques. That included assessment of the vision-based detection and tracking algorithm,[23] as well as effectiveness of the developed intercept guidance (*see Figure 33*). The follow-on project involves modification of the existing fleet of twenty drones and involvement of two other universities to come up with the best tactics for the counter-UAS missions, simulate them and then deploy and evaluate in the real flight tests.

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[21] Engebråten, S. A., Nummedal, O. R., Gilbreath, D., Yakimenko, O, and Glette, K., "UAV Swarm with Mesh Radios: Development Update," The 3rd International Symposium on Swarm Behavior and Bio-Inspired Robotics, Okinawa, Japan, Nov. 20-22, 2019.

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

[23] Ang, W.K., Teo, W.S., Yakimenko, O.A, "Enabling an EO-Sensor-Based Capability to Detect and Track Multiple Moving Threats Onboard sUAS Operating in Cluttered Environments," International Conference on Control and Robots, Jeju Island, Republic of Korea, Dec 12-14, 2019.

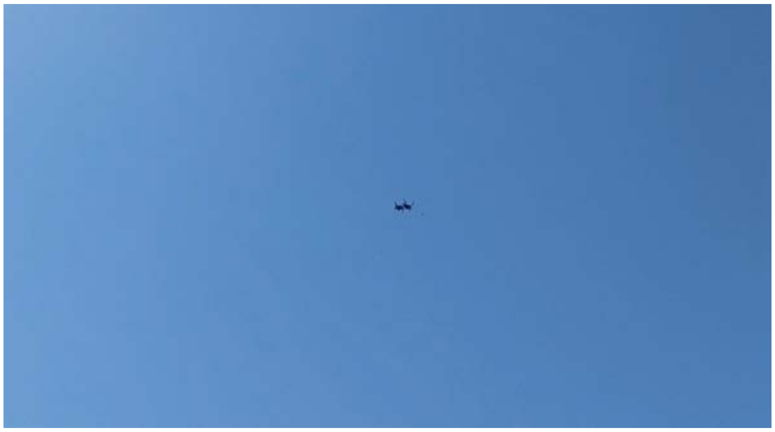

Figure 33. Blue UAS intercepts Red UAS in a suicidal mission.

This NPS research team included Oleg Yakimenko (NPS Systems Engineering), Anthony Pollman (NPS Systems Engineering), and Fabio Alves (NPS Physics) and was completed in affiliation with the University of Missouri–Kansas City, the University of Oslo, Rajant Corporation, the Norwegian Defence Research Establishment, and the National University of Singapore. This project benefited six NPS courses (SE3201, SE3202, SE3203, SE4354, ME4821, AE2440), generated four NPS Masters theses[24] (*included in Appendix B*), and resulted in three papers[25] (*included in Appendix A*). A three-state proposal was submitted for the Coalition Warfare Program as a follow-on to this work.

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:

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[24] Tan (SEP 2019), Chew (SEP 2019), Fleming (DEC 2019), and Laddusaw (DEC 2019)

[25] Engebråten et. al. (2019), Ghosh et. al. (2017), and Ang et. al. (2019)

- **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.

JIFX: The Joint Interagency Field Experimentation Program (JIFX) program exists to provide an opportunity for NPS faculty and students to demonstrate and evaluate new technologies related to the Department of the Navy and the Department of Defense research in an operational field environment. JIFX also provides a field experimentation resource for the Unified Combatant Commands (COCOMs) and other federal agencies. JIFX began in 2012 under the sponsorship of the Office of the Secretary of Defense and the Department of Homeland security.

JIFX events are held quarterly, normally at NPS facilities on the California National Guard's Camp Roberts. In addition, State, local and international emergency management, disaster response and humanitarian assistance organizations are most welcome to help create an innovative cooperative learning environment. Summaries and results of FY19 JIFX experimentation are reported separately, and Quick Look reports for each quarterly experimentation are posted on the JIFX website. [26]

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, 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 Curriculum Support

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

a. Campus Resources

Physics Autonomous Robotics Lab: in 2019 CRUSER supported the Naval Postgraduate School Physics Department to develop an advanced robotics program. Teams of two or three NPS students are tasked to enable their robot to perform autonomous tasks. Each robot was based on a tracked ground vehicle platform (*see Figure 34*). Computational command-and-control of the robot used a Field Programmable Gate Array (FPGA) robotic controller. The robotic controller interfaced through a wireless hub to communicate between each team's laptop. Each team was able to interface with their robot from distances of over 300 feet.

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

Figure 34. Student preparing robot for GPS tracking.

In addition to the controller, multiple sensors were provided to enable situational awareness to the robot. The sensors included Real-Time Kinetics GPS with centimeter positional accuracy (*see Figure 35*), LIDAR, sonar, video camera system with processor, encoders, accelerometer and IMU. In addition to the sensors a NERF ball pneumatic cannon was mounted onto each robotic chassis to enable the robot to both position and fire at a target.

Figure 35. GPS base station enabling RTK GPS with 1 cm precision.

Within this class students would program the autonomous capabilities using LabVIEW software. A series of eight labs introduced the students to integration of each of the listed sensors. In addition, the later labs introduced students into data fusion where information from multiple sensors can be combined to enable improved autonomous capabilities to the robotic system. At the end of the semester all of the students participate in a robotic competition. The robotic competition incorporates a field 120’ x 60’. During the competition students are timed to enable their robot to autonomously traverse through the obstacles within the course, ending up at a designated coordinate point. From the designated point the robot must scan for a target using the camera system (*see Figure 36*). Once the camera system has detected the target it will track on the target and range to the distance between the robot and target where the NERF gun trajectory will hit the target. The robot will autonomously fire the NERF ball into the target area when in range. The team that can complete the course in the shortest amount of time while enabling the NERF projectile to go into the target will be declared the winner. For each semester the top team will have all the team members placed on the robotic challenge plaque.

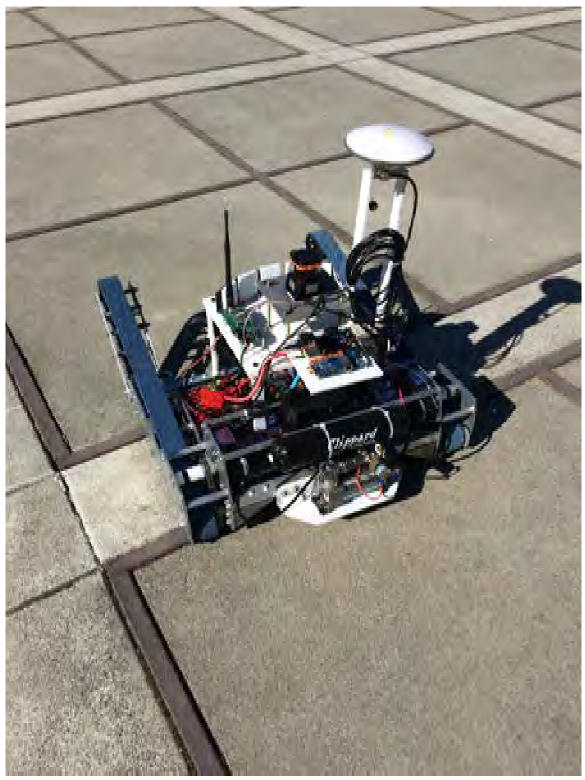

Figure 36. Image of robot outdoors implementing searching for an inputted GPS location.

The total cost to implement this effort was approximately $50 K. Funding was provided by both CRUSER and the NPS physics department. The cost covered all of the robotic components as well as support components including battery chargers, spare parts, additional batteries and additional components including air compressors and holding tanks for the NERF gun system and 3D printed hardware to mount the different sensors.

Students that take the Physics Department advanced robotics course learn a great deal about hardware/software integration as well as data fusion. The software capabilities are developed incrementally within each of the labs. Each lab incrementally introduces different sensors enabling students to learn both how they work as well as their limitations. Students then learn the interface between the sensors and the robot where a large selection of different interfaces including analog and digital input/output, pulse width modulation, serial communication and other communication protocols (SPI, I2C, UART and serial) enabling hardware sensors to interface to the robotic control system.

The Physics Department is very grateful to both the CRUSER program as well as the Office of Naval Research (ONR) for their financial support which this new robotic effort would not have happened without the support.

Figure 37. Students repairing combat robots built in the RoboDojo before an arena battle.

RoboDojo: the RoboDojo supports courses and curriculum on campus in three primary ways; 1) several courses use the RoboDojo for a classroom and/or lab space – these include Introduction to *Prototyping for the Warfighter (**DA4500**)*, *Computer Network Attack and Defense (**DA3104**), Defensive Cyberspace Operations (**CY4700**), Technology in Homeland Security (**IS4010**), Wargaming Applications (**OA4604**),* and a couple of courses for Systems Engineering; 2) Departments regularly include the RoboDojo on their new student orientation tours introducing the space as a valuable student resource – students in Modeling and Simulation, Undersea Warfare, and SFS curriculums are shown the RoboDojo during their new student orientation tour; 3) students in a variety of courses across campus are encouraged to use open lab hours in the RoboDojo for class projects (*see Figure 37*), thesis work, and to fabricate materials such as wargaming components (*see Figure 38*).

Figure 38. NPS students building prototypes in the RoboDojo.

b. Class Projects & Capstones

Systems Engineering Analysis (SEA): Guided 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 29 PROJECT: **"Logistics in Contested Environments"** Design a cost effective, deployable and resilient unmanned and manned system of systems employed to provide logistics in contested environments by near peer competitors in the 2030-2035 timeframe. Consider system delivery rates of dry stores, fuel, and ammunition at sea and to forward operating areas ashore; system vulnerability, survivability, and reliability; and costs. Where possible, include joint contributions in the systems of systems. Develop alternative architectures and their operational employment concepts. Investigate current commercially available lift and technologies for rapid acquisition as one alternative.

Consider both Pacific and Atlantic operating areas. **POC:** Professor Matt Boensel (mgboense@nps.edu)

c. Courses

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

Introduction to Scientific Programming (AE2440): The Introduction to Scientific Programming course offers an introduction to computer system operations and program development. The main goal of this course is to provide an overview of different structured programming techniques, along with introduction to MATLAB/Simulink and to use modeling as a tool for scientific and engineering applications. Among others the course teaches techniques for rapid prototyping of mission building / control development for unmanned vehicles. **POC:** Professor Oleg Yakimenko (oayakime@nps.edu)

Robotic Multibody Systems (AE4820): This course focuses on the analytical modeling, numerical simulations and laboratory experimentation of autonomous and human-in the loop motion and control of robotic multibody systems. Systems of one or more robotic manipulators that are fixed or mounted on a moving vehicle are treated. Applications are given for under-water, surface, ground, airborne, and space environments. The course reviews basic kinematics and dynamics of particles, rigid bodies, and multibody systems using classical and energy/variational methods. The mechanics and control of robotic manipulators mounted on fixed and moving bases are considered. The course laboratories focuses on analytical and numerical simulations as well as hands-on experimentation on hardware-in-the-loop. **POC:** Dr. Marcello Romano (mromano@nps.edu)

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

Introduction to Control Systems (ME2801): The Introduction to Control Systems presents classical analysis of feedback control systems of dynamic systems including unmanned vehicles using basic principles in the frequency domain and in the s-domain. Performance criteria in the time domain such as steady-state accuracy, transient response specifications, and in the frequency domain such as bandwidth and disturbance rejection are introduced. Simple design applications using root locus and Bode plot techniques are addressed. Laboratory experiments are designed to expose the students to testing and evaluating mathematical models of physical systems, using computer simulations and hardware implementations. **POC:** Dr. Brian Bingham (bsbingha@nps.edu)

Introduction to Unmanned Systems (ME3720): An Introduction to Unmanned Systems is an introductory graduate level course in robotics with an emphasis on learning through hands on projects. It provides an overview of unmanned aerial, surface and underwater systems technology and operations including guidance, navigation, control, sensors, filtering and mapping. All three class projects currently use a small dual water jet USV as the demonstration robot. Each project is broken down into simulation and operation sections. The first project involves the implementation of a Proportional, Integral and Derivative heading controller. The second project goal is to design and implement a cross track error controller. The final project involves real-time path planning and path following through a dynamically changing environment. Course work includes programming the robot in Python. **POC:** Dr. Douglas Horner (dphorner@nps.edu)

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

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 Verification and Validation (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 and Product Development (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. CRUSER Seminars

In 2019 CRUSER continued to present CRUSER Seminars, formerly CRUSER Colloquiums, on the NPS campus for the community of interest. 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 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)

On Tuesday 16 April 2019, Dr. William Bundy, the Associate Provost for Warfighting Research and Development at the U.S. Naval War College in Newport, Rhode Island, and the Director of

VADM Samuel L. Gravely, Jr. Naval Warfare Research Group, presented his seminar – *The Fourth Age of Technological; Evolution: Smart Weapons, Controllers and Processors Delivered by AMAZON* – for the CRUSER community.

> *Abstract:* Byron Reese offers a description of our entry into the Fourth Age of Technological Evolution. That social evolution is driven by the increasing adoption of smart robots, "thinking" computers and a society that has come to depend on and demand ever improving technologies. The accelerating adoption of technology is causing multiple revolutions in social, business and military affairs. According to Reese, "Technology has changed the face of warfare dozens of times in the past few thousand years…Robots and AI will change it again".
>
> In our seminar, we ask ourselves how will the defense establishment deliver sensors, control systems and weapons that are evolving on an accelerating basis. How will warfighters keep pace with "smarter – thinking" systems that communicate in natural language and hold deeper knowledge sets than human operators. Rather than years of development and testing, evolving systems and components are delivered to warfighters in "Amazon" speed, inserted in standard slots and launchers with "quick start" instructions, intuitive controls and natural language operation. Imagine receiving your new fire control processor in a box with a link to online installation instructions. Impossible. Well, we adopted online banking without formal training and operate smarter cars with voice commands. Imagine commanding ship or fleet operations from a command center where battle management displays, video images and decision makers are informed by augmented reality and recommendations provided by – OSCAR, the voice of the battle management system. We'll explore the art of the possible with a view toward warfare in the Fourth Age.
>
> *Biography:* Dr. Bundy served in the Navy for more than 30 years prior to returning to the Naval War College as a Center for Naval Warfare Studies (CNWS) faculty member. He has led warfighting concept development and advanced research projects that have been deployed in the Fleet and the Joint Force. Dr. Bundy created the initial concept of operations for Navy Ballistic Missile Defense, warfighting concepts for the Ohio Class Guided Missile Submarine and recently contributed to introduction of Distributed Lethality in the Navy. He has mentored more than 330 war college graduate research students. Dr. Bundy passed away in December 2019 and will be missed by the entire community.

On Thursday 10 October 2019 CRUSER presented a seminar by LCDR Arthur Anderson, USN where he discussed maritime projects related to Unmanned Vehicle Autonomy, Artificial Intelligence and Machine Learning (AI/ML), and Space Systems work related to Naval Sea Systems Command (NAVSEA) Engineering Directorate initiatives like the Autonomy Integration Lab (AIL) as well as Defense Innovation Unit (DIU) collaboration efforts.

Abstract: With the purchase of XLUUV from Boeing, we also purchased an autonomy software system that will control how the vehicle perceives its world and makes decisions. The problem with this is that what we will get from Boeing is a proprietary black box that we have little insight in to. Testing, evaluation, and ultimately certification of the autonomous system by a government authority will prove difficult. Solutions like this for all the unmanned vehicles across the Unmanned Program Office's (PMS 406's) portfolio is going to prove to be costly and ineffective.

The solution consists of multiple steps. The first is contractually enforcing a set of standards known as the Unmanned Maritime Autonomy Architecture (UMAA), which forces developers to split their solutions into smaller, manageable pieces (called services) that speak a common language, and then to enforce government purpose rights on those services so that they can be re-used as much as possible across the multitude unmanned vehicles being procured. The standards writing and compliance documents for UMAA is expected to be completed by the end of FY20.

In mid-October of '20, PMS 406 (CAPT Small) is pitching to PEO USC (RDML Moton) that we need a new approach to autonomy. The proposal includes the creation of an Autonomy Integration Lab (AIL) to be run by a newly proposed Autonomy Program Office. The AIL would be funded in FY21 first by taxing each of the unmanned programs in 406, and then in FY22 by its own line of funding that is being planned for now in the POM process.

The purpose of the AIL isn't to be a developer of new services, but rather to be an integrator of them. The AIL will acquire those services from third party autonomy software developers such as industry, UARCs, and Warfare Centers, and provide a rapid, automated pipeline so that those services can be rigorously tested for functionality and security and deployed on the vehicles. This process for updating software, including testing and deployment will be done in cooperation with autonomy vendors on a time scale of minutes and hours, using modern DevOps software practices used in industry today, unlike the months and years we experience with the Navy's traditional software development practices.

In this seminar, the presenter shared what an autonomy system looks like, how UMAA fits in and why it is important, what the Rapid Refresh process is and why it lends itself to the creation of an Autonomy integration Lab, and finally the current ongoing discussion about a 406 proposal to create an Autonomy Program Office.

Biography: LCDR Arthur Anderson, a native of Chadds Ford, Pennsylvania, began his Navy career as a midshipman at the Pennsylvania State University Navy ROTC program in 2002. In June of 2006, he completed his degree, receiving a B.S. in Engineering Science and Mechanics. Upon graduation, he attended graduate school to study Islamic and Middle Eastern Studies at the Hebrew University of Jerusalem in Israel as a part of the Anna Sobol Levy Fellowship Program. In October 2007, LCDR Anderson received his commission as a Surface Warfare Officer and reported to the USS LASSEN (DDG 82), based out of Yokosuka, Japan, where he served as the Electrical Officer and First Lieutenant. During his time there he conducted multiple major exercises with the Japanese and South Korean Navies, and operations throughout the Western Pacific.

In May 2010, he began his graduate education at the Massachusetts Institute of Technology (MIT) where he earned an Engineer's degree in Naval Construction and Engineering, and also his M.S. and PhD in Mechanical Engineering, with concentrations in marine vehicle autonomy and acoustics, graduating in June 2015. He followed MIT by attending the Joint Diving Officer and Mixed Gas Courses at the Naval Dive and Salvage Training Center, graduating in November 2015, and then served as a project officer at the Southwest Regional Maintenance Center (SWRMC) through July 2018. He is currently working at the Naval Sea Systems Command (NAVSEA) Engineering Directorate, Technology Office (05T), where he works on projects related to Unmanned Vehicle Autonomy, Artificial Intelligence and Machine Learning (AI/ML), and Space Systems. He is currently TDY on a 4-month assignment to the Defense Innovation Unit (DIU).

LCDR Anderson is entitled to wear the Navy and Marine Corps Achievement Medal, Battle Efficiency "E" Ribbon, National Defense Service Medal, Global War on Terrorism Service Medal, the Korean Defense Service Medal, the Sea Service Deployment Ribbon (two awards), the Navy and Marine Corps Overseas Service Ribbon (two awards), and the Navy Expert Rifle and Pistol Shot Awards.

3. 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 FY19 (2018 DEC, 2019 MAR, 2019 JUN, and 2019 SEP) as well as those mentored at the start of FY20 (DEC2019) as the period of performance for this report ends with the calendar year.

Table 2. FY19 CRUSER mentored NPS student theses and dissertations (*reverse chronological by date*)

AUTHOR(s) [advisor(s)]	TITLE	DATE (year-mo)	URL
LT Ash Mielke USN	*Using Deep Convolutional Neural Networks to Classify Littoral Areas With 3-Band And 5-Band Imagery*	*Anticipated 2020 DEC*	
A.G. Fleming	*Feasibility of Detecting and Classifying Small Unmanned Aerial System Threats*	2019 DEC	Pending processing

	Using Acoustic Data		
LT J.A. Laddusaw USN [Yakimenko/Pollman]	*Combining a Proton Exchange Membrane Fuel Cell and Ultracapacitors to Replace Batteries and Extend Flight Time for a Vertical Take-Off Unmanned Aerial System (UAS)*	2019 DEC	*http://hdl.handle.net/10945/64000*
LT Kehinde A. Adesanya USN and LCDR Santhosh K. Shivashankar USN [MacKinnon/Gallup]	Trust and Understandability in Autonomous and Unmanned Surface Vehicles	2019 SEP	*http://hdl.handle.net/10945/63429*
Major Zhaolin Chen, Republic of Singapore Air Force [Thulasiraman/Bingham]	*Performance Analysis of ROS 2 Networks Using Variable Quality of Service and Security Constraints for Autonomous Systems (MSSE)*	2019 SEP	*http://hdl.handle.net/10945/63441*
Captain Jian Ming Chew, Republic of Singapore Army [Yakimenko/Papoulias]	*Assessment of Mesh-Network Performance for Small Aerial Drones in Urban Environment*	2019 SEP	*http://hdl.handle.net/10945/63442*
Maj Ryan P. Keller USMC [Horner/Monaco]	*Observational Oversight for Understanding Trust in Interactive Human and AI Systems*	2019 SEP	*http://hdl.handle.net/10945/63466*
Maj. Jarrod P. Larson USMC	*Deriving DRFM False Target Coefficients from Experimental Tests (reference title)*	*2019 SEP*	*Restricted access*
Capt Caliph Lebrun USMC [Yun/Calusdian]	*Vision-Based Terrain Classification and Learning to Improve Autonomous Ground Vehicle Navigation in Outdoor Environments*	2019 SEP	*http://hdl.handle.net/10945/63474*
Capt Alexander S. Miyakawa USMC [Yun/Calusdian]	*Autonomous Ground Vehicle Low-Profile Obstacle Avoidance Using 2D LIDAR*	2019 SEP	*http://hdl.handle.net/10945/63486*
Hugh W. Pollard	*Improving Close Air Support Missions with the Use of Machine Learning Decision Aids*	2019 SEP	*Controlled access*
LT Joshua Sale USN [Bingham/Kaminer]	*Precise Localization to Support Autonomous Ship-Scale Operations*	2019 SEP	*http://hdl.handle.net/10945/63501*

LT Richard Schroyer USN	*FM Pulsed Imaging Radar Manipulation Using FPGAS*	*2019 SEP*	*Controlled access*
Maj James E. Streams Jr. USMC [Appleget/Alt]	*Utilizing Adaptive Design of Experiments with Logistics Battle Command to Determine the Most Important Factors for a Decision Maker*	2019 SEP	*http://hdl.handle.net/10945/63507*
Major Kang Hao Tan, Republic of Singapore Air Force [Yakimenko/Papoulias]	*Vision-Based Relative Position Estimation and Intercept Trajectory Planning for Small Unmanned Aircraft Systems*	SEP 2019	*http://hdl.handle.net/10945/63509*
Ryan M. Ackland and James Husted	*Using Machine Learning to Detect Anomalous Transactions in Large Datasets*	2019 JUN	*Controlled access*
Maj Brandon Bowman USMC [Norton/Alt]	*Anomaly Detection Using a Variational Autoencoder Neural Network with a Novel Objective Function and Gaussian Mixture Model Selection Technique*	2019 JUN	*http://hdl.handle.net/10945/62853*
LT Britt J. Campbell USN [Davis/Giles]	*Autonomous Cueing Within Heterogeneous Robot Swarms*	2019 JUN	*http://hdl.handle.net/10945/62758*
LCDR Beverly Crawford and LT Inna Stukova [Bordetsky/Mullins]	*Short-Term Self-Moving Tactical Networks in Austere Environments*	2019 JUN	*http://hdl.handle.net/10945/62794*
LCDR Jose Fernandez USN [Thulasiraman/Bingham]	*Quality of Service and Cybersecurity Communication Protocol Analysis for The Robot Operating System 2 (MSSE)*	2019 JUN	*http://hdl.handle.net/10945/62809*
LT Joseph Gilley USN [Newman/Minelli]	*Reconstruction of Satellite Decryption and Data Handling Processes*	2019 JUN	*http://hdl.handle.net/10945/62698*
Lieutenant Dimitrios Kanavaros, Hellenic Navy [Cristi/Calusdian]	*Implementation of Active and Reactive Power Flow Control in a Single Phase Microgrid*	2019 JUN	*http://hdl.handle.net/10945/62816*
Capt John O. Mutton USMC [Singh/Alves]	*Acoustic Ground Sensors to Triangulate Bomb Impact in Support of Airfield Damage Assessment*	2019 JUN	*http://hdl.handle.net/10945/62813*
LT Steven Seda USN [Smith/Deal NUWC NPT]	*Evaluation of Ship Noise Levels Using a Single Vector Sensor on a Bottom-Mounted System*	2019 JUN	*http://hdl.handle.net/10945/62762*
Maj Christopher A.	*Artificial Intelligence (AI) Strategy and*	2019 JUN	*http://hdl.handle.net/10945/62806*

Rodney USMC and Capt Yusef Akbarut USMC [Boger/Miller]	*Design for Marine Corps Intelligence*		
Systems Engineering Analysis Cohort 28 [Atkinson/Beery]	*Seabed Infrastructure Defense Analysis*	2019 JUN	http://hdl.handle.net/10945/62767
Maj Nicholas L. Lee USMC [Koyak/Alt]	*Utilization of Machine Learning Techniques to Detect Anomalies in Department of Defense Contract Data*	2019 MAR	http://hdl.handle.net/10945/62268
LT Tai-shan Lin USN [MacKinnon/Sanchez]	*Unmanned Surface Logistics Concept of Support*	2019 MAR	http://hdl.handle.net/10945/62270
John T. Martin	*Optimizing Employment of the Autonomous Surface Vessel Sea Hunter*	2019 MAR	*Controlled access*
LT Aaron M. Stalford USN [Dobrokhodov/Bingham]	*Autonomous Agents Utilizing Passive Optical Sensing for Control*	2019 MAR	http://hdl.handle.net/10945/62299
Curtis Blais	*Rich Semantic Track (RST) Ontology: Unified Semantics and Pragmatics for Track Data Interchange (Doctorate Dissertation)*	2018 OCT	
Major Sergio Sandoval USMC [Thulasiraman/Tummala]	*Cyber Security Testing Of The Robot Operating System In Unmanned Aerial Systems*	2018 SEP	http://hdl.handle.net/10945/60458
LT Devon Cobbs USN	*Influence of Command and Control Thresholds on Campaign Outcomes Utilizing the Synthetic Theater Operations Research Model*	*2019*	*Restricted access*
MAJ Justin Murphy USMC	*Proof Of Concept Into Bursty/Short-Living Tactical Communication Networks Interconnected By Aerial Biological Nodes (Birds)*	*2019*	*Controlled access*

CRUSER dedicated just over $96k to support 55 NPS student travel activities in FY19 and the start of FY20 to further 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 travel was funded out of individual project funds.

Table 3. CRUSER supported student travel, FY19 (*in chronological order*)

STUDENT	DESTINATION	DPT DATE	PURPOSE

Capt Michael Franco USMC	Indianapolis IN	6 NOV 2018	Observing Army platoon attacks using UGS/UAS at Muscatatuck Training Center
Capt Steven Spada USMC	Indianapolis IN	6 NOV 2018	Observing Army platoon attacks using UGS/UAS at Muscatatuck Training Center
CAPT Ian Carter USMC	Quantico VA	26 NOV 2018	Attending the 2018 Naval Additive Manufacturing Tech Interchange (NAMTI) conference
LT Benjamin Carpenter USN	Keyport WA	6 DEC 2018	Thesis research experiment
Maj Jeffrey D. Parker USMC	SWEDEN	6 DEC 2018	2018 Winter Simulation Conference Session Chair
LCDR Santhosh Shivashankar USN	Honolulu HI	8 DEC 2018	Participation as a RobotX competition judge
MAJ Jay Parsons US Army	Lillestrom and Harstadt NORWAY	26 JAN 2019	Evaluate resilient self-moving maritime-land mesh networks capabilities for austere Arctic environment during the NORSOF Arctic Challenge
LT Jason Cash USN	Sandestin FL	27 JAN 2019	Attend the ONR Unmanned Maritime Science and Technology (UMST) program review
LCDR Beverly Crawford USN	Camp Roberts CA	4 FEB 2019	Participate in JIFX for CENETIX experiments
LT Inna Stukova USN	Camp Roberts CA	4 FEB 2019	Participate in JIFX for CENETIX experiments
LT Austin Fleming USN	San Diego CA	10 FEB 2019	Attend SPAWAR NAML Conference
LCDR Adam Humphrey USN	San Diego CA	13 FEB 2019	UAS insider threat research at SRT-1, SPAWAR, NSW Mission Support Command

Capt Michael Cybulski USMC	Camp Pendleton CA	14 MAR 2019	Observing a I Marine Expeditionary Force (I MEF) training exercise for thesis research
Capt Edward Yarbro USMC	Camp Pendleton CA	19 MAR 2019	Observing a I Marine Expeditionary Force (I MEF) training exercise for thesis research
LT Tricia Nguyen USN	San Diego CA	22 MAR 2019	Research on possibility of microbial fuel cells augmenting autonomous systems' life spans.
LT Inna Stukova USN	Beersheba ISRAEL	4 APR 2019	Thesis research collaboration with Ben-Gurion University's Autonomous Robotics Laboratory Intelligent Vehicle Operator (IVO) project.
LCDR Beverly Crawford USN	Beersheba ISRAEL	11 APR 2019	Thesis research collaboration with Ben-Gurion University's Autonomous Robotics Laboratory Intelligent Vehicle Operator (IVO) project.
Maj Justin Murphy USMC	Colorado Springs, CO	14 APR 2019	Conduct final thesis experiments with USAFA live falcons
MAJ Kang Hao Tan, Singapore AF	Camp Roberts CA	30 APR 2019	Testing computer vision algorithms during drone flight for thesis research.
Maj Jeffrey Parker Jr USMC	Memphis TN	18 MAY 2019	2019 International Conference on Design of Experiments (ICODOE) Presentation
Capt Alex Preston USMC	Camp Pendleton CA	14 JUN 2019	Attendance of unmanned aerial logistics demonstrations with NEXLOG.
LT Tricia Nguyen USN	San Diego CA	17 JUN 2019	Research on possibility of microbial fuel cells augmenting

			autonomous systems' life spans.
LT Bryan Lowry USN	Newport RI	15 JUL 2019	Undersea Warfare Artificial Intelligence Workshop and initial wargames
CDR Henry Bush USN	Camp Roberts CA	30 JUL 2019	Observation of mobile network device testing
LT Eva Castillo USN	Camp Roberts CA	30 JUL 2019	Observation of mobile network device testing
Capt Alex Preston USMC	Camp Roberts CA	7 AUG 2019	Observe and plan air operations for Elroy Air UAS.
MAJ Jian Ming Chew, Singapore AF	Camp Roberts CA	14 AUG 2019	Conduct field testing for thesis research in COTS quadrotor UAV
MAJ Kang Hao Tan, Singapore AF	Camp Roberts CA	14 AUG 2019	Conduct field testing for thesis research in COTS quadrotor UAV
Maj Matthew Parsons USMC	Pentagon City VA	19 AUG 2019	Counter UAS Conference USA, for thesis data collection
LT Megan Silvester USN	Pentagon City VA	19 AUG 2019	Gather Counter UAS topics from senior reps at Conference USA, for thesis research
Capt Haley Nowak USMC	Cedar Park TX	21 AUG 2019	Sharing information for subsurface to orbital communications experiment during DREAM Payload Initial Planning Conference at Firefly Aerospace HQ
Capt Jeremy Barton USMC	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
MAJ Asaf Berger, Israeli AF	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
ENS Andrew Borgdorff USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LT Edward Crapino USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine

LT Ryan Dishman USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
1st Lt Leonard Dunovant USMC	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LCDR Colin Dyer USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
Capt Casey Escamilla USMC	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
ENS Owen Esposito USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
Maj Benjamin Gardner USMC	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
Capt Brandon Hee USMC	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LT Matthew Henricks USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LT Joseph Jablonski USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LT Daniel Reuter USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LT Richard Rodriguez USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
Maj Aaron Rosenblatt USMC	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LT Xisen Tian USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
LTJG Kristin Vanboxtel USN	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
Capt Eric Wikman USMC	Brooklyn Naval Yard	5 SEP 2019	Participate in Hack the Machine
Capt Alex Preston USMC	San Francisco CA	13 SEP 2019	Planning session with Elroy Air on UAS.
LT Andreina Rascon USN	San Diego CA	16 SEP 2019	Conducting experiments with NIWC Pacific on the feasibility of using actively lit fiducial markers on ROVs and UUVs for underwater localization/navigation

LT Tricia Nguyen USN	San Diego CA	19 SEP 2019	Research on possibility of microbial fuel cells augmenting autonomous systems' life spans.
LT Meagan Way USN	London UNITED KINGDOM	28 SEP 2019	Gather research on counter-UAS technologies from other countries, such as NATO, UK, AUS, and France
Maj Brandon Davis USMC	Camp Roberts CA	5 NOV 2019	Conduct experimental research at JIFX event.

D. CONCEPT GENERATION

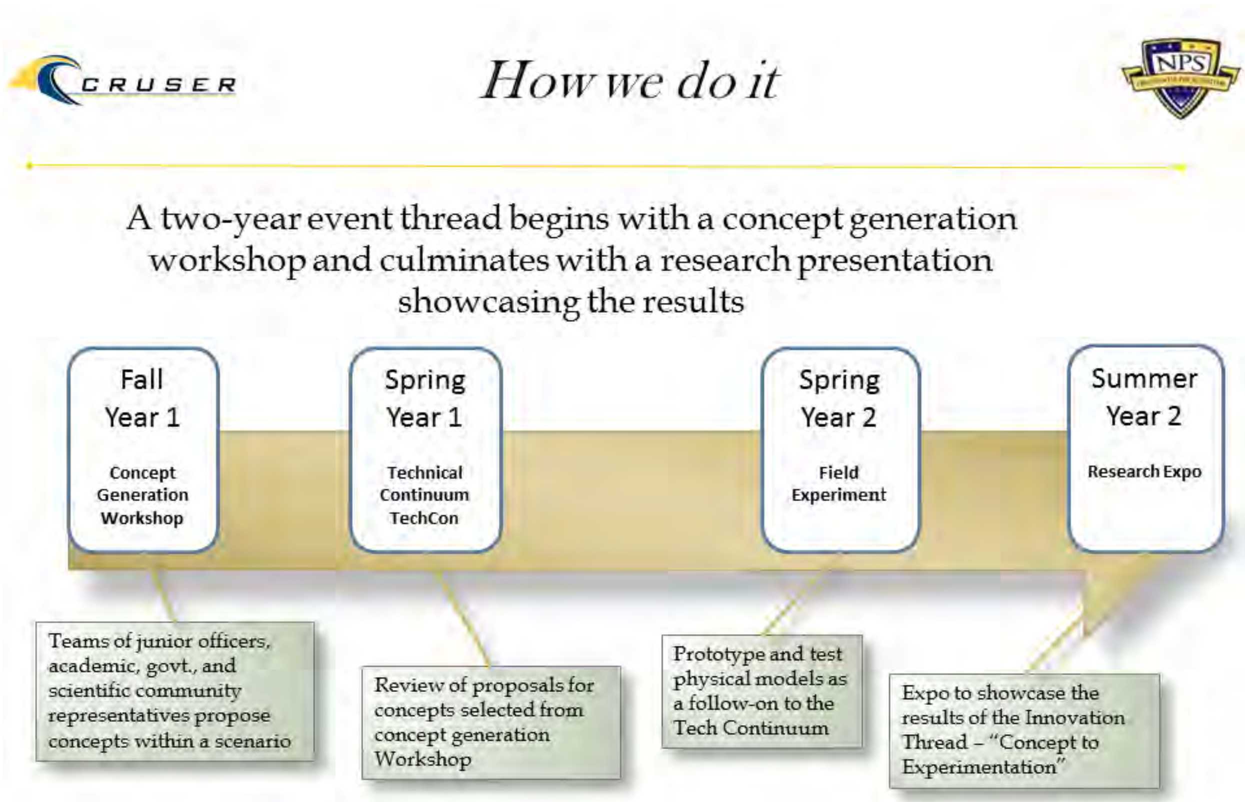

Figure 39. CRUSER innovation thread structure.

The CRUSER concept generation work initiates each new programmatic innovation thread (*see Figure 39*) and at the time of this 2019 annual report we have just launched our ninth innovation thread, *Logistics in Contested Environments*. The first NPS Innovation Seminar supported the CNO sponsored *Leveraging the Undersea Environment* wargame in February 2009. Since that time, rapid concept generation 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 2019

The first CRUSER sponsored rapid concept generation workshop was in March 2011, shortly after the formal launch of the Consortium. Since that time CRUSER has sponsored twelve 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
12) Logistics in Contested Environments, September 2019

Our most recent workshop, *Logistics in Contested Environments*, was held 23-26 September 2019 on the NPS campus. This workshop included nearly 130 participants representing a wide variety of stakeholder groups.

The September 2019 workshop "Logistics in Contested Environments" (*see Figure 40*) tasked participants to apply emerging technologies to shape the way we fight. Within a near future extended conflict scenario, concept generation teams were given a design challenge: How might emerging technologies be employed to support logistics in contested environments to accomplish missions more effectively and/or with less risk? With embedded facilitators, teams had three days to meet that challenge, and presented their best concepts on the final morning of the workshop.

This September 2019 WIC workshop included 130 registered participants in the roles of team members, presenters, mentors, and observers – the full participant pool included representatives from 45 different organizations. Half of the workshop participants were NPS students drawn from curricula across the NPS campus. For this workshop, the final roster also included participants from The Johns Hopkins University Applied Physics Lab (JHU/APL), the Naval War College (NWC), Draper Labs, and Lockheed Martin. Fleet commands included Naval Air Systems Command (NAVAIR), Naval Undersea Warfare Center (NUWC) Newport, several Naval Surface Warfare Centers (NSWC), U.S. Fleet Forces (USFF), the Office of the Chief of Naval Operations (OPNAV), and the Office of Naval Research (ONR). The Royal Australian Navy (RAN) and the New Zealand Defence Force also sent representatives.

Figure 40. September 2019 Warfare Innovation Continuum (WIC) Workshop, "Logistics in Contested Environments."

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 robotic and autonomous 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 leadership reviewed all the proposed concepts and selected ideas with potential operational merit that aligned with available resources for further research and development. All concepts are described fully in this report, but in summary these concepts include:

- **Assured Comms and Navigation:** cross-domain system of assets that requires ad hoc network for comms and navigation
- **Business Use Case:** organizational solutions that may require cost-benefit analysis, policy revision or development, or other business process
- **Ship-to-Shore Delivery:** concepts that aide the delivery of supplies from ship to shore
- **Undersea Infrastructure:** development of the undersea infrastructure to support logistics
- **Concept Development:** logistics support concepts in process that may warrant modification and further development

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 FY21 Call for Proposals. NPS students participating in *Directed Study for the Warfighter (ME4901* or *IS4800*) will have the opportunity to prototype and test concepts of interest. and technical members of the CRUSER community may present proposals at a future technical continuum gathering such as TechCon 2020. A final workshop report is posted on the CRUSER website (cruser.nps.edu).[27]

[27] A summary and full report are both downloadable from the CRUSER website at https://my.nps.edu/web/cruser/workshop

2. Technology Continuum (TechCon) 2019

Figure 41. CRUSER Technical Continuum (TechCon), April 2019.

NPS CRUSER held its eighth annual Technical Continuum (TechCon) on 17 April 2019 (*see Figure 41*) in the NPS Mechanical Engineering Auditorium. CRUSER's annual NPS TechCon provides the greater CRUSER Community of Interest an opportunity to gather and explore research topics of mutual interest. Responding to SECNAV direction, TechCon 2019 focused specifically on how NPS researchers might work more successfully with industry. Highlights from the panel discussions included:

- Innovation benefits from having a space and place for building partnerships.
- Competition and collaboration are both necessary to move forward.
- Laws and regulations can be an impediment but need good faith to work through the challenges.
- There is “magic” in having a short space between NPS student work and putting innovation into practice.
- It is important to understand ecosystem for innovation – identify your innovation hub

- There is not one-size-fits-all agreement – each arrangement takes time and energy in order to be effective.

- For small businesses, a rapid on-ramp with small (~$300k) investments would be a great way to engage more new concepts more rapidly.

With 40 resident and 20 remote participants, 17 panelists and three moderators, CRUSER TechCon 2020 included about 20 representatives from industry, 20 NPS faculty members and about 15 NPS students. An event report is posted on the CRUSER website (cruser.nps.edu).[28]

3. Rapid Prototyping in the RoboDojo

The RoboDojo is the NPS community maker lab for learning about robotics and electronics. The RoboDojo lab offers tools, equipment, hands-on workshops, competitions, and user groups around rapid prototyping and emerging technologies. All NPS departments are using the lab for class work, thesis projects, and emerging technologies/rapid fabrication exploration. Five courses used the RoboDojo for some if not all of their class meetings, eighteen tours were provided to a range of visitors from JROTC to Congressman Jimmy Panetta's team, and one government consortium used the lab to teach a portion of its Small Satellite University classes where participants experimented with technologies supporting small satellite prototyping and fabrication.

There is always something new to learn in the RoboDojo. Indeed, this past year, the RoboDojo hosted 135 hands-on learning workshops, and most workshops are led by faculty, staff, or student volunteers. Some workshop leaders are even Navy reservists, DIU or SOFWERX experts, or knowledgeable guides from the local Monterey community. The RoboDojo holds workshops based on the interests of the NPS user community, and these interests change according to current campus population. RoboDojo users have experimented with FPV drone flying with Inductrix drones, built their own racing drones, and flown their drones at Impossible City in Ft. Ord (*see Figure 42 top row*).

[28] The CRUSER TechCon 2019 report is available for download on the CRUSER website at https://my.nps.edu/web/cruser/techcon

Figure 42. Assembling racing drones (*top left*), learning to fly Inductrix FPV drones (*top center*), racing drones at Impossible City (*top right*), Intro to Arduino workshop (*bottom left*), GNU Bash session (*bottom center*), microcontroller explorations (*bottom right*).

Figure 43. 3D printing (*top left*), circuit board printing (*top center*), laser cutting and engraving (*top right*). Cyber Capture the Flag meetings (*bottom left*), Combat Robot informational session (*bottom center*), and Combat Robots during Discover NPS Day (*bottom right*),

Users have explored computing opportunities by learning programming, delving into GNU Bash (*see Figure 43 bottom center*), experimenting with Raspberry Pis, and joining the NPS Cyber

Capture the Flag team. They have even made their own custom games for legacy Nintendo Entertainment Systems. Users have fabricated their projects with our laser cutter/engraver (*see Figure 44 top right*), CNC, 3D printers (*see Figure 44 top left*), and many other tools. In the spirit of friendly competition, lab users have competed in Ant Weight Combat Robot competitions and have explored Cyber Capture the Flag competitions (*see Figure 43 bottom row*).

Figure 44. NPS Cyber Club and Makers Club activities in the RoboDojo: sewable circuits (*left*), 3D modeling and 3D printing with resins (*center*), and a ham radio session (*right*).

The NPS Foundation-funded Cyber Club and Makers Club often choose to meet in the RoboDojo as the lab is open to all users on campus and is not tied to just one curriculum (*see Figure 44*). We also request that other campus labs hold lunchtime tours in order to allow our community to explore other academic disciplines and endeavors (*see Figure 45 top row*). We strive to stay involved in our local STEM and Maker community. During our volunteer time, we are members of the Monterey Bay Aquarium-based Maker Meetup, support local youth STEM initiatives, and have reached out to junior sailors at DLI (*see Figure 45 bottom row*).

Figure 45. STEM outreach activities: visit to ScanEagle in NPS CAVR Lab (*top left*), visit to NPS Metal 3D printing lab (*top center*), visit to NPS MOVES modeling and simulation lab (*top right*), visit with Defense Language Institute BOSS Program (*bottom left*), Boy Scouts merit badge activity (*bottom center*), and Lyceum of Monterey *Expanding Your Horizons* Conference and Career Fair for Girls (*bottom right*)

At the end of 2019 the RoboDojo began establishing the new RoboDojo Shop (*see Figure 46*). This space will house all of the lab's milling and safety-related equipment. Once all safety protocols and procedures are completely vetted, the new RoboDojo Shop will be open to campus. This coming year, our goals are to open our new Shop to the campus, to work with the new Innovation curriculum being developed on campus, and to further develop our teaching materials so that lab users may explore our lab and equipment even if they can't attend our workshops.

Figure 46. New shop: French Cleat installation (*left*), tools and drawers (*center*), and French Cleat utilization and air filtration (*right*)

POC: email Kristen at ktsolis@nps.edu.

E. OUTREACH AND RELATIONSHIPS

1. Community of Interest

CRUSER's membership remained steady throughout 2019. At the end of FY11, CRUSER's first program year, the CRUSER community of interest had grown to include almost 400 members. 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. FY15 brought the community over the 2,000-member mark, and CRUSER membership reached 3,000 members just after March 2016 (*see Figure 47*) and has remained at that level since.

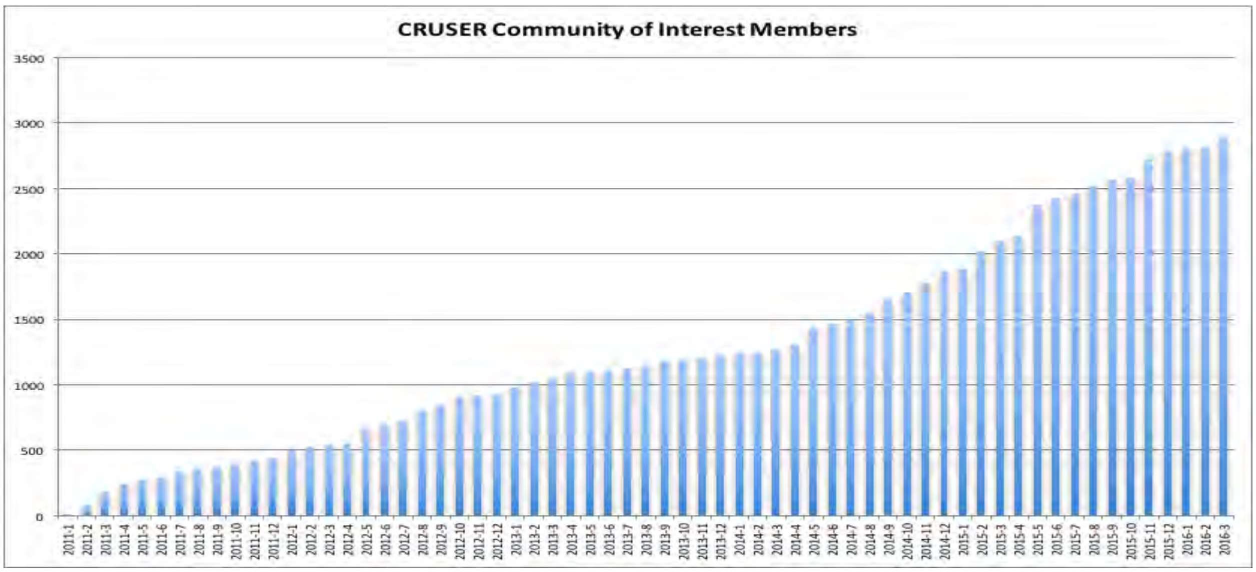

Figure 47. CRUSER community of interest growth from January 2011 to March 2016.

Beyond NPS campus members, the CRUSER community of interest (CoI) includes stakeholders from across the DoD, industry and academia (*see Figure 48*) with industry members making up the most significant stakeholder group.

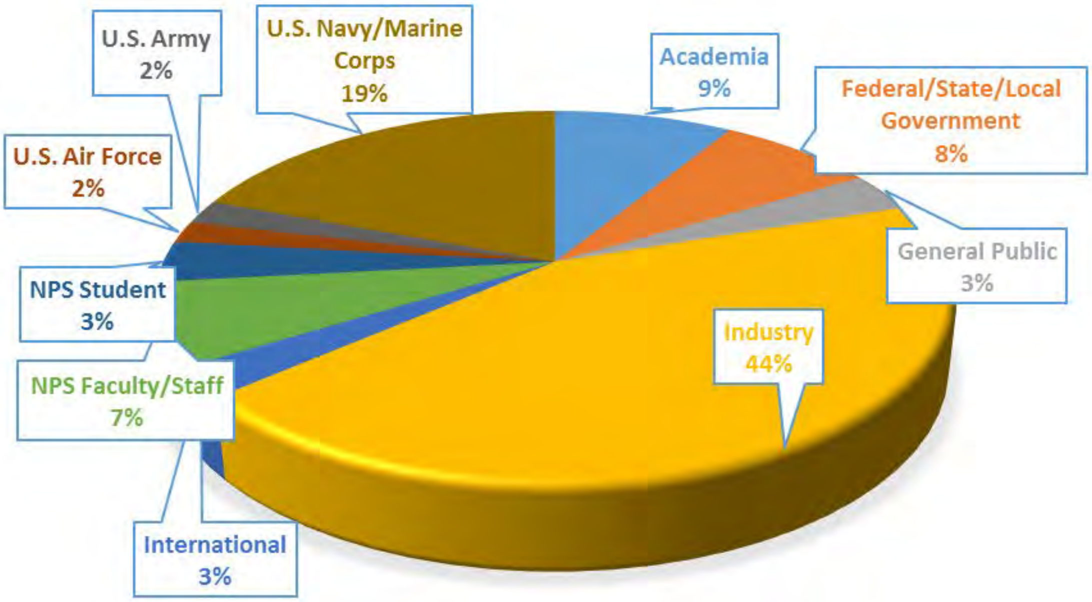

Figure 48. CRUSER community of interest breadth of membership as of 31 December 2018.

In 2019 CRUSER migrated the CoI database to meet new compliance requirements and have not yet recovered full functionality to produce updated data analysis. However, there is no reason to believe that the percentages in each stakeholder group have changed in a statistically significant way.

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 Zoom meeting.[29] 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

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[29] **Join via Web: https://zoom.us/j/789288103**
Join via Zoom App on your mobile device:
+16699006833,,789288103# US (San Jose)
+14086380968,,789288103# US (San Jose)
Dial by your location
+1 669 900 6833 US (San Jose)
+1 408 638 0968 US (San Jose)
+1 646 876 9923 US (New York)

Find your local number: https://zoom.us/u/advoTyGPRt

the non-resident CRUSER community that has a significant topic to share. From October 2018 through December 2019 there were thirteen NPS CRUSER monthly meetings featuring 22 presentations (*see Table 7*).

Table 4. FY19 NPS CRUSER Monthly Meeting presentations.

Date	Presentation(s)
NOV 2018	***LT Ross Eldred USN, NPS Systems Engineering*** *– AUV Prototype Development for Wreck Interior Exploration* ***Dr. Mara Orescanin, NPS Oceanography*** *– Classification of Littoral Environments using Deep Learning*
DEC 2018	***Dr. Fabio Alves, NPS Physics*** *– Acoustic detection of Small Flying UAS using bio-inspired MEMS sensors* ***Dr. Margo Edwards, Director Applied Research Laboratory Researcher at the University of Hawaii****: The Applied Research Laboratory at the University of Hawaii*
JAN 2019	***Capt Mike Franco USMC and Capt Steve Spada USMC*** *– Fundamentals of C2 as applied to Manned-Unmanned Teaming*
FEB 2019	***LT Justin McCorkle USN*** *- Active Sonar Matched Waveform for Resonant Spherical Mine Target (Romero)*
MAR 2019	***LT Austin Fleming USN*** *- Naval Applications of Machine Learning 2019 Workshop Round-up* ***Capt Ashley Brown USMC*** *- Effective Humanitarian Logistics Delivery using Space-filling Curves*
APR 2019	***Dr. Curt Blais, NPS MOVES Institute*** *- Unmanned System Interoperability Standardization CRUSER Project Update: U.S. Navy and International Community Efforts* ***MAJ Gonzalo Santiago and LT Gary L. Lattimore USN -*** *Scan Eagle Research Update (Kragelund/Monarrez)*
MAY 2019	***MAJ Joshua Gordon USMC*** *- Simulation analysis of tactical unmanned aerial systems' capabilities in support of the Marine Air Ground Task Force (Sanchez)* ***MAJ Justin Murphy, USMC*** *– Proof of concept into bursty/short-living communication networks interconnected by aerial biological nodes (birds) **DISTRO E – DoD Components Only (Administrative/Operational Use; Direct Military Support).** (Bordetsky)*

JUN 2019	***Jeremy Metcalf, NPS Physics Dept*** *- Analysis of Spectral Imagery using Map Information* ***Dr. Marcello Romano, NPS MAE Dept*** *- Minimum-Time Control of Linear Systems between Arbitrary States*
JUL 2019	***MAJ Zhaolin Chen, Republic of Singapore Air Force, NPS student –*** *Network Performance Evaluation of ROS 2 for Unmanned Systems using NS3 Simulations* ***Mr. Josh Metz, Economic Development Manager, Fort Ord Reuse Authority*** *– Monterey Bay Drone, Automation & Robotics Technology (DART) Initiative: A regional economic development strategy*
AUG 2019	***Ms. Lyla Englehorn, NPS CRUSER Associate Director*** *– Royal Australian Navy's Warfare Innovation Workshop* ***Col. John Dillard (Ret.), Senior Lecturer, NPS Systems Engineering*** *- Emerging results on the "Expeditionary Countermine Measures Sustainment" study*
SEP 2019	*No meeting in lieu of Warfare Innovation Continuum Workshop*
OCT 2019	***MAJ Michael Senft USMC, LT Richard Rodriguez USN, and LT Matthew Hendricks USN, NPS students*** *– Hack the Machine 2019, New York*
NOV 2019	***Noah Weitz, NPS Space Systems Academic Group –*** *Mobile CubeSat, Command, and Control (MC3) Ground Station Automation and Situational Awareness*
DEC 2019	***LT Meagan Way USN, NPS student*** *- SMi 4th Annual UAV Technology Conference* ***NPS Systems Engineering Student Team*** *- sUAV-E project: UAV Swarm Potential Uses*

Monthly meeting details are available on the CRUSER website (cruser.nps.edu).[30]

3. Briefings and Presentations

Over the nine years of the program CRUSER leadership team has become regarded experts on robotics and autonomy issues – on the NPS campus and throughout the greater community of interest – 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

[30] Go to **cruser.nps.edu** and click on **Monthly Meeting** under the Events tab on the top navigation bar

exchange of information that educates all parties involved. A sampling of those that received CRUSER briefings in FY19 are included in the following table (*see Table 8*):

Table 5. FY19 CRUSER program briefings and presentations

DATE	**ORGANIZATION**
OCT 2018	Brigadier General William Bowers USMC, President; Marine Corps University
NOV 2018	Navy Tech Transition Team (lab tour) Dr. Thomas Cutler, U.S. Naval Institute Press Bruce Nagy, NAWC China Lake Dr. Reg Beer, Global Security Directorate, and Dr Adam Conway; Lawrence Livermore National Labs NASA Armstrong (visit); Code 35, ONR Global
DEC 2018	Mike Alban, Director of Operations for the Center for Innovation in Ship Design (CISD); Dr. Mike Bosworth, CISD Director; Kieran Rutherford, UK Engineering CISD Exchange; Code 8202, NSWC Carderock CAPT Pete Small, the Program Manager for Unmanned Maritime Systems, and SURFOR/10th Flt Science Advisors RDML Dave Welch USN, Commander Naval Surface and Mine Warfighting Development Center Brute Krulak Center for Innovation and Creativity delegation; Marine Corps University
JAN 2019	CAPT Harrison, Program Manager, PMS 404, Undersea Weapons Reid F. McAllister, NSWC-Carderock, Director, Integrated Unmanned Maritime Mobility
FEB 2019	Commander Operational Test and Evaluation Force (COMOPTEVFOR): Mark Lucas, COTF Technical Director, CAPT Mark Stoops USN, Commander Action Group, LT Tom Craig USN, USW Division, Operational Test Director (OTD) UUV COL Adrian Donahoe USMC, CDR Brett McDaniel USMC, MAJ Nic Guillet USMC, Mr. Mike Meyers; J59 CDI, United States Special Operations

	Command RADM Kenneth M. Perry USN (ret); General Dynamics Electric Boat Dr Brian Maher and CAPT Jamie Sands, SOCOM Joint Special Operations University (JSOU) Kevin Owens Applied Research Laboratories at The University of Texas (ARL:UT)
MAR 2019	CAPT Brian Connon, U.S. Navy (ret); Director of The University of Southern Mississippi's (USM) Hydrographic Science Research Center (HSRC) Charles Blakely, Technology Product Manager; Houston Mechatronics COL Mike Maguire, CDD Director, SGM Angel Zajkwoski, Project Lead, Josh Berglund, CDD LNO in Silicon Valley; Combat Development Directorate (CDD), United States Army Special Operations Command (USASOC) Ng Ee Chong, Director, Unmanned Systems; DSO National Laboratories DTIC Industry Day (meeting and lab tour) JD McCreary, Chief, Disruptive Technology Programs; Georgia Tech Research Institute
APR 2019	Naval Research Working Group (NRWG) WIC Workshop Overview (presentation) Mr. Robert Moralles, COMSPAWARSYSCOM, Trident Warrior Liaison Outreach Dr. Tom Choinski, Deputy Director for Undersea Warfare at NUWC Headquarters Mr. Ng Ee Chong, DSO Singapore CAPT George Galdorisi, USN (ret), Director, Strategic Assessments & Technical Futures, NIWC PAC Dr. William F. Bundy, Associate Provost, Warfightng Research and Development and Director, VADM Samuel L Gravely, Jr. Research Group; U.S. Naval War College CAPT Mike Smith, Royal Australian Navy

MAY 2019	Dr. Dianne Egnor, Signal Processing Engineer, MITRE Corporation CAPT Mel Yokoyama USN, Commanding Officer NIWC Pacific CAPT Douglas Adams USN, PMS 485 VADM Richard Brown, Naval Surface Warfare Center
JUN 2019	CDR William Fiack USN, Special Reconnaissance Team ONE, Naval Special Warfare Mr. Mike Bochna (COL USA Retired), the Director of the Defense Attaché Service (DAS) RADM David Goggins USN, PEOSUBS
JUL 2019	CAPT Mike Saum, Commanding Officer NAVFAC Expeditionary Warfare Command, and delegation; NAVFAC CTO Dr. Tod Schuck, Lockheed Martin Fellow Emeritus Dr. Anthony Ruffa, Director For Transition of Science and Technology, Office of the Chief Technology Officer, Naval Undersea Warfare Center (NUWC) Newport, Rhode Island Science Advisors from Naval Surface & Mine Warfighting Development Center (NSMWDC), Mr. Jeff Butcher, NSMWDC Science Advisor, Mr. Chris Zito, Prospective Science Advisor, LT Kristen Alexander, SURFDEVRON, LT Ailorrarizz Brunin, Experimentation, Travis Bateman, N8/9 Deputy for Sea Control Dr. Jack Keane & Dr. Tom Urban, Precision Strike Systems Branch Office, Force Projection Sector, Johns Hopkins University Applied Physics Lab
AUG 2019	CAPT Terry Miller USN (ret), Business Development Manager – DC Operations, Advanced Acoustic Concepts, Llc. former OPNAV N952 – Mine Warfare Branch Head, OPNAV N95 IDA Operational Evaluation Division, Research staff visitors: Sabrina L. Cales, Ph.D., Robert Atkins, Ph.D., Daniel Kim, Ph.D. Mr. Jay Tilden, Associate Administrator and Deputy Under Secretary for Counterterrorism and Counterproliferation, Mr. Brian Rose, CP Studies Program Manager National Nuclear Security Administration

SEP 2019	
OCT 2019	BAE Systems. Jeffrey M. Smith, Director of Unmanned Undersea Vehicle Systems at BAE Systems. Previously president and founder of Riptide Autonomous Solutions. LCDR Arthur Anderson, USN, PhD, NAVSEA Eng. Directorate (O5T) & DIU L3Harris, Integrated Mission Systems, Goleta CA. CRUSER Brief to Joe Carnes - Lead Systems Engineer, Ryan Frommelt - Business Development Manager, MariPro; and Geoffrey Ball - Senior Ocean Engineer CAPT Todd Massidda, USN, (ret.), Director of Sub Security Program, JHU/APL
NOV 2019	Mr. John T. Phillips, ONR Science Advisor to MARFORCOM (ST&E) Naval Surface and Undersea Warfare Centers visitors: • Dr. Denise Crimmins, SSTM, USW Rapid Prototyping Director, DASN(RDT&E), and Co-Lead AI/ML portfolio • Mr. Christopher Egan, SSTM, Co-Lead Unmanned Vehicles and Autonomous Systems Working Group, and Co-Lead UxS/Autonomy portfolio • Ms. Debra Powers, Chairperson, Naval Counter-Improvised Threat Knowledge Network and UxS Technical Exchange • Mr. Reid McAllister, Co-Lead Unmanned Vehicles and Autonomous Systems Working Group, and Co-Lead UxS/Autonomy portfolio
DEC 2019	Raytheon Missile Defense Systems, Tucson, AZ • Julie Leeman, Director, Advanced Naval Programs /CRADA Sponsor • Tod Newman, Engineering Fellow / Lead, Raytheon Center for AI & ML • Mark Meisner, Engineering Fellow / CRADA Co-PI • Mike Aden, Engineering Fellow / CRADA Co-PI • John Beaver, Manager III, Advanced Naval Programs Business Development

	• Hsin-Fu "Sinker" Wu, Senior Principal Systems Engineer, Operations Research Dept., Modeling Sim Analysis Ctr / CRADA Co-PI • Ketal Petal, Manager II, Advanced Naval Programs Business Development

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-related NPS FX activities, programs, and events in FY19. 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 NPS FX (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 2019 seven reservists supported NPS FX CRUSER- related programs (*see Table 9).*

Table 6. Reservist support for NPS FX programs in 2019.

Month	**Number of Officers**	**Project (s)**
MAR 2019	1	Cybersecurity Evaluation and Testing of the ROS 2 Architecture for Networked UAV Systems
APR 2019	(1)	(project started in March and extended into April)
MAY 2019	3	JIFX 19-3
AUG 2019	2	JIFX 19-4
SEP 2019	1	WIC Workshop 2019
TOTAL:	**7**	

III. CONCLUSION

The year 2019 was another year of program growth and learning. Beyond seeding research and hosting our concept generation workshop, technical gathering and monthly meetings CRUSER experimented with different systems, platforms, and processes to better communicate with our vast community of interest. Programs are often asked to quantify outcomes to demonstrate return on investment so as of December 2019, CRUSER "by the numbers" stands as follows:

CRITERIA	**VALUE**
Community of Interest Members	2948
Research Projects Seeded	166
Seed Funding Distributed	$14M
NPS Theses & Dissertations Supported	216
NPS Student Trips Supported	159
Concept Generation Workshops	13
Technical Symposia Hosted	6
Field Experimentation Events	32
Seminars & Lectures Offered	20
Panel Discussions Held	7
Monthly Meeting Presentations Shared	180
Research Fairs & Expos Held	8
Papers & Presentations	174
Concepts Generated	523

A. PROPOSED FY20 ACTIVITIES

FY20 got underway as the twenty 2019 seeded projects completed their period of performance, the eighth innovation thread concluded, and the ninth began. 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"* in FY20 CRUSER will:

- Support NPS faculty and student research involving projects associated with robotics and autonomous systems.
- Support the integration of robotics and unmanned systems issues into appropriate courses and educational materials that will enable the Navy and Marine Corps officers to become familiar with the challenges associated with the development and operational employment of these systems.
- Support robotics and autonomous systems educations through a new graduate certificate in Robotics Engineering available to resident students and DoD civilians.
- Provide financial support for NPS student travel to participate in research and experimentation dealing with all aspects of unmanned systems.
- Host field experimentation opportunities for NPS students and researchers throughout FY20 in collaboration with the Joint Interagency Field Experimentation (JIFX) program at NPS.
- Host the ninth 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 (20-21 May 2020).
- Co-sponsor, along with the System Engineering Analysis program, the Warfare Innovation Workshop to initiate the ninth innovation thread (21-24 September 2020).
- Grow the community of interest (including DoD, industry and academic members) and host monthly community-wide meetings.
- Sponsor and participate in STEM outreach events relevant to robotics education.
- Sponsor summer research internships for service academy students to work in research laboratories across NPS.

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 FY20 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 four 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.

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

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

<u>Upcoming:</u>

Fernandez, J. and B. Allen, P. Thulasiraman, B. Bingham (2020). "Performance Study of the Robot Operating System 2 with QoS and Cyber Security Settings," accepted for publication in IEEE International Systems Conference (SYSCON), *April 2020 (anticipated)*

<u>Added in FY19 report:</u>

Ang, W.K., Teo, W.S., Yakimenko, O.A (2019). “Enabling an EO-Sensor-Based Capability to Detect and Track Multiple Moving Threats Onboard sUAS Operating in Cluttered Environments,” International Conference on Control and Robots, Jeju Island, Republic of Korea, Dec 12-14, 2019.

Blais, C. (2019). Presentation: "Toward Semantic Interoperability across Command and Control Systems, Simulation Systems, and Unmanned Systems," Defense Modeling and Simulation Coordination Office Workshop on "Modeling and Simulation in Support of Autonomy," Alexandria, VA, 21 November 2019.

Blais, C. (2019). Presentation: "Summary of DMSCO Workshop on Modeling and Simulation in Support of Autonomy," Raytheon Missile Systems Technical Interchange, Naval Postgraduate School, Monterey, CA, 10 December 2019.

Blais, C. (2019). Presentation: "Rich Semantic Track (RST) Ontology: Unified Semantics and Pragmatics for Track Data Interchange," Raytheon Missile Systems Technical Interchange, Tucson, AZ, 28 October 2019.

Blais, C. (2019). Presentation: "Project Status Report: Unmanned Systems Interoperability Standardization: US Navy and International Community Activities," CRUSER Monthly Seminar, Naval Postgraduate School, Monterey, CA, 1 April 2019.

Blais, Curtis L. 2019. “A Robotics and Autonomous System Use Case to Guide Specification of the Command and Control Systems - Simulation Systems Interoperation.” Simulation Innovation Workshop, Simulation Interoperability Standards Organization, Orlando, FL. February 2019.

Blais, Curtis L., Schade, Ulrich, Sikorski, Lukas, Wolski, Magdalena, Singapogu, Samuel, and Gautreau, Bruno. 2019. “A Transformation Process for Generating an Extensible Markup Language (XML) Schema from a Formal Ontology for Practical Application in C2SIM Implementations. Simulation Innovation Workshop, Simulation Interoperability Standards Organization, Orlando, FL, February 2019.

Blais, Curtis L., Reece, Douglas, and Singapogu, Samuel. 2019. “From Information Description to Information Understanding: The Role of Ontology in Emerging SISO Standards.” Simulation Innovation Workshop, Simulation Interoperability Standards Organization, Orlando, FL. February 2019.

Engebråten, S. A., Nummedal, O. R., Gilbreath, D., Yakimenko, O, and Glette, K. (2019). “UAV Swarm with Mesh Radios: Development Update,” The 3rd International Symposium on Swarm Behavior and Bio-Inspired Robotics, Okinawa, Japan, Nov. 20-22, 2019.

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

Leary, P. and V.N. Dobrokhodov, K.D. Jones, K.B. Smith (2018). “Embedded real-time processing of acoustic vector sensors using a lightweight open-source microcontroller,” The Journal of the Acoustical Society of America vol.144, published online 18 October 2018 https://doi.org/10.1121/1.5068515

Leary, P. and V. Dobrokhodov, K., Smith, K.D. Jones (2019). “Real-time multi-channel acoustic beamforming using a lightweight microcontroller processor,” in Proceedings of IEEE “The OCEANS 2019” conference, Seattle, October 27-31, 2019.

Orescanin, M.M. and W. Young, J. Coughlin, D.W. Herrmann, J. Metcalf (2019). “Seasonal Morphological Change at a Bar Built Estuary: Carmel River, CA” Coastal Sediments 2019, pp. 674-683. Posted online at World Scientific https://doi.org/10.1142/9789811204487_0059

Pullen, J. Mark, Corner, Douglas, Singapogu, Samuel, Blais, Curtis L., Reece, Douglas, and Ruth, Jim. 2019. “Command and Control System to Simulation System Interoperation: Development of the C2SIM Standard.” Simulation Innovation Workshop, Simulation Interoperability Standards Organization, Orlando, FL. February 2019.

Rabelo, Renato, Fabio Alves, and Gamani Karunasiri (2019). "MEMS directional acoustic sensor with charge amplifier based electronic readout." The Journal of the Acoustical Society of America 146.4 (2019): 2997-2997.

Rabelo, Renato, Fabio Alves, and Gamani Karunasiri (2019). " Electronic phase shift measurement for the determination of acoustic wave DOA using single MEMS biomimetic sensor. " Submitted to Scientific Reports (Dec/2019).

Sandoval, S. and P. Thulasiraman (2019). "Cyber Security Assessment of the Robot Operating System 2 for Aerial Networks," IEEE International Systems Conference (SYSCON), April 2019

Sands, T. Underwater deterministic artificial intelligence. Applied Sciences. 2020, 10, invited submission.

Thulasiraman, P. "Performance Study of the Robot Operating System 2 with QoS and Cyber Security Settings," presented at the IEEE Symposium on Unmanned Air Transportation, University of North Texas.

Weitz, N., Bailey, M., Minelli, G., Newman, J. (2019, April). Ground Station System Automation. Poster presented at the 2019 CubeSat Developer's Workshop, San Luis Obispo, CA.

Included in FY18 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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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-	2018	http://hdl.handle.net/10945/59685

	DIRECTION COMMUNICATION FERRY NODES FOR DENIED COMMUNICATIONS ENVIRONMENTS (NPS Outstanding Thesis 2018)	JUN	
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	2018 SEP	http://hdl.handle.net/10945/60353

	DATA (NPS Outstanding Thesis 2018)		
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 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	2017 DEC	http://hdl.handle.net/10945/56859

	OF HYDRODYNAMIC MODELS OF NEAR-SURFACE UNMANNED UNDERWATER VEHICLE OPERATIONS		
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) missions*	2014-12	http://hdl.handle.net/10945/44659
Joong Yang Lee, NTU Singapore	*Expanded kill chain analysis of manned-unmanned teaming for future strike operations*	2014-09	http://hdl.handle.net/10945/43944
Montrell Smith, DON Civilian	*Converting a manned LCU into an unmanned surface vehicle (USV): an open systems architecture (OSA) case study*	2014-09	http://hdl.handle.net/10945/44004
CDR Ellen Chang, USNR	*Defining the levels of adjustable autonomy: a means of improving resilience in an unmanned aerial system*	2014-09	http://hdl.handle.net/10945/43887
Chee Siong Ong, NTU Singapore	*Logistics supply of the distributed air wing*	2014-09	http://hdl.handle.net/10945/43969
LT Barry Scott, USNR	*Strategy in the robotic age: a case for autonomous warfare*	2014-09	http://hdl.handle.net/10945/43995
LT Blake Wanier, USN	*A modular simulation framework for assessing swarm search models*	2014-09	http://hdl.handle.net/10945/44027
Chung Siong Tng, NTU Singapore	*Effects of sensing capability on ground platform survivability during ground forces maneuver operations*	2014-09	http://hdl.handle.net/10945/44018
LT Nicole R. Ramos, USN	*Assessment of vision-based target detection and classification solutions using an indoor aerial robot*	2014-09	http://hdl.handle.net/10945/43984
Ceying Foo, NTU Singapore	*A systems engineering approach to allocate resources between protection and sensors for ground systems for offensive operations in an urban environment*	2014-09	http://hdl.handle.net/10945/43914

Team Amberland, Cohort 311-131O	*A systems approach to architecting a mission package for LCS support of amphibious operations*	2014-09	http://hdl.handle.net/10945/43992
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-Defender Model*	FY13	
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 AFFILIATION ROSTER

This is a representative listing of the CRUSER community of interest at the conclusion of FY18. In FY19 CRUSER migrated our community database, and affiliation and organization data is not yet available for the full community as of December 2019. This roster is not meant to be inclusive but demonstrates depth and breadth of interest.

ACADEMIA

AFIT
AFJROTC Jefferson High School
Alaska Center for Unmanned Aircraft Systems Integration
American University
Applied Physics Laboratory - University of Washington
Argonne National Laboratory
Arizona State University
ASU Research Enterprise
Australian Defense Force Academy
AUV IIT Bombay
AUVSI Foundation
Bangalore Robotics
Ben-Gurion University of the Negev
Cal Poly, San Luis Obispo
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
California State University – Long Beach
California State University – Monterey Bay
Center for Unmanned Aircraft Systems, 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- Prescott
Faculdade de Engenharia da Universidade do Port (FEUP)
FIRST
Florida Atlantic University
Florida Institute for Human Machine Cognition
Francis Parker School
French Air Force Academy
Georgia Institute of Technology
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)
Kasetart University
Kennesaw State University
Kansas State University
Ludwig Maximilians Univeristat
Macquarie University
Marine Advanced Technology Education (MATE) Center
Maritime State University
Monterey Bay Aquarium Research Institute (MBARI)
McGill University
Memorial University of Newfoundland
Mississippi State University
Massachusetts Institute of Technology (MIT)
Massachusetts Institute of Technology (MIT) - Lincoln Laboratory
Monterey Peninsula College
National Defense University
Naval Air Warfare Center
Naval War College
Netherlands Defense Academy
New Mexico State University
New Jersey Institute of Technology (NJIT)
New Mexico State University (NMSU)
North Carolina Central University
North Carolina State University
Northwestern Polytechnic University
Northwestern University

Notre Dame
Oklahoma State University
Old Dominion University
Oregon Institute of Technology
Ohio State University
Rensselaer Polytechnic Institute (RPI)
Saint Louis University
San Diego Christian College
San Diego City College
San Diego State University
South Dakota School of Mines and Technology
Southwestern College
Space Systems Academic Group
St. Georges College
St. Mary's University
Stanford University
Stony Brook University
Teach for America
Technion – Israel Institute of Technology
Texas A&M
Thomas Jefferson High School for Science and Technology
Technical University of Munich (TUM)
University of South Florida
U.S. Naval Academy
University of California - Berkeley
University of California - Davis
University of Central Florida
University of California – San Francisco
University of Florida
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 Alaska - Fairbanks
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)
University of Las Vegas
Unmanned Vehicle University
United States Coast Guard Auxiliary
Universities Space Research Association
Utah State University
Utah State Space Dynamics Lab
Unmanned Vehicle University
Virginia Tech
Wake Forest University
Wichita State University

<u>Federal/State/Local Government:</u>

Aeronautics Research Directorate
Allied Command Transformation
Ames Research Center
Aircraft Owners & Pilots Association (AOPA)
Argonne National Laboratory
Arlington County Police Department
Armstrong Flight Research Center
ASDRE
Bakersfield Police Department
Banning Police Department
Business Oregon
CA Dept of Insurance Fraud
CA DMV Investigations
California EMA
Calexico Police Department
California Highway Patrol
Customs and Border Protection (CBP)
United States Central Command (CENTCOM)
Chicago Fire Department
California Highway Patrol
City of Las Vegas
Cleveland VA Medical Center
CRIC
CS OEM
CSU Fresno Police Department
Defense Advanced Research Projects Agency (DARPA)
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
Department of Homeland Security Immigration and Customs Enforcement
Department of Homeland Security Office of Operations Coordination
Defense Intelligence Agency (DIA)
Defense Manpower Data Center (DMDC)
Department of Defense Office of Inspector General
Department of Transportation Office of Inspector General
Defense Threat Reduction Agency (DTRA)
Eldorado Sheriff's Office
Elk Grove Police Department
Federal Aviation Administration (FAA)
Federal Emergency Management Agency (FEMA)
Fremont Police Department
Georgia Emergency Management and Homeland Security Agency (GEMA/HS)
Office of the Assistant Secretary for Preparedness and Response within the United States Department of Health and Human Services (HHS/ASPR)
Houston Police Department
Headquarters NORAD/USNORTHCOM
Headquarters TRADOC
Irvine Police Department
Jet Propulsion Laboratory (JPL)
Joint Staff J-7
Joint Staff Remote/Unmanned Futures Office
Joint Vulnerability Assessment Branch
Lawrence Livermore National Laboratory
Marin County Sheriff
Marina Police Department
Monterey County Sheriff
Mountain View Police Department
National Aeronautics and Space Administration (NASA)
National Aeronautics and Space Administration - Jet Propulsion Laboratory
National Aeronautics and Space Administration - Langley Research Center
National Aeronautics and Space Administration - CSUMB
National Air Security Ops Center - CBP
National Defense University
National Geospatial-Intelligence Agency
National Guard Bureau
National Transportation Safety Board
Naval Air Systems Command (NAVAIR)
Naval Air Warfare Center Weapons Division - NAVAIR (NAWCWD)
Naval Oceanographic Office
Naval Research Laboratory
Naval Sea Systems Command
Naval Undersea Warfare Center Division Newport
Naval Sea Systems Command (NAVSEA)
Naval Air Warfare Center Aircraft Division (NAWCAD)
National Defense University (NDU)
National Electrical Manufacturers (NEMA)
Nevada Institute for Autonomous Systems
National Oceanic and Atmospheric Administration (NOAA)
Naval Postgraduate School (NPS)
National Science Foundation (NSF)
Naval Surface Warfare Center Dahlgren Division (NSWCDD)
Oakland Police Department
Office of Naval Intelligence
Office of Sen. Kirsten E. Gillibrand
Office of the Under Secretary
Oklahoma City Chamber of Commerce
Office of the Secretary of Defense (OSD)
Under Secretary of Defense for Research and Engineering (OSD ASDR&E)
Under Secretary of Defense for Acquisition and Sustainment (OUSD AT&L)
United States Indo-Pacific Command (PACOM)
PMW 750
Riverside District Attorney's Office
RS Special Research Access
Sacramento County Sheriff
Sacramento Office of Emergency Services
San Diego Sheriff's Department
San Leandro Police Department
San Mateo County Sheriff
San Mateo Police Department
Sandia National Laboratories
United States Special Operations Command (SOCOM)
Space and Naval Warfare System Center Pacific
SPAWAR Systems Center
SPAWAR Systems - Central Pacific
State of Alaska (DOT)
State of Oklahoma
State of Utah - Economic Development Office
State of Utah, Governor's Office of Economic Development

State of Wisconsin
United States Strategic Command (STRATCOM)
Swedish Defense Material Administration
The Aerospace Corporation
Transport Canada Safety & Security
Tulsa Chamber of Commerce
Tustin Police Department
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 Special Operations Command
US Coast Guard Research, Development, Test and Evaluation (RDT&E)
USEUCOM
USG
US Naval Academy
USSOCOM
USTRANSCOM
Ventura County Sheriff
Ventura County Economic Development Association
Ventura Police Department
Visalia Police Department
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 Development & 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 Rocketdyne
Aeroprobe Corp
Aeropsace Corp
Aerospace & Def INO Parts
Aerospace Analytics
AeroTargets International
Aerovel Corp
AeroVironment
Affordable Engineering Services
Ag Eagle
AgriSource Data, LLC
Air Concepts Group
Air Law Institute
Air View Consulting
Airbus Defense & 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, 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 Digital Device Corp
Artemis
Advanced Scientific Concepts Inc. (ASC)
Aeronautical Systems Inc. (ASI)
Assured Information Security
ASV Global
ASYLON
ATC
ATI
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
Copacetic 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 Organization
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
Defense Research Associates (DRA)
Dragonfly Pictures
Draper Laboratories
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 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 Sensors
GTRI
GTS Consulting
H.O. JOHNSON RESULTANTS LLC
Hangar Technology
Harris Corp
Harwin
Hawaii Hazards Awareness & Resilience 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 Unmanned 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
L-3 Technologies
Laser Shot
Latitude Engineering
LDRA
Leidos
Lenny Schway Photography
Leucadia Group
Lightspeed Innovations
Liquid Robotics, Inc.
Llamrai Enterprises
Lockheed Martin Aeronautics Company
Lockheed Martin Co (LMCO)
Lockheed Martin Missile & Fire Control
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)
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.
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
Northrop Grumman Corp (NGC)
NiederTron Robotics
NLD MOD (Defense Materiel Org)
NNS
North Dakota Counter UAS Task Force
Northeastern University
Northrop Grumman Corporation
NorthWind
NUAIR Alliance
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
Physical 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
Q-Bot
QinetiQ
QUALCOMM
Quanterion Solutions Incorporated
Quartus Engineering
Quatro Composites
R Lynch Enterprises
R-3 Consulting
R3SSG
Rajant
Ramona Research
Rand Corporation
Radiance Technologies
Range Networks
Rapid Imaging Software
Raytheon Company
RD Integration
Red Hat
Red Six Solutions
Redwall Technologies
Reference Technologies INC.
Renaissance Strategic Advisors
RFMD
Riegl USA
Riptide Autonomous Solutions
RIX Industries
RJ Vincent Enterprises LLC
RMV Technology Group
ROBOTEAM
Robotics Research
Rockwell Collins
Rocky Mountain Institute
Rogue Tactical LLC
Rolls Royce
Roving Blue
RT Logic
RTI
Rumpf Associates International
Rupprecht Law
SAAB
Saab Defense and Security USA
SAGE Solutions Group, Inc
Sagetech Corporation
SAIC
Saildrone
SAP National Security Systems (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
Sebastian Conran/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
Sierra Nevada Corporation (SNC)
Soar Oregon
Soar Technology, Inc.
Society of Experimental Test Pilots
Soliton Ocean Services, Inc.
Sonalysts, Inc.
Sonitus Technologies
Space Micro

Sparton Corporation
Sparton Defense and Security
Spatial and Spectral Research
Spatial Integrated Systems
Spectrabotics
Spectrum Aeronautical, LLC
Spinner
Spiral Technology, Inc.
SRC, Inc.
SRI International
SSL
ST Aerospace
Stark Aerospace Inc.
Steinbrecher & Span LLP
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 Technologies
Telephonics Corporation
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 Institute
Unmanned Systems Research & Consulting LLC
Unmanned Vehicle Systems Consulting, LLC
Unmanned World Wide
US Nuclear Corp.
UTC Aerospace 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 Defense Development)
Be MoD
British Consulate - General LA*
Business France
Canadian Forces Aerospace Warfare Centre
Canadian Forces Maritime Warfare Centre
C-Astral
Defense 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
UCAL-JAP Systems LTD.

U.S. Air Force:
26th Special Tactics Squadron
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
Air Combat Command
Air Education and Training Command
Air Force Institute of Technology (AFIT)
Air Force Research Laboratory (AFRL)
Air National Guard
COMPATRECONWING TWO
HQ NORAD
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 Excellence
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 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
COMPATRECONWING ELEVEN
COMPATRECONWING TWO (N7)
COMPHIBRON EIGHT
COMPHIBRON SIX, N1
COMSUBDEVRON FIVE
COMSUBDEVRON TWELVE
COMSUBDEVRON-5, DET UUV
COMSUBPAC (Code N7C)
COMSUBPAC / CTF 34
COMTACGRU ONE
COMTHIRDFLEET
COMUSNAVSOUTH
Crane Division, Naval Surface Warfare Center
CRIC
CRUSER
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 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 & Missile 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 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 (ONI)
Office of Naval Research (ONR)
Office of Naval Research - Reserve Component
Office of the SecNav
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 & Logistics
USMC Pentagon
USNA
USNR
USS Chung-Hoon
USS MCCAMPBELL
UXOCOE
UxS Cross Functional Team
VMU-3
VR-55
VX-30
Warfare Analysis & Integration Department

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APPENDIX D: CRUSER FY19 CALL FOR PROPOSALS

The FY19 call for proposals was released in mid-July 2018.

CRUSER FY19 Call for Proposals

Due Date: 16 Aug 2018

Submission Procedures: See details below

On-Line submission ONLY

Selection Date: 20 Sep 2018

Funding Start Date: 1 Dec 2018

Funding Expiration Date: 31 Dec 2019

Funding Levels: up to $150,000

Proposal Type: Single-Year Proposals

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

Anticipated Funding Amount: Funding has not yet been received for FY19; 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.

1. 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: "**Distributed Maritime Operations: Combined, Joint, and Coalition Warfare at Sea"** originated from the Warfare Innovation Continuum Workshop (WICW) held in Sep 2018. CRUSER encourages proposals in all areas of research that involve unmanned systems, but is particularly interested in research related to the following topic areas:

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

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

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

4. Other robotics and unmanned systems concepts.

Classification Level:

1. Unclassified (Preferred) but Classified work will be considered.

Required Documents:

1. 5-7 page proposal in MS Word (.docx) (Use CRUSER template & submit on-line. **Do not** submit via the Research Office).

2. Current Year Research Office Budget form. {List CRUSER as the Sponsor. If selected, the CRUSER director will sign and route via RSPO. No sub-JONs will be created}.

3. Quad Chart (use the CRUSER provided template) and submit as a .pptx file.

Submission Procedures:

1. All FY19 proposal packages will be submitted online via Lime Survey – active link posted at cruser.nps.edu

Review and Selection Board:

1. 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 involvement
2. Interdisciplinary, interagency, and partnerships with other Naval labs
3. Partnerships with another sponsors' funding
4. Research related to various unmanned systems' categories:
    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 systems area may be proposed, though proposals related to any CRUSER innovation thread are preferred. (See website and above focus areas)
7. Alignment with the ASN (RD&A) Navy Unmanned Systems Goals
8. Researchers are members of the CRUSER Community of Interest
9. Proposals should aim to make an immediate impact on the community.

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):

1. Monthly meeting attendance
2. A presentation at a monthly meeting and at the annual CRUSER TechCon
3. Participation in CRUSER sponsored events

4. Contributions to the CRUSER Annual Report

5. Providing updated labor plans and budget projections as requested

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: 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 served 10 years as Naval Nuclear Propulsion Plant Operator while earning his Associate's and Bachelor's degrees. He holds a Master of Science in Systems Engineering degree from the Naval Postgraduate School and a Doctorate degree in Civil and

Environmental Engineering from Stanford University. From 2003 to 2005, Dr. Buettner served on the faculty at the Naval Postgraduate School (NPS) and was the Information Operations Chair. He is the Chair of Technical Operations, in which he liaisons between NPS and the Joint Staff J39.He is the Principal Investigator for multiple research projects with budgets exceeding $6 million dollars a year, including the TNT, RELIEF, and JIFX projects. http://faculty.nps.edu/rrbuettn/about.html

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

LIST OF FIGURES

LIST OF TABLES

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 dedicates this annual report to the memory of two CRUSER members who passed away in December 2019 – one old, one new. CAPT Wayne Hughes USN (ret) was an early and enthusiastic member of CRUSER, and Dr./CDR William Bundy USN (ret) was one of our newest CRUSER members. *Fair winds and following seas gentlemen as you journey to the great beyond.*

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

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

The CRUSER Director acknowledges the efforts of the CRUSER Advisory Board

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 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 FY19 annual report summarizes CRUSER activities in its ninth year of operation and highlights future plans.

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

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