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

Cross-Domain Operations (CDO)

Warfare Innovation Continuum (WIC) Workshop September 2018

After Action Report

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NAVAL POSTGRADUATE SCHOOL

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- To all the participants for your time, professionalism, input based on your unique experience and expertise, and especially your willingness to help shape the future of our Navy.

EXECUTIVE SUMMARY

This Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) sponsored Warfare Innovation Continuum (WIC) workshop was held 17-20 September 2018 on the campus of the Naval Postgraduate School (NPS) in Monterey, California. The three and a half day experience allowed NPS students focused interaction with faculty, staff, fleet officers, and visiting engineers from Navy labs and industry. Featuring a keynote address by the Vice President of the Defense Acquisition University (DAU), Mr. Frank Kelly (USMC retired), the workshop culminated in a morning of final concept briefs and fruitful discussion regarding the role of unmanned systems in the future naval force. This workshop also directly supported the Secretary of the Navy's (SECNAV) direction that CRUSER foster the development of actionable operational concepts for robotic and autonomous systems within naval warfare areas and work with our industry partners.

The September 2018 workshop "Cross-Domain Operations" tasked participants to apply emerging technologies to shape the way we fight. Within a near future conflict in an urban littoral environment, concept generation teams were given a design challenge: *How might advancements in autonomy, machine learning, manned-unmanned teaming, emergent technologies, and unmanned systems be employed to enhance cross-domain operations in highly 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 2018 WIC workshop included just over 80 active participants, observers and guests – the full participant pool representing nearly 30 different organizations. Half of the workshop participants were NPS students drawn from over a dozen curricula across the NPS campus. For this workshop, the final roster also included participants from The Johns Hopkins University Applied Physics Lab (JHU/APL), the Naval War College (NWC), Battelle, L3 Technologies, and Lockheed Martin. Fleet commands included OPNAV N2N6FX, Naval Air Systems Command (NAVAIR), Naval Undersea Warfare Center (NUWC) Newport, 12th Flying Training Wing, Space and Naval Warfare Systems Command (SPAWAR) Systems Center (SSC) Pacific, Naval Surface Warfare Center Panama City Division (NSWC PCD), U.S. Fleet Forces (USFF), the Office of Naval Research (ONR) the Royal Australian Navy (RAN), and the New Zealand Defence Force.

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:

1) ***Counter UxS:*** this topic area includes concepts to counter attacks by adversary autonomous assets (real and virtual) in multiple domains envisioned in a future contested region. Examples of specific concepts within this topic area include *Algorithm Capture* and *Weaponized*

Autonomous Sensor Persistence (WASP) – many smaller unmanned systems (UxS) blocking and/or attacking another UxS.

2) ***Cross-Domain Connectivity***: this topic area includes concepts to establish robust and resilient communication networks between autonomous manned and robotic assets operating across multiple domains simultaneously in a future contested environment assuming degraded or denied communications. Examples of specific concepts within this topic area include *Underwater Disaggregated Architecture* and *C3PO for Machines – a universal translator*.
3) ***Human-Autonomy Teaming:*** this topic area includes concepts to integrate manned and unmanned assets working as an integrated force in a future battlespace. Examples of specific concepts within this topic area include *Virtual Battlefield Sim* and *Third Eye – a human worn augmented data collector*.
4) ***Autonomy for Deception:*** this topic area includes concepts employing autonomy to spoof, decoy, or otherwise deceive future adversary forces, human and robotic. Examples of specific concepts within this topic area include *Trash Camo, Bio Buoys* and the *Submarine Investigation, Revelation, and Exploitation Network (SIREN) - many UxS elements mimicking a high value unit*.

Selected concepts will begin CRUSER's next Innovation Thread, and members of the CRUSER community of interest will be invited to further develop these concepts in response to the FY19 and FY20 Call for Proposals. Technical members of the CRUSER community of interest will present proposals at a technical continuum gathering such as TechCon 2019 to prototype and test concepts of interest in lab or field environments. A final report, the FY19 CRUSER Annual Report, detailing process and outcomes will be released before the end of the 2019 calendar year to a vetted distribution list of leadership and community of interest members.

I. BACKGROUND

Sponsored by the OPNAV N91 Chair, Systems Engineering Analysis, and the Consortium for Robotics and Unmanned Systems (CRUSER), this Warfare Innovation Continuum (WIC) workshop was held on campus during Naval Postgraduate School (NPS) Thesis & Research Week, 17-20 September 2018. Tasked with developing concepts of operation (CONOPS) in a near future global scenario with simultaneous conflicts on several distinct fronts, participants generated and proposed technologies to support their CONOPS.

A. ORIGINS

Innovation and concept generation are key drivers for CRUSER and other NPS research efforts, and these workshops are a central element of the overall strategic plan for the CRUSER program. The first NPS Innovation Seminar supported the Chief of Naval Operations (CNO)-sponsored Leveraging the Undersea Environment war game in February 2009. Since that time, workshops have been requested by various sponsors to address self-propelled semi-submersibles, maritime irregular challenges, undersea weapons concepts and unmanned systems concepts generation. Participants in these workshops have included junior officers from NPS and the fleet; early career engineers from industry, U.S. Department of Defense (DoD) laboratories, and other Federal agencies; and officers from allied nations.

One of CRUSER's primary mandates is to develop a community of interest for unmanned systems education and research, and provide venues for communication. These workshops were also designed to maximize relationship building to strengthen the CRUSER community in the future. During Enrichment Week in September of 2012, the Navy Warfare Development Command (NWDC) and CRUSER sponsored a concept generation workshop that was focused on advancing the Design for Undersea Warfare.[1] The March 2013 workshop, Undersea Superiority 2050, took a more focused look at the undersea domain aspects of the September 2012 workshop outcomes. The September 2013 workshop looked at distributed surface and air forces. The September 2014 workshop explored operations in contested littoral environments. The September 2015 workshop was designed to explore the concept of electromagnetic maneuver warfare, and tasked participants with employing unmanned systems in cross domain operations. Following the fleet interests, last year's workshop focused on developing autonomy to strengthen Naval power in response to CNO Richardson's release of the Design for Maintaining Maritime Superiority focusing document in January 2016. The September 2017 workshop "Distributed Maritime Operations" tasked participants to apply emerging technologies within a near future conflict in an urban littoral environment.

In the September 2018 WIC workshop focused on cross-domain operations (CDO) with the design challenge: *How might advancements in autonomy, machine learning, manned-unmanned teaming, emergent technologies, and unmanned systems be employed to enhance cross-domain operations in highly contested environments to accomplish missions more effectively and/or with less risk?* With embedded facilitators, six concept generation teams had three days to meet that challenge, and

[1] *Design for Undersea Warfare Update One*, November 2012: http://www.public.navy.mil/subfor/hq/PDF/Undersea%20Warfare.pdf

presented their best concepts at the end of the workshop. Participants from government, industry and academia worked this design challenge and presented over 20 unique concepts. Their work is the subject of this report.

B. PLANNING AND EXECUTION

Planning for this workshop began in earnest several months in advance of the event. CRUSER concept generation workshops are scheduled during the week between the end of classes and graduation in September or March each academic year to maximize the utility of NPS student time. NPS Thesis & Research Week, formerly Enrichment Week – a week without regularly scheduled classes – is intended to allow all NPS students to participate in an activity to further their intellectual growth in specialized areas of study. These concept generation workshops are an ideal fit for this mission.

1. Workshop Participants

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

Figure 1. September 2018 Warfare Innovation Continuum (WIC) workshop participants

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

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

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

2. Workshop Design

The September 2018 workshop, “Cross-Domain Operations,” leveraged the innovation lessons learned in previous workshops and was designed specifically to inspire innovative concept generation and development.

Scenario

All participants were given an overview of the future scenario titled “Global War 2030” focused on a future global conflict in multiple theaters. Derived from current open source media reports, this scenario reflects published thinking by current global military stakeholders. Teams were tasked with developing concepts of operations to counter multiple threats in a global warfare scenario but were not required to address the conflict in its entirety. A copy of their scenario is included at the end of this report (*see Appendix B*).

Process

The U.S. Navy (USN), and DoD writ large, have encouraged innovation at all levels and have pointed to Silicon Valley as an innovation exemplar. Product and software development based on user needs led Silicon Valley to become an innovation leader. These user-focused processes have evolved into what is now practiced as “Design Thinking” in industry, academia, and now the military. The WIC workshop employs tools of design for rapid and effective concept generation.

With the help of embedded facilitators, the teams use these tools to address the given design challenge. User input is gleaned from a variety of subject matter experts, and senior military, academic, and industry leaders serving as mentors. Some of this input is given formally in the form of plenary briefs to assembled participants or as part of organized interviews, or informally throughout the workshop. This user input, as well as the assembled team’s experience in the given problem space is the data that begins their concept generation process. The second day of the workshop is focused on divergent creation of choices, and the third day begins by converging on concepts to fully describe for presentation. Summaries of these six team presentations are included at the end of this report (*see Appendix A*), as well as the full workshop schedule (*see Appendix C*).

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II. CONCEPT SUMMARY

Knowledge-leveling concept overviews and technology injects related to the design challenge started the exploration into the problem space. Stakeholder perspective statements also focused the concept generation work. Based on the plenary session guidance, read-ahead materials, and subject matter expert input, each team generated numerous concepts and then selected their best ideas to present in their final briefs. Following the final briefs on Thursday 20 September 2018, CRUSER and WIC leadership identified ideas with potential operational merit that aligned with available resources for broader dissemination within the CRUSER community of interest.

A. Concepts and Technologies

Several emerging concepts and technologies were introduced during the plenary sessions on the first three days of the workshop.[2] Teams were encouraged to consider how these concepts and technology injects might benefit combined and allied forces in the scenario presented, but they were not required to include presented technologies in their final selected concepts. Plenary topics included:

- Cross-Domain Operations (CDO)
- Emerging technologies – military robotics and autonomy including FDECO and seabed cables
- Seabed environment and geology
- Undersea infrastructure defense
- Fielding unmanned systems in multiple domains
- Rapid concept generation and innovation
- Moving from concept development to fielding – acquisitions

The knowledge-leveling plenaries on Monday included an overview of Cross-Domain Operations (CDO) from a USFF perspective, a portfolio of emerging robotics and autonomy related technologies from a DoD lab and an industry perspective, and an introduction to elements of undersea infrastructure defense by a leading academic. Participants were also encouraged to look at the seabed as topography much as infantry might look at terrain – considering geologic features and other environmental and meteorological elements that might impact battlespace effectiveness. Tuesday and Wednesday morning each started with broader plenary talks before teams were released to their breakout rooms. The keynote address by the new Vice President of the Defense Acquisition University (DAU), Mr. Frank Kelley, detailed his thoughts on how good ideas move through acquisitions to the field. Throughout the plenaries, speakers several examples of military approaches to innovation – some successful, some not – and lessons learned through past efforts.

B. Concepts of Interest

Key criteria used by the CRUSER selection committee to select concepts from all those proposed for further development were:

[2] A full schedule is available as Appendix C of the full workshop report.

1) Is the concept feasible (physically, fiscally)?

2) Is the concept unique?

3) Is the concept testable?

The following taxonomy of systems was developed from selected concepts presented by each team, as well as additional concepts submitted, but not developed. Identified categories of interest include:

1) ***Counter UxS:*** this topic area includes concepts to counter attacks by adversary autonomous assets (real and virtual) in multiple domains envisioned in a future contested region. Examples of specific concepts within this topic area include *Algorithm Capture* and *Weaponized Autonomous Sensor Persistence (WASP) – many smaller unmanned systems (UxS) blocking and/or attacking another UxS.*
2) ***Cross-Domain Connectivity***: this topic area includes concepts to establish robust and resilient communication networks between autonomous manned and robotic assets operating across multiple domains simultaneously in a future contested environment assuming degraded or denied communications. Examples of specific concepts within this topic area include *Underwater Disaggregated Architecture* and *C3PO for Machines – a universal translator*.
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Unclassified details of these concepts as presented are included in Appendix A of the full workshop report.

III. WAY AHEAD

Of all the ideas generated through the facilitated design process, each team selected concepts to further explore and present in their final briefs. Following the final briefs on 20 September 2018, CRUSER leadership identified ideas with potential operational merit that aligned with available resources. In brief, identified concepts fell into four primary topic areas:

1) ***Counter UxS:*** this topic area includes concepts to counter attacks by adversary autonomous assets (real and virtual) in multiple domains envisioned in a future contested region.
2) ***Cross-Domain Connectivity***: this topic area includes concepts to establish robust and resilient communication networks between autonomous manned and robotic assets operating across multiple domains simultaneously in a future contested environment assuming degraded or denied communications.
3) ***Human-Autonomy Teaming:*** this topic area includes concepts to integrate manned and unmanned assets working as an integrated force in a future battlespace.
4) ***Autonomy for Deception:*** this topic area includes concepts employing autonomy to spoof, decoy, or otherwise deceive future adversary forces, human and robotic.

In addition to the concepts and technology proposals, the September 2018 workshop also supported other equally vital elements of CRUSER's charter: 1) the advancement of general unmanned systems knowledge among the participants; and 2) a greater appreciation for the technical viewpoints for officers, or the operational viewpoint for engineers. The information interchange and relationship building that occurred during this event were characteristic of the workshop venue, and support CRUSER’s overall intent.

A. Warfare Innovation Continuum (WIC)

The Warfare Innovation Continuum (WIC) encompasses the successful research, education, and experimentation efforts, which are currently ongoing at NPS and across the naval enterprise. The goal of the continuum is to align regularly scheduled class projects, integrated research and special campus events into a broad set of coordinated activities that will help provide insight into the opportunities for future naval operations, fleet architectures, and fleet design. Exploring a new topic area each fiscal year, the WIC is a coordinated effort to execute a series of cross-campus educational and research activities that share a central theme. Classes, workshops and research projects are synchronized to leverage and benefit from prior research that results in a robust body of work focused on each annual topic area.

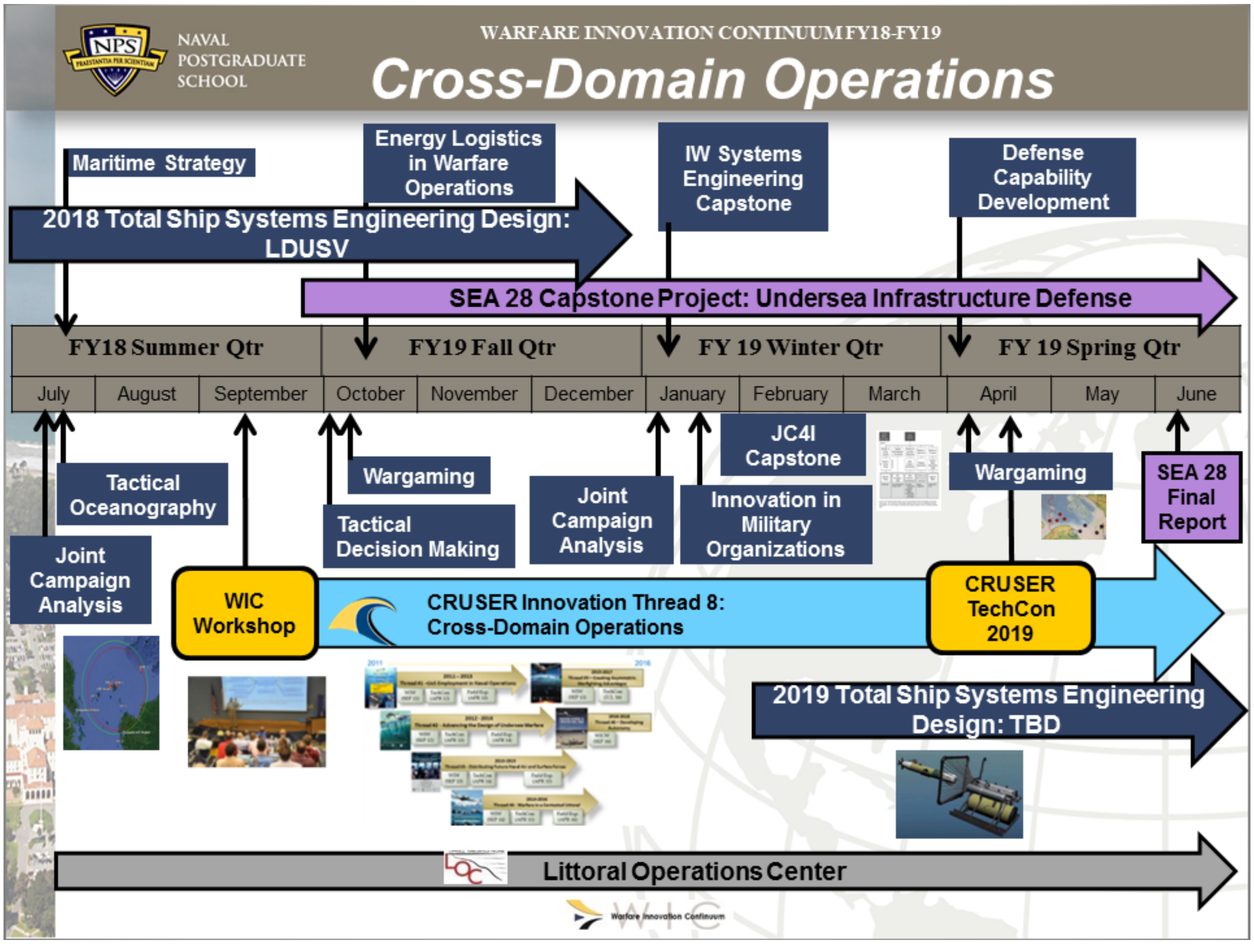

Figure 2. FY18-19 NPS Warfare Innovation Continuum (WIC).

The WIC consists of a series of coordinated cross-campus educational and research activities with a central theme. By incorporating topics of fleet interest into established academic courses and by supporting student thesis project research, students and faculty promote research that aligns with fleet priorities while simultaneously achieving the educational requirements for the graduate students. The FY18-19 WIC, "Cross-Domain Operations" (*see Figure 2*), address the question, *"How might emerging technologies enhance cross-domain operations?"* Final reports are available for all prior continuums dating back to 2013.

B. CRUSER Innovation Thread

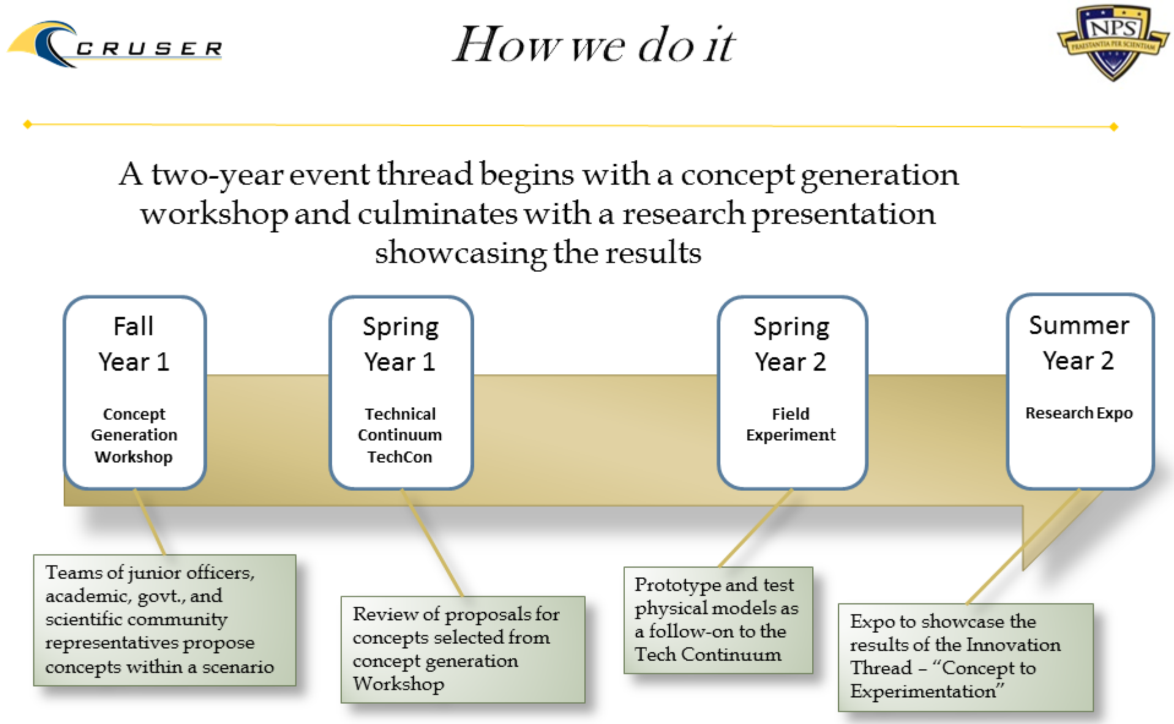

Figure 3. CRUSER Innovation Thread structure.

CRUSER organizes activities around a programmatic Innovation Thread structure (*see Figure 3*) in parallel with the Warfare Innovation Continuum thread. Each innovation thread starts with a concept generation workshop traditionally in September each year. Concepts of merit are identified, and technical members of the CRUSER community of interest are asked to submit proposals on how these concepts might actually work. Proposals are presented at an annual Technical Continuum (TechCon) or demonstrated at the annual NPS CRUSER research fair, and then several are selected to take to field experimentation. Finally, results of field experimentation are presented to CRUSER sponsors and other community of interest members.

Since 2011 CRUSER has made progress along seven innovation threads (*see Figure 4*). The first six Innovations Threads are complete, the seventh thread is underway, and Innovation Thread #8 started with this September 2018 Warfare Innovation Workshop and will finish in FY20.

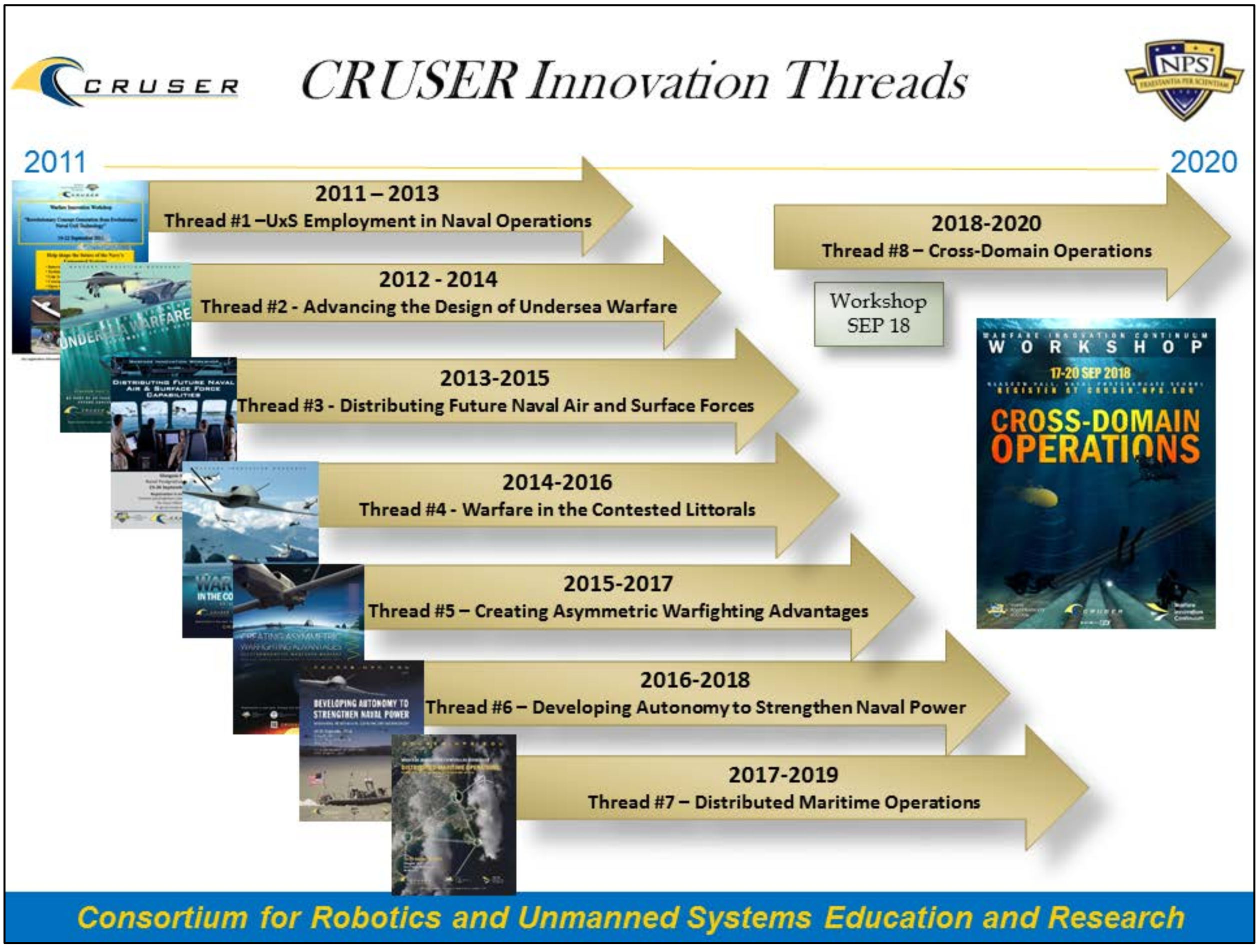

Figure 4. CRUSER Innovation Thread overview as of October 2018.

APPENDIX A: Final Concepts

Five teams presented their final briefs on Thursday 20 September 2018, and were each given 15 minutes to present their most developed and promising concepts. The following concept summaries detail these final presentations. The team working the challenge at the classified level presented on Wednesday afternoon. A truncated, unclassified summary of the concepts they generated is included in this report.

A. Team Ursula

Figure 5. Members of Team Ursula included *(pictured from left to right)* LT John Hawley USN, LCDR Jonathan Durham USN, Dr. Kristen Collar, Maj Christopher Phifer USMC, Trevor Tallos, LT Scott Constantine USN, Kerri Williams, Jeremy O'Neal, and ENS Kylie Bradley USN.

The members of this team (*see Figure 5 and Table 1*) included five junior and mid-level officers from both the U.S. Navy and U.S. Marine Corps, three early career engineers, one NPS faculty member, and three NPS students.

Table 1. Members of Team Ursula (*alphabetical by last name*)

NAME	PERSPECTIVE	AFFILIATION
ENS Kylie Bradley USN	*Undersea warfare*	NPS Undersea Warfare
Dr. Kristen Collar	*Electrical engineer*	JHU/APL
LT Scott Constantine USN	*Air warfare*	NPS Systems Engineering Analysis
LCDR Jonathan Durham USN	*IP officer*	OPNAV N2N6D
LT John Hawely USN	*Facilitator*	USFF
Jeremy O'Neal	*Systems engineer*	L3 Technologies
Maj Christopher Phifer USMC	*Expeditionary warfare*	NPS Physics
Trevor Tallos	*Electrical engineer*	Battelle
Kerri Williams	*Facilitator*	NPS Information Sciences

Team Ursula presented their final generated concepts on Thursday morning, adding “Team PAC-MAN” as their alternate team name to better reflect their ideas. Their problem statement was: *How might we share and enhance knowledge cross-domain?* The team identified an issue across the DoD where from branch to branch of the armed services, and from subsea all the up to space, operators do not get all the available information they need to complete their missions most efficiently and effectively. The team worked from this starting point to generate concepts to critically and tactically move necessary information quickly to those who need it – “one piece of the puzzle all the way across to the other piece of the puzzle.” As they begin their work, the team assumed that our future force would have in place robust cyberspace policies governing this emerging domain, and enhanced and sustainable power capabilities to ensure endurance of operations. The team also assumed a future with enhanced data replication techniques and available local communications.

A team member shared anecdotally their experience working across military branches as being without exception hampered by non-integrated communications equipment, access, and protocols. The team envisioned one system where all operators regardless of branch of service could access the information they required, and communicate with any other team member to help them make the best decision with the best collection of information available. The team imaged future warfighters logging into this one network in preparation for a future operation to gain access to all pertinent information – not just information generated or posted by their own military branch – about their area of operation (AOR). After action reports from previous similar operations, equipment available, and situation reports (SITREPS) for the AOR would all be readily available and not because you “pounded on your intel guy to find out what was going on.” Once your unit is deployed to the AOR, this one network would not only allow your unit to locate equipment and sensors, but would allow you to interact with all these assets seamlessly in real time. Right now sensors are branch specific – “as a Marine I can’t pull information from an Army sensor.” One network would allow for quicker informed decision making “to do our job better”, allow branches to learn from each other, and better understand the adversary through integrated information gathering.

1. *Joint Information Filtration System (JIFS)*

Recognizing this communication obstacle, Team Ursula proposed the *Joint Information Filtration System (JIFS)*. This system will connect across services and cross-domain to help mitigate the current stove piped information sharing obstacles. *JIFS* would allow a future commander to see what sensors are in the field, and to access information in real time to enhance situational awareness. The user would experience a coordinated data feed that is customized to meet their unit needs, not an unwieldy flood of all available data feeds. This orchestrated effort would pull required data and suggest optional data to be accessed upon user discretion, informing our military, improving communications, and enhancing situational awareness. The team gave a Google Maps like example (*see Figure 6*) showing available sensors in a fictional AOR. With one click the user could access the asset point of contact, exact location, mission, and availability. Beyond this active pull feature, AOR data would also be pushed alerting a user if a nearby sensor is triggered with information pertinent to their unique mission. It is then up to the user to pursue a suggested report to consider.

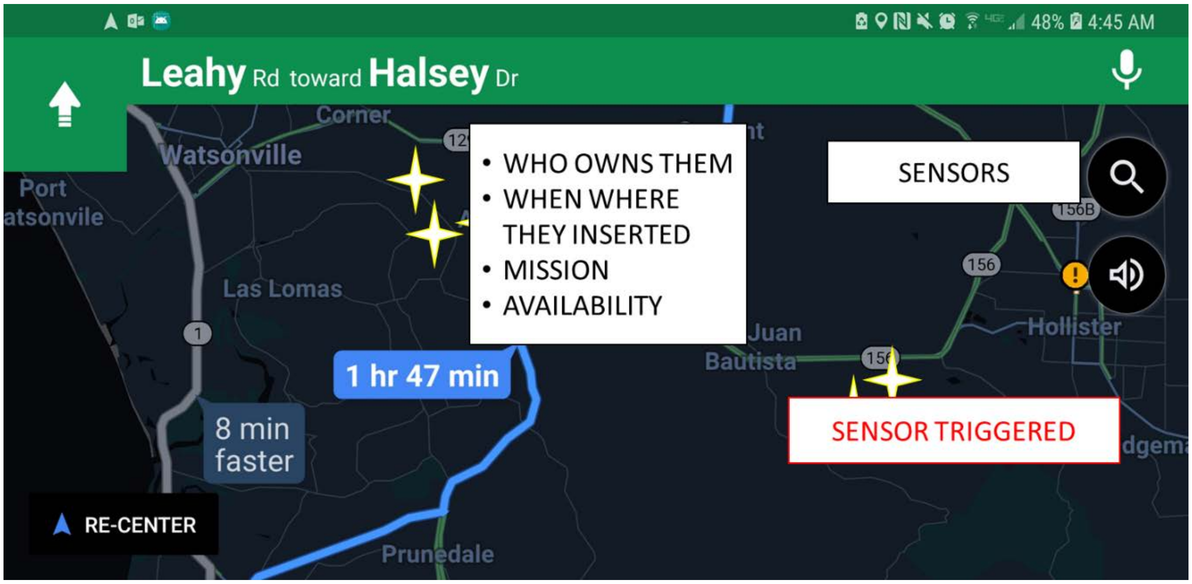

Figure 6. ***Joint Information Filtration System (JIFS)*** **envisioned graphical user interface (GUI).**[3]

This network should incorporate non-traditional sensor feeds as well, such as data collected by sensor assets operated by the National Oceanographic and Atmospheric Administration (NOAA), academic experiments, as well as information collected by our allies. Eventually, *JIFS* would provide command and control (C2) guidance, and would also log meta-data to increase confidence intervals facilitating the use of artificial intelligence (AI) algorithms to improve a unit's battlespace effectiveness and protect human warfighters.

2. C3PO for Machines – Universal Translator

JIFS will assist warfighters by enhancing situational awareness giving commanders more engagement options. Current communications architecture interrupted by organizationally driven stove piping does not allow for the seamless mesh network required to support *JIFS*. To mitigate this obstacle, Team Ursula proposed a "protocol droid for machines" – or a universal translator. In response to a search, *JIFS* will identify sensors already in an AOR. If the data set available is outdated *JIFS* would make the unit aware of the issue and suggest using an available asset of opportunity such as a nearby unmanned underwater vehicle (UUV) swarm to collect new data to reflect current conditions. Once the commander accepts the suggestion, *JIFS* – using this universal translator – sends the swarm to collect the required data relieving the commander of the logistics and planning burden. When a helicopter pilot is assigned to provide a protective screen for a carrier, searching for enemy submarines. Knowing the sound velocity profile of the AOR is essential for mission success. Currently, we physically deploy a mission specific BT buoy. *JIFS* would allow the helicopter pilot to quickly identify pre-deployed assets to provide the required preparation data, rather than using valuable time and resources to deploy an additional asset. Marines preparing for a beach landing might review satellite images of the terrain without any assurance that the imagery is current. A request sent through the universal translator for real time beach imagery would allow *JIFS* to deliver much more useful preparation for the Marine unit.

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[3] Graphic derived from Google Maps.

3. *JIFS* CONOPS

JIFS will give the warfighter the information they ask for, and based on the operator requests *JIFS* will also suggest information that may be useful – allowing commanders to make more informed decisions more rapidly – "better, faster, safer." CNO Richardson[4] has encouraged use of all technological tools available to tighten up our OODA loop.[5] *JIFS* will speed up the observe, orient, and decide phases of that loop. In a future battlespace spanning from subsea all the way to space, *JIFS* will help close network loops across domains and across diverse assets. There is more sensor data available than human operators are able to use effectively on their own. *JIFS* will maximize the utility of the data available in any future AOR. Future AI integrated into *JIFS* will play a central role, augmenting the efforts of a human operator in a timely manner.

Figure 7. Ad hoc mesh network of autonomous nodes working in tandem with human operators (command and control (C2) cell continental U.S. *at right*) providing real-time analyzed data to commanders in the field.[6]

Currently, our networks communicate vertically rather than across services and domains, and are heavily dependent for functionality on human operators. A future envisioned by the Defense Advance Research Projects Agency (DARPA) and others will rely on ad hoc networks between autonomous nodes with a heavy reliance on AI for functionality. Team Ursula suggested staring in the middle of that range, focusing on ad hoc networking with autonomous nodes working in tandem with human operators incorporating emerging AI for functionality (*see Figure 7*). This allows for nimble adjustments based on warfighter stated and perceived needs and battlespace conditions, but does not push us past what is envisioned by 2030 in AI. This will allow engineers time to address initial questions such as: *What fiber*

[4] CNO Richardson remarks, CSIS 25 May 2017 last accessed 8 OCT 2018 at https://www.csis.org/analysis/remarks-cno-adm-richardson

[5] *The cycle of "observe, orient, decide, and act" developed by military strategist and United States Air Force Colonel John Boyd.*

[6] Dr. Tim Grayson, Director DARPA STO "Mosaic Warfare" 27 July 2018. Source: https://www.darpa.mil/attachments/STO-Mosaic-Distro-A.pdf last accessed 24 October 2018

protection do we need for undersea communications cables? What technologies will we need to bridge the sea-air interface, or for effective underwater-to-underwater communications? There are currently significant limitations that we need to overcome to get to the point where this sort of ad hoc networking is possible.

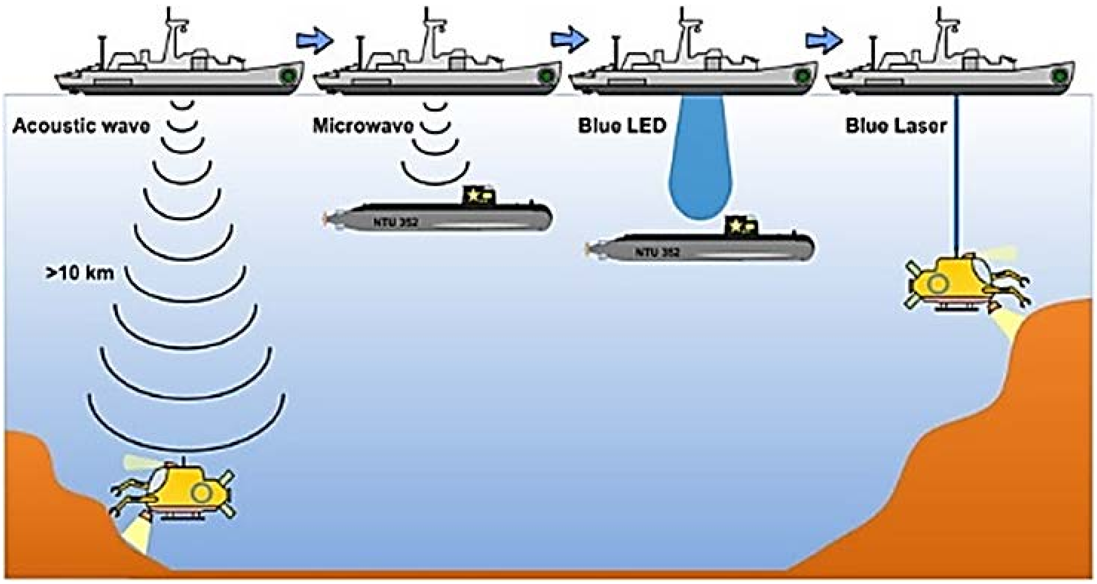

Figure 8. Schematic of acoustic wave-, microwave-, blue LED-, and blue LD-based underwater communications.[7]

Recognizing the significant challenges associated with undersea communications, the team suggested that mitigating current obstacles in underwater-to-underwater networking and communications should be the first step to develop *JIFS* (*see Figure 8*). Underwater-to-air networking and communications will be the next interface to address. Pre-staged optics, such as Blue lasers, may create many new opportunities for underwater communications. A disaggregated network architecture – specifically disaggregated data, such as cloud-based data storage (*see Figure 9*) – will still allow for locally stored data, but will also allow these data sets to inform decisions of the entire force.

[7] Tsai-Chen Wu, Yu-Chieh Chi, Huai-Yung Wang, Cheng-Ting Tsai & Gong-Ru Lin "Blue Laser Diode Enables Underwater Communication at 12.4 Gbps" *SCIENTIFIC REPORTS* | 7:40480 | DOI: 10.1038/srep40480, 17 January 2017. Source: https://www.nature.com/articles/srep40480 last accessed 24 October 2018

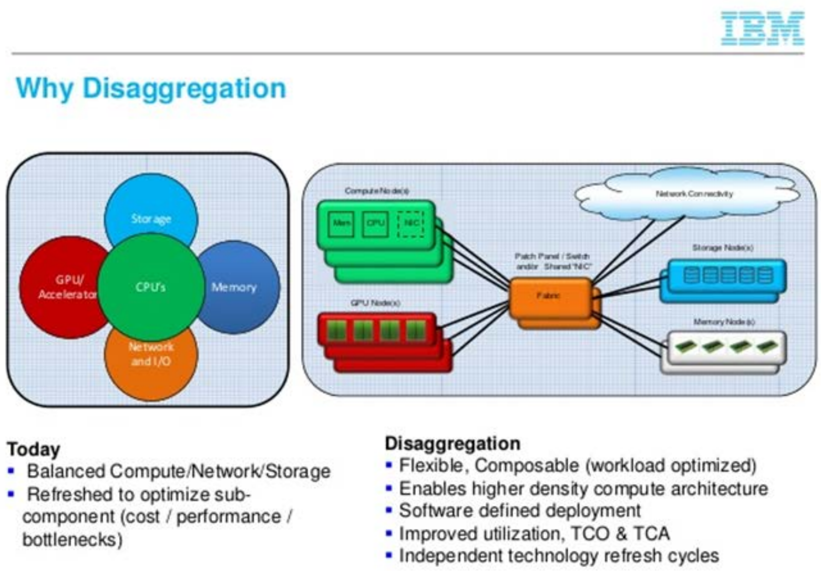

Figure 9. Disaggregation network architecture enables flexible and composable computing while relieving the system of a single point of failure .[8]

Team Ursula proposed that *JIFS* represents a $2M initial development investment, and a startup effort could involve a minimal unmanned vehicle (UxV) swarm of three UUVs, four unmanned aerial vehicles (UAVs), and two unmanned surface vehicles (USVs) focusing on effective situational awareness in an undersea AOR. This mixed asset swarm would use limited AI-enabled push/pull information sharing over a self-forming and self-healing network with a disaggregated architecture seamlessly integrating in situ sensors. The team proposed testing *JIFS* in the NPS Sea, Land, Air Military Research (SLAMR) facility in 2020 on a kill chain mission.

[8] Graphic source: Anand Haridass, Chief Engineer IBM Development for Inspur Power Commercial Systems "The Cloud & Its Impact on IT" Invited Talk, IEEE Electrical Design of Advanced Packaging and Systems (EDAPS) posted 9 SEP 2015. Last accessed 11 OCT 2018 at https://www.slideshare.net/aharidass/the-cloud-its-impact-on-it

B. Team Proteus

Figure 10. Members of Team Proteus included *(pictured from left to right*) LCDR Chris O'Connor USN, LCDR Matthew Larkin USN, Ryan Cummiskey, ENS Austin Douglas USN, Michael LaBarre, Peng Zhang, Capt Benjamin Miles USMC, LCDR James Gowling RAN, and LT Jared Asmus USN.

The members of this team (*see Figure 10 and Table 2*) included six junior and mid-level officers from the U.S. Navy and U.S. Marine Corps and the Royal Australian Navy (RAN), three early career engineers, one foreign officer, one NPS military faculty member, and three NPS students.

Table 2. Members of Team Proteus (*alphabetical by last name*)

NAME	PERSPECTIVE	AFFILIATION
LT Jared Asmus USN	*Surface warfare*	NPS Systems Engineering Analysis
Ryan Cummiskey	*Mechanical engineer*	LMCO
ENS Austin Douglas USN	*Undersea warfare*	NPS Undersea Warfare
LCDR James Gowling RAN	*Information warfare*	Royal Australian Navy
Michael LaBarre	*Engineer, ISR*	JHU/APL
LCDR Mathew Larkin USN	*Facilitator*	NPS Business School
Capt Benjamin Miles USMC	*Tank officer*	NPS Physics
LCDR Chris O'Connor USN	*Facilitator*	USFF
Peng Zhang	*Electrical engineer*	SSC- PAC

Team Proteus named their concept *Ready Player 2* and first presented two primary components – cyber and physical.

1. Virtual Battlefield

Borrowing from the *StarCraft*[9] gaming world, Team Proteus presented a hierarchical virtual battlefield (*see Figure 11*) giving operators a common operating picture (COP). This virtual COP with the ability to update sensors and asset locations in real time using iridium and satellite communications (SATCOM) would display the "big picture" as well as important granularity for mission essential data sets. Operators could also select assets or units to display specific information, and could then select units and move them to different locations within the AOR – the unit would respond autonomously, and idle units could then be tasked to explore an area of interest.

Figure 11. Virtual battlefield graphical user interface (GUI).

The proposed interface is "completely software" – there is no hardware requirement. The AI platforms all use open source software such as *Open AI Gym*[10] and *TensorFlow™*.[11] All the collected data is valuable to create rigorous training for machine learning algorithms based on actual activity in real and tangible environments. This proposed virtual battlespace environment is based on two primary assumptions: 1) that the future cyber domain would be safe, and 2) 95% of users would have on-demand access to the COP to both inform decisions and communicate orders.

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[9] *"On March 31, 1998, Blizzard Entertainment released StarCraft, a revolutionary real-time strategy game pitting three powerful and distinctive races against each other in a war-torn galaxy. In StarCraft, the resourceful terrans, mysterious protoss, and relentless zerg find themselves in a confluence of events that has only one possible outcome: an epic war for conquest and survival."* Source: https://web.archive.org/web/20080402134120/http://www.blizzard.com/us/press/10-years-starcraft.html

[10] ***Gym*** *is a toolkit for developing and comparing reinforcement learning algorithms. It supports teaching agents everything from walking to playing games like Pong or Pinball.* Source: https://gym.openai.com/

[11] ***TensorFlow™*** *is an open source software library for high performance numerical computation. Its flexible architecture allows easy deployment of computation across a variety of platforms (CPUs, GPUs, TPUs), and from desktops to clusters of servers to mobile and edge devices. Originally developed by researchers and engineers from the Google Brain team within Google's AI organization, it comes with strong support for machine learning and deep learning and the flexible numerical computation core is used across many other scientific domains.* Source: https://www.tensorflow.org/

Data and time consolidation is a key element in this virtual battlespace. All the units and sensors in the environment are being updated in real time to provide operators the most recent information available to inform decisions. Not only is all this information being transmitted, but it is also being logged. This allows an operator to use a time scale slider to review past activity, and then scroll to the future for a prediction based on machine learning algorithms or a predicted future location of an individual unmanned asset or swarm operating autonomously. This time slider is a key discriminator in that it intuitively bridges the gap between human users and artificial intelligence. It leverages the power of AI in a display so simple a child could understand it (think weather radar past/future animation). The default view would be a simple clear picture, but the operator could add complexity by clicking on a unit for more complete information or on an enemy asset to view metadata about that asset. Users could draw radii of interest to receive information relevant to their operations while filtering away chaff outside their area of regard.]. Finally, this concept is seamlessly scalable. The same tool will inform the decisions of a combatant command (COCOM)[12] commander as well as an individual drone pilot – same platform, but tailored interface to meet the user's needs.

2. Weaponized Autonomous Sensor Persistence (WASP)

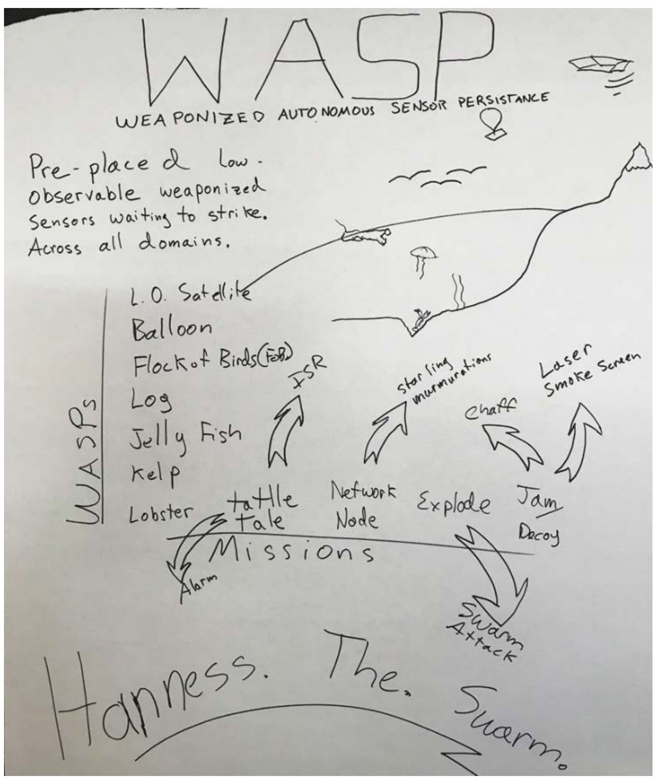

Figure 12. Weaponized autonomous sensor persistence (WASP) concept.

The team named their physical component the *Weaponized Autonomous Sensor Persistence (WASP)*, a prepositioned swarm-of-swarms of low-observable weaponized sensors prepositioned in multiple domains (*see Figure 12*). Depending upon where each individual swarm is operating – the seafloor to

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[12] *The Defense Department has 10 combatant commands, each with a geographic or functional mission that provides command and control of military forces in peace and war.* Source: https://www.defense.gov/know-your-military/combatant-commands/ last accessed 24 October 2018.

space – *WASP* will leverage varied technologies to remain camouflaged. For instance, aerial assets could be made of radar absorbent materials and employ other stealth technologies. Assets operating in the water column could be designed to mimic marine life or blend in with the seafloor itself if deployed primarily in the benthic domain. *WASP* will operate across all domains, and swarm technology will help mitigate the overhead associated with commanding numerous payload-carrying assets individually.

Once prepositioned, *WASP* will wait to be triggered. When it detects a triggering action it will report through the *Ready Player 2* system what it has detected and through what kind of sensor such as an electro-optical trigger, a pressure change in the water column, or an electromagnetic anomaly. The human operator will then make the decision to act or ignore. If the operator decides to engage, WASP will conduct and consummate an engagement using the combination of assets with the highest probability to accomplish the assigned mission – resulting in better targetability and higher mission success. For instance, if the operator decides to go for mission kill on adversary war ship, WASP could target the weapon systems or target the sensors themselves – whatever is determined to provide the highest probability of mission kill. In the future contested theater assets will need to remain passive to avoid being targeted and killed by enemy sensors and weapon systems. WASPs will appear dormant, passively sensing acquiring situational awareness and will autonomously decide when that knowledge is worth transmitting back to the COP.

3. *Ready Player 2* CONOPS

To further describe *Ready Player 2*, Team Proteus described three potential CONOPS.

Cross-Domain Assets

Imagine we have a large displacement UUV (LDUUV) prepositioned on the seafloor, and *Ready Player 2* detects and an enemy UAV threat inbound that could threaten an allied seabed pipeline. Using *Ready Player 2*, an operator could activate the LDUUV to deploy with a nearby swarm of Aquabotix SwarmDivers[13] or any small UUV that the LDUUV could reposition in close proximity to the targeted pipeline for protection. The operator could then decide to airdrop something like DARPA's Ocean of Things – tens of thousands of inexpensive buoys scattered across the surface of the targeted area to serve as sensors and communication repeaters using iridium phones. Balloons could also be deployed to serve as repeaters, closing the detection loop. Through *Ready Player 2* the human operator could confirm a valid contact and authorize prosecution of that target through an order sent down through the "Oceans of Things"[14] buoy array to the UUVs on the bottom – "swarm and kill that contact."

Murmuration

Swarms in the battlespace are not new. However, *Ready Player 2* uses hard-to-detect swarms prepositioned across multiple domains and reconfigurable for multiple missions based on common building blocks. "Laying in Wait" may be one common disposition, waiting to strike while passively sensing. Another building block disposition might be communications related, autonomously forming ad

[13] Reference: http://www.aquabotix.com/ last accessed 16 October 2018

[14] DARPA *Ocean of Things Aims to Expand Maritime Awareness across Open Seas: DARPA envisions ocean-based "internet of things" made of small, low-cost floating sensors.* 6 DEC 2017 Source: https://www.darpa.mil/news-events/2017-12-06 last accessed 20 October 2018

hoc networks when the system identifies a need to transmit data in an emission controlled (EMCON) operational environment or otherwise communications degraded environment. A current challenge in ad hoc mesh networking is the immense amount of data bandwidth required to transmit with a huge number of nodes. Team Proteus proposed mitigating this challenge using a Starling murmuration[15] technique where emergent group behavior results from a simple group goal – so each individual member of the group only needs to communicate with its closest neighbors, not the entire group or back to a command node. This method would allow *Ready Player 2* to scale to an enormous number of nodes without maxing out available bandwidth, and prevent the enemy from gaining an advantage through sheer numbers by flooding the battlespace with our own assets.

Ready Player 2 will remain scalable in the future by incorporating new payloads in response to unforeseen future threats. Imagine payloads such as radio frequency (RF) jamming and launching chaff replaced in the future by payloads and techniques to defend against directed energy attacks on high value units. Aerial swarms might create a large cloud of smoke to physically attenuate the directed energy signal before it could damage a ship.

Cyber Sold

If a hard kill is not appropriate in a particular phase of the conflict, the team proposed a cyber-alternative. Using autonomy for deception and manipulation, their CONOPS *Cyber Sold* forces the enemy to take an action of our choosing. Delivering convincing misinformation about their own system is one proposed option. Initially, a cyber-payload or effect designed to simulate a critical situation requiring immediate action would attack an identified vulnerability in enemy sensors, safety systems, or networks. In a situation where we create coordinated sensor readings that indicate trouble across an implausibly large field may raise enemy suspicions of a cyber-attack, so it is important to scope and target any efforts. To make this cyber CONOPS effective, it is also important to coordinate *Cyber Sold* with a physical effect such as swarming UxVs that look convincing enough to have carried out the attack simulated by the cyber payload. *Cyber Sold* is asymmetric because the autonomous vehicles do not need to be especially “smart” as they do not actually carry out the attack, but only need to operate with convincing complexity. Effects are also reversible which introduces plausible deniability and increases uncertainty for the enemy, giving our forces an advantage.

[15] *Murmuration refers to the phenomenon that results when hundreds, sometimes thousands, of starlings fly in swooping, intricately coordinated patterns through the sky.* Source: https://www.npr.org/sections/13.7/2017/01/04/506400719/video-swooping-starlings-in-murmuration

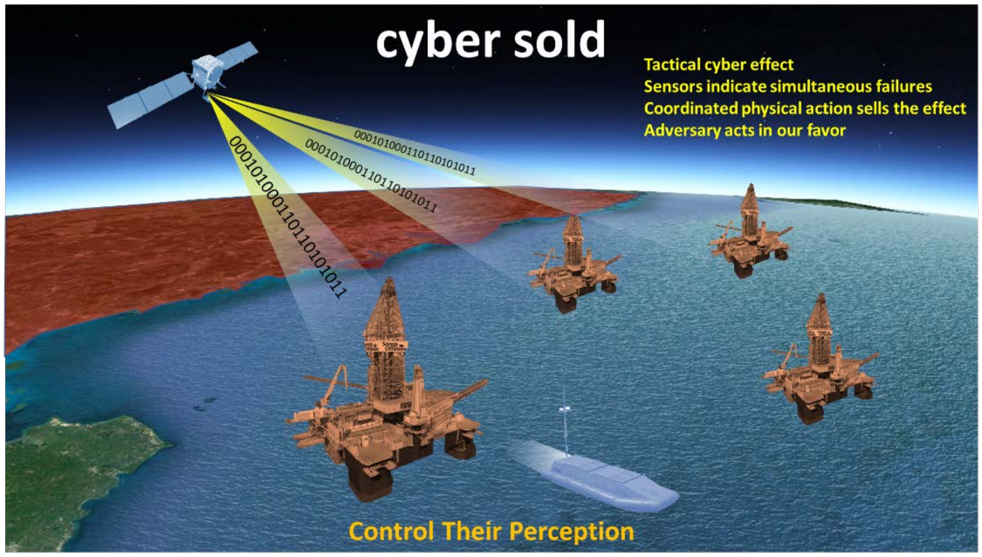

Figure 13. ***Cyber Sold*****, a concept to deliver tactical cyber effects.**

Cyber Sold could be a force multiplier by simulating a military effect, or simulate a natural disaster or random failure. This cyber package could also simulate a non-attributable rouge attack. Non-attribution could be key in any future conflict, introducing just enough uncertainty to gain advantage. A low-input/high-output infrastructure attack in the littoral area such as an offshore oilrig (*see Figure 13*) could be executed in a two pronged coupled cyber and physical manner starting with a cyber package introducing a series of false positive critical alert readings such as chemical imbalances or flowrate issues. These alerts coupled with a visible unmanned asset loitering near the platforms may interrupt enemy operational tempo and slow their decision making cycle as they determine the source of the perceived malfunction or non-attributed attack. Introducing controlled confusion in military and non-military realms may result in a forced shutdown of critical enemy infrastructure while they investigate the perceived threat, diverting attention and resources that might otherwise be opposing allied operations.

C. Team Grindylow

Figure 14. Members of Team Grindylow included *(pictured from left to right*) LT Derek Bergren USNR, Dr. William Elmer VI, CAPT Tony Nelipovich USNR, Stephen O'Grady, Capt Kyle Rainwaters USAF, LT Nick Morgan USN, ENS Christian Sorenson USN, David Swedberg, and LCDR Santhosh Shivashankar USN.

The members of this team (*see Figure 14 and Table 3*) included five junior and mid-level officers from both the U.S. Navy and U.S. Air Force, three visiting engineers, a representative from the Department of Energy, two U.S. Navy reservists, and three NPS students.

Table 3. Members of Team Grindylow (*alphabetical by last name*)

NAME	PERSPECTIVE	AFFILIATION
LT David Bergren USNR	*Submarine Warfare*	ONR
Dr. William Elmer VI	*Civil engineer*	LLNL Department of Energy
LT John "Nick" Morgan USN	*Surface warfare*	NPS Systems Engineering Analysis
CAPT Tony Nelipovich USNR	*Facilitator*	ONR
Stephen O'Grady	*Facilitator*	NUWC Newport
Capt Kyle Rainwaters USAF	*Air warfare*	12th OSS
LCDR Santhosh Shivashankar USN	*Information Warfare*	NPS Computer Science
ENS Christian Sorenson USN	*Undersea warfare*	NPS Undersea Warfare
David Swedberg	*Mechanical engineer*	NSWC Panama City

Team Grindylow presented a concept they titled *DECEPTICON*, a semi-autonomous battlefield creation through deception and lethality optimization. Assuming that the conflict zone is the enemy's backyard, they will start to have uncontested control in every domain. With technologies available today we can deceive and defeat the enemy of tomorrow in which autonomous unmanned systems will dominate the battlefield.

As presented in the scenario, China has home field advantage. They have their naval fleet, the mainland, the island chains, all their other maritime assets such as their fishing fleet constantly collecting signal intelligence (SIGINT), as well as over-the-horizon (OTH) capabilities in the AOR. The problem addressed was that U.S. Forces are outnumbered and their general position is known when operating around mainland China and the island chains. The solution proposed was to prepare the battlefield and confuse the enemy in their own backyard – deceive, disrupt, and destroy enemy intel, communication, detection, and combat capabilities by desensitizing enemy forces with the presence and pre-positioning of autonomous vehicles.

The team proposed a five-element arsenal of autonomous assets as elements of military deception (MILDEC):

1) Saildrone Deception Fleet
2) Seabed Crawler Distractor
3) LDUUV SSN Decoy
4) Trash Cover
5) Dense Swarms for Collaborative Lethality

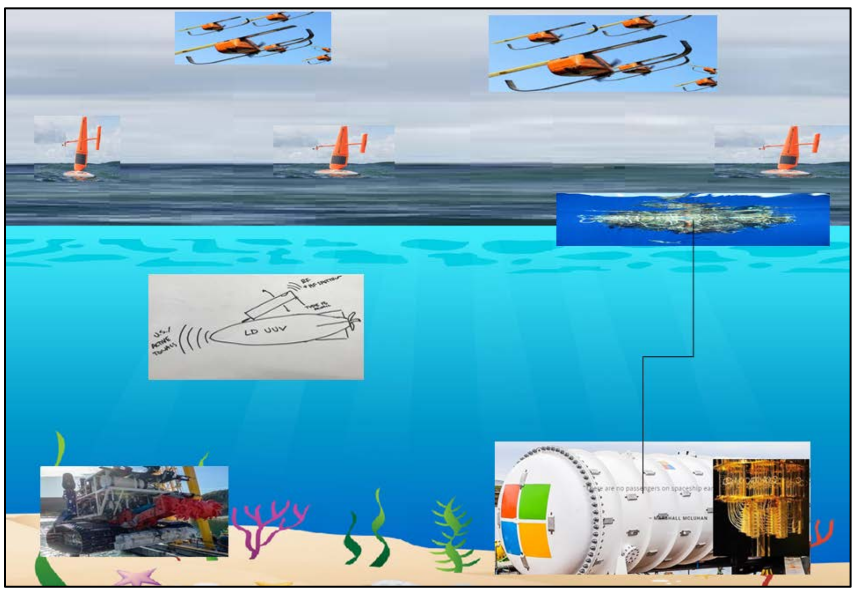

Figure 15. Key autonomous MILDEC elements of *DECEPTICON*.

Deployed together in a cross-domain CONOPS and powered by seabed quantum computing, these elements working in tandem make up their full concept titled *DECEPTICON* (*see Figure 15*). Facing an adversary with sizable forces in their own backyard with extensive surveillance capability will require employment of an offset strategy. *DECEPTICON* will exploit the battlespace, leveraging environmental elements as camouflage to distract the enemy from realizing actual intent, and employ existing and emerging technologies in integrative new ways – across the domains of air, surface, subsurface, and the seabed. *DECEPTICON* will also employ disruptive technology to optimize strike capability, use SIGINT to manipulate enemy attention, and force them to expend resources sorting and filtering inputs to determine what is real and chasing false signals. The cross-domain elements of *DECEPTICON* working collaboratively will ensure maritime superiority in the South China Sea.

1. Saildrone Deception Fleet

Figure 16. Saildrones deployed by the National Oceanographic and Atmospheric Administration (NOAA), 30 June 2018.[16]

An example of available technology to deceive and desensitize the enemy is the saildrone (*see Figure 16*). Prepositioning saildrones or other USVs as weather collection craft will desensitize the enemy as they will be used to the presence of these seemingly innocent assets in international waters near their mainland. These assets would sit dormant until activated for SIGINT collection and transmission. Equipped with radio frequency (RF) transmitters to mimic carrier strike groups or other vessel transmissions to deceive enemy in a future conflict, these assets could conceal the movements of high value assets or create a distraction in the AOR forcing the adversary to commit resources – sending a ship or tasking a satellite – to investigate erroneous signals.

2. Seabed Crawler Distractor

Another proposal to distract the enemy and force them to divert resources is to deploy a seabed crawler (*see Figure 17*). This unmanned ground vehicle (UGV) designed for benthic transit could attract enemy attention through very noisy transit or perceptible interaction with underwater infrastructure leading the enemy believe we are conducting seabed operations (drilling, cutting, or placing assets on the seabed) – ultimately forcing the enemy to commit resources to investigate this seabed disruption.

[16] Pictured: Four saildrones launched from Dutch Harbor, Alaska on30 June 2018, intended to make their way northward, surveying more than 20,000 miles, through Bering Strait and beyond, to measure carbon dioxide and the abundance of Arctic cod in the Arctic Ocean. Last accessed 18 October 2018 at https://www.aoos.org/alaska-ocean-acidification-network/saildrones-are-in-the-arctic-read-the-noaa-update/

Figure 17. Seabed crawler as tested by the ¡VAMOS! Consortium, October 2017. [17]

3. LDUUV SSN Decoy

Using UUVs to deceive enemy forces, forcing them to employ assets to verify and destroy possible submarine subsurface assets, the team proposed a large displacement UUV (LDUUV) with a dummy periscope capable of mimicking a U.S. nuclear powered attack submarine (SSN) periscope (*see Figure 18*).

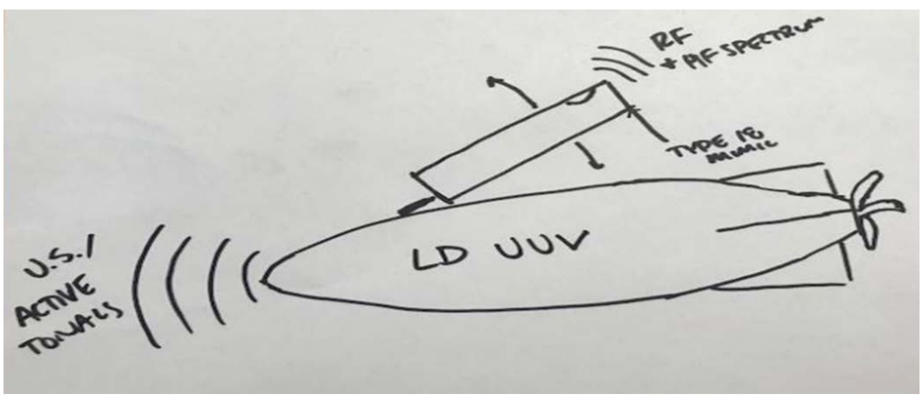

Figure 18. LDUUV with a false periscope and other SSN features deployed as a decoy.

This LDUUV would emit active tonals to mimic known US and allied submarines, and the visual mimicry element type 18 scope would emit RF and HF spectrum signals as the enemy might expect from an SSN.

[17] On the 24th of October 2017 the ¡VAMOS! consortium, Advisory Board Members, and interested external parties were invited for a live demonstration of the ¡VAMOS! technology at the Imerys Minerals Ltd. test site in Lee Moor, Devon, UK. Last accessed 18 October 2018 at http://vamos-project.eu/news/

4. Trash Cover

Once the enemy detects our unmanned assets in their AOR they will likely launch a counter effort to locate and disable our assets. To protect the *DECEPTICON* MILDEC arsenal, the team proposed artificial floating trash (*see Figure 19*).

Figure 19. Proposed "trash cover" element.

If the enemy cannot find our MILDEC assets they cannot disable them. Leveraging a floating raft of plastic trash, *DECEPTICON* assets could hide in plain sight using the trash as cover. These artificial rafts of trash could also emit decoy signals on a random timer, further confusing the enemy and forcing them to commit more resources to investigate suspect signals. When the enemy got close to the suspect signal all they would see would be trash – an unfortunate but common element in most ocean environments – that they would likely ignore and continue their search for the signal source, or abandon the effort. The unmanned assets themselves could also be embedded in the artificial trash raft.

5. Dense Swarms for Collaborative Lethality

A final element of the autonomous cross-domain MILDEC arsenal would be a swarm of heterogeneous UxVs in multiple domains operating in swarms to distract, disorient, degrade and destroy the enemy. These dense lethality-capable swarms leveraging payloads such as directed energy weapons would only be deployed once the conflict reached the kinetic phase – a shooting war requiring kinetic effects. However, operating a large swarm requires individual tasking of each individual asset on the battlefield – which is currently quite human resource intensive. More weapons and operators usually results in a bigger gap between outcome and an optimal solution. Fulfilling commander's intent while optimizing tasking outcome – not leaving unprosecuted targets while avoiding over-kill – requires a new way of operating in a future battlefield.

A networked solution requires too much communication to be effective. To achieve effective distributed lethality in a future battlefield requires precise delivery of smaller warheads within microseconds of one another. The team approached this like a "Traveling Salesman" problem of cross-domain lethal effects, and looked at the United Parcel Service (UPS) for a solution. A UPS driver may have 25 packages in their truck, and we rely on human intuition to choose the best option of the 15 trillion, trillion delivery options. Driving one mile less saves UPS $30 million a year. If UPS purchases $30 million worth of time on Amazon Web Services (AWS) – server farms plugged into the US grid – UPS now has access to about

20 megawatts of computing power[18] that they could now use to autonomously optimize their delivery routing. To access this sort of computing power in a future battlespace to optimize collaborative lethality of dense swarms the team proposed a combination of two existing technologies – an underwater data center using quantum computing (*see Figure 20*).

Figure 20. Seabed quantum computing center.

A quantum computer could solve the dense cross-domain swarm tasking optimization swarm problem with only 10 kilowatts of power, however it produces a lot of heat while doing so. Microsoft has placed a data center on the seabed in the North Sea allowing the naturally cold ocean waters to carry away heat leaving the technology functioning at an operationally sound temperature. Placing a quantum computer on the seabed in the AOR would solve the optimization and heat problems. Batteries could power this proposed seabed quantum computing center for several days, and could be replenished by the same UUVs that masked the initial delivery of the seabed computing asset which is envisioned as either a CONEX[19] style container or designed to look like a natural seabed element such as a volcanic seamount or large rock. The LDUUV might also be an ideal resupply vehicle, and the seabed quantum computer could leverage the trash covers as communications nodes. Complete internal processing means that the quantum computing center would not impact the communications network traffic while calculating all possible options for optimization.

Once placed the seabed quantum computing center would run “dark” only responding when “pinged” to deploy antenna to the surface with trash disguise. The Commander would then feed battlespace awareness inputs such as the costs and benefits associated with different assets, order of battle, Commanders intent, and the locations and capabilities of all assets in the AOR – allied and enemy, as well as the ideal end state. Using these inputs, the seabed quantum process would go dark again to compute optimal cross-domain swarm tasking, and when complete would go live again to transmit a

[18] A tenth of what a U.S. aircraft carrier generates

[19] *In 1948 the U.S. Army Transportation Corps developed the "Transporter", a rigid, corrugated steel container, able to carry 9,000 pounds (4,082 kg). It was 8 ft 6 in (2.59 m) long, 6 ft 3 in (1.91 m) wide, and 6 ft 10 in (2.08 m) high, with double doors on one end, was mounted on skids, and had lifting rings on the top four corners. After proving successful in Korea, the Transporter was developed into the Container Express (CONEX) box system in late 1952.* Source: Wikipedia https://en.wikipedia.org/wiki/Conex_box last accessed 24 October 2018.

battle plan in one blast to the Commander for action. This optimum battle plan to deliver maximum lethality in a combined strike – integrating Tomahawks on surface platforms, drones preposition in the AOR on the seabed, in the water column, on the surface, and in the air – concludes the information war! Upon Commander approval, the battle plans would be forwarded to assets in theater for execution.

6. Undeveloped Concepts

As requested by workshop leadership, Team Grindylow submitted the following list of concepts generated during their divergent work, but not developed:

- DNA trail for attribution. Use by Special Operations Command (SOCOM) or ground locations?
- *Jefferson Starship* – high-power microwave (HPM) equipped UAVs or UXVs
- *Pipe Rider* - rail on underwater cable; checks for hacks / threats / UUV
- *Proa-type* - indigenous, low cost sailing drones. Provide components in form of kits (easy to assemble) that friendly, local populations would use to disrupt enemy forces. Kits would be easy to deploy (via air, surface, etc)
- *Det-Ruptor* - multi- modal UxV (UAV to UUV, for instance) to locate / identify / report / disrupt enemy sensors or weapons in localized area of interest using electromagnetic pulse (EMP)
- *Fuzz Buster* - HF disruption device which knocks or washes out communications for "fishing" / small vessels
- *Sea FART* – utilizing underwater methane deposits to sink enemy ships
- *Flipper* – rotary launcher for torpedo tube with miniaturized explosively-pumped EMP missiles.
- *Glider Mines* – smart, mobile sea mines utilizing existing water glider propulsion to transit to littoral choke points

D. Team Kraken

Figure 21. Members of Team Kraken included *(pictured from left to right*) Lance Lowenberg, George Hwang, Jay Melillo, LT Bryce Christensen USN, Maj Clayton Schuety USAF, LT Todd Coursey USN, LT Joseph Hanacek USN, and Michael Graves (*not pictured, LT Meghan Wilkens USN*).

The members of this team (*see Figure 21 and Table 4*) included five junior and mid-level officers from both the U.S. Navy and U.S. Air Force, four visiting engineers, and four NPS students.

Table 4. Members of Team Kraken (*alphabetical by last name*)

NAME	PERSPECTIVE	AFFILIATION
LT Bryce Christensen USN	*Naval aviation (rotary)*	NPS Business School
LT Todd Coursey USN	*Facilitator*	NPS Physics
Michael Graves	*Electrical engineer*	JHU/APL
LT Joseph Hanacek USN	*Surface warfare*	NPS Systems Engineering Analysis
George Hwang	*Autonomy engineer*	NAWCAD/NAVAIR Pax River
Lance Lowenberg	*Robotics engineer*	SSC-PAC
Jay Melillo	*Engineering management*	NUWC Newport
Maj Clayton Schuety USAF	*Air warfare*	NPS Defense Analysis
LT Meghan Wilkens USN	*Facilitator*	USFF

Computational power has been increasing at an extraordinary rate and has been for quite some time. Moore's Law[20] holds that computational power will double every 18 months to two years. Although popularized in the 1970s, this axiom has held true since the early days of mechanical switches and vacuum tubes through to today's silicon wafer based nano-transistors. As the team looked to 2030, they did not assume only slightly better technology as that is not what happened in the past – they anticipate exponential advances in technology, and started their ideation with that assumption.

Figure 22. OpenAI Five playing the best OpenAI employee team, 2018.[21]

Based on the initial assumption of exponential technological advances, they also assumed a tremendous capability to analyze massive amounts of data will be a near future state. In experimentation with

[20] *Moore's Law is a computing term which originated around 1970; the simplified version of this law states that processor speeds, or overall processing power for computers will double every two years.* Source: http://www.mooreslaw.org/ last accessed 19 October 2018.

[21] Photo source: https://blog.openai.com/openai-five/ last accessed 19 October 2018.

AlphaGo Zero[22] and OpenAI Five[23], AI was able to train an algorithm to beat the best Dota players. Team Kraken titled their overall concept *BATTLE-SIM*, a computational simulation and modeling of the battlespace. Predictive machine learning algorithms can simulate possible outcomes and effects based on world conditions in order to guide strategic policy. Given the right initial conditions, using a strategic planning algorithm AI will be able to effectively predict the strategic outcome of an entire battle scenario. However, they cautioned that a simulation is only as good as its initial conditions. A robust and useful output is directly correlated to the quality of inputs.

"We think this is how to win, but how do we get the data to build the right initial conditions?"

With good data – geography, weather, friendly and enemy assets – and then a clever algorithm will be able to predict each move, and the outcome of each move throughout a full battle scenario. In the future we will need field sensors to provide reliable data to develop high-fidelity simulations. Team Kraken proposed three new concepts to generate the data needed for *BATTLE-SIM* to be effective:

1) ***FellyFish***: biomimetic jelly field sensors
2) ***SmellyJelly***: decentralized swarm control using digital phermones
3) ***ThirdEye***: human and environmental data tagging

A high fidelity simulation will give decision makers what they need to be successful. To build the right simulator requires the right inputs. "*To get good sim you need good data*." Working backwards from that ideal data set the team proposed a three step query: *What will it take to get that in real time; what do we need to do in the interim to get us the data in the field when we need it; and what can we start doing today?* We need a swarming collection of intelligence gathering assets. In order to get to this point by 2030, we need to start providing training and tagging data now for that level of technology we will need.

1. *FellyFish* Fiber Sensors

Producing an accurate simulation requires a robust data set. This requires robust sensing. Fiber optics is an offset technology and is primarily used for communications; however, fiber optics could also be used for sensing. If you make changes in the fiber structure you get a reflective wave length called a frag wave length. So anything that changes that microstructure and gives you a reflective wave length will give you a sensing element (*see Figure 23*). With fiber optics, you could sense temperature, strain, pressure, sound waves, and even magnetic anomalies. A fiber about the size of a human hair has multiplexing capabilities. You could have multiple fibers depending on how many microstructures you

[22] *AlphaGo Zero is the latest evolution of AlphaGo, the first computer program to defeat a world champion at the ancient Chinese game of Go. Zero is even more powerful and is arguably the strongest Go player in history.* Source: https://deepmind.com/blog/alphago-zero-learning-scratch/ last accessed 19 October 2018.

[23] *Our team of five neural networks, OpenAI Five, has started to defeat amateur human teams at Dota 2. […] OpenAI Five plays 180 years worth of games against itself every day, learning via self-play. It trains using a scaled-up version of Proximal Policy Optimization running on 256 GPUs and 128,000 CPU cores […]*. Source: https://blog.openai.com/openai-five/ last accessed 19 October 2018.

make. For instance, a ten-foot fiber could provide you hundreds of sensing elements, and all of these sensing elements could sense different things all along the same length of fiber.

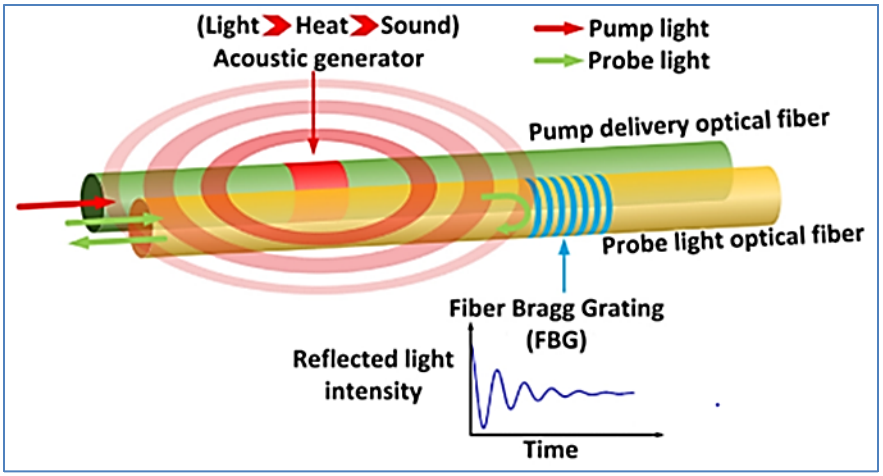

Figure 23. The principle of operation for a single AFO-SHM sensing node.[24]

The team proposed operationalizing these lengths of fiber optic sensing cables as swarms of biomimetic jellies UUVs with fiber optic "tentacles" (*see Figure 24*) with multi sensor capabilities such as acoustic, electromagnetic, and thermal. These *FellyFish* might sense a submarine or UUV by picking up a magnetic anomaly or acoustic signature. The fiber optic sensor may also pick up a change in pressure as something moves through the water column. Using machine learning we might also *train* these systems to *hear* specific harmonic or acoustic sounds in the water.

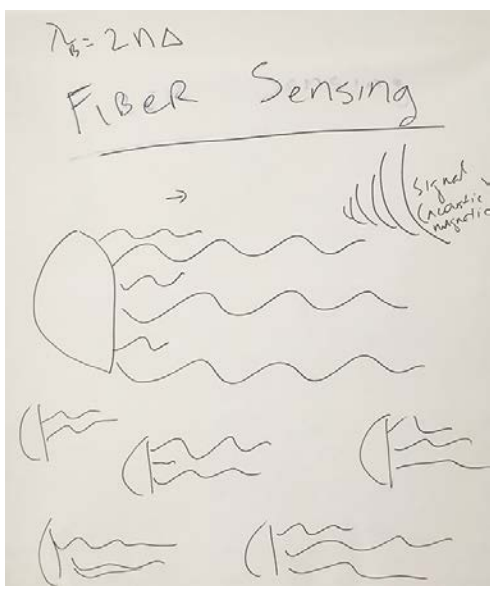

Figure 24. *FellyFish* concept would use jelly biomimicry replacing a jelly's tentacles with fiber optics.

[24] Photo source: Physics.org https://phys.org/news/2016-09-fiber-optic-harsh-environments.html Credit: Optics Express (2016). DOI: 10.1364/OE.24.020287.

Saturating the battlefield with sensors will provide the most ideal data set for the most accurate simulation. However, this saturation presents challenges such as asset mobility, control, communications, data export, and persistence.

2. *SmellyJelly* Decentralized Swarm Control

In order to collect the required data will require some sort of algorithm that works with UxVs in multiple domains operating in a swarm, which the team defined as 1,000 or more cheap and simple vehicles acting synergistically to achieve a collective objective. Collecting required data and achieving required level of autonomy simultaneously may require a tradeoff in computational capability. There are heavy computational costs required to centralize swarm operations. The team proposed “souping up” inexpensive UAVs to maximize their data collection capabilities, and address command and control through simple digital means. To minimize the amount of autonomy required to maximize data collection the team proposed digital pheromones, titling their concept *SmellyJelly*.

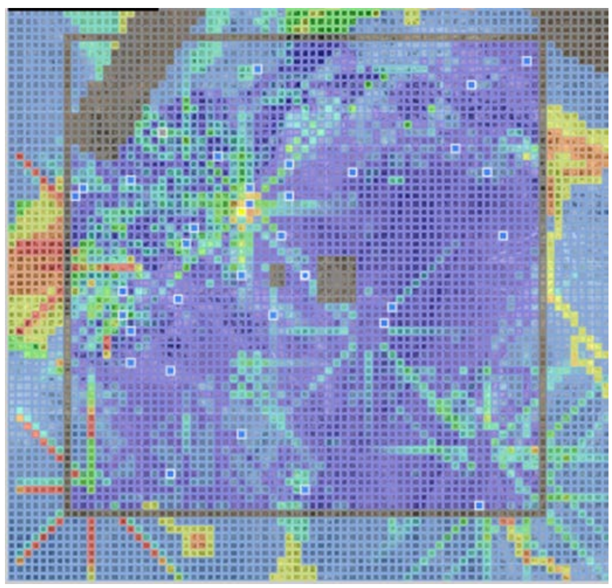

Figure 25. Digital pheromones conveying a common operating picture (COP) to UxVs in multiple domain on an ISR mission.[25]

Digital pheromones are low power signals, or other digital or physical signature, that allow us to convey very simple behavioral instructions to drive a swarm’s search characteristics in a contested environment. Pheromones build individual agent’s COP and then relayed to other vehicles in a mesh network building the whole picture. Instead of collecting data, pheromones would incorporate grid space and operational environments, localizing communication amongst the swarm. If a swarm of cross-domain UxVs are tasked with an intelligence, surveillance, and reconnaissance (ISR) mission, multiple vehicles may identify targets and will convey that information to the rest of the mission assets using digital pheromones appearing in the form of heat map (*see Figure 25*) creating the full network COP. Based on this simple information transfer, multiple assets will converge on the areas of interest. Harnessing

[25] Adapted from NPS thesis research by Maj Clayton Schuety USAF and Maj Lucas Will USAF, anticipated graduation December 2018

emergent behavior from simple interactions will minimize computational power required for autonomous operations, maximizing data collection capability.

Although the localized communication of this digital pheromone swarm is harder to jam or deny, communication challenges are still present. Other challenges include deconfliction and self-organizing.

3. *ThirdEye* EEG/EMG Bio Sleeve

There is a need for good data – data that has been tagged and processed, that is then useful to feed into machine learning algorithms or combat simulators. Using human operators teamed with machines to collect this data in a new way, the team proposed *ThirdEye*. What if we could have real time tagging of incoming data as the operator sees or experiences it?

The *ThirdEye* is a human to machine interface that allows the user to tag images using subvocal communication technology. By just looking at an object, or even just thinking about environmental elements present, an operator could quickly create a sharable COP (*see Figure 26*). Taking the burden off the operator, *ThirdEye* contributes to data collection to help train strategic wartime simulations.

Figure 26. *ThirdEye* graphical user interface (GUI).

Imagine soldiers out on patrol with *ThirdEye* technology integrated into their helmets and gear. Tracking the human operator eye movements, *ThirdEye* would be able to correlate the operator eye movements with the element of interest in their surroundings. Coupled with a technology developed by NASA enabling subvocal communication,[26] *ThirdEye* would be able to read the neural impulses sent to the operator's voicebox to receive commands without vocal input. All this tagged data would then be autonomously fed into the battle simulator to create a real time COP.

[26] NASA subvocal speech demo (2004): https://www.nasa.gov/centers/ames/news/releases/2004/subvocal/subvocal.html last accessed 20 October 2018.

To manage the amount of data the human-in-the loop needs to process and avoid cognitive overload, biometric data could be used to train an algorithm to filter relevant data to the human in the human-autonomy team. Leveraging persistent and cumulative biometric monitoring (*see Figure 27*) using electroencephalogram (EEG) inputs and electromyography (EMG) *ThirdEye* would allow the network to supportively respond to the condition of the human operator. The biometric feedback to the system will allow *ThirdEye* to detect operator information saturation so the network will optimize the presentation of the required COP information, or task the UxV partner to operate at a higher level of autonomy allowing the human operator to focus on other tasks until conditions change. This scalable autonomy based on operator or mission conditions will ensure the machine team elements are a continuous asset to the unit.

Figure 27. Persistent biometric monitoring of human operators.[27]

ThirdEye promotes human-machine teaming through a cooperative interface. The operator would be able to identify threats, and based simply on cerebral inputs, such as eye movements, the autonomous machine team member – such as a UAV – would be familiar enough with the individual pilot (*see Figure 27*) to investigate and, if warranted, prosecute the threat and provide more data to the user. Like *J.A.R.V.I.S* in *Iron Man*[28] or *Siri*[29] on steroids – *ThirdEye* is a system that would be able to interact with the human and actually have a conversation. If, in training environments, the human team member presents a set of standard bio inputs this profile would then be used by the machine team member as a standard profile in future missions. If the human presents alternate inputs, the UxV team member

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[27] *Pulling heavy G-forces can cause a pilot or astronaut to black out. A biometric sensor could monitor heart rate and other indicators to give a warning when he or she hits a danger zone.* "Biometric Sensors Optimize Workouts" NASA Spinoff. Source: https://spinoff.nasa.gov/Spinoff2018/hm_2.html last accessed 24 October 2018.

[28] *J.A.R.V.I.S. (Just A Rather Very Intelligent System), is Tony Stark's artificially intelligent computer. It is programmed to speak with a male voice in a British accent*. Source: http://marvel-movies.wikia.com/wiki/J.A.R.V.I.S. last accessed 20 October 2018

[29] *Siri (pronounced /ˈsɪəri/ SEER-ee) is a built-in, voice-controlled personal assistant available for Apple users. The idea is that you talk to her as you would a friend and she aims to help you get things done, whether that be making a dinner reservation or sending a message.* Source: https://www.pocket-lint.com/apps/news/apple/112346-what-is-siri-apple-s-personal-voice-assistant-explained last accessed 20 October 2018

would be able to identify this behavior and assist the human to mitigate their stress to bring them back to the operational environment and threats at hand.

4. *BATTLE-SIM* CONOPS

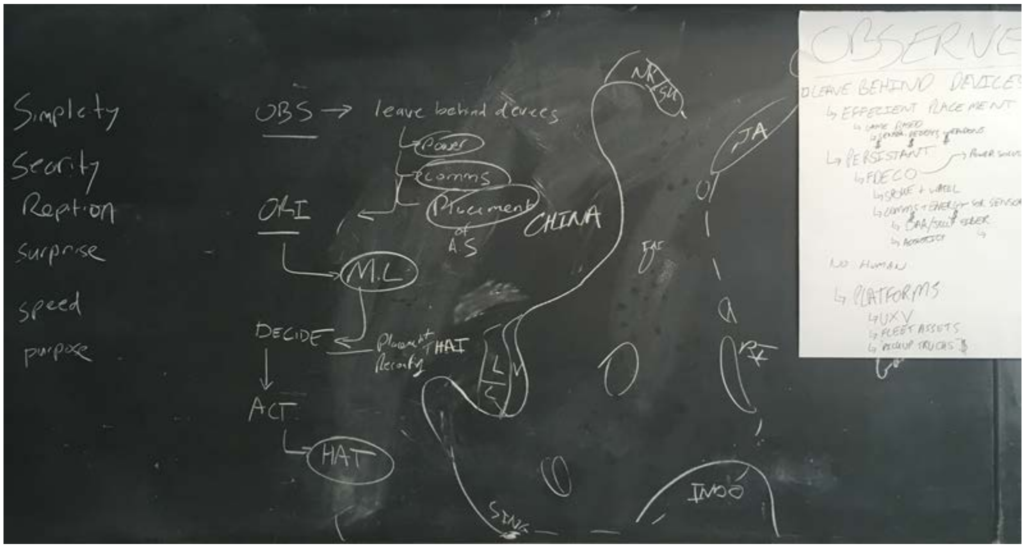

Figure 28. Team Kraken *BATTLE-SIM* CONOPS in three phases.

Team Kraken then presented a *BATTLE-SIM* CONOPS in the South China Sea structured in three phases:

1) observation and reconnaissance
2) collection and orientation
3) decide and act

Due to threats to human life at the start of any potential conflict, allied ships in the AOR will likely get pushed out of the South China Sea. Employment of technology and UxVs in multiple domains enable us to take precautions to protect human life and still present and active forward presence and engagement. Prior to their departure for the AOR, ships would be required to maintain a myriad of unmanned assets on board in the event of conflict. These UxVs would use systems, information, and data already preloaded to autonomously execute missions such as: insert themselves into enemy territory, hide amongst shoals and reefs to gather copious amounts of data, and work amongst one another to coordinate and send data back to the ships and other personnel. This minimizes human threat and maximizes technology to our advantage to still maintain “eyes on target.”

Observation and Reconnaissance

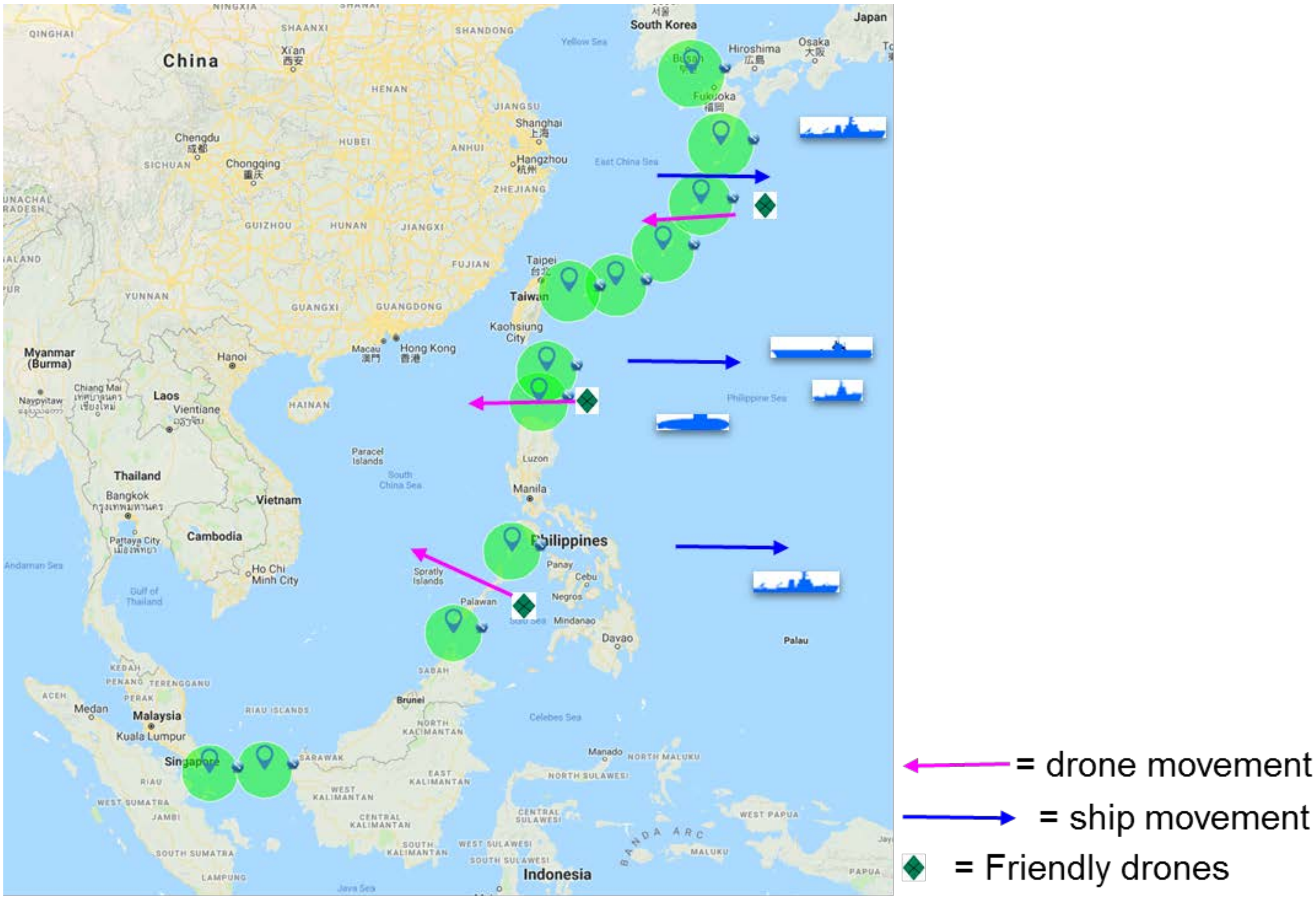

Figure 29. *BATTLE-SIM* CONOPS OV-1 observation and reconnaissance.

To address the first of the four phases of the OODA loop,[30] phase one of the *BATTLE-SIM* CONOPS is observation and reconnaissance. *BATTLE-SIM* integrates artificial or unmanned intelligence for reconnaissance, minimizing the risk to human lives. By 2025 all ships will be required to have ample UxV equipment on board and be ready to offload these assets overboard at a moment's notice and then egress the high risk areas. At the start of a conflict, units forward deployed in the AOR would deploy a massive swarm of UxV assets (*see Figure 29*) with fiber sensors and use digital pheromones to quickly build a COP. Using existing high-voltage direct current (HVDC) lines,[31] the UxV swarm would autonomously develop war tactics, recommend courses of action (COAs), and determine their own efficient locations in water to hide and operate to remain safe for prolonged usefulness.

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[30] *Observe, orient, decide, act*

[31] *HVDC (high-voltage direct current) is a highly efficient alternative for transmitting large amounts of electricity over long distances and for special purpose applications. As a key enabler in the future energy system based on renewables, HVDC is truly shaping the grid of the future*. Source: https://new.abb.com/systems/hvdc last accessed 20 October 2018.

Collect and Orient

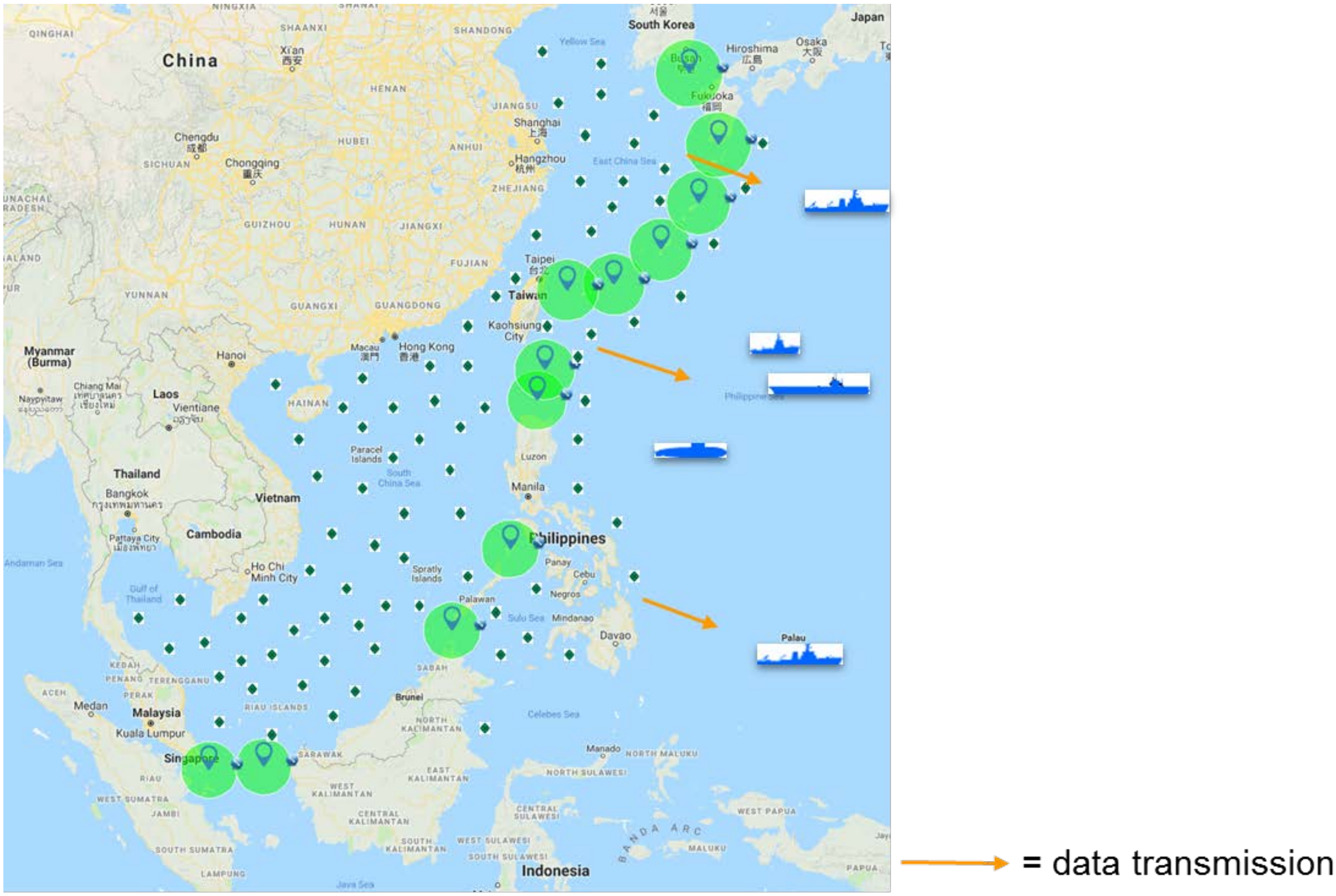

Figure 30. *BATTLE-SIM* CONOPS OV-1 collect and orient.

Not only will a large swarm of UxVs meet the data collection need for *BATTLE-SIM*, but flooding the South China Sea with biomimetic swarms of jellyfish-like autonomous vehicles (*see Figure 30*) would overwhelm the enemy. Drawing focus to the unmanned systems within their territory would force the enemy to redirect resources to investigate and drawing their attention away from other allied force activity and movement. This may also force a prolonged conflict and starve the enemy of resources and any potential advantage in battle they may have previously established. Data fed back to *BATTLE-SIM* for analysis would result in multiple possible COAs, some of which would come at the recommendation of the UxVs themselves.

Decide and Act

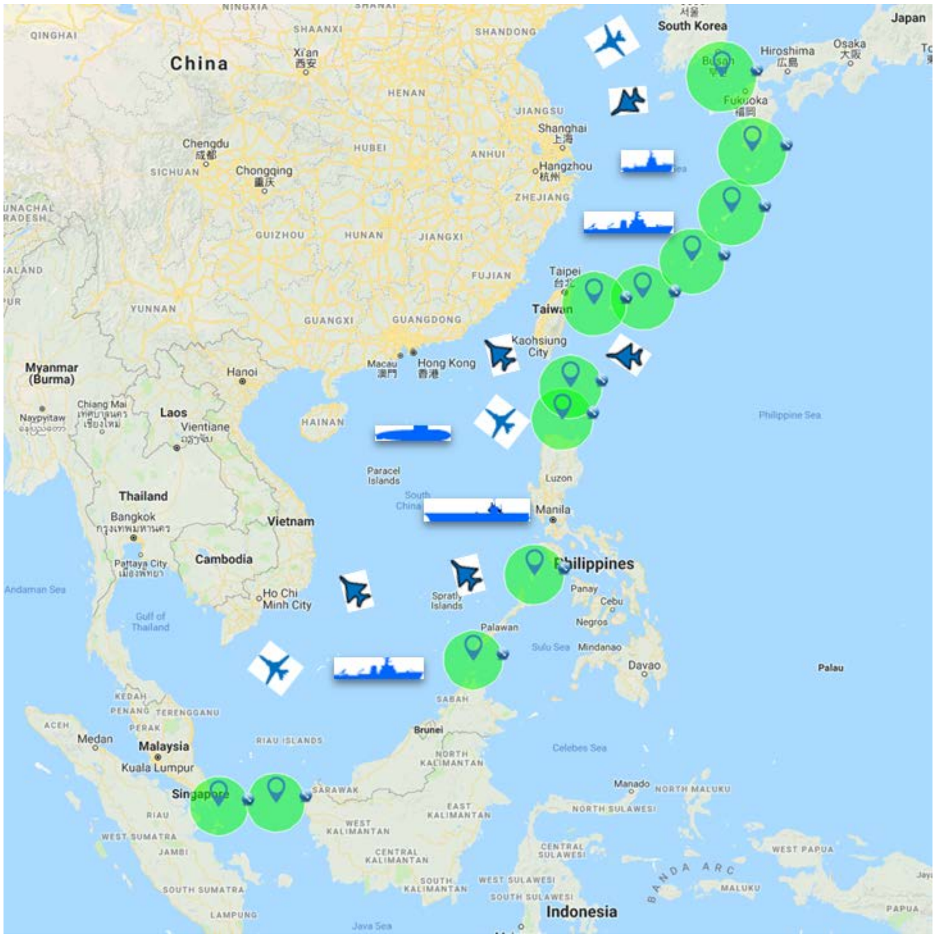

Figure 31. ***BATTLE-SIM*** **CONOPS OV-1 decide and act phase.**

With loss of human life minimized, leadership will chose a *BATTLE-SIM* developed and recommended COA, and send physical assets and personnel to coordinate with the UxV swarm to conduct offensives (*see Figure 31*). Employing human systems integration through persistent biometric EEG/EMG bio sleeve feeds (*see Figure 32*) in coordination with the autonomous UxV swarm, the AOR command would act – moving human assets such as ships, submarines, and aircraft to strategic points in the AOR for the next phase of the conflict.

Figure 32. Flight demonstration using EMG Bio-sleeve.[32]

5. Undeveloped Concepts

The following are the runner up technologies that would also be required or would contribute significantly towards aiding US forces in a 7th fleet conflict in 2030.

Tag as You Go

On the same page as the *ThirdEye d*ata collection process in order to supplement better AI, there is no need to wait for high tech solutions to data collection. In fact, even with those systems in place, without the right human efforts to build the formation of data collection, a tool like *ThirdEye* would only be of limited use. In the meantime, the DoD could implement simpler software solutions that would allow watchstanders to "tag" sensor video and audio data either while they are on watch or in after action "tape sessions." In much the same way that a football team will get together and watch post-game video of themselves and other teams to identify strengths, weaknesses, and other important inputs, DoD personnel should be conducting similar evolutions to build up a database of potentially important information so that when AI collection systems begin to come on line, they already have a database from which to work with and build upon.

[32] *NASA Ames Technology Capabilities and Facilities, Extension of the Human Senses: This research group specializes in developing alternative methods for human-machine interaction as applied to device control and human performance augmentation.* Source: https://www.nasa.gov/centers/ames/research/technology-onepagers/human_senses.html last accessed 24 October 2018.

FSO Communications Network for Denied Environments

Figure 33. UAV "Airship" used for free space optical (FSO) communications.[33]

Long duration UAV swarm concept, perhaps leveraging hybrid airship (*see Figure 33*), employs a ship, USV, UUV, or shore station-launched network of strategically placed UAVs to provide medium range free space optical (FSO) communications in a conventional communications-denied environment. This technique might be considered in conjunction with improved blue laser communications.

HVDC Island Connecter

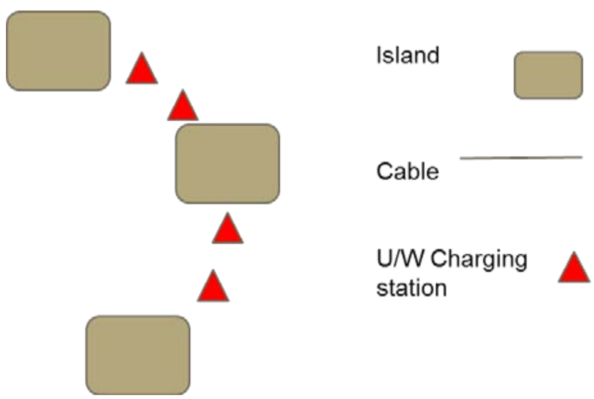

Figure 34. HVDC *Island Connector* concept.

The team considered an HVDC power line connecting island islands (*see Figure 34*) from South Korea to Singapore, providing charging stations for UXVs and other assets defending the allied island chains. The team also considered deploying fiber sensors on biomimetic jellyfish UxVs to augment this concept (*see Figure 35*).

[33] Eric Adams "Lockheed's Hybrid Airship Is Part Blimp, Part Hovercraft, No Hot Air" *WIRED* 7 October 2016. Source: https://www.wired.com/2016/10/lockheeds-hybrid-airship-part-blimp-part-hovercraft-no-hot-air/ last accessed 24 October 2018.

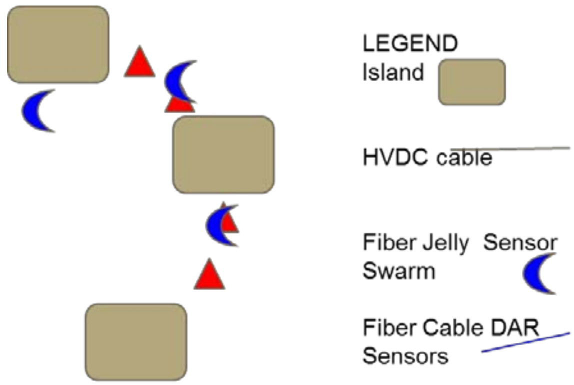

Figure 35. Biomimetic jelly UxVs with fiber sensors deployed to augment HVDC *Island Connector* concept.

E. Team Hydra

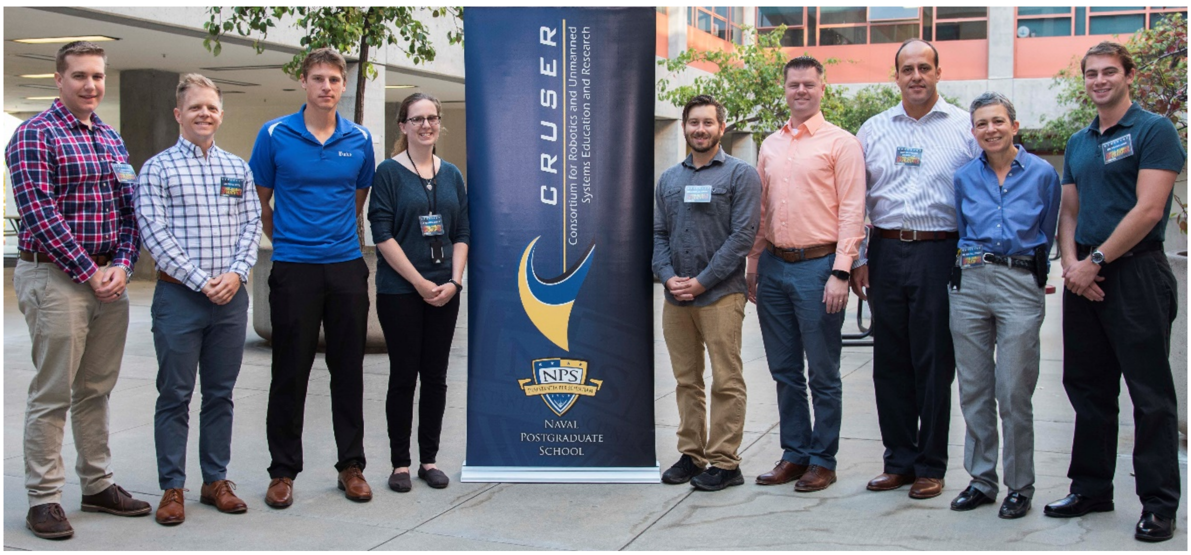

Figure 36. Members of Team Hydra included *(pictured from left to right)* LT Jonathan Formanek USN, Dr. Brian Reitz, Dr. Andrew Schicho, LT Kristen Ainslie USN, Dr. Michael Ouimet, LCDR Brian Newgren USN, CDR Santiago Carrizosa USNR, Ann Gallenson, and Travis Aion.

The members of this team (*see Figure 36 and Table 5*) included four junior and mid-level officers from the U.S. Navy, four visiting engineers, one U.S. Navy reservist, one NPS faculty member, and three NPS students.

Table 5. Members of Team Hydra (*alphabetical by last name*)

NAME	PERSPECTIVE	AFFILIATION
LT Kristen Ainsle USN	*Submarine warfare*	NPS Undersea Warfare
Travis Aion	*Facilitator*	TANG JHU/APL
CDR Santiago Carrizosa USNR	*Oceanography*	ONR
LT Jonathan Formanek USN	*Surface warfare*	NPS
Ann Gallenson	*Facilitator*	NPS Center for Executive Education

LCDR Brian Newgren USN	*Air warfare*	NPS Systems Engineering Analysis
Dr. Michael Ouimet	*Aerospace engineer*	SSC-PAC
Dr. Brian Reitz	*Research engineer*	NAVAIR China Lake
Dr. Andrew Schicho	*Mechanical engineer*	NSWC Panama City

From the scenario, Team Hydra focused on the South China Sea. China has invaded and occupied a sovereign nation, and allied forces are trying to enter that conflict zone and remove the occupying forces. By 2032 the team assumed that the entire South China Sea region will be "rich and dense with lots of smart networks" and unmanned systems in multiple domains – air, surface, and subsurface. After an assumed two-year absence from the region, the team envisioned that allied forces will be operating in a global positioning system (GPS) and SATCOM denied environment. Battery technology will continue to improve providing a longer life and higher power level at a lower cost available to all future UxVs.

Narrowing their design challenge to the question *How might we defeat a network of adversary unmanned systems?* They proposed a solution in three phases: ***interrogate*** enemy UxVs in order to gain access to the enemy OODA loop[34] through ***observation***, and then ***exploit*** the enemy network. They named their concept *Hydra IOeX.* "By interrogating, observing and finally exploiting that knowledge we will gain control of and defeat the enemy network of unmanned systems."

1. Interrogate

Assuming a future conflict will rely on UxVs countering UxVs in all available domains, a traditional war of attrition[35] will not work. The adversary has "home field advantage" with manned and unmanned assets available in all domains close to their mainland industrial base, and shorter supply lines for logistics. If we go one to one against their unmanned systems we will lose that fight. How do we use our swarms of UxVs to defeat their systems? Team Hydra proposed that the best way to defeat the adversary's UxVs was to learn how their systems operate, and then predict how our adversary may use these assets. Armed with this knowledge, allied forces will then be able to exploit their systems to our advantage.

[34] The cycle of "observe, orient, decide, and act" developed by military strategist and United States Air Force Colonel John Boyd.

[35] *A struggle in which you harm your opponent in many small ways, so that they become gradually weaker.* Source: Longman Dictionary of Contemporary English https://www.ldoceonline.com/dictionary/war-of-attrition last accessed 22 October 2018

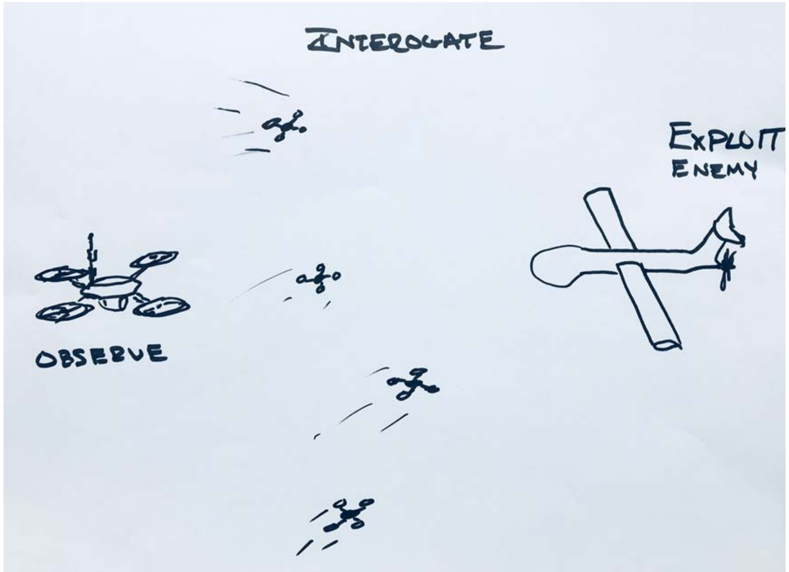

Figure 37. Aerial example of interrogation and observation phases of *Hydra IOeX* using low-cost UAVs to charge an enemy asset.

The first phase of *Hydra IOeX* is interrogation – using our UxSs to elicit a response to gain intelligence. For instance, a massive swarm – hundreds up to 1,000 – of low-cost UAVs (*see Figure 37*) might perform a series of actions to instigate an enemy response. Using very simple programming and without satellite communications, this aerial swarm could charge an enemy asset (*see Figure 37*) to see how it responds, then retreat and observe the enemy response. Does the response change if charged with intent to attack? What if the UAV swarm approaches an island or ship that the enemy asset is loitering near? Does this elicit a response? How close does our asset need to be to elicit a response? What kind of response? Will it retreat, follow, or attack? There are thousands of actions we could take to elicit many more potential responses in all domains. The knowledge gained from these interactions will enable more effective exploitation in the third phase.

2. Observe – Bio Buoys

The next phase of *Hydra IOeX* is the observation phase, the team proposed a biological buoy with embedded sensors. Like the trash cover proposed by Team Grindylow (*see Appendix A:C:4 page 31*) the biological buoy would use biomimicry as camouflage, such as a buoy designed to look like kelp (*see Figure 38*).

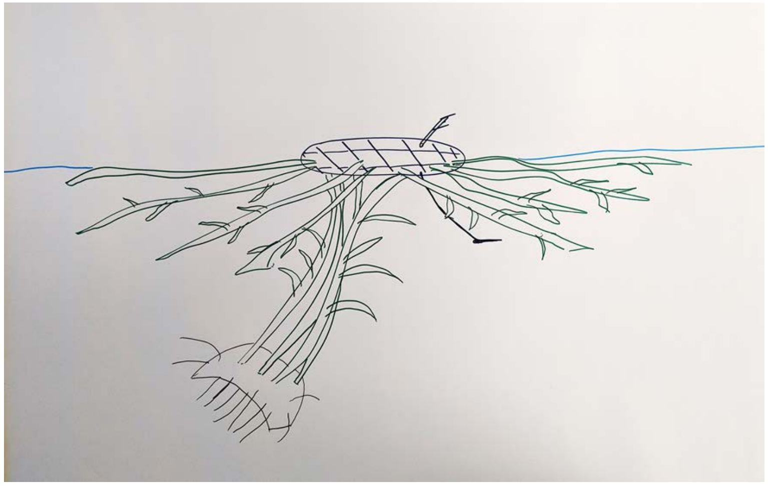

Figure 38. Biological buoy with embedded sensors designed to look like kelp.

Designed to expand out and down when it comes in contact with the water, this kelp buoy could be deployed in a pill form by a maritime patrol aircraft such as a P-8 (*see Figure 39*).

Figure 39. P-8A Poseidon maritime patrol aircraft.[36]

Once deployed in the AOR, the biological buoy would provide persistent passive observation of enemy behavior using systems hiding in plain sight or onboard complex UxVs surrounded by low cost decoys. As a passive receive sensor, the kelp buoy would remain dormant until triggered by nearby activity. Once triggered, the biological buoy would collect data until cued to transmit the collected data – potentially through a network of these passive biological buoys. Working in tandem with other UxVs in the AOR to complete hunter-killer[37] type maneuvers, these buoys could help control the AOR undersea space.

3. Exploit – Algorithm Capture

One of the ways we could exploit is not by actually physically capturing an asset, but by understanding the predictability that are inherent in algorithms. Presuming that all drones of a certain class run the same software, one stimulus will elicit the same response in an entire class of UxVs programmed with

[36] J. Keller (2014) "Boeing to equip Navy's new P-8A Poseidon maritime patrol aircraft for high-altitude ASW missions" December 15, 2014. *Military Aerospace Electronics*. Source: https://www.militaryaerospace.com/articles/2014/12/p8-high-altitude.html last accessed 22 October 2018

[37] *denoting a type of naval vessel, esp a submarine, designed and equipped to pursue and destroy enemy craft.* Source: https://www.collinsdictionary.com/us/dictionary/english/hunter-killer last accessed 23 October 2018

the same algorithm. We need to have good data about the enemy. Once we understand how enemy assets respond to a certain set of conditions or a certain stimulus will help us more effectively predict how the enemy will respond to planned or proposed actions.

Although in the future we might employ machine learning or reinforcement learning, but we might also do this in more simple ways. For instance, if we know that in response to certain actions the enemy assets in an area will respond by giving chase we may use that knowledge to our advantage by provoking an enemy patrol to give chase and then sending a second wave of assets through the unpatrolled area left behind. If we emit certain signals it might provoke enemy assets to transmit reports over and over again resulting in drained batteries or clogged communications channels, minimizing adversary bandwidth. If the enemy UxVs are programmed return to a charging station when drained we could then follow enemy UxVs to their forward deployed energy and communications outpost (FDECO) nodes, tagging enemy seabed infrastructure for prosecution, lay in wait to capture enemy assets, leveraging their FDECO nodes to recharge our assets or replace their FDECO node with one of our own.

4. Exploit – Physical Capture

Once we have access to the adversary's network, we could use their network to gather intelligence, or disrupt their network through jamming communications, hacking, or spreading disinformation to disrupt enemy operations. Capturing physical UxV assets might be another effective tactic to gain this access. Analysis of captured software will expose algorithms, but capture of hardware could be effective as well. The enemy will likely have deployed hundreds, if not thousands of UxVs in their AOR operating under one large network or several disparate networks.

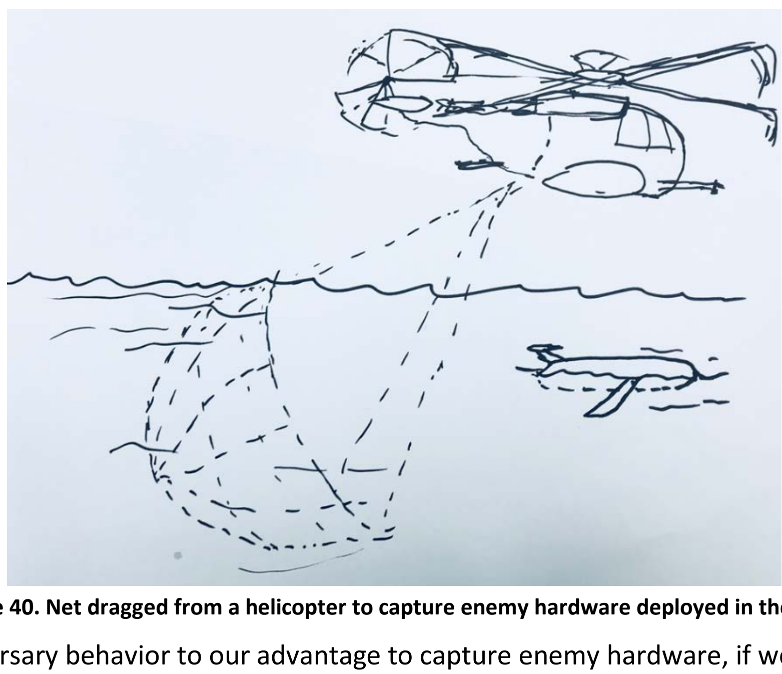

Figure 40. Net dragged from a helicopter to capture enemy hardware deployed in the AOR.

Using learned adversary behavior to our advantage to capture enemy hardware, if we collect a sample UxV asset we could take it apart for analysis. One proposed method to collect an enemy UUV or USV is to drag a net from a helicopter (*see Figure 40*). Not only could we gain access to the enemy network through analysis of their hardware, but we could also reassemble and release their asset with an alteration – maybe one small replaced or removed part – to render it useless.

5. *Hydra IOeX* Quick Response Team Module

Interrogating, observing and physically capturing either UxV assets or their algorithms will give allied forces and advantage in the enemy home field. The final element of *Hydra IOeX* is a mobile unit of analysts ready to respond (*see Figure 41*).

Figure 41. Hydro IOeX quick reaction team deployment suggestion.[38]

The *Hydra IOeX* quick response team is a highly trained quick reaction team deployed to take apart and hack enemy networks. Through analysis of captured software or hardware, the quick response team will provide commanders the information necessary for mission success. Through examination of captured hardware and software, the analysts will determine how the vehicles are operating, identify key hardware and algorithms, and expose their communications protocols. "What are things we could potentially take advantage of?" As enemy assets are intercepted and collected we will note the location to determine where higher densities of enemy assets might be operating as this may indicate where deployed charging is taking place, or other centralized hubs or vulnerabilities.

[38] Graphic source: https://shippingcontainers.net/conex-shipping-containers.html combined with https://en.wikipedia.org/wiki/Amphibious_transport_dock last accessed 22 October 2018.

F. Team Loch Ness

Figure 42. Members of Team Loch Ness included *(pictured from left to right*) Brett Vaughan, Maj Stephen Maddox USAF, Daniel Eby, LT Aaron Antonio USN, Erik Hanssen, LT Dolph Eich USN, and Andrea Leichtman (*not pictured, Dr. Misha Blocksome*).

The members of this team (*see Figure 42 and Table 6*) included three junior officers from both the U. S. Navy and the U.S. Air Force, three early career engineers, one representative from the Pentagon, a Naval War College faculty member, and two NPS students.

Table 6. Members of Team Loch Ness (*alphabetical by last name*)

NAME	PERSPECTIVE	AFFILIATION
LT Aaron Antonio USN	*Surface warfare*	NPS Systems Engineering Analysis
Dr. Misha Blocksome	*Irregular warfare*	Naval War College
Daniel Eby	*Mechanical engineer*	JHU/APL
LT Dolph Eich USN	*Surface warfare*	NPS Systems Engineering Analysis
Erik Hanssen	*Electrical engineer*	LMCO
Andrea Leichtman	*Facilitator*	JHU/APL
Maj Stephen Maddox USAF	*Air warfare*	12th Flying Training Wing
Brett Vaughan	*Facilitator*	OPNAV N2N6FX

Team Loch Ness worked the design challenge at the classified level, although their plenary injects of data was unclassified with the rest of the participants. The two concepts they generated were:

1. Bathymetric Explorer for Neutralizing and Disrupting Enemy Resources (BENDER)
2. Submarine Investigation, Revelation, and Exploitation Network (SIREN)

These concepts were presented in the classified space and full details are available through appropriate channels by vetted request emailed to wiw@cruser.edu.

APPENDIX B: Scenario

Developed by retired Navy Captain and Professor of Practice in the NPS Operations Research Department Jeff Kline, the following scenario was the environment given for the design challenge:

Global War of 2030
A fictional scenario to support academic work

2030 Political, Social, and Economic narrative:
Although **China's** economic growth began to slow in 2018, she continued her political, fiscal, economic, and military expansionism. In 2030 China is the world's first economy, has a large and growing middle class population and consequently generates a higher demand for oil and natural gas. Relationships between **Russia** and China are thriving, underwritten by a strong energy trade and common desire to challenge the United States national power. China depends on the Trans-Siberian pipeline developed after negotiations with Russia on oil purchases were signed in 2014. Further economic ties were generated by a series of trade agreements that began in 2020.

In 2030, Russia's economy is stabilized by Europe's and China's consistent demand for her oil. They have the fifth largest GDP and are beginning to address internal social challenges. They have maintained control of Crimea, retain forces on the Ukraine-Russian border, have modernized their missile program, execute annual military exercises on the borders of neighboring Baltic countries, and have built a modern submarine fleet. President Putin's successor continues the rhetoric of a greater Russia through exploitation of opportunities provided by a warming Arctic, and reclaiming traditional Russian lands. Since the agreement signed in 2017 between **Russia and Syria** to allow Russian expansion, sovereignty and use of the naval facility at Tartus, Russia formed a permanent naval group and improved the facilities to homeport 11 ships there. They also retain their use of the Syrian Hmeymim airbase. With extensive aid from Russia, Syria was able to rebuild their land and air forces.

Turkey continued distancing from its NATO allies as more Islamic politicians were elected to leadership. By 2025 Turkey was a member of NATO in name only, and requested all NATO forces leave its territory. As a result, by 2027 no U.S. Forces were based in Turkey.

Since 2015 the increased economic and social ties between mainland **China and Taiwan**, combined with an economically (yet not necessary democratically) more liberal Chinese central government, resulted in a 2027 non-aggression treaty between the two states with agreements to begin discussions on unification. By 2030, although not yet under "one government", the Taiwan parliament has Communist party representation and the joint government, military and economic initiatives between China and Taiwan have grown to the point they are a de-facto Chinese economic and military federation. For example, Taiwan has allowed China to build High Frequency Surface Wave radar stations and passive collection systems on Taiwan with joint intelligence sharing responsibilities. Taiwan no longer relies on military sales from the United States.

China populated several islands terra-formed through dredging in 2015 with military installations. For example, Fiery Cross Reef has a squadron of J-20s (fifth generation plus) with 10 Dark Sword UCAVs, while Fiery Reef, Mischief Reef, Gaven Reef, and Hughes Reefs have surface to air installations (S-500), anti-surface cruise missile mobile sites (advanced YJ-62s), electronic surveillance and communication sites, and ship support facilities. China is now building facilities on terra-formed islands made from the western end of the Scarborough Shoal reef, protested by the Philippines and the United States.

Tensions have eased somewhat on the Korean Peninsula after North Korea's participation in the 2018 Olympics and follow-on leadership summits. However, North Korea continues developing greater ballistic missile and cruise missile capabilities. The successful submarine launched ballistic missile in 2017 was followed by a series of failures, then successes of both land launched and sea launched ballistic missiles and well as shore to ship cruise missiles.

Japan and the United States have strengthened their social, economic, and military ties in response to the growing influence of both China and Russia. The Yokosuka naval facility has evolved to a joint JMSDF and United States Navy base with GEORGE WASHINGTON and its air wing, three United States DDGs, eight United States LCSs, and the Japanese fleet sharing the installation. In Sasebo, the United States Navy retains LHA-6, LPD-25 and LSD-52 and two LCS for mine clearance and protection.
The United States also established closer ties to **Singapore**, stationing eight LCSs, a squadron of P-8s and their shore support in the city-nation. In addition, the United States now maintains logistic support bases in Diego Garcia and pre-positioned expeditionary supplies in Subic, with joint agreements with the U.K. and Philippines respectively. These bases can act as "rapid build-up" support bases if the host country agrees. Additionally, the Philippines have invited the United States Air Force to use Clark AFB as an expeditionary field, expanding its role beyond joint training exercises. The United States Air Force has retained Kadena AFB on Okinawa, and III MEF completed its move from Futenma to the newly constructed land-fill air base in Henoko village. In addition, a battalion landing team is stationed in **Darwin, Australia**.

Australia has executed the programs envisioned in their 2015 defense white paper and built up their air and naval forces with the intent of closer cooperation with the United States. For example, 8 of a planned 12 Shortfin Barracuda SSKs are now operational and the RAAF operates 15 P-8 and 7 MQ-4C Triton from Edinburgh conducting frequent bi-lateral exercises with the United States.

<u>Central and Eastern Mediterranean</u>
In late 2029, Israel launched extensive air and cruise missile attacks into southern Syria in response to month-long attacks into the Golan Heights by rockets, swarming aerial vehicles, and explosive unmanned ground vehicles traveling through the southern end of the U.N. Disengagement Observer Forces. A combination of Hamas, Iran Revolutionary Guard, and Syrian forces were the sources of these attacks, and Israel's responses hit military installations and supply depots from all these organizations. Several Israel aircraft and cruise missiles were shot down by surface to air missile sites believed to be manned by Russian "civilian" advisors.

Within days Palestinian riots occurred throughout the West Bank and Gaza creating a new Intifada. Israel declared martial law, called up their reserves, and put their forces on the Golan Heights in high alert. With its allies, Syria amassed forces along the Golan Heights threatening similar invasion paths as the 1973 Yom Kippur War, tying down Israeli armor, artillery, and infantry positions. Russian naval forces in Tartus sortied, the Hmeymim Russian air wing began continuous combat air patrols, and Russian air defense stations went on high alert. While this was occurring, the undersea "Quantum Cable" providing high speed digital connectivity into Israel went dead.

The Syrian attack came a week later with massive swarming air vehicles, rockets, air launched missiles, cruise missiles, and unmanned ground vehicles along the Golan Heights border. Three divisions of Syrian forces crossed UNDOF Line Bravo and Alpha in the southern border of Golan Heights near Ramat

Magshimim, rapidly bridging ravines and rivers. This, however, did not turn out to be the main effort. Syrian forces on the northern Golan Heights border swung northwest and traveled 20 miles through Lebanon to invade Israel on its northern border with Lebanon, and were joined by insurgents from that state. At the same time, approximately one hundred civilian boats carrying up to twenty light infantry each landed near Acre after traveling the 100 nautical miles from various ports in southern Syria and northern Lebanon. These forces were escorted one LSM and by 5 new Syrian missile ships (1,300 tons, 308 feet long) purchased from the Russians known as Project 22160 featuring capabilities from long range Klub ship and land-attack missiles to helo support for ISR. These ships also carried special forces which landed with the other amphibious troops. In all, 2000 light fighters were placed on the beach near Acre.

Israel now faced a three pronged attack on its northern border, and rockets attacks from insurgents in Gaza.

South and East China Sea:

In the spring of 2029, a Vietnamese fisher was rammed and sunk by a Chinese maritime security ship. The Chinese government justified the unfortunate action as an enthusiastic Captain defending China's EEZ rights, although similar incidents have occurred over the past 20 years. Vietnam did not accept the rationale and vowed their fishing fleet, as well as their at sea drilling rigs, would henceforth be protected. Two weeks later a Chinese deep-sea exploration ship exploded without warning 100 nautical miles north of Natuna Besar. China claimed either Vietnam, Indonesia or the Philippines were responsible. They mobilized their South China Seas fleet and demanded restoration from all three countries or they would "secure" their sea. One month later the Chinese sank a patrolling Vietnamese ship using a land-based surface to surface missile launched from Woody Island (YJ-83) in the Paracels and moved a squadron of SU-37s to Woody Island. They announced all traffic through the South China Sea would henceforth be subject to inspection and control by Chinese forces. They threatened to assume governorship of the island of Natuna Besar Indonesia to control the South China Sea's southern approaches and in compensation for the attack on their deep sea exploration ship. The 1st Marine Brigade at Zhanjiang, Guangdong has embarked in the South China fleet's amphibious flotilla (13 landing ships modernized Type 71 LPDs and Type 72II LSTH). They can be underway in one day's notice and intelligence indicates their objective is the occupation of Natuna Besar.

During these events, a Philippine helicopter fired on a PLAN Type 56 corvette conducing gunnery exercises four miles from Palawan Island. In response, China also threatened invasion of Palawan. Increased activity by the PLA's 124th Amphibious Mechanized Infantry Division in Guangzhou district indicates they may be readying for this operation.

Indonesia, Vietnam, and the Philippines have requested UN support, specifically calling on the United States and Japan to act. In response, China has warned Japan and the United States any interference with their enforcement policy will lead to war, with the threat of nuclear escalation. To show their resolve, China mobilized the East Sea and South Sea fleets and sailed at least 50 submarines from both fleets, including two SSGN on what are assessed to be strategic deterrence patrols. They have declared a quarantine on all military logistics support (including oil) to Okinawa and have set up ships in blocking positions around the island to conduct MIO.

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APPENDIX C: Workshop Schedule

The three and a half day workshop started on Monday morning with a series of knowledge leveling briefs, followed by initial team meetings. Both Tuesday and Wednesday started with full group technical inject sessions followed by a full day of team generation work. Teams presented their final concepts on Thursday morning and the workshop adjourned by noon to accommodate outgoing travel.

MON – 17 September

0745	Registration	**GLASGOW 109**
0800	Welcome	VADM Ronald Route USN (ret), NPS President
0815	CRUSER Overview	Dr. Ray Buettner, NPS FX Director
0835	NPS Warfare Innovation Continuum & Scenario	CAPT Jeff Kline USN (ret), NPS Chair of Systems Engineering Analysis (SEA)
0915	Cross Domain Operations	CDR Roy Wilson, USFFC N92
0940	Achieving Emerging Technology	Mr. Mike Tall, SSC-PAC
1005	Undersea Infrastructure Defense	Dr. David Alderson, NPS Operations Research
1030	**BREAK**	
1040	FDECO	Mr. Jose Chavez, SSC-PAC
1105	Seabed Topography	Mr. George Zvara, NUWC Newport
1130	Team Introductions	Ms. Lyla Englehorn, NPS CRUSER Associate Director
1200	**LUNCH**	
1300	Tools of Design	Ms. Lyla Englehorn, NPS CRUSER Associate Director
1330	Industry Perspective Statement	Mr. Glen Sears, LMCO
1355	Seabed Cables	Mr. Steven Powell, Trans Bay Cable
1420	Tasking	CAPT Jeff Kline USN (ret), NPS SEA Chair
1500	Initial Team Meetings	**BREAKOUT ROOMS**
1600	Icebreaker	**TRIDENT ROOM**

TUES – 18 September **GLASGOW 109**

0800	Welcome	Dr. Brian Bingham, NPS CRUSER Director
0810	Keynote Address – Crossing the Valley of Death	Mr. Frank Kelley USMC (ret), DAU Vice President

0900	Innovation Challenges	Dr. Maura Sullivan, FATHOM5 Founder & COO
0925	Lessons Learned in Innovation	Mr. Stephen O'Grady & Mr. Mark Dalton, NUWC Newport
1000	Discovery Interviews – ***Mentors***	**BREAKOUT ROOMS – *Mentors meet in GLASGOW 128***
1100	Concept Generation – **Divergent**	**BREAKOUT ROOMS**
1200	**LUNCH**	
1300	"Just One Thing" launch – ***Mentors***	***GLASGOW 128***
1300	Concept Generation – **Divergent to Convergent**	

<u>WED – 19 September</u>		**<u>GLASGOW 109</u>**
0800	Welcome	Ms. Lyla Englehorn, NPS CRUSER Associate Director
0810	MTX & SLAMR	Dr. Raymond Buettner, NPS FX Director
0835	On Undersea Infrastructure Defense	Mr. William Glenney, Institute for Future Warfare Studies
0900	Fielding Unmanned Systems in Multiple Domains	CAPT George Galdorisi USN (ret), SSC-PAC
0930	Concept Generation – **Convergent**	**BREAKOUT ROOMS**
1000	NPS Lab Tour – ***Mentors***	***Guided tour leaves from Starbucks***
1030	Directors & Chairs Rotation	**BREAKOUT ROOMS**
1200	**LUNCH**	
1300	Concept Development – **Final Push**	**BREAKOUT ROOMS**
1300	"Just One Thing" quick look – ***Mentors***	***GLASGOW 128***

<u>THUR – 20 September</u>		**<u>GLASGOW 109</u>**
0800	Team Photos & Evaluation	
0830	Final Briefs	
1200	**ADJOURN**	

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LIST OF ACRONYMS AND ABBREVIATIONS

AI	artificial intelligence
AOR	area of responsibility
AWS	Amazon Web Services
BENDER	*Bathymetric Explorer for Neutralizing and Disrupting Enemy Resources*
C2	command and control
CDO	cross-domain operations
CNO	Chief of Naval Operations
COA	course of action
COCOM	combatant command
CONEX	Container Express
CONOPS	concept of operations
CONUS	continental United States
COP	common operational picture
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
DARPA	Defense Advanced Research Projects Agency
DAU	Defense Acquisition University
DoD	U.S. Department of Defense
EEG/EMG	electroencephalogram and electromyography
EMCON	emissions controlled
EMP	electromagnetic pulse
FDECO	Forward-Deployed Energy Communication Outpost
FSO	free space optical
GPS	global positioning system
GUI	graphical user interface
JIFS	*Joint Information Filtration System*
JHU/APL	The Johns Hopkins University Applied Physics Laboratory
LDUUV	large displacement unmanned undersea vehicle
MILDEC	military deception
NAVAIR	Naval Air Systems Command
NOAA	National Oceanographic and Atmospheric Administration
NPS	Naval Postgraduate School
NSWC	Naval Surface Warfare Center
NUWC	Naval Undersea Warfare Center
NWC	Naval War College
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
OTH	over-the-horizon
RAN	Royal Australian Navy
RF	radio frequency

SATCOM	satellite communication
SECNAV	Secretary of the Navy
SIGINT	signals intelligence
SIREN	*Submarine Investigation, Revelation, and Exploitation Network*
SITREP	situation report
SLAMR	Sea, Land, Air Military Research facility (NPS)
SOCOM	Special Operations Command
SPAWAR	Space and Naval Warfare Systems Command
SSC	SPAWAR Systems Center
SSN	nuclear powered attack submarine
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
UPS	United Parcel Service
USAF	U.S. Air Force
USFF	U.S. Fleet Forces
USMC	U.S. Marine Corps
USN	U.S. Navy
USNR	U.S. Navy Reserves
USV	unmanned surface vehicle
UUV	unmanned undersea vehicle
UxS	unmanned systems
UxV	unmanned vehicle
WASP	*Weaponized Autonomous Sensor Persistence*
WIC	NPS Warfare Innovation Continuum

September 2018 Warfare Innovation Continuum (WIC) Workshop: *Cross-Domain Operations Final Report*

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