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This paper will describe the proposed tactical employment of autonomous unmanned surface vessels within the US Navy's surface fleet. I will evaluate several existing technologies currently being developed by private and DOD programs in order to analyze the feasibility of its tactical use within set parameters established within a developed concept of operations scenario. The objective of this research is to maximize the combat readiness of surface forces by applying autonomous and unmanned surface technology for near-term tactical use in naval operations.

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Concept of Operations for the Tactical use of Autonomous Unmanned Surface Systems

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A paper submitted to the Faculty of the United States Naval War College Newport, RI in partial satisfaction of the requirements of the Department of Joint Military Operations.

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Contents

LIST OF FIGURES

Abstract

This paper will describe the proposed tactical employment of autonomous unmanned surface vessels within the US Navy's surface fleet. I will evaluate several existing technologies currently being developed by private and DOD programs in order to analyze the feasibility of its tactical use within set parameters established within a developed concept of operations scenario. The objective of this research is to maximize the combat readiness of surface forces by applying autonomous and unmanned surface technology for near-term tactical use in naval operations. This concept of operations targets the decision makers, operational planners and those responsible for the manufacturing, acquisition, delivery and use of autonomous unmanned surface system to the fleet. The Navy relies heavily on the operational readiness of our manned surface platforms to conduct a variety of complex missions. As the Navy continues to balance force requirements between the maintenance, training and operational readiness of the force, autonomous unmanned systems provides an additional capability helps sustain the health and material readiness. This research seeks to conduct comparative analysis through task performance of autonomous and unmanned systems and capabilities that are available in the near future for integration. This will ultimately providing a stop-gap for the eventuality of a dip in the sustained readiness of the naval force.

The use of unmanned platforms within the US military has dramatically improved. Wartime and steady-state use of unmanned platforms in the aviation community have dramatically improved military operations over the past 10 years. Unmanned Aerial Vehicles (UAVs) have made significant contributions to the warfighting capability of operational forces abroad. They have greatly improve the timeliness of critical information flow while

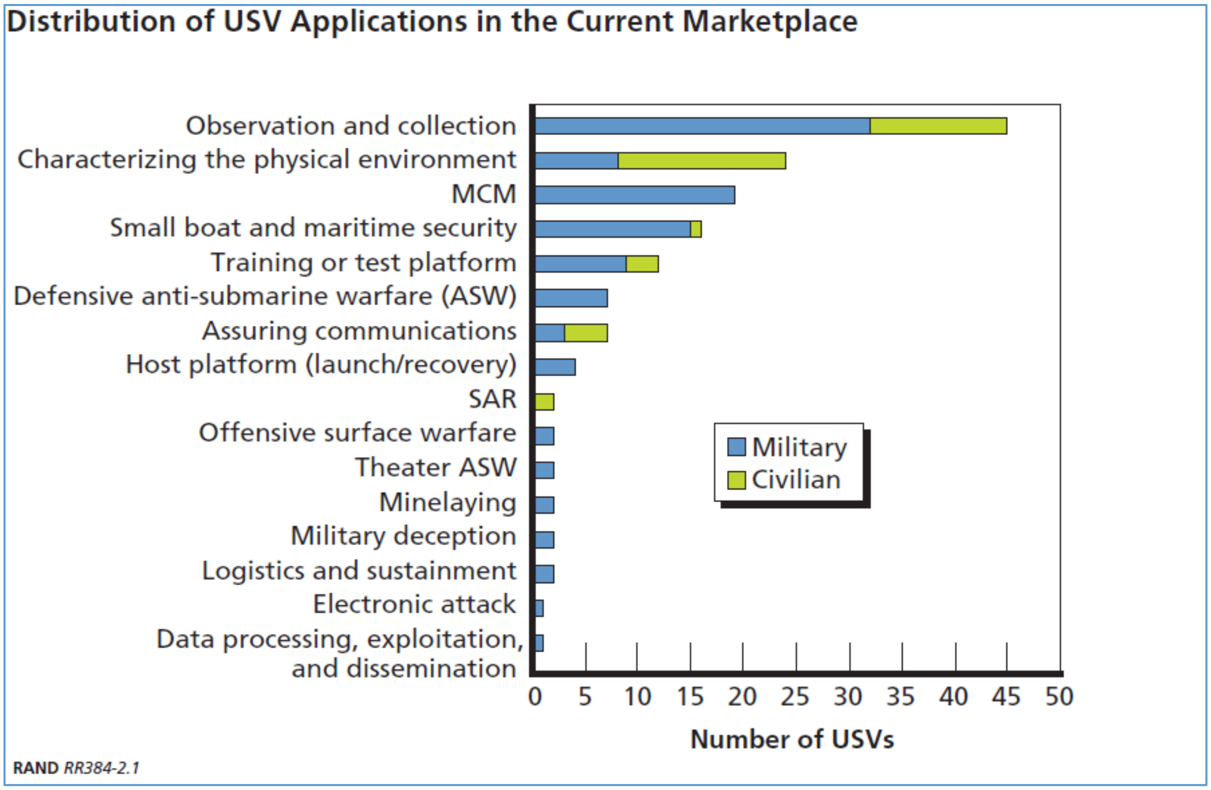
reducing the risk of military personnel in the realm of Intelligence Surveillance and Reconnaissance (ISR). UAV's have also enhance the offensive strike capability of the aviation force by increased on station-time, increased the number of strike operations and have reduced the overall cost, life-cycle maintenance and versatility of existing manned aerial platforms. In recent history, the application and operational use of autonomous unmanned technology has received less attention and limited investment within the surface navy. More recently, there has been a developed motivation from the department of defense for enhanced interest in developing and using unmanned surface systems for ISR and mine-hunting missions. The application and use of technology in autonomous modes has primarily been studied in academic and scientific arenas. As the navy continues use of the target unmanned surface vehicles (drones) for surface gunnery and missile systems target evaluation and simulation continues, the technological application and a more complex operational capacity becomes viable.

The technology necessary for the development of autonomous unmanned surface systems is mature and available. However, the trust of autonomous unmanned systems technology remains the most controversial topic among Navy leaders. Autonomous unmanned systems can utilized for missions that manned platforms consider too dangerous and mundane for humans to perform effectively or efficiently. As the capabilities of the automated unmanned systems improve, it could perform these routine actions such as intelligence surveillance reconnaissance, maritime domain awareness and navigation more efficiently than its manned counterpart.

CHAPTER 1: INTRODUCTION

As the United States navy works to apply existing operational principles and refine operational practices to meet the evolving threat, there are question that need to be addressed to adequately anticipate the future needs of the force. How can we efficiently and effectively utilize technology within the maritime environment? How do we effectively apply technology in a way that strengthens the attributes of the naval force? How do we properly demonstrated them in a way that doesn't negatively alter our warfighting proficiency? These are some of the type of questions that need to be addressed when you consider the application of future technology. The emerging market and increased availability of unmanned surface capability is characterized by the broad capabilities of the platform, the multitude of companies that manufacture the technology, and the enabled, but limited, performance of existing prototypes. According to RAND Corporation, in an analysis of the US Navy employment of Unmanned Surface Vessels, "the current USV market has approximately 63 identified within the market." Furthermore, "current USV platforms range in missions and functions, but the majority of activity in the marketplace tends to be centered in the following categories:"[1] The below graphic depicts the distribution of use of the USV platform within the current marketplace.[2] For the purposes of this CONOP, we'll be focusing of the following applications: 'Observation and Collection', 'Characterization of the Physical Environment', 'Maritime Security', 'Offensive Surface Warfare', and 'Electronic attack'. These applications transfer easily to the overall tactical and operational mission sets of the surface community. While these applications can prove to be viable within the context of surface warfare mission sets, there is little to no development in the use of these applications that are currently being applied in the surface and/or maritime environment.

[1] Scott Savitz, Irv Blickstein, Peter Buryk, Robert W. Button, Paul DeLuca, James Dryden, Jason Mastbaum, et al. 2013. U.S. Navy Employment Options for Unmanned Surface Vehicles (USVs) RAND Corporation.
[2] Ibid, 9.



(Figure 1: USV Application Marketplace[3])

As far as the suitability of the application of unmanned surface technology as viable to the existing force structure, there are several approaches to consider.

In a May 2017 white paper on "The Future Navy," the Chief of Naval Operations (CNO), Admiral John Richardson, he posits that, in order to stay relevant and competitive in this complex environment, "The Navy must get to work now, to both build more ships, and to think forward - innovate - as we go. To remain competitive, we must start today and we must improve faster."[4]

Problem Statement

The problem statement is focused on an assessment of the tactical use of the autonomous unmanned surface vessel (TUASV) in support of the development of a Concept

[3] Ibid

[4] Richardson, John M. "The Future Navy." US Navy Chief of Naval Operation White Paper, 17 May 2017.

of Operation (CONOP) and associated system architecture. The associated platforms are developed from existing technology, both commercial and retrofitted naval platforms to be used for deployment for use in tandem with manned platforms as a framework for an assessment of its enhanced performance and interoperability.

"Does an tactical autonomous unmanned surface vessel (TUASV) working in a shared Common Operational Tactical Picture (COTP) with manned organic surface combatant units achieve a more effective execution of various navy surface missions?"

Scene Setter

A wide range of enemies, peer and non-peer competitors, hybrid threats, rogue states, hyper-empowered individuals and violent extremist groups are committed to defeating the US way of war. They reside in multiple regions of the world. Peers and adversaries are now focused on higher-end asymmetric capabilities that the US hasn't had to deal with for a while. They have had to evolve and learn to contest us in a variety of domains; similar to the same domains that have challenged the international order in the Pacific. Our adversaries, in recent conflict, have incorporated low-cost technology, speed of digital information and social media. They have taken away our advantage by incorporating dynamic capabilities that have chipped away at the geopolitical and demographic climates. Our adaptation of current strategies must be used to deter and defeat these dynamic capabilities. To counter-balance our presence abroad, our adversaries, within a regional hegemonic context, they have attempted to fix us in separate domains and dimensions. To combat this, the joint force must design an integrated and converged solution set by reducing stove piped individual efforts. [5] *Joint multi-domain operations start with the use of networked sensors and weapons*

[5] Multi-Domain Battle Space Scenario. Performed by US Army Training and Doctrine Command. YouTube. July 17, 2017. https://youtu.be/car1O_qfkW0.

that provide a multi-dimension perspective devised for the exploitation of the enemy's efforts in each individual domain. This creates and exploits small windows of advantage. This fight starts through simultaneous and sequential operations. Autonomous unmanned systems can be used at the Phase 0 of the battle to gain early entry into the contested battlespace through ISR and maritime domain awareness operations that takes advantage of water space gaps prior to hostilities.

In the future combat technology book "Ghost Fleet," by P.W. Singer and August Cole, the Littoral Combat Ship (LCS) USS Coronado, is equipped with the ATHENA program.[6] *The Automated Threat Enhanced Network Awareness Program (ATHENA) is the ship's autonomous battle management system that tracks targets and coordinates with other systems, both internal and external, faster than a human crew can. The network of nodes and sensors connect all vital systems onboard the LCS. This system truly integrates and maximizes the terms "fight the ship" and "save the ship," and the book details how this represent a giant leap forward in surface combat operations. The best example can be read in the early moments of the escalation of hostilities. As the Coronado's crew was dealing with initial damage control actions to assess, isolate and repair damage, Captain Riley, as advised from the XO, decided to configure the ATHENA system in "watch mode,"* or *semi-autonomous state. The decision was made in order to keep the system from engaging hostile contacts and engaging on its own.*

Future Operational Environment

[6] Singer, P. W. and August Cole. "Ghost fleet: a novel of the next world war. Boston." Houghton Mifflin Harcourt, 2016. Pg. 65-66.

The advancement of multi-domain approaches to contested battlespace operations and techniques of our adversaries suggests that we need to utilize the innovation of autonomous and unmanned technology designed into marine systems capable of detecting and classifying targets in support of over-the-horizon targeting (OTH-T) by organic assets. This research considers the coordinated use of manned and semi-autonomous unmanned systems in an effort to develop an organic OTH targeting capability for U.S. Navy surface force structure. The coordinated use of autonomous unmanned systems provides area access within Phase 0/1 operations enabling naval forces to develop maritime domain awareness well ahead of the onset of hostilities.

Strategic & Operational Guidance

When applying the Third Offset strategy to the DOD's approach to building and configuring a fighting force, the long-term strategic for competitiveness requires the innovation and application of technology. The CNO, in his guidance to the Navy, "A Design for Maintaining Maritime Superiority," the Department of the Navy continues to work closely with academia and private industry to introduce and incorporate technology into its fighting force. The utilization of autonomous and unmanned combatants for the domination of battlespace within the maritime domain should be a primary driver for the challenging and maintaining maritime superiority.[7] Secretary of Defense Ash Carter, in November 2012, issued a directive for verification & validation (V&V) and Test & Evaluation (T&E) of autonomous systems functioning as weapons systems.[8] In the memorandum, he addressed directives for the COCOMs to develop Rules of Engagement (ROE). He also addressed the

[7] Bundy, William F. "Future Maritime Forces – Maritime Unmanned and Hybrid Systems." US Naval War College, January 24, 2016.
[8] Carter, Ashton B. "Department of Defense Directive 3000.09." Autonomy in Weapons Systems, November 21, 2012. Updated May 8, 2017.

need for specific guidance for human-machine interfaces for activating and de-activating autonomous systems, along with TTP for the execution of human judgment within the decision-making chain of operations of autonomous systems. Lastly, the memo referenced DOD directive 3000.03E, which addresses military use of Non-Lethal Weapons interfaces in conjunction with autonomous systems. While the directive doesn't speak specifically to the use of autonomous systems, it does highlight initiatives by the COCOMs to adapt and tailor escalation of force options to the operational environment.

Development of the operational use of a TAUSV system is nested within the principles of the 'Fleet Design' processes disseminated by Commander US Fleet Forces, Admiral Phil Davidson. In June 2016, during the Maritime Security Dialogue panel session, with Center for Strategic and International Studies (CSIS) and the US Naval Institute (USNI), Admiral Davidson highlighted the core elements associated with the Navy's fleet design construct. The design focuses on the integration through the efficient use of battlespace and weapons systems.[9] Two specific elements, that are at the core of the justification for the operational use of autonomous unmanned systems are distribution and maneuver. The use of autonomous and unmanned systems can aid the fleet concept of 'distribution' in that it leverages additional weapons and sensors over large areas of congested battlespace. Additionally, the operational use of autonomous unmanned systems can improve 'maneuverability' in a way that optimizes operations and strategic depth of the force. It adds speed and agility to the force, thereby challenging the adversary's ability to engage fixed forces. During a recent NSDM practitioner session at USNWC, the honorable Dr. Dov Zakheim, Senior Advisor at the Center for Strategic and International Studies and CNA Corporation, sees "the biggest

[9] Hicks, Kathleen. "Fleet Design in the Current Environment with Admiral Philip Davidson." Center for Strategic and International Studies: A Maritime Security Dialogue Event. Washington, DC. 24 June 2016. https://www.csis.org/events/fleet-design-current-environment-admiral-philip-davidson

impediment to innovation and cultural use of technology in our government as bureaucracy." He also thinks real change only happening, if we can change (1) reliance on the classic defense industrial complex, (2) substantive change in defense acquisition regulations, and (3) subsequent changes in incentive structures that keep certain processes and structures in place.

Distributed Lethality

Enhancing U.S. naval forces control the seas highlights the need for maintaining maritime dominance through the concept of "distributed lethality." This can only be accomplished by the individually capable offensive capacity of surface ships. Within a contest battlespace, this presents unacceptable risk for the employment and presence of a CVN or LHD to provide additional targeting capability for U.S. Navy surface combatants. The surface combatant will always defend the high-value and mission-essential units; that is in our core doctrine. However, it is imperative that "surface-force lethality—particularly in our offensive weapons and the concept of operations for surface action groups (SAGs)—will provide more strike options to joint-force commanders, provide another method to seize the initiative, and add battlespace complexity to an adversary's calculus."[10] The operational use of the tactical autonomous unmanned surface vessel allows for the adversary to maintain a defense posture, taking the focus away from the movement and targeting of manned units. They would be forced to "allocate critical and limited resources across a larger set of defended targets,[11]" and away from the manned organic units who continue to advance into contested water space. This concept is doctrinally founded within the JP 3-32, which highlights the five core capabilities of the naval maritime force: Forward presence,

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[10] Thomas Rowden, Peter Gumataotao, and Peter Fanta. 2015. "Distributed Lethality—The Beginning of the Beginning." Proceedings 141(1): 18–23. http://www.usni.org/ magazines/proceedings/2015-01/distributed-lethality.

[11] Ibid

Deterrence, Sea Control, Maritime Power Projection, and Maritime Security.[12] There must be a concerted effort on the part of the Department of the Navy to optimize the force structure to be able to counter the congested battle space threat of our adversaries, which are inherent in the A2AD.[13] The implementation and operational use of the TAUSV offers a way to enhance Distributed Lethality concept at the tactical and operational level to challenge specific sea denial mechanism that are inherent to the Navy's specific maritime strategy.[14]

Grey Zone Tactics

Gray zone conflict is known as the coercive and aggressive activity that is deliberately designed to remain below the threshold of conventional military conflict and war. Hal Brand, Professor of Global Affairs at the Johns Hopkins University School of Advanced International Studies (SAIS), suggests that "gray zone approaches are mostly the province of revisionist powers—those actors that seek to modify some aspect of the existing international environment—and the goal is to reap gains, whether territorial or otherwise, that are normally associated with victory in war."[15] In the South Pacific, China is using these tactics as a way to expand territory along the South China Sea island chain in a way to garner region hegemony and extend their coastal defenses well beyond their territorial borders. Iran has also grown proficient at using gray zone tactics and capabilities to achieve its regional objectives over the last 30 years. The Iranian Islamic Revolutionary Guard Corps-Navy (IRGC-N) uses small maritime craft known as Fast Attack Craft (FAC) and Fast Intermediate

[12] United States. Joint Chiefs of Staff. Command and control for joint maritime operations. Washington, D.C.: Joint Chiefs of Staff, 2013.
[13] Hipple, Matthew, "Distributed Lethality: Old Opportunities for New Operations," Center for International Maritime Security, last modified February 23, 2016, accessed May 12, 2016, http://cimsec.org/distributed-lethality-old-opportunities-for-new-operations/22292.
[14] Thomas Rowden et. al. Distributed Lethality.
[15] Brands, Hal. "Paradoxes of the Gray Zone." SSRN Electronic Journal, 2016. doi:10.2139/ssrn.2737593.

Attack Craft (FIAC) to agitate US naval warships in the Gulf of Arabia. They avoid conventional war by incrementally challenging the US and its partners through brief and exploitive skirmishes that push the envelope of escalatory actions of the enemy without actually executing hostile acts that are known to start a war. The use of TAUSV in concert with conventional navy platforms allows for an added dimension of capability to counter the gray zone threat. According to an Army War College report, ‘Outplayed: Regaining Strategic Initiative in the Gray Zone,’ argues that the US should adopt a more joint integrated and self-sustaining maritime force by creating a more persistent and capable regional presence[16]:

> “The United States will need operational capabilities and concepts targeted at demonstrating resolve, gaining and regaining initiative, and creating dilemmas for adversaries in decidedly gray environments. Prevailing against purposeful high-end military adversaries in traditional campaigns remains an inviolable defense priority. However, joint general purpose and special operations forces, as well as joint functional capabilities and enablers will need to provide greater persistent gray zone utility.”[17]

CHAPTER 2: OBJECTIVES

Current Technologies

Global Cognitive Computing Market is expected to generate revenue of $13.8 billion by 2020, registering a Compound Annual Growth Rate (CAGR) of 33.1% during the forecast period of 2015 - 2020. North America currently leads in innovation and market share for machine learning with the global industry, followed by Europe.[18] In addition, automated reasoning technology is expected to grow at the fastest rate, with a CAGR of 37% within the

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[16] Freier, Nathan P., Charles R. Burnett, Cain,William J.,,Jr, Christopher D. compton, Sean M. Hankard, Robert S. Hume, Kramlich,Gary R.,,II, et al. Outplayed: Regaining Strategic Initiative in the Gray Zone, A Report Sponsored by the Army Capabilities Integration Center in Coordination with Joint Staff J-39/Strategic Multi-Layer Assessment Branch: Strategic Studies Institute, U.S. Army War College, 2016. P.86-87.
[17] Ibid
[18] "Cognitive Computing Market is Expected to Reach $13.7 Billion, Globally, by 2020 - Allied Market Research." PR Newswire, Jul 28, 2016.

same time period.[19] The growth of cognitive computing is primarily being driven by the increased volume of dark data, increased development of cloud-based technology and big data analytics. Example machine learning applications that are pertinent to autonomous unmanned systems are decision making, forecasting and optimization, and threat detection enterprises. The trending of cognitive computing technology stems from the need for more powerful computing capabilities and smart algorithmic functionality for intelligent agent systems. The TAUSV system capabilities must be able to access and analyze cognitive computing and machine learning technologies to prove valuable to DOD applications within the maritime operational environment. Growth in the robotics systems industry ($66.9 Billion) has also increased by +9% of previous growth estimates.[20] Robotic technology is inevitable going to converge with autonomous technology. The cultivation of big data processing, motion sensor technology, voice and image recognition, and software development, robotics is quickly developing at a rate that man-machine interaction and decision-making processes will become seamlessly integrated.

To transition from the hull construction requirements to the unmanned and autonomous applications of the technology that makes it “unmanned”, the engineering must have the following basic framework:

(1) Have the ability to sense its environment and the health of its own systems [21]*(Radar and other sensor technology, which already exists)*

[19] Ibid
[20] Rohling, Glitta. “Robots: Building New Business Models.” Seimens: Pictures of the Future- Magazine for Research and Innovation. April, 20, 2016.
[21] Antanitus, David. "Maritime Autonomy–Reducing the Risk in a High-Risk Program." CHIPS: DON Information Technology Magazine. January 12, 2016. Accessed February 13, 2018. http://www.doncio.navy.mil/chips/ArticleDetails.aspx?ID=7314.

(2) Be able to make intelligent decisions to optimize machinery lineups and sensor employment[22] (*Autonomous decision-making algorithms & intelligent agent software… see CARACAS*)

(3) Ability to avoid other ships and obstacles[23] *(collision avoidance software)*

(4) Ability to execute intended mission[24] *(mission program and command and control software)*

Leidos Sea Hunter

As of Jan. 30, 2018, Defense Advanced Research Projects Agency (DARPA), announced the formal transition of research to the Office of Naval Research (ONR). The Leidos built unmanned surface craft is now being designated as a Medium Displacement Unmanned Surface Vessel (MDUSV). The plan for ONR is to take the Sea Hunter (USV) technology at apply autonomous technology. Alexander Walan, a program manager in DARPA's Tactical Technology Office (TTO), said in an official statement. "Our collaboration with ONR has brought closer to reality a future fleet in which both manned warships and capable large unmanned vessels complement each other to accomplish diverse, evolving missions."[25] During a test run in September 2017, the Sea Hunter has showed significant progress in COLREG and collision avoidance testing. DARPA also tested the Towed Airborne Lift on Naval Systems (TALONS), which is a low-cost, elevated sensor mast that can carry intelligence, surveillance, reconnaissance (ISR), and communications payloads of up to 150 pounds between 500 and 1,500 feet in altitude—many times higher than current ships' masts—and greatly extend the equipment's range and effectiveness. Since

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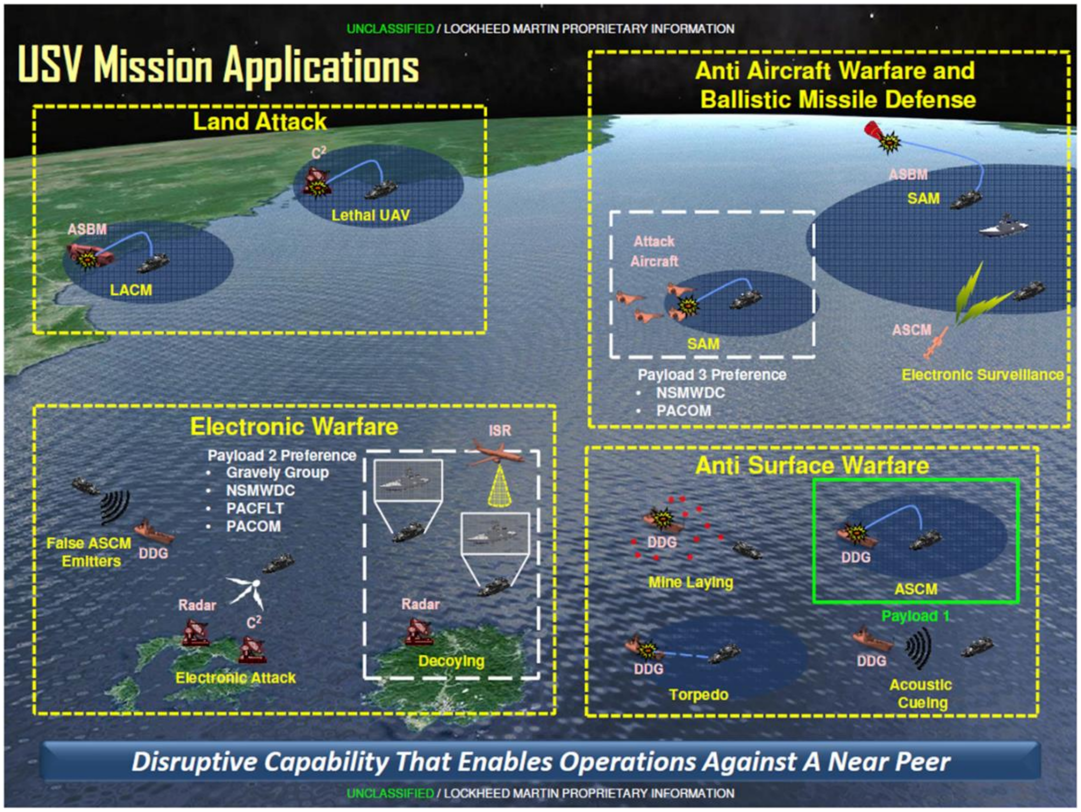
[22] Ibid
[23] Ibid
[24] Ibid
[25] https://www.darpa.mil/news-events/2018-01-30a

2016, DARPA and ONR have been working on technological advancements to Sea Hunter's sensing and autonomy suites. The next phase of testing will be automating payload and sensor data processing, rapidly developing new mission-specific autonomous behaviors, and exploring autonomous coordination among multiple USVs. ACTUV's cost is approximately $23 million—significantly less than the best-case-scenario $480 million price tag attached to an LCS.[26]

Lockheed Martin UxS

Lockheed Martin (LM) believes that UxS will become a critical enabler for future Aegis operations against near peer threats by incorporating low cost, high volume, and persistent UAVs, USVs, and UUVs. LM can repurpose existing commercial and military components and rapidly field an USV that will complement the AWS and increase CRUDES lethality / survivability.[27] The options for the refurbished use of existing platforms would be to either utilize the LCS hull type for an USV concept.

[26] CRS Report RL33741, Navy Littoral Combat Ship (LCS)/Frigate Program: Background and Issues for Congress, by Ronald O'Rourke.
[27] Johnson, Jabari, and Chris Abt. "Fleet SUW USV: Affordable Sea Control and Power Projection." Lockheed Martin Rotary & Mission Systems, November 2016.



(Figure 2: LM depiction of USV mission tasking.[28])

Existing system characteristics: top speed: 20-30kts, range: 600nm - 3,000+nm, payload, 124,000lbs payload, survivability @ sea state 5, and cost average of $3M - $15M. The advantages for the operational use of this system:

- Low cost USVs allow for high volume employment across entire AORs[29]
- USVs counter advanced threats w/o risking valuable manned assets[30]
- Rapid production of re-purposed systems[31]

OSD UxS

The "Ghost Fleet" concept uses the concept of creating autonomous unmanned systems kits allowing integration through existing surface platforms. OPNAV N96 Director,

[28] Ibid
[29] Ibid
[30] Ibid
[31] Ibid

Rear Admiral Ronald Boxall, talks of the need to build a future surface fleet that has a range of options and capabilities using autonomy. He goes on to say, “On the low end…,” the MDUSV “…is that type of vessel- maybe it’s the Mark VI, maybe it’s the LCS.”[32] With the LCS program currently having a cost of about $570M, with modularity packages ranging from $75-$100M, there is little optimism for the conversion costs associated with adding autonomous unmanned technology.[33]

- *LCS specifications: 389 ft length, speed 40-50 kts, 4300 nm range @ 16 kts, and 1000 nm @ 40 kts.*
- *Mk VI specifications: 85 ft length, speed 45 kts, 750-800 nm range @ 25 kts.*

The Secretary of the Navy presents a prioritized portfolio of unmanned system (UxS) for application towards rapid development technology initiatives based on Navy warfighting needs and capability gaps. The Department of the Navy’s FY16 Joint Staff budget submissions for the justification for advanced component development and prototypes (ACD&P) is projecting $15 Million through FY 2021 with the goals and objectives of the Chief of Naval Operations (CNO) Navigation Plan and the Cooperative Strategy for 21st Century Sea power, CNO’s Navigation Plan, and Design for Maritime Superiority. Additionally, this project supports the Secretary of the Navy's (SECNAV) Innovation Vision and the Implementation Directive for Better Buying Power 3.0. The project will increase the use of rapid prototyping and demonstration to quickly introduce technologically advanced UxS capabilities to the Fleet and provide warfighters with direct opportunities to explore and

[32] Eckstein, Megan. "Navy Wants To Weave LCS, Unmanned Systems, Subs into ..." USNI News. December 12, 2016. Accessed February 14, 2018. https://news.usni.org/2016/12/12/navy-wants-to-weave-lcs-unmanned-systems-subs-into-new-battle-network.

[33] "Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress." September 21, 2016. Accessed February 14, 2018. https://www.everycrsreport.com/files/20160921_RL32665_4ab7d76f523fb45ca7b69a12ff645b254ac9cee0.pdf.

refine operational concepts. Department of Navy (DON) leadership has acknowledged that maintaining maritime superiority depends in part on our ability to accelerate the speed of warfighting and technological innovations in order to extend our advantage to offset our adversary's growing capabilities.[34]

Assumptions

- Cultural paradigm shift within the US Navy for the **acceptance of the operational use** of autonomous unmanned systems
- Autonomous and unmanned systems that reach **initial operational capability** (IOC) by 2020[35]
- Requirements, limitations, **bandwidth and connectivity, electromagnetic (EM)** degradation, interoperability, and compatibility will be identified[36]
- The effectiveness of the TAUSV is based on basic assumption about its **operability** within the defined maritime environment
- The TAUSV can **observe changes within the operating environment** and make the necessary adjustments
- TAUSV **susceptibility** to adversary collision and/or weapons.
- The TAUSV will have **scalable levels** of autonomy
- Realization of the **innovation of power generation technology** needed to support extended operational use

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[34] "Department of Defense Justification Book for Research, Development, Test & Evaluation (RDT&E)." Office of the Secretary of Defense, FY16 DOD Joint Budget Submission, Feb. 2016. Deputy Under Secretary of Defense (Comptroller)
[35] Johnson, Cale. "Organic Over-The-Horizon Targeting for the 2025 Surface Fleet." Systems Engineering Analysis Capstone Project Report / Cohort 21/Alpha Team, June 2015. Naval Postgraduate School.
[36] Ibid, 2.

Horizonal Use of Technology

This paper defines the applied use of technology as "near-term use" of autonomous and unmanned technology (3-5 years).

Intelligent Agent Software

Society of Automotive Engineers (SAE) AS4 Joint Architecture for Unmanned Systems (JAUS) is an international standard that defines communication protocols for unmanned vehicle systems, some of their internal components, and their interaction with operator control stations. JAUS employs a Service Oriented Architecture (SOA) approach to enable distributed command and control of these systems.[37] According to David Antanitus, "the autonomy engine is a set of algorithm-level specifications for the behaviors and capabilities of the autonomy platform. It lists all the important, high-level, mission-oriented tasks either planned or implemented in the context of the vehicle scenario."[38]

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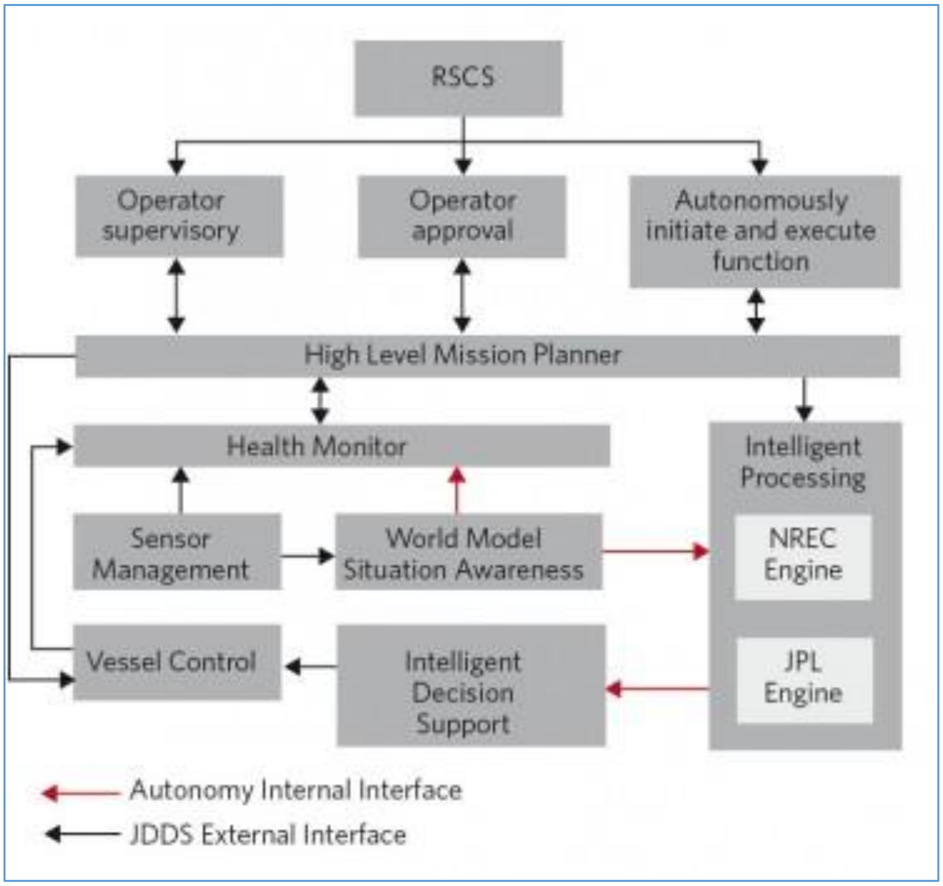
[37] http://openjaus.com/understanding-jaus/
[38] http://www.doncio.navy.mil/chips/ArticleDetails.aspx?ID=7314



(Figure 3: Autonomy Architecture with Remote Supervisory Control Station (RSCS). Image courtesy of DARPA.)[39]

States of Autonomy

Dr. Jacquelyn Schneider, assistant professor at the U.S. Naval War College, advocates for autonomous systems as the key components of the third offset. "The victors of future war will be those states that are best able to harness autonomy and human-machine integration."[40] In contrast, "the first or second offsets, in which the United States was able to double down on the development of physical components of technology (tactical nuclear weapons, precision-guided munitions)…,"[41] the autonomy arms race will feature systems and Artificial Intelligence (AI) that enhances the talent and manpower of the current force. For

[39] Ibid
[40] Schneider, Jacquelyn. "Blue Hair in the Gray Zone - warontherocks.com." War on the Rocks. Accessed February 9, 2018. https://warontherocks.com/2018/01/blue-hair-gray-zone/.
[41] Ibid

the purposes of this research, and within the scope of this CONOP, TAUSV will be operating at the semi-autonomous state.

Solon Mias, consultant with Research, Development and Innovation, identifies the levels of autonomy as the level of decision making capability available to the unmanned vessel, "…given the communication link, the type of decisions and the associated risks."[42] He lists five levels of autonomy; (1) full human-remote operated *(simple observe)*, which delineates continuous communications and C2 from the human; (2) human-tele-operated mode *(simple observe and orient)*, in which the platform, using organic sensor and radar data, provides the human with information; (3) human-directed mode *(O.O., observe and orient ~with "man in-the-loop")*, where the human makes all of the critical decisions through the sensor data provided by the autonomous vessel; (4) human-assisted *(O.O.D., observe, orient, and decide ~with "man on-the-loop")* where the vessel provides and disseminates sensor data to the human-operator and also makes its own decision and action but are only non-critical; and lastly, (5) fully autonomous *(complete OODA~ "no man on-the-loop")* where the vessel is capable of perceiving, deciding, and acting on its own independent of the human.[43][44] For the purposes of this CONOP, The technology applications that are currently offered with the three systems identified within this research, the autonomous level most favorable to the interoperability of the TAUSV and host unit will be (1) unmanned, man-in-the-loop, (2) semi-autonomous, man-on-the-loop, and (3) fully autonomous.[45][46]

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[42] Mias, Solon. "Technologies and Applications for Unmanned Maritime Systems." International Journal of Unmanned Systems Engineering 1, no. S4 (2013): 23-30.
[43] Ibid, 25.
[44] The phrase OODA loop refers to the decision cycle of observe, orient, decide, and act, developed by military strategist and United States Air Force Colonel John Boyd.
[45] Jeffrey S. Thurnher, "No One at the Controls: Legal Implications of Fully Autonomous Targeting," Joint Forces Quarterly, issue 67 (Fourth Quarter 2012), p. 83.
[46] Docherty, Bonnie. "LOSING HUMANITY The Case against Killer Robots." International Human Right Clinic (IHRC) Human Rights program at Harvard Business School, November 2012. https://www.hrw.org/sites/default/files/reports/arms1112_ForUpload.pdf.

Constraints

Operational Constraints:

- The TAUSV must be able to perform within doctrinal navy mission standards for Anti-submarine warfare (ASW), Mine Warfare (MIW), Strike warfare, Anti-Air Warfare (AAW), Amphibious Warfare, Surface Warfare (SUW), and Electronic Warfare (EW). For the purposes of this research and CONOP, operations will be limited to ISR and OTH capabilities.
- The TAUSV will need to have the speed and maneuverability capable of maintaining operations with host unit (surface combatants). (30 knots at max displacement)
- TAUSV will need to operate at ranges sufficient to be deployed to a theater of operation, similar to host unit.
- TAUSV must meet all survivability and reliability standards set by NAVSEASYSCOM and other appropriate authorities.
- TAUSV maintenance cycles are commensurate with the Chief of Naval Operations Director of Surface Warfare (N96), Fleet Forces and Surface Forces requirements in accordance with O & M funding.

C2 Considerations

Command and Control (C2) capabilities are essential to the interoperability and execution of operations of the TAUSV and host unit. Existing doctrine lays out guidance for the tasking and decentralized use of the TAUSV. According to the Naval Doctrine Publication 1, "... Naval doctrine is based on current force structure and capabilities. It incorporates time-tested principles and builds upon approved joint doctrine in standardizing terminology and processes among naval forces."[47] Moreover, C2 "…forms the foundation of unity of command and is essential to the decision process at all levels," which is essential with the use of autonomous and unmanned systems.[48] For the purpose of this paper and CONOP construction, I intend to utilize a C2 notional concept authored by Coleman Ward, Center of International Maritime Studies. His notional C2 architecture concept, known as Adaptive Force Packages (AFPs), encompasses the traditional doctrinal concept of the Composite Warfare Commander (CWC) to enable the host unit CO's to control the AFPs.[49] This allows for the effective operational use of the TAUSV. Deputy CNO for Information Warfare (N2/N6), is the Navy's lead agency for C2, which includes CWC battle management concepts, electromagnetic spectrum management, and information network capabilities for the fleet. The Information Warfare (IW) community will need to align the 'Assured C2' and 'Balance Act' priorities as an investment in engineering that not only delivers IW capabilities to fleet assets, but also must address the integration of autonomous and unmanned systems as well.[50]

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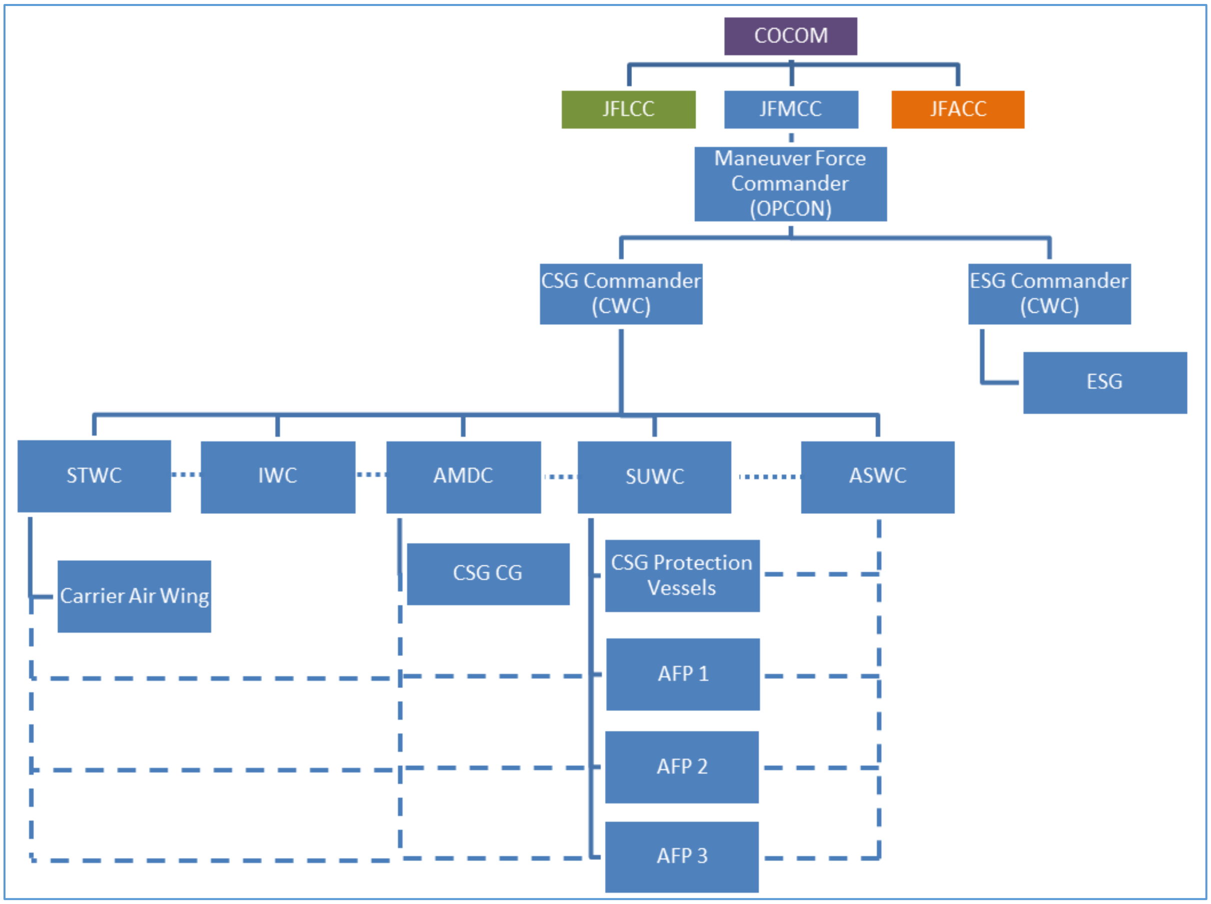
[47] United States Navy. Naval Doctrine Publication (NDP) 1: Naval Warfare (Government Printing Office: Washington D.C. March 2010).
[48] Ibid, 61.
[49] Ward, Coleman. "Autonomous Warfare: An Operational Concept to Optimize Distributed Lethality." Center for International Maritime Security; Capability Analysis, Tactical Concepts, 26 Oct. 2016, cimsec.org/autonomous-warfare-operational-concept-optimize-distributed-lethality/28629.
[50] Norton, Nancy. "Information Pillars." Lecture, Information Warfare Principles, June 14, 2016.



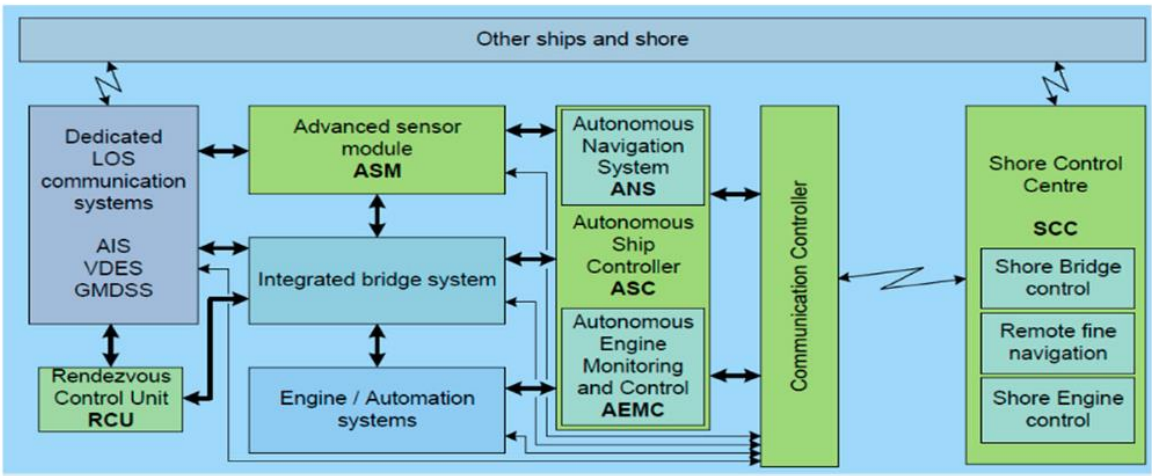
(Figure 4: Traditional CWC Operational C2 Structure for a DL Task Force[51])

Hull Mechanical and Electrical Considerations

For an analysis of the control and functionality of ship's control, navigation and engineering control systems, the framework of system's operability was founded by the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) research project. The three-year project, which completed in August 2015, provided a template for the future development of integrated autonomous and unmanned control systems. This study helped developed a technical architecture for the operational concept of an unmanned

[51] Ibid, 12.

merchant vessel. The test vessel was operated by an automated on-board decision system but controlled remotely by an operator in a shore side control station.[52]



(Figure 5: MUNIN developed a technical concept for the deep-sea navigational process of the autonomous and unmanned ship.[53])

- Autonomous ship controller (ASC) (voyage, navigation, and collision avoidance systems)

- Autonomous engine monitoring and control (AEMC) system (engine control and subsystem critical controls of pressures and indicators)

- Rendezvous control unit (RCU) (port entry and departure system)

- Advanced sensor module (ASM) (AIS, radar and CCTV feeds)[54]

Control & Navigation Systems

MARTAC TASKER

Maritime Tactical Systems (MARTAC) has developed a ‘system of systems’ command and control system called TASKER that acts as the command and control module

[52] Hogg, Trudi, and Samrat Ghosh. "Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships." Australian Journal of Maritime & Ocean Affairs 8, no. 3 (2016): 206-22.
[53] Ibid
[54] Ibid

for the multiple autonomous unmanned vehicles simultaneously.[55] The TASKER workstation is a point and click software system that enables operator to have variable control in semi-autonomous mode or manual mode. The TASKER system encompasses a Mobile Command Center (MCC) and Vessel Control System (VCS) module that enables communications with the autonomous unmanned system.[56]

ASV Control Systems

ASV Unmanned Marine Systems has the 'ASView' server system that connects manned and unmanned systems for operator interface. ASView's server/client architecture allows for seamless connectivity within a wide-range of control configurations like navigation, sensor control data, video feed and payload information.[57] The system works in a variety of control modes; remote, automatic, mission, autonomous, and external. The control modes correspond to the level of autonomy need during operation.

CARACAS

Control Architecture for Robotic Agent Command and Sensing (CARACaS) is a command and control product developed for controlling either a single autonomous robotic vehicle or multiple cooperating but otherwise autonomous robotic vehicles. The Office of Naval Research (ONR) utilized the CARACAS system to convert unmanned systems into autonomous systems. This commercial off-the-shelf system that, when used with radar and electro-optical/infra-red sensors, offers versatility for navy maritime operations for targeted and controlled by a supervising host unit. CARACaS is applicable to diverse robotic systems

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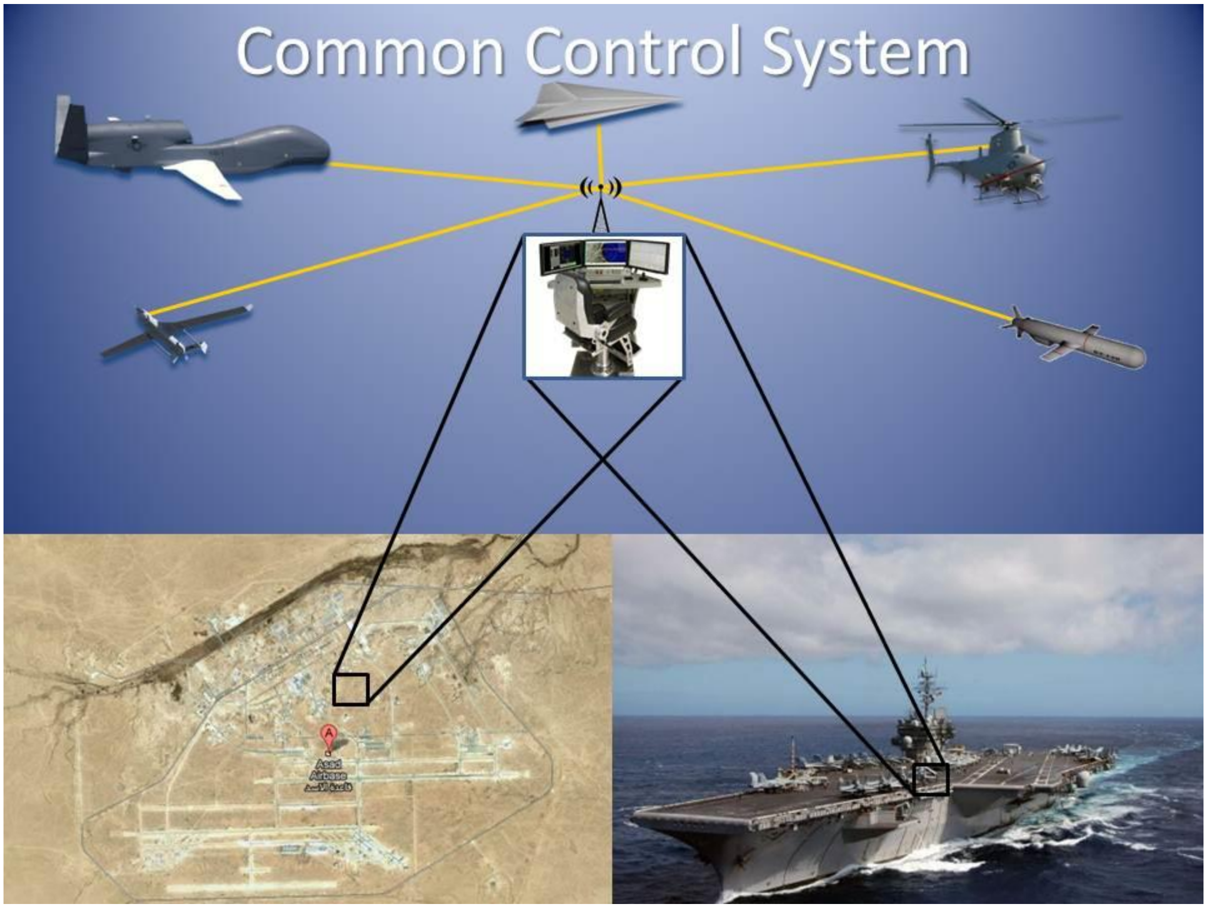
[55] Rowley, U.H. Jack. "Transitioning from USV to UUV: Maritime Tactical System adds Hybrid USV/UUV to its Autonomous MANTAS USV." Marine Technology, January 2017. http://www.sname.org/sname/mt.
[56] http://martacsystems.com/Tasker.aspx
[57] https://www.asvglobal.com/asview-technology/

that could include aircraft, spacecraft, ground vehicles, surface water vessels, and/or underwater vessels.[58]

Common Control System (CCS)

The Assistant Secretary of the Navy, Strike Planning and Execution Systems Program Office (PMA-281), has developed Common Control System (CCS), a software architecture with a common framework, user interface and components that can be integrated on a variety of unmanned systems. CCS provides U.S. Navy unmanned vehicles hardware and software that works across several different systems. The directorate for Unmanned Systems' (OPNAV N99) roadmap intends for CCS to be compatible across all domains – air, surface, undersea and ground. It will provide common vehicle management, mission planning, and mission management capabilities for the Naval Unmanned Systems (UxS) portfolio.[59]

[58] http://www.navaldrones.com/CARACAS.html
[59] http://www.navair.navy.mil/index.cfm?fuseaction=home.displayPlatform&key=1391AB27-A135-474E-99EA-5006E8D75E39



(Figure 6: CCS Software and Hardware system integration.[60])

NAVAIR is already using CCS in conjunction with the Unmanned Carrier-Launched Airborne Surveillance and Strike system (UNCLASS) which provides command and control systems capabilities in order to communicate and share data with multiple unmanned systems. The CCS system could be used in conjunction with autonomous unmanned systems as well.

CHAPTER 3: OPERATIONS ANALYSIS

Stakeholders

DOD, OSD, DON, ONI, ONR, OPNAV (N2/6, N3/5, N83/84, N96), DARPA, NSWDC, USFF, NAVSEA, SPAWAR, NWDC

[60] Ibid

CHAPTER 4: CONCEPT OF OPERATIONS

This CONOP has been developed to capture and analyze interoperability effectiveness, and focuses on the combined operations of the Tactical Autonomous Unmanned Surface Vessel and manned US Navy platform (DDG, LCS, and CG). Most of the communications and coordination will occur of the manned platform, or host ship. The scenario will take place within the multi-domain battlespace to demonstrate fleet integration.

Operations requirements: mission operations focused on describing the process, approach and results of the coordinated use of TAUSV and manned surface assets in execution of various scenarios.

Scenarios: CONOPS will be designed to execute and analyze effectiveness of interoperability of the TAUSV and manned surface combatant. Command and control of the scenario and operations decision making will be maintained on the manned surface combatant (host ship) via the TAO in CIC.

Scenario 1*: Formation Steaming (Stationing, Plane Guard, Picket unit)*

Objective: To facilitate the movement of the TAUSV and manned ship from one place to another; and to organize ships for optimum tactical effectiveness.

Types of formations: Phase 1 (single TAUSV & host ship) Phase 2 (2 x TAUSV and host ship)

(a) Screen formation

(b) Line Formation *(Single Column, Line Abreast, and Diamond)*

Scenario 2*: Maritime Domain Awareness (MDA)*

Objective: Demonstration of Intelligence, Surveillance and Reconnaissance (ISR) operations for optimum tactical effectiveness.

(a) Search Area Planning *(4W grid, Vector logic, Common Geographic Reference System, and Wagon Wheel)*

(b) Common Maritime Picture *(COP/CTP procedures)*

(c) Sensor Coordination and Classification *(using organic and non-organic sensors)*

***Scenario 3**: Chokepoint Transit*

Tasks

Mission Essential Task List (NMETLs) were referenced from the Universal Naval Task list (UNTL) and Navy Tactical Task List (NTTL) for validity and relevancy.[61]

Doctrine

-NWP 3-20 Surface Warfare Manual

-NWP 3-56 Composite Warfare Doctrine

-Navy-wide OPTASK SUW

-NTTP 3-20.1 Surface Warfare Coordinator Manual

-NTTP 3-20.3 Surface Ship SUW Tactics

-NTTP 3-22.5 Maritime TACAIDs

-NTTP 3-20.7 Over-The-Horizon Targeting (OTH-T)

-NTTP 3-60.1 Multi-Service TTP

-NTTP 3-20.5 Counter FAC FIAC

-ATP 31(D) (2) NATO Above Water Manual

-ATP (1) Volume 1 Allied Maritime Tactical Publication

-APP 7 Joint Brevity

[61] https://jdeis.js.mil/jdeis/index.jsp?pindex=43

CHAPTER 5: RECOMMENDATIONS

Future Needs

Law

International Maritime Organization (IMO) regulations and laws governed under (COLREG) currently prevent autonomous unmanned systems from being tested at sea with no lookout onboard. Although, autonomous system technology is maturing, the maritime law standards do not allow leniency in testing without a man onboard an unmanned platform. It is a regulatory conundrum considering 50-80% of all collisions are caused by human error.[62] I don't think that current laws will prevent the application of the use of autonomous unmanned systems, as long as the platform can be controlled via a "man in the loop" concept while in traffic dense areas. Rolls Royce is leading the way with trying to develop and use autonomous vessel technology and have a commercial system in use by the end of the decade. They are also spearheading efforts to change IMO regulations.[63] October 2016, Last year, Sea Hunter passed a series of technology integration tests, which relate to the International Regulations for Preventing Collisions at Sea (COLREGS). It seems as though the Navy's RD&T of autonomous unmanned systems is maturing at a rate that we could see CONOPs and testing of these platforms within the near-term timeframe. International Maritime Organization (IMO) regulations, such as in Solas, the collision regulations (COLREGs) and STCW (Standards for Training, Certification and Watchkeeping), can be revised. But, it seems as though IMO regulations could hamper the operational us of this technology. Lloyd's of London, during a public forum at London International Shipping Week in September, examined what were the insurance implications of a maritime accident involving an unmanned ship. An affordable insurance policy would need to be developed by

[62] https://www.maritime-executive.com/editorials/autonomous-ships-regulations-left-in-their-wake#gs.e4K2gF8
[63] http://www.auvsi.org/industry-news/darpa-successfully-completes-actuv-program-actuv-sea-hunter-prototype-transitions-onr

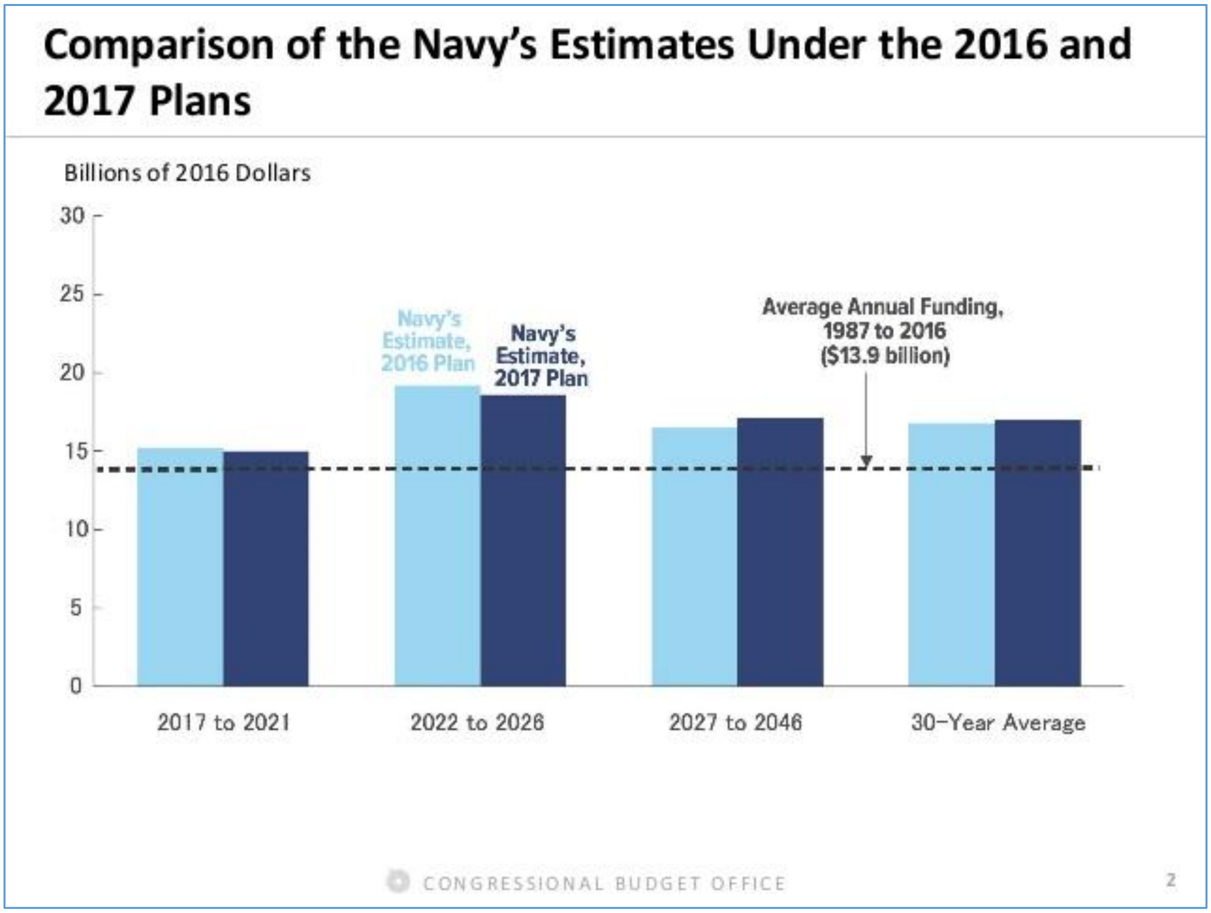
modifying existing coverage for maritime liability.[64] Ultimately, the technology needed to construct and operate remotely controlled and semi-autonomous ships is available. However, there would need to be major changes to regulations and insurance cover. A number of rules in COLREGS determine that whenever seafarers are in control of ships, they are required to have lookouts and someone is able to act to prevent accidents.

Cost

"CBO estimates that the cost of the Navy's 2017 shipbuilding plan—an average of about $21 billion per year (in 2016 dollars) over 30 years—would be $5 billion higher than the average funding that the Navy has received in recent decades."[65]

[64] https://maritimeintelligence.informa.com/resources/product-content/2017/08/31/10/19/maritime-and-commercial-law-august-2017-round-up

[65] "An Analysis of the Navy's Fiscal Year 2017 Shipbuilding Plan." Congressional Budget Office (CBO), Feb. 2017, www.cbo.gov/sites/default/files/115th-congress-2017-2018/reports/52324-shipbuildingreport.pdf.



(Figure 7: United States Congressional Budget Office (CBO) FY2016-17 shipbuilding estimates.[66])

According to the CBO study on the projection of the Navy's average annual shipbuilding costs with an estimate of the total costs per year between the years 2022-2028. The Department of Defense (DOD) submitted the Navy's 2017 shipbuilding plan, which covers fiscal years 2017 to 2046, to the Congress in July 2016. The average annual cost of carrying out that plan over the next 30 years—about $21 billion in 2016 dollars, CBO estimates—would be one-third more than the average amount of funding that the Navy has received for shipbuilding in recent decades. The Navy's 2017 shipbuilding plan is similar to its 2016 plan with respect to the goal for the total inventory of battle force ships, the number and types of

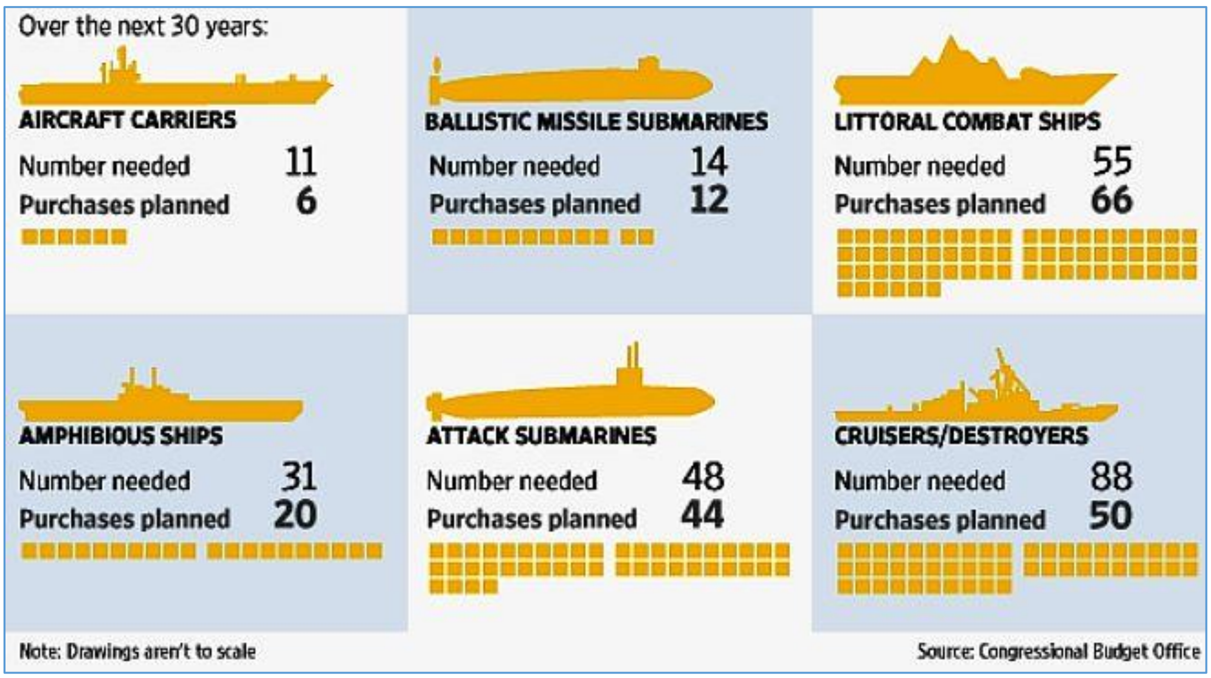
[66] Ibid

ships that the Navy would purchase, and the funding proposed to implement its plans. The Navy's goal), as stated in its 2017 shipbuilding plan, was to maintain a fleet of 308 battle force ships. To that end, the Navy would buy a total of 254 ships over the 2017–2046 period (209 combat ships and 45 combat logistics and support ships). If the Navy adhered to its current schedule for retiring ships, it would meet the goal of 308 ships under the 2017 plan by 2021, and still be able to maintain its inventory at that level or higher through 2028. After that, however, the fleet would fall below 308 ships. By the 2030s, the fleet would number fewer than 300 ships.[67] These estimates don't take into consideration the 'wear & tear' aspect of having to execute maintain minimum maintenance and upkeep requirements. Additionally, the retirement scheduling of ships currently in the fleet doesn't account for extended requirements for keeping active ships in an active operational cycle. In a statement to the US Senate Committee on Armed Services, Subcommittee on Sea Power, Naval Affairs Analyst, Ronald O'Rourke, expounded on the point of the US Navy's expectations and requirement to achieve a 300-plus Navy. As the United States Navy addresses growing concern of China's increase build-up of platforms and modularization, the current support for a 355-ship force-level plan, only exacerbates the idea of building a future fleet architecture with the procurement of autonomous unmanned vehicles.[68]

When you look at the comparative costs of an autonomous unmanned medium displacement craft, we'll substitute the life cycle figures reflected in the MCM (Avenger Class) ship based on structural similarities (according to the length of the Sea Hunter at 132 ft). According to CBO analysis, for a small vessel with a relatively large crew, such as the MCM-1 class mine countermeasures ship, personnel costs represent 38 percent of the ship's

[67] Ibid
[68] O'Rourke, Ronald. "Options and Considerations for Achieving a 355-Ship Navy." 2017. Congressional Research Service 7-5700 www.crs.gov

life-cycle cost, compared with 29 percent for a CG-47 class cruiser, which is seven times bigger but has only four times as large a crew. Fuel costs account for a much smaller share of the life-cycle cost: 8 percent to 11 percent in the case of the frigate, destroyer, and cruiser. For the mine countermeasures ship, fuel costs make up only 1 percent of the life-cycle cost, largely because that ship travels at very slow speeds during mine-clearing operations.[69]



(Figure 8: CBO depiction of US Navy projections by ship class.[70])

CHAPTER 6: CONCLUSION

Specific outcomes for this research:

- Increased fleet integration of autonomous and unmanned technology
- Identify fleet mission priorities and initial employment concepts while integrating autonomous technology

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[69] Elmendorf, Douglas W. "O & S life-Cycle Costs of Four Classes of Navy Ships." Received by Honorable Jeff Sessions, US Senate, 18 Apr. 2010. US Congressional Budget Office

[70] Ibid

- Apply CONOPs to test and validate capable mission sets and how autonomous systems will be used.
- Identify shortfalls and mitigate against the identified mission priorities

The challenges in applying a comprehensive approach to the development of a concept of operations is to consider the following:

- In incorporation of propulsion, electrical, and auxiliary systems integration to the autonomous control architecture;
- What will the operations look like within the EM spectrum with consideration of spectrum management and sensor integration (emissions)? (Dark battle?)
- Will autonomous systems effect change in ROE and the employment of weapons systems?
- A closer look at the modularization of sensors and weapons payloads will greatly restrict options for the tactical use of the smaller autonomous unmanned systems
- We’ll need more R&D of AI processing for sensor data and queuing to support and easy the human DM process.
- What are the physical security and force protection applications for TAUSVs?
- Maritime Regulations and Legal restrictions should be addressed concurrently.

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