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NATIONAL DEFENSE UNIVERSITY
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AY23-24 – Individual Research Study Paper

Silence the Naval Guns. The future is calling again.

Steven Lovatt MBE

Commander, Royal Navy

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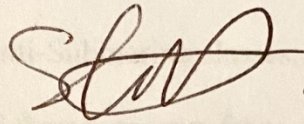
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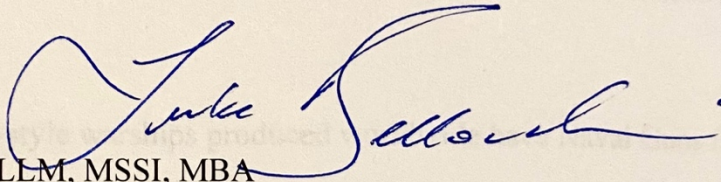
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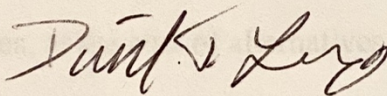
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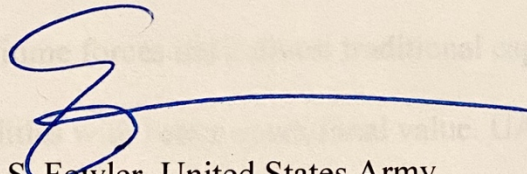
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Abstract

The trend for maritime defense procurement is increasing complexity and cost, leading to fewer complex warships available to satisfy operational demands against increasing asymmetric threats. Maritime force designs are particularly exposed, and fleet capacities struggle against increasing operational demands for the persistent strategic value warships/submarines uniquely provide in dangerous or difficult-to-access locations.

The need to innovate and find ways to reverse the effect of this trend or unlock greater combat mass from smaller fleets is greater than ever. Traditional assumptions of warship capabilities, particularly Destroyers and Anti-Submarine classes, need review with a system of systems approach. As new capabilities and threats emerge from war or technological revolution, opportunities must be exploited and integrated into the fleet faster than our adversaries to retain or gain competitive advantages.

Today, non-aircraft carrier-style warships produced worldwide have Naval Guns fitted, competing against a broadening proliferation of anti-ship missiles and uncrewed air systems (UAS) or drones. The gun has held on to its prominent position on the foc'sle because of a belief in its contribution to Joint Fires, at the cost of alternatives with greater range and operational utility through modular payloads evolving with the fourth industrial revolution.

Western maritime forces must divest traditional capabilities to repurpose space and resources for capabilities with better operational value. UAS should not replace or compete with crewed air systems but complement them, and their introduction should not be isolated to aircraft carriers or delayed for future platforms. It is possible to unlock a new source of air power and disperse the center of gravity inherent to carrier-centric fleet designs. This evolution could be achieved using existing infrastructure, resources, and people in today's warships.

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Dedication

To my family, for their trust and for leaving our home to move our lives across the ocean.

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Chapter 1: Introduction

Artificial Intelligence (AI) and robotic drones, specifically Uncrewed Aerial Systems (UAS), are two separately maturing Revolutions in Military Affairs (RMA) offering radical warfighting advantages. The intersection of these RMAs manifests in AI-enabled, managed, and networked robotics. This is Algorithmic Warfare. The maritime force best able to integrate and augment its people with it will hold a significant advantage in warfighting efficacy while reducing overall operational risk to life. Traditional main Naval Guns are obsolete and high-risk for their main task; maritime forces should seek greater Joint Force combat mass and replace guns with Algorithmic Warfare capabilities offering broader strategic value, such as UAS.¹

The rise of the Aircraft Carrier as the centerpiece of maritime power projection, in place of the Battleship, changed the domain forever, framing exactly why maritime forces must adapt quickly. Western and Chinese military leaders have expressed that those able to deploy algorithmic warfare capabilities in high numbers will dominate future conflicts. Historically, however, status quo culture delayed recognition of the evolutionary change represented by the Aircraft Carrier, and this cultural trend continues today at the expense of faster adaptation.²

The scope of the analysis will explore Western and Chinese trends in battle management systems and UAS for military operations, then consider the overall benefit of adopting them for all warships. It will not argue for an overhaul in maritime fleet design, replacement of Aircraft Carriers, or attempt to displace crewed flight with robotics. It will use aviation's historical displacement of naval gunnery to illustrate the implication and potential for Algorithmic Warfare to maritime forces. Finally, it presents an opportunity for change in the near term that could expedite the integration of AI-enabled robotics and add valuable combat mass dispersed throughout the existing fleet to enhance the Joint Force.

In times of rapid technological advancement, the military aspect of Great Power Conflict (GPC) is particularly exposed to unexpected developments and confirmation bias-led obsolescence. This is because estimating the real-world combat capabilities of new technologies and ideas is very challenging, and they tend to fit inside the existing model until time of war reveals their advantages. To be defined as an RMA, a capability must impact strategy, operational art, and tactics, making previous versions of warfare less effective against forces augmented by the RMA. Prominent examples are ships, airplanes, tanks, and networks. The RMA of focus, Algorithmic Warfare, is emergent in Ukraine and demonstrates outsized advantage when integrated with existing means and augmenting human conduct warfare.³

Algorithmic Warfare - The Emerging Advantage

The fourth industrial revolution is shaping the current era of GPC: artificial intelligence, quantum computing, autonomous robotics, additive manufacturing, nanotechnology, and biotechnology. All of these increase the chance of unanticipated changes in the character of war. There are two crucial and accelerating trends in which governments and their militaries are aggressively investing: Advanced robotics and AI (Machine Learning is a discipline of AI. They will be used interchangeably within the definition of AI). The combination of AI and robotics used to augment military forces at war has been termed Algorithmic warfare.⁴

Robotics and AI have already changed the character of war, especially in Ukraine. Robotics have been used extensively over the past two decades, providing military effects beyond the limits of human capability or risk appetite that can circumvent traditional defense systems or make existing attack systems far more accurate. AI-augmented Battle Management Systems support military leaders in Ukraine to guide their operational campaigns, filtering and

analyzing vast swathes of data to clear the fog of war. When available, their combined use provides a significant capability to the Ukrainian or Russian forces augmented by it.⁵

AI stands out as a technology that may, in the future, even change the nature of war by offering a path toward artificially generated military strategy or better operational art. However, current AI systems cannot yet match the abilities of human decision-makers at the complex strategic level. That said, AI can match human-like abilities in some scenarios and, in specialist cases such as fighter jet dogfighting, perform beyond humans' biological and cognitive limits.⁶

The opportunity for maritime forces is that they have the presence and persistence to deliver effects or gather data in remote and challenging environments. Maritime platforms are well suited logistically and operationally to adopt Algorithmic Warfare technology, gathering valuable data to feed into institutionally sized AI systems by efficiently placing high numbers of sensors and strike systems in high-risk areas at the edges of operational reach.

Military aerial robotics, commonly called drones (although UAS will be used), have already demonstrated operational value and are widely recognized as an RMA. Demonstrated clearly during the U.S. wars in Iraq, Afghanistan, Ukraine, and recently, the Red Sea.⁷

The risk of conducting missions is no longer necessarily assessed against human life because UAS can sometimes step in. In specific assignments, UAS allows for a higher risk appetite and operate with performance levels beyond the scope achievable by humans. This creates a paradigm shift in the simple cost versus benefit-estimate at the heart of every strategy, operational plan, and tactical decision across the entire spectrum of warfare. While there are examples of robotics failing to produce the desired effect, the iteration speed makes the overall trend robust. Increasingly, smaller start-up defense companies develop UAS and their payloads, seeking to take advantage of new manufacturing methods and technology.⁸

Several defense companies are proposing new operating systems for warfare that specialize in enabling human-machine teaming, allowing a single person to operate many autonomous systems to complete missions. This is the cutting-edge of Algorithmic Warfare and enabled by new products such as Lattice OS by Anduril, and Gotham by Palantir, both battle management systems are currently being used in the defense of Ukraine.⁹

Combined with AI-augmented theatre Battle Management Systems, military decisions for action, even taking life, can theoretically be automated at a scale and speed incomprehensible to a human mind. The approval of each possible action then depends upon the level of interest, ethical assessment, intent, and legal framework of the actor operating the system. But such a system requires adjustment to existing military infrastructure to build out the network and real-world layers that underpin the Battle Management System and provide it with data. Ethically, an automated, lethal system remains taboo for Western militaries. Still, the potential must be explored to understand the opportunities it may offer adversaries to seize advantage.¹⁰

The current status quo for global military maritime aviation capability is still heavily invested in crewed flight. This represents an access problem for UAS in congested flight decks where they will compete with a crewed flight in a pilot-dominated culture onboard Aircraft Carriers and other aviation-capable warships. This problem requires resolution before UAS can be deployed in sufficient combat mass to demonstrate the true value of Algorithmic Warfare systems to maritime forces and Joint Forces.

Chapter 2: Historic Inflection Point: The Aircraft Carrier and the Battleship

One significant RMA in the maritime domain was the Aircraft Carrier, which supplanted the Battleship as the symbol of maritime strength due to its utility and power projection. The trends that led to this RMA took a long time to mature, were rejected several times, and took many acts of fate to set the course for the modern carrier-centric Fleet. The trends in aviation that brought the carrier-centric maritime force into being continue today in robotics, and they already have significant implications for what maritime forces can bring to the operational theatre.¹

During the Second World War, a generational change occurred in the design of maritime forces and how they project power. The USN victory over the Imperial Japanese Navy in the Coral Sea and Midway confirmed what many had proposed decades earlier. Maritime aviation would become the dominant offensive power of the domain because of its range advantage over Battleships. But it took many years, defeats, and a cultural revolution to become reality; a similar story for many RMA as they become recognized for their advantages.

Since 1910, the USN and the RN progressed through one of the most significant RMAs the maritime world has witnessed since steam replaced sail in warship design. At the time, the Battleship or Ship of the Line was considered the dominant maritime force. Each Battleship design included ever greater guns to fire enormous shells over tens of miles to conduct shore bombardment and engage enemy ships at sea.

These technical giants were indeed formidable, but they had an Achilles heel. Their effective firing range was limited by the energy density of chemical gun propellant, and their accuracy depended upon a high level of crew training. Often, they had little information about the effectiveness of their fire or if it ever hit the target unless it caused a detonation within a visual enemy ship. The effect that they had in military terms is potentially not as useful as

envisaged either. Shore Bombardment often had little real effect on the adversary troops ashore because it was so inaccurate and ineffective against forces able to prepare for it. The United States Marine Corps reported the frustrating lack of effect that naval bombardment had against Japanese forces at Iwo Jima or Saipan, and its efficacy at Normandy is still debated.²

The revolution that ended the reign of the Battleship happened due to the arrival of an alternative technology with greater utility, range, and less complex warship-build requirements. Not only that, but the technology changed the risk equation, reducing the cost per mission and risk to life, enabling greater sea control than the Battleship could offer. Battleships, which were once the dominant maritime capability before World War Two, were obsolete by the end of the war and increasingly became vulnerable to air attacks.³

The evolutionary story of the Aircraft Carrier is important to explore because history tends to repeat. In 1910 Eugene Ely launched his wooden bi-plane from the deck of the USS Birmingham at anchor near Norfolk, Virginia. A year later, he landed it back onto the deck of USS Pennsylvania. By 1916, Navy Secretary Josephus Daniels envisioned naval aircraft conducting reconnaissance and surveillance missions, including guiding Battleship guns onto their targets from the air. The RN had a parallel program and, in September 1916, acquired the ocean liner 'Conte Rosso' for conversion to a flat-topped aircraft carrier to be named HMS ARGUS. The requirement set by the Admiralty was for "A Parent Ship for Naval Airplanes and Torpedo Boat Destroyer." The RN made quick progress and, by 1918, had resolved the challenges of launching and recovering aircraft while underway at sea.

The next phase in the evolution of the Aircraft Carrier was critical to unlock the true potential. Captain Joseph Reeves USN became pivotal in realizing the power projection of the Aircraft Carrier. In 1925, Reeves assumed Command of USS Langley and revolutionized how

aircraft operations were conducted. His leadership and guidance allowed the U.S. Navy to overtake the RN in their ability to launch and recover multiple aircraft in the shortest time possible, known as sortie rate. By introducing new technologies for arresting wires and crash barriers, he unlocked cultural safety barriers and kept aircraft on the upper deck as much as possible. This removed the need to take aircraft below decks between launch or recovery operations and massively increased the sortie rate ahead of the British. From an initial rate of ten aircraft within an hour, after eight months, Reeve's crew could launch seven aircraft within 41 seconds. A record 127 landings quickly followed this in a day, and a doubling of the aircraft complement from 14 to 28 airplanes available for tasking.

The crucial 1942 victories of the United States in the Coral Sea and Midway were won by effectively using Aircraft Carriers against the Imperial Japanese. For the first time in history, neither navy came within visual sight of the other. The tenfold range advantage of naval aviation over the Battleships confirmed that the carrier was more effective in offensive operations. In 1944, Admiral Ernest J. King, USN, Chief of Naval Operations, deferred the building of five Battleships in favor of more carriers and escort ships, sealing the fate of battleships to defensive roles and relegation from the centerpiece of the maritime force. The USN then focused on the development of a carrier-centric maritime strike force. Culminating today in the latest nuclear-powered, electromagnetically launching carrier, the USS Ford. This ship, its aircraft, and escorts permit the U.S. to project power and hit targets over a thousand miles in any direction.⁴

The same technological opportunity and cultural obstruction during the emergence of maritime air power are repeating themselves as robotics compete with traditional crewed capabilities. The opportunities for AI-enabled robotics in military theatres are immense, and the dominant power may be leapfrogged if it cannot evolve past a prevailing culture.

Chapter 3: Maritime Forces: Carrier Strike Groups

USN Carrier Strike Groups usually consist of 1 Aircraft Carrier, 2 Guided Missile Cruisers, 2 Anti-Aircraft Destroyers, and 1-2 Anti-Submarine Frigates. The smaller escort ships augment and defend the carrier, projecting air power with missiles/torpedoes while protecting high-value units and logistics ships to sustain the strike group. Frigates often assume the role of anti-submarine and anti-surface screen defense, Destroyers for Area Air defense, anti-surface defense, land attack, and Submarines for anti-submarine defense or land attack.¹

This is similar to Expeditionary Strike/Amphibious Ready Groups, which focus mainly upon amphibious operations centered around smaller non-nuclear carrier type ships called Landing Helicopter Dock (LHD) or Assault (LHA) ships capable of launching F-35B.²

Escort warships typically have vertical launch missile silos (VLS), hosting missiles that are highly specialist but high-cost, and most escorts have at least one main large caliber gun for a

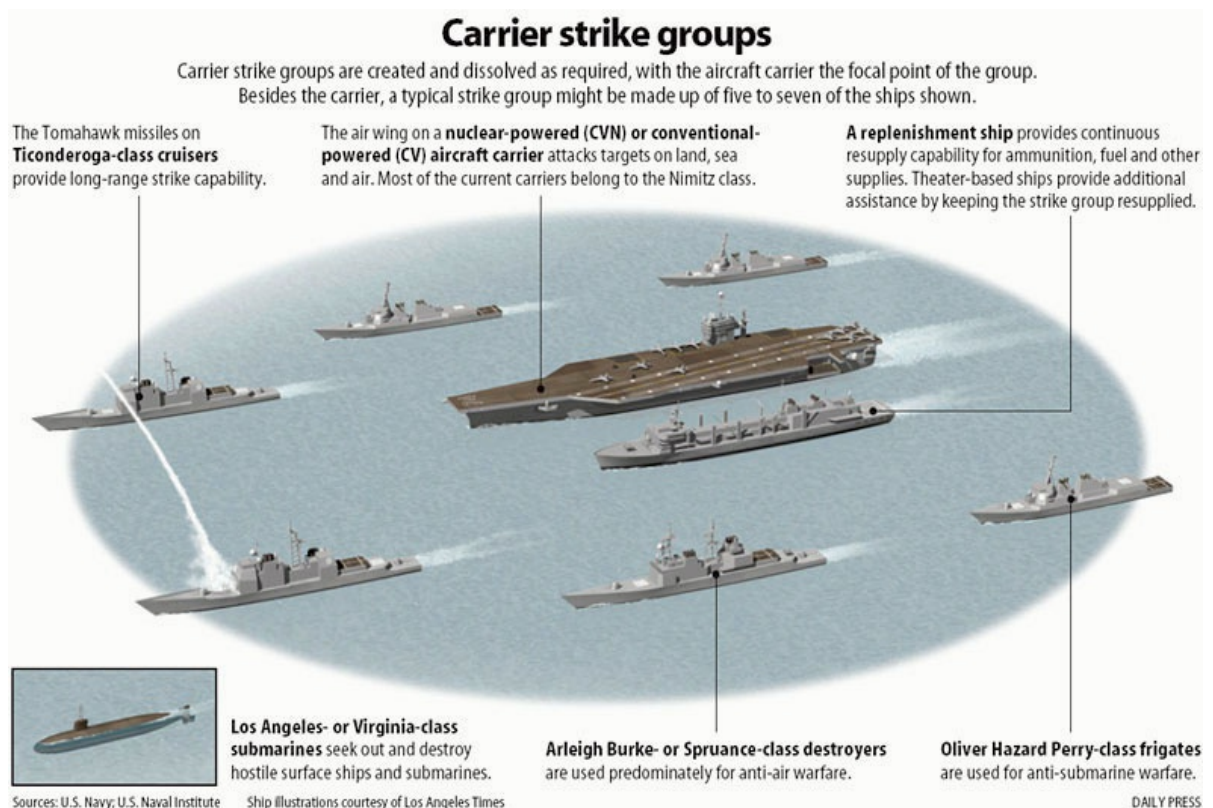


Figure 1: Example USN Carrier Strike Group composition, Daily Press, 2016.

limited role in surface warfare and to support forces ashore. The VLS missiles are highly specialist and expensive, often serving several independent requirements, which could mean they are quickly depleted in a conflict. Yet, because of their complexity, they are difficult to replenish.³ A new lower-cost capability might reduce the stress upon these critical stockpiles.

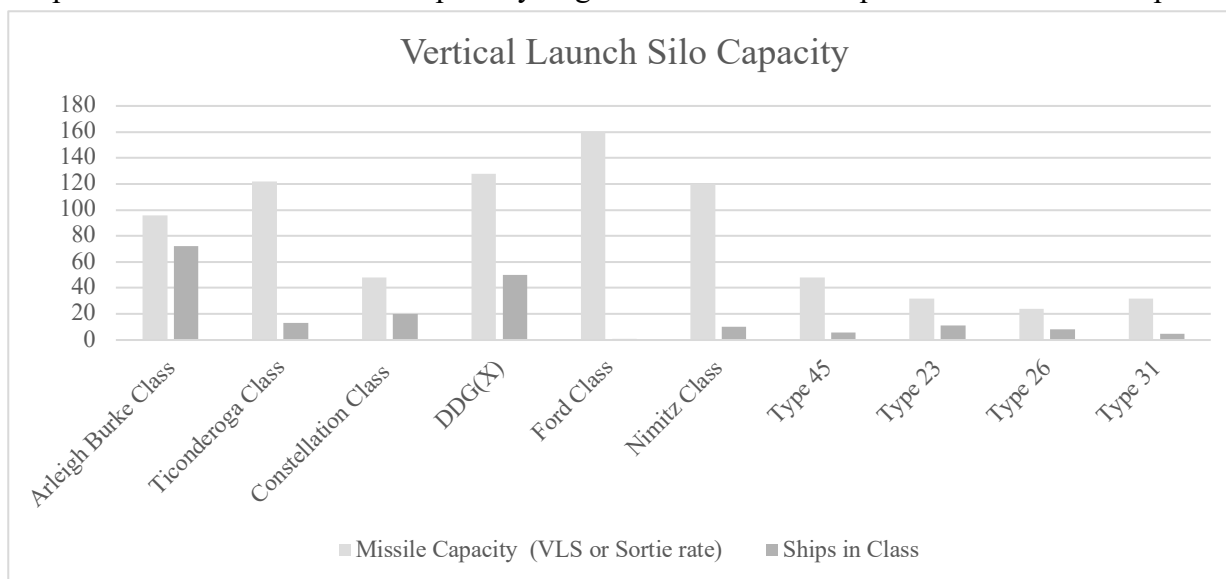


Table 1: VLS capacity and number of ships in each class

The Carrier Task Group manifests in a complex coordinated group of dozens of ships, and submarines costing billions, with thousands of lives participating. It has worked well for decades, is battle-proven in many campaigns, and has been uncontested as a modern monolith of maritime strength since the end of the Second World War.⁴ The most advanced aircraft carrier of the United States Navy (USN), the USS Gerald R Ford, has cost the U.S. Taxpayer \$13B and will crew 6000+ personnel in war-going condition. It holds approximately 75-100 aircraft and is expected to generate 160 sorties (flights) per 12-hour window, surging to 270 in 24 hours compared to the Nimitz Class, capable of 120 per day (240 per day if surged).

Maritime aerial combat mass is generated almost solely from the Aircraft Carrier. Providing an obvious center of gravity to attack and disable the power projection capacity of the Carrier Strike Group. This should not change because the exquisite high-value roles of its crewed

jet aircraft will be required for many years. But it could be more effective if augmented by growing numbers of lower cost robotic capabilities launched from escorting warships.

Threats and peer competition to western maritime forces

Adversaries have invested in technologies designed to seek out an Achilles heel in the Carrier Task Group. Long-range Ballistic Missiles and Hypersonic Glide vehicles now threaten the carriers at ever greater ranges and speeds, making their defense a very difficult and expensive task. The focus of peers to develop ‘carrier killer’ weapons is a testament to the continued relevance of the aircraft carrier strike force and its ability to project power. But it also highlights the carrier’s exclusive control over combat air power in the maritime.

The latest non-nuclear PLAN Type 003 Aircraft Carrier, called CV-18 *Fujian*, and its 70-strong J-15 air wing, combined with Z-9C anti-submarine helicopters, is an attempt by China to replicate US carrier capabilities. The conventionally powered *Fujian* is being developed as a challenge to the nuclear-powered USS Gerald R Ford class of aircraft carriers, with its electromagnetic launch system. However, in terms of sortie generation and real operational capability, PLAN is still far behind the U.S. Navy.⁵ There is a tendency to overestimate the equivalency of capabilities between two nations, and the U.S. is unique in its ability to deliver persistent high-end maritime air operations globally.

China's experimentation with carrier based UAS reflects Beijing's intention to match the US Navy's ability to operate UAS from naval vessels. Unlike the *Liaoning* and the *Shandong*, which have greater political value than strategic, the *Fujian* will support Beijing's ambitions to develop a true blue-water navy for operations beyond the second island chain and into the Indian Ocean. If the PLAN prioritizes its development of UAS and avoids conflict for long enough, it may see the opportunity to advance its technology faster than the U.S. and the U.K. There is a

real risk that the latter dedicate significant resources to protecting crewed aircraft development due to a deeply embedded pilot culture.

The Chinese have emphasized the Dong Feng 21D (DF-21D) and their hypersonic DF-17D systems. Whether the DF-21D and DF-17D missiles work perfectly is not the issue; the issue is the deterrent risk it presents. China has been developing anti-ship ballistic missiles (ASBM) and testing them on fake carriers in the desert to provide overt proof of their ability.⁶

Russia, too, has been developing the Zircon hypersonic anti-ship missile and maintains that the Poseidon nuclear-powered torpedo has an anti-carrier role. It also has the Kinzhal air-launched ballistic missile, which is claimed to be an ASBM.

Rising cost of maritime platforms

Global-reaching, blue-water maritime forces are especially susceptible to sustaining obsolete technology because of the procurement processes for large capital equipment. Traditional procurement of warships is expensive, and a great deal of military equipment is delivered already installed by the shipbuilder. However, warships are increasingly expensive to build, and fleets are struggling to build enough new ships to meet operational demand. RAND studied the cost trend of warships from 1950 to 2000 and showed that Warships have become, on average, over \$1B per platform today compared to an adjusted \$50M per platform in 1950. They

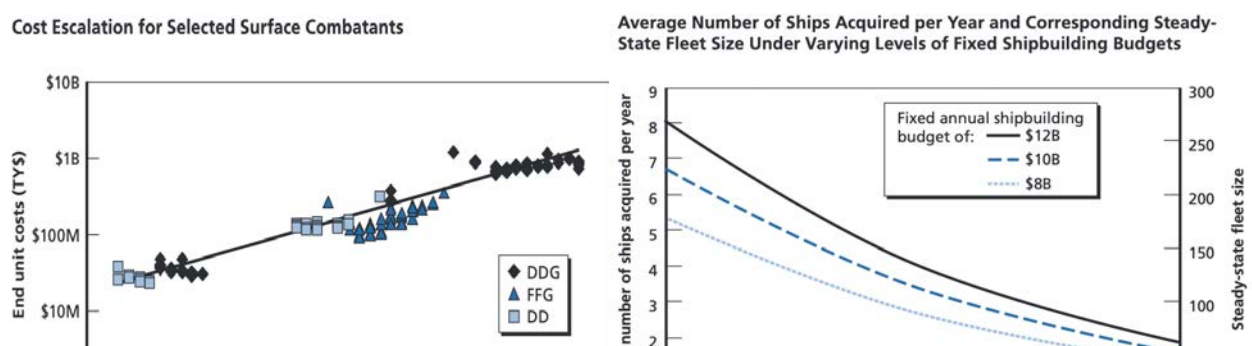


Figure 2: Mark Arena et al, *Why Has The Cost of Navy Ships Risen?: A Macroscopic Examination of the Trends in U.S. Naval Ship Costs Over the Past Several Decades*, RAND Corporation, 2006

also measured the purchasing power of a fixed budget to determine the size of a sustainable fleet over time, showing a significant decrease in fleet size if current cost trends continue.⁷

RAND then conducted a similar study to evaluate the cost of crewed fast jet capability with the same conclusions, a one-hundredfold increase in baseline cost per airframe. In conflicts of attrition, the rising costs and reducing combat platform numbers may quickly exhaust the ability of Western militaries to fight at the scale necessary to defeat a peer adversary.⁸

Because of the high cost of warships, they are typically inflexible to major adaptation despite technology evolving, with some notable exceptions. An example is the U.S. Navy's adaptation of the Iowa battleships to accommodate Tomahawk land attack missiles for the First Gulf War. This enabled the battleships to launch missiles that out-ranged their guns 50 times over. The tendency to resist major change to baseline capability is at odds when the case for using it increases the risk of losing ever more precious warships; Naval Gunnery plays to this fallacy with its extremely short range compared to the missiles designed to sink the ship.⁹

Maritime forces and digital battlespace management systems

The USN and Royal Navy (RN) invest heavily into their shipborne Battle Space Management systems both onboard and at the fleet level. For the U.S. the AEGIS (named after the shield of Zeus) and the RN, the Combat Management Systems (CMS). The purpose of such systems is to compile a four-dimensional simulation of the outside world and present it in a two-dimensional interface for human operators to make decisions. The quality of the representation is dependent upon the quantity and performance of organic sensors and network protocols feeding the Battle Management System.¹⁰

The scope of representation available in a single ship can be extended globally by sharing data via satellites or radio using a common network protocol. The most common being the U.S.-

designed Link 16 Tactical Data Link system used within NATO. This system broadcasts a message between units to share detected real-world objects as digital tracks for display across all Battle Management Systems, transmitted via multiple communication bearers. In the future, NATO maritime forces will upgrade to the Maritime Multi-Link to increase data rates.

Traditional Maritime Battle Management Systems can be improved by increasing the number of sensors feeding into the system or augmenting the operators with AI and Machine Learning techniques. But current generation technology has limits. It is often difficult to communicate across a Joint Force with enough bandwidth and rely intensely on operator input.

New Battle Management System architectures are being rapidly developed and deployed into theatre with significant impact. Investing in emergent AI-augmented Battle Management Systems with Joint force networks is at the heart of several national defense strategies. The strategies must include upgrading the fleetwide software management systems as autonomous systems become increasingly adopted. The battle management systems of warships must manage growing numbers of robotics that rely upon critical software deployments to centralized, federated and edge processing systems. Steps are being taken toward this goal by the US Navy. Lockheed Martin, builder of its AEGIS battle management system, has partnered with Palantir, a data engineering company, to support the goal of achieving the project OVERMATCH.¹¹

Chapter 4: Progress toward Algorithmic Warfare

Algorithmic Warfare at scale will depend upon coherent digital networks enabling robotics to input, process and feedback into decision cycles of a battlespace management system. Robotic systems are already able to conduct missions without being connected permanently, depending upon their role and capability, but at some point, they must sync with the digital network to download updates or upload their processed data; the exception being those systems assigned for sacrificial missions such as strike or deception. Such an architecture doesn't yet fully exist, but several nations have this within their visions for digital defense infrastructure.

The DoD Chief Digital and Artificial Intelligence Office (CDAO) is responsible for AI strategy and guiding investment and policy for AI integration. Project Maven, which began in 2017, recently transferred its ownership to the U.S. National Geospatial Agency (NGA). Project Maven aims to “integrate artificial intelligence and machine learning more effectively across operations to maintain advantages over increasingly capable adversaries.” It is a well-reported project and, initially controversial with Silicon Valley partners struggling to align their culture with the aims of the project.¹

The U.S. Department of Defense is leading this with a strategy to implement Joint All-Domain Operations (JADO), which integrates platforms, sensors, weapons, and Joint All-Domain Command and Control (JADC2). JADC2 is “Originally envisioned to improve the joint force's interoperability (e.g., making sure radio systems can communicate with one another). The JADC2 strategy expanded this focus, developing an information-sharing approach that enables joint operations by providing data for decision making”.²

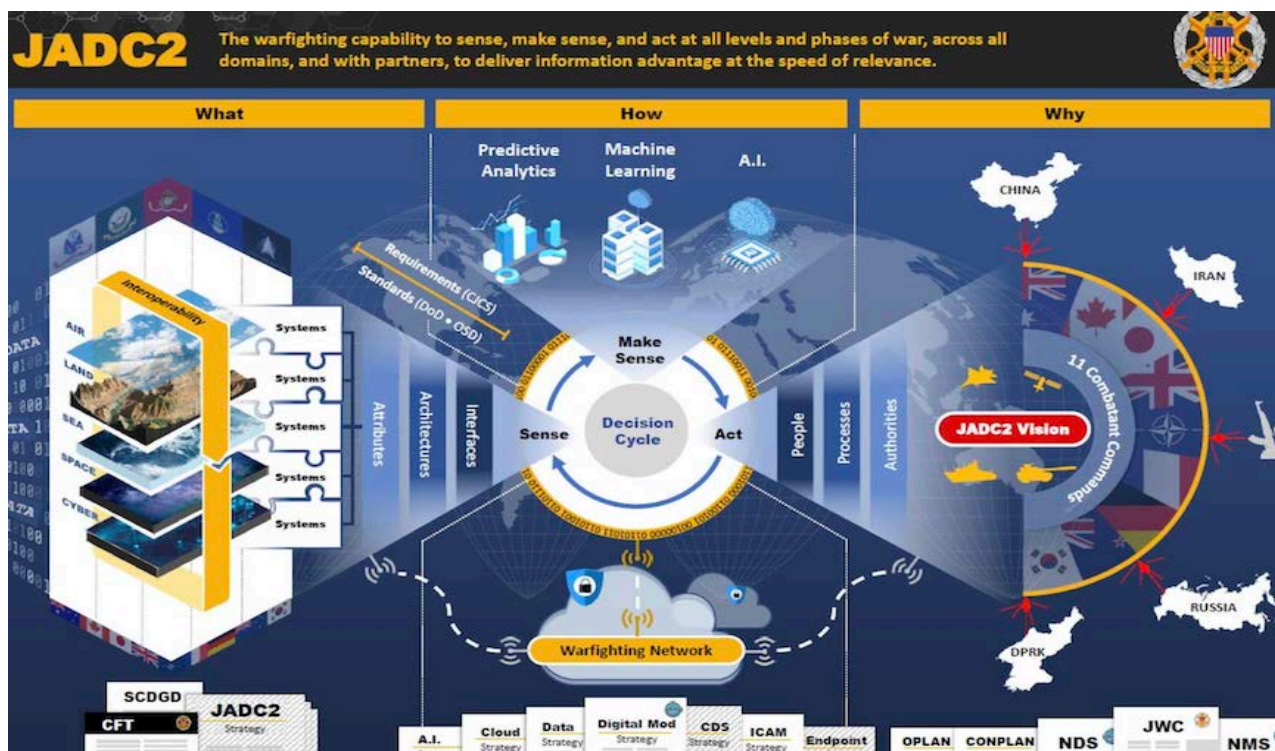


Figure 3: U.S. Department of Defense, DoD Announces Release of JADC2 Implementation Plan, 2023

The U.S. Navy has Project Overmatch, which aims “to enable a Navy that swarms the sea, delivering synchronized lethal and nonlethal effects from near-and-far, every axis, and every domain. Further, it has set up a robotic experimentation Task Force 59 operating with the 5th Fleet in the Persian Gulf. The objectives are to advance the experimentation of using robotics in real-world environments with real-world adversaries.”³

The U.S. Army has Project Convergence, “the Army’s new campaign of learning organized around a continuous, structured series of demonstrations and experiments” designed to meet the challenges posed by JADC2”. Several exercises with joint and multi-national actors have taken place, and this is at the forefront of exposing NATO to how the U.S. Army intends to fight in the coming decades.”⁴

The U.S. Air Force has the Advanced Battle Management System (ABMS) project, which aims to create a “Digital Network Environment that connects warfighting capabilities across all domains, and every echelon, to achieve global decision advantage.”⁵

The People's Republic of China are pursuing a 'system destruction warfare' strategy called Multi-Domain Precision Warfare (MDPW) to align its Joint Force in a counterinvestment to the U.S. JADC2. MDPW is intended to become a system of systems able to use AI to identify vulnerabilities of a strong enemy (强敌) military operational system and then combine Joint forces across domains to destroy them with precision strikes. The People's Liberation Army is funding MDPW to enable next-generation combat capabilities for future conflict, which it refers to as 'Intelligentized Warfare'. It views modern warfare as a contest between opposing operational systems, referred to as systems confrontation [体系对抗]. This strategy is comparable to Western joint warfighting concepts, but there are nuanced differences. The PLA, for example, is increasingly implementing dual-use civilian and military capabilities to enhance resilience and mass, whereas Western nations tend to keep them separate.⁶

The U.K is pursuing a pan-defense digital strategy for a 'digital backbone' announced in 2021 that will "value data as a strategic asset, recognising it as the mineral ore that fuels integration and enables a system-of-systems approach. These capabilities will be secure, integrated, easy to use and delivered at scale and pace to all". Since then, it has been reported that the military is struggling to achieve the implementation to the project timescale. The knock-on effect being that any autonomous or networked system cannot be integrated into a standardized network, instead requiring single service or bespoke solutions to compensate.⁷

The Royal Navy has announced its digital and data plan 2022-25. Which includes the Naval Strike Network, designed to enable autonomous systems at scale and include standardized network protocols to simplify the integration process to plug and play systems developed with industry partners. The overarching idea is to enable the vision for a disaggregated fleet of crewed and uncrewed system of systems.⁸

Chapter 5: The trend of military robotics – Uncrewed Air Systems (UAS)

The term Drone emerged in 1917 with the British Aerial Target, a small radio-controlled aircraft flown for tests but deemed unsuitable for operations. The United States led the evolution toward modern UAS during the Vietnam War, where UAS were used for reconnaissance, to launch missiles, or drop leaflets for Psychological Operations.¹

The digital age saw drone technology evolve toward increasing autonomy. UAS software development has considerably enhanced their capabilities, enabling them to execute some missions without human intervention. Today, UAS appear in many sizes and serve routinely in multi-mission roles, including strike, targeting, intelligence, and logistics delivery. The MQ-9 Reaper, RQ-4 Global Hawk, and Kratos XQ-58 represent cutting-edge operational systems with long-endurance, high-altitude operational capabilities, and advanced sensors and weapon systems. These UAS now out-compete crewed aircraft in specific roles.²

In 2011, the United States Department of Defense classified the various sizes and performances of UAS into five groups, as shown:

UAS Group	Max weight (lb)	Max Altitude (ft)	Speed (kts)
1	<20	<1200	100
2	21-55	<3500	<250
3	<1320	<18000	<250
4	>1320	<18000	Any
5	>1320	>18000	Any

Table 2: US DoD UAS Groups (2011)

A new sub-category of Uncrewed Combat Aerial Vehicles (UCAV) has advanced into combat roles once the preserve of crewed flight. They have become a key part of military operations; during President Obama's period in office, the White House authorized 542 UAS strikes, and the trend continues to increase. UAS cannot win wars alone, but wars in Nagorno-

Karabakh and Ukraine have shown that they can easily be lost without them. UAS are becoming highly valued, especially when combined with AI software to enable targeting. They are also reducing in size and increasing the capability of their modular sensor and weapon payloads.³

There are smaller UAS aimed at supporting ground troops and augmenting their existing mortar and artillery systems, such as the AeroVironment Switchblade series. These are too slow, small, and single use loitering munitions; therefore, they are not suitable for the long-range, modular payload, and maneuverability requirements that are the focus of this study.

Cross-pollination between capability categories

The boundary between fighter jets, missile technology, and UAS has blurred. Missile technology, such as rocket engines, gas jet maneuver systems, compact warheads, and seekers, enable extreme performance and are being adopted by UAS. Missiles such as the Northrop Grumman Grey Wolf also appear ‘UAS-like’ as the need for lower costs, open architecture, swarming, networked sensors, modular payloads, and data gathering increase in operational value, especially battle damage assessment data from the terminal phase.

Lockheed Martin’s Long Range Anti-Ship Missile (LRASM) is a good example of this modular technological blending across categories of military aviation and weapons. It has technology from a heritage of aircraft, the F-35 Lightning II and F-22 Raptor, for stealth and survivability, making it more lethal in its anti-ship role. This mantra contributes to the new, experimental Speed Racer UAS, a networked UAS swarm designed to augment F-35 on combat missions, from Lockheed’s Project Carrera, announced in 2022.⁴ This project aims to submit solutions to the USAF Collaborative Combat Aircraft competition, seeking UAS to augment 5th

and 6th Generation Fighter aircraft (likely the Next Generation Air Dominance (NGAD) fighter) from 2028.⁵



Figure 4: Top left to bottom right: Lockheed Martin LRASM, F-35, Speed Racer, and Boeing Grey Wolf missile). Lockheed Martin 2023, Boeing 2023.

Next-generation projects such as DARPA's Control of Revolutionary Aircraft with novel Effectors developed X-65, with a fixed frame containing Active Flow Controls to modify external airflow pressure without traditional control surfaces. This novel capability will likely be first adopted by UAS because the performance advantages in maneuverability go beyond the biological limits of a human pilot.⁶



Figure 5: DARPA X-65 Active Flow Control prototype. DoD 2022

Swarming Robotics are becoming operational

The concept of swarm technology is not new, but it is emerging as the capability to set modern UAS apart from previous weapons. Swarm technology enables UAS to operate in autonomous or collaborative groups, much like birds or bees. This is distinctly different from a mass of UAS operated individually, as seen in Ukraine or Nagorno-Karabakh.⁷

A collaborative swarm of UAS can have tailored payloads, sharing information and awareness to act as a single dynamic system spread across a wide area. Once deployed, such a coordinated mass of UAS may overwhelm traditional defenses and achieve strategic effect.

The U.S. DoD has announced its ‘Replicator’ project to accelerate the introduction of robotics into theatre by 2025, specifically aimed at overcoming the challenges posed by the growing mass and ability of the PRC.⁸ The USN’s Low-Cost UAS Swarming Technology (LOCUST) program is another notable initiative aiming to develop swarm UAS capable of executing complex missions in a coordinated manner.⁹

The USAF, USN, and USMC have already tested the Kratos XQ-58A Valkyrie as a ‘loyal wingman’ to accompany F-16 Fighter jets and evaluate what missions it may adopt. The XQ-58A has an operating range of 3,000 miles with lethal and non-lethal payloads and does not need a runway to launch. The USAF labels these as Collaborative Combat Aircraft (CCA) or Autonomous Collaborative Platforms (ACPs).¹⁰

UAS integration into the Maritime Force

Several navies are developing their ability to conduct UAS operations, mainly focused on Aircraft carriers or ‘flat top’ style warships. The United States had the lead in maritime UCAV with its now-canceled Unmanned Carrier-Launched Surveillance and Strike (UCLASS) program.



Figure 7: X-47B landing on an aircraft carrier and refueling in flight. Northrop Grumman, 2023

In 2013, its X-47B airframe successfully took off and landed from USN Aircraft Carriers, and in 2015, it refueled in flight. Two significant milestones not yet achieved by any other UAS. A successor, the X-47C, has been debated to exist, but little is known. The UCLASS program originally required a long-range penetrating strike UAS with an ability to strike high-value targets at ranges up to 2000 miles, well beyond any crewed fighter jets. But it was canceled and replaced with a Carrier Based Aerial Refueling System (CBARS) program in 2016 to provide autonomous refueling of the piloted fighter jets. Boeing produced the MQ-25 Stingray, which can perform the task today and is due to be operational from 2026.¹¹ If modified, it could potentially refuel UAS swarms in flight, extending their ranges with no risk to human life.



Figure 6: MQ-25 Autonomous tanker refueling an F-18 Superhornet. Boeing, 2022

The RN is proceeding with Project Ark Royal to establish a multi-use flight deck for crewed and uncrewed systems. It aims to develop a multi-use flight deck with specialist launch areas for UAS to enable rapid testing and evaluation.¹²

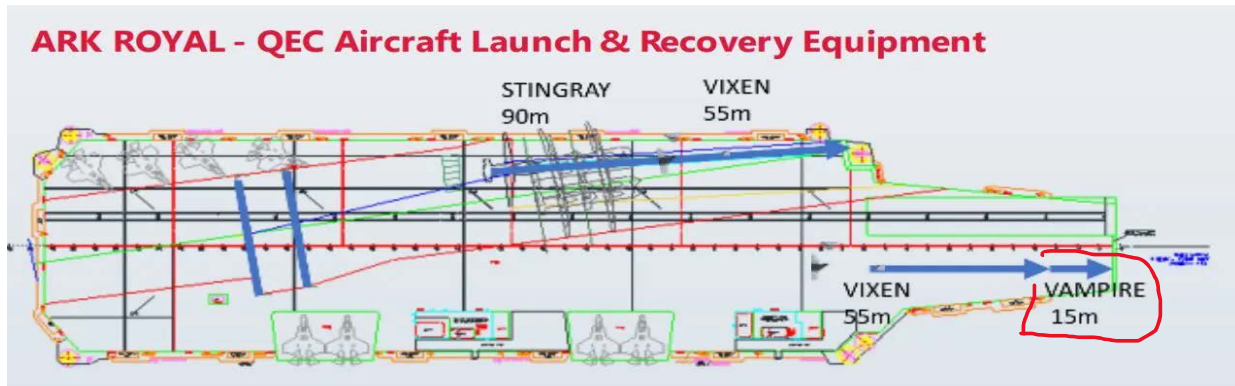


Figure 8: Queen Elizabeth Carrier flight deck arrangement for UAS operations. Royal Navy, 2023

Small fixed-wing UAS of the VAMPIRE project are suitable for launching from escort ships. They are currently catapult-launched, \$120,000 UAS under 440lbs with an 8ft wingspan, speeds of 400kts, 30,000ft altitude ceiling, 3hr endurance, and modular payload up to 66lbs. This UAS category sits between the DoD groups 3 and 4 and best fits the requirements for the proposed opportunity later in this ISRP. They were originally designed as targets to mimic attacking missiles; when repurposed to offensive roles, they can seduce adversaries into using up valuable missile stocks. But when combined with modern stealth technology, offers a very capable, low-cost payload delivery vehicle.¹³

Options such as the Anduril Technologies recently announced UAS called Roadrunner, also appears to fit this requirement. It is jet-powered and high sub-sonic, a modular payload capacity and has a vertical landing capability for launch, recovery, and re-flight.¹⁴



Figure 9: Roadrunner UAS, Anduril Technology, 2023

Disperse air power to smaller platforms for greater combat mass

UAS are already operated from escort-style warships but are limited to single UAS. The Boeing Insitu Scan Eagle or the Shield AI V-BAT are both used operationally for single sorties ISR missions. Shield AI produces V-BAT and combines squadrons of networked VBAT UAS with its proprietary Hivemind swarm software and bidding for the DoD's replicator program.¹⁵ Once the concept is proven, the network and software could be applied to different UAS designs without a completely new network architecture or swarm software.

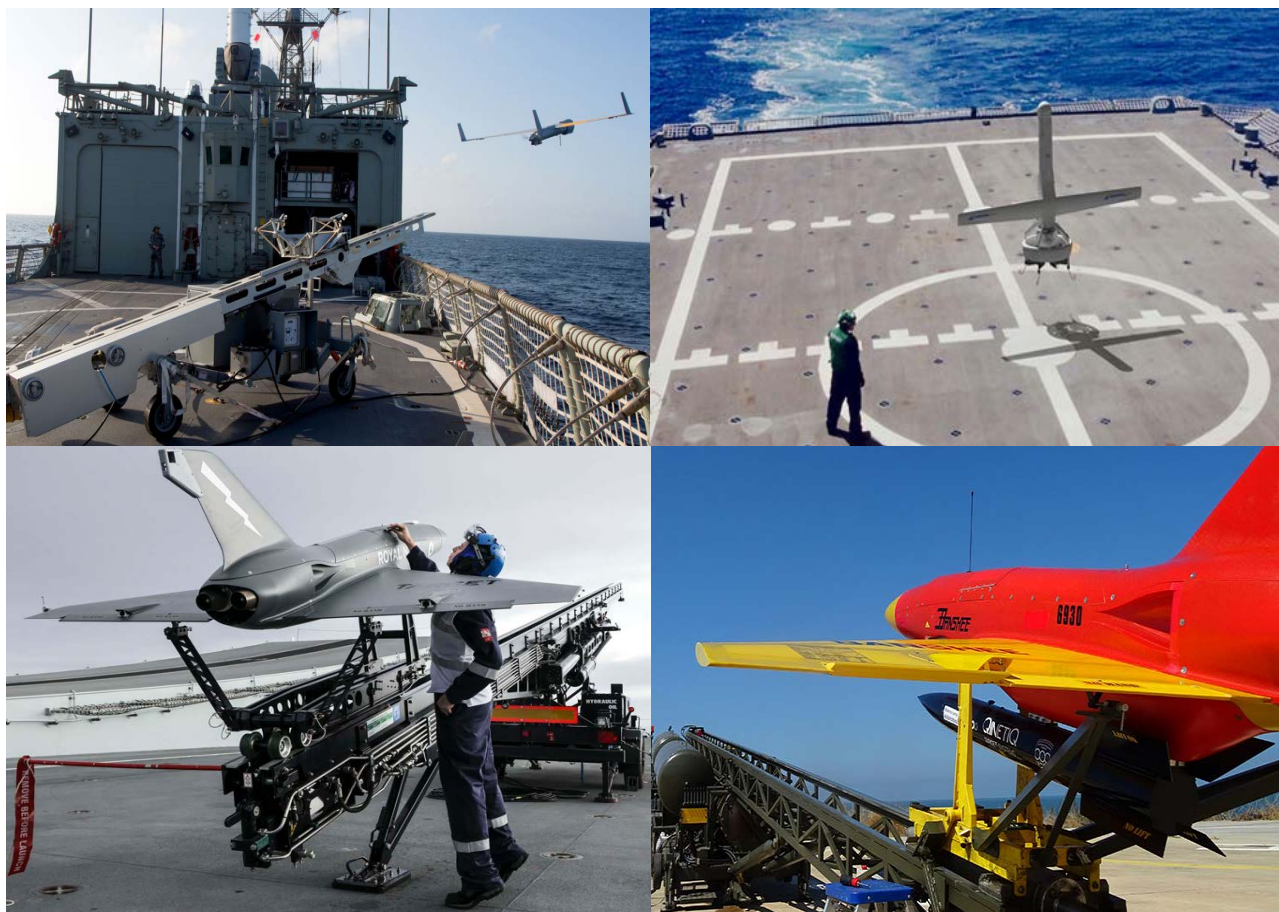


Figure 10: Top left to bottom right: Scan Eagle, Boeing, 2023. VBAT Shield AI, 2023. Vampire, Royal Navy, 2023. Banshee UAS and supersonic 'Rattler' missile attached to undercarriage, QinetiQ, 2023

However, these remain limited in scale, scope, and mission sets, primarily because they have no dedicated infrastructure for launch and/or recovery, being forced to share valuable flight deck space with a ship's helicopter. There is a need to re-assess the military value of UAS against

existing capabilities, and if they offer greater value, create the space and infrastructure for launching and recovering UAS swarms to augment Joint naval, air and ground forces.

Since beginning this ISRP, the USN released a Request For Information in September 23 (Appendix A) to industry partners for a Common Aircraft Launch and Recovery Technologies project. This states: *“The Navy is seeking revolutionary launch and recovery technologies to operate low-cost, attritable, fixed wing, Group 3-5 UAVs on sea-based platforms other than aircraft carriers. The ALRE technologies shall allow the Navy to deploy a high volume of low-cost aircraft to supplement the Air Wing of the Future (AWOTF), promote critical asset survivability, and improve distribution of Naval airpower... From Air Capable Ships (ACS) including Destroyers.”* This represents recognition of the requirement within this paper, and is at a very early stage of enquiry, seeking all available options and ideas from industry, to generate concepts for where the USN believes UAS can effectively add combat mass.¹⁶

Progress of the People’s Republic of China

Analysis of PRC UAS technology often lacks performance details, making comparison to Western designs difficult. However, the PRC has produced UAS that appear highly capable and are thought to be focused on ISR, Electronic Warfare, Targeting, and Strike missions over the East and South China Seas. They do appear in state media and military parades as a focus of the PRC, as it seeks asymmetric advantages over Western militaries. The PRC’s most well-documented advanced UAS are the KDV002 and TB-001 for long-duration surveillance and precision strikes; in October 2023, the TB-001 flew around the island of Taiwan, the first PRC UAS to do so. The PRC also has less well-understood stealth UAS that appear like the USAF X-47B, namely the GJ-11 Sharp Sword, and the supersonic WZ-8 stealth reconnaissance UAS.¹⁷

The PLA has not released any publicly available strategy that directs the development of military doctrine for UAS swarms. However, state-owned Chinese military technology companies have released media showing tests. A recent USAF China Aerospace Institute study of PRC UAS swarm technology concluded, “the PRC defense apparatus appears to be focusing on multiple lines of effort to evaluate the most effective technologies to improve swarming capabilities. It remains to be seen how this collaboration technology will develop into tactics, techniques, and procedures and, further, into PLA doctrine”. Mingxi Wu, deputy director of Intelligent Weapons and Equipment Technology Committee of the China Ordnance Society, discusses the benefits of swarm technology in his book ‘Intelligent Warfare’, concluding ‘human-machine integration of intelligent swarming UAS releases huge combat potential’.¹⁸



Figure 11: Left PLA GJ-11 Sharp Sword UCAS and right PLA WZ-8 Supersonic ISR UAS. Department of the Air Force's China Aerospace Studies Institute, 2023

The PRC has reportedly launched UAS from its Shandong Aircraft Carrier and recently launched the Zhu Hai Yun, a dedicated ‘drone carrier’ ship to test and trial UAS technology at sea. It is also rapidly developing smaller military UAS jets for swarming attacks and exploring the teaming of Uncrewed Surface Vehicles and UAS at sea for recovery and re-launch. This would allow the PLAN to deploy significant aerial combat mass in the near maritime theatre with little to no risk to life, making it exceptionally lethal.¹⁹

Conclusions

The evolution of military UAS from surveillance tools to sophisticated autonomous systems highlights their growing importance to military operations for all nations. Progress toward swarming and AI integration confirm a future with UAS being pivotal in warfare. Through advancements in speed, stealth, and autonomy, coupled with their integration into AI-driven battle management systems, UAS have changed military conflict significantly and quickly adapted to maritime needs. In Ukraine, Russia was forced to move its entire Black Sea fleet from its base port in Crimea because of its vulnerability to medium-sized UAS and missiles.²⁰

The iteration rate of UAS designs means that even low-cost UAS must be disabled or destroyed due to their capability, putting pressure on precious missile stockpiles. This is exacerbated in the maritime, where replenishing missile silos is not practiced at sea or the limits of operational reach. Once ‘shot out’ of missiles, warships are vulnerable, and this risk can limit operational freedom to exercise sea denial. Further, UAS launched from the sea could be transferred to augment forces ashore or in the air, adding combat mass or new capabilities.

The USN has recognized the need to increase its UAS launch capable platforms to add combat mass. It released an RFI to explore options to distribute air power throughout the fleet to augment its ships and Aircraft Carriers. But achieving high sortie rates of UAS from existing ships will require giving something up first or re-prioritizing congested flight decks.²¹

The PLAN has tested civilian/military UAS and USV swarming, trying to team them autonomously. Except for the PLAN Zhu Hai Yun ‘drone carrier,’ the predominant maritime integration strategy of the PLAN today aims to deploy UAS from Aircraft Carriers.

Similar to Western approaches, this will exacerbate flight deck congestion and conflict with crewed aviation. An alternative approach to UAS integration may offer a better solution.

Chapter 6: Naval Gunnery - culturally important but not competitive

Naval guns have come a long way from their rudimentary beginnings on the wooden decks of warships to their modern iterations. Over centuries, they have undergone significant advancements, witnessing transformation in design, calibers, and functionality.

Naval guns commenced with the advent of cannon placements on ships in the 14th century, marking the rudimentary inception of naval artillery. As naval warfare evolved, so did the design and functionality of Naval Gunnery until the zenith of the Dreadnought Era. Characterized by large battleships solely fitted with large caliber, long-range guns to sink ships and bombard coastal batteries.

In military operations today, a visible main gun can serve as a deterrent, showcasing a ship's firepower and responding rapidly against surface threats, particularly smaller fast attack vessels. It also has a role in attacking land targets or bombarding shore defenses. However, today's Naval Gun range is limited (up to 15 miles), even for the most advanced specialist ammunition (up to 83 miles), which no modern navy currently uses due to cost.

Though not a primary role, they can also provide a limited defense against low-flying aircraft, UAS and provide some distraction for sub-surface targets. Automated gun systems can, in specialist cases, defend against incoming missiles as a final protective measure.

Naval Gunfire Support (NGS)

In support of land operations, Naval Gunfire Support (NGS) can strike land targets near the shore to support ground forces either directly (when the target can be seen) or indirectly (using a spotter to provide target data). Within its limited range, it can be more cost-effective than attacking targets with missiles or aircraft. When more sophisticated weapons systems might fail

or be jammed, traditional Naval guns remain a reliable backup. To illustrate the typical range disparity between Naval guns and Anti-Ship missiles, a comparison table is below:

Navy	Main Naval Gun	Effective Range (Conventional Ammunition)	Anti-Ship Missile	Effective Range
United States Navy (USN)	Mk 45 Mod 4 Naval Gun System	13 nautical miles	Harpoon SM-6 Tomahawk	67 nautical miles 200+ nautical miles 700+ nautical miles
Royal Navy (RN)	4.5-inch Mark 8 naval gun	12 nautical miles	Harpoon Naval Strike	67 nautical miles 100+ nautical miles
Marine Nationale (French Navy)	Compact 100 mm naval gun	12 nautical miles	Exocet	97 nautical miles
German Navy	127 mm Lightweight Gun	13 nautical miles	RBS15	108 nautical miles
Japanese Maritime Self Defense Force (JMSDF)	127 mm/54 caliber OTO Melara gun	13 nautical miles	Type 90 (SSM-1B)	93 nautical miles
Republic of Korea Navy (ROKN)	Mk 45 Mod 4 Naval Gun System	13 nautical miles	Harpoon, Haeseong	67 nautical miles 83 nautical miles
People's Liberation Army Navy (PLAN)	H/PJ-38 130mm dual-purpose naval gun	12 nautical miles	J-83 C-802	115 nautical miles 65 nautical miles

Table 3: Ranges for main guns compared to anti-ship missiles

NGS is often stated as the core requirement to keep large caliber guns as a capability. In the 1960's the Royal Navy designed the Type 22 frigate without a main gun, replacing it with four Exocet anti-ship missiles and the air defense system called Sea Wolf. Lessons from the Falklands War in 1982 challenged and exposed the consequential lack of mass available to support forces ashore, a requirement that Exocet was not designed for. The Type 22 was later modified (extended) to allow for the re-installation of the 4.5 Gun.

NGS has been used again as recently as 2016, the USS Carney in Operation Odyssey Lightning fired 285 rounds from its 5" Gun onto ISIS targets in Sirte, Libya, combined with Helicopter and Fighter Jet attacks from the 22nd Marine Expeditionary Unit. It was also used by the RN and French Marine Nationale in the 2011 Operation ELLAMY in Libya. The main requirement was to fire red phosphorous 'Starshell' rounds (discontinued) to illuminate enemy

positions and High Explosive (HE) shells against targets within the 12nm range. First Sea-Lord Admiral Sir Mark Stanhope stated in 2011 that “Naval fires simply using the 4.5 guns, which some people have suggested was not appropriate in this modern era, was proven again in terms of the ability to put fire on the ground where necessary with some considerable precision. We had to work up our standard procedures to be able to do that, to ensure the required precision that was again necessary to guarantee the safety of life.”¹²

The modern relevance of Naval Gunfire Support

The more likely truth in the 2016 and 2011 examples is that NGS provided the only means available to contribute to Joint Fires, despite the obvious risk of missile attack, due to a lack of better options other than launching their helicopters. This is important because warships are increasingly expensive and fewer in number, with no reversion of the trend, making any close approach of an adversary’s coast high-risk given the proliferation of anti-ship missiles.³

Submarines and aircraft contribute to most maritime land attack joint fires today (except marines ashore). During Operation ELLAMY in 2011, Tomahawk Land Attack Missiles (TLAM) and aircraft carrier-delivered bombs from Harrier Jets were used far more extensively. The USN launched over \$500 million worth of TLAM against 320 targets within 20nm of the shoreline. Although successful, this demonstrates a trade-off cost in the poor range of Naval Gunnery. The dependency upon air support and TLAM to fill the gap represents a very costly exchange and is likely unsustainable in a large campaign against a peer adversary.⁴

The persistence of Naval Gunnery may result from a cultural miscommunication between Naval force requirements and Marine/Expeditionary force requirements. Each has a poor grasp on who owns the actual requirement for NGS capability, and both are culturally entrenched.⁵

While the evolution of naval guns has undoubtedly contributed significantly to naval capabilities over centuries, their relevance in contemporary warfare scenarios is quickly overshadowed when more advanced and capable weaponry is available. The preference to use missiles and aircraft highlights the limitations of naval guns in range and accuracy and because they put expensive warships near the shore with high risk of attack from mines, anti-ship missiles, UAS, and improvised explosive devices such as the attack against USS COLE in 2000.⁶

Budgetary value of Naval Gunnery and future options

Cost is often used to justify retaining the main Naval Gun; a typical HE shell costs \$3-4,000, and ships hold between 5-800 rounds. They typically fire at a rate of 20-25 rounds per minute, meaning that a full engagement depletes the ship's magazines after 22 - 40 minutes of bombardment per ship for \$1.5-3.2 million, less than a single TLAM.

Modern Naval Guns have an accuracy measured by circular error probable, which measures precision and is defined as the radius of a circle in which 50% of the fired rounds are expected to land. A 2016 RAND study found that the modern CEP of 50m of NGS resulted in typical NGS scenarios requiring 60-200 rounds per target and more munitions than today's ships can carry for missions in densely populated areas, with a high likelihood of collateral damage.⁷

The limitations of traditional munitions force modern navies to consider modern versions to close the gap between what is in use now and what is expected in modern precision warfare. Known as guided projectiles, rounds have been upgraded with internal guidance systems, data links, and configurable warheads, enabling greater range, maneuverability, and accuracy. Three notable examples are the Vulcano (48-mile range), Excalibur (50-mile range), and Long-Range Land Attack Projectile (LRLAP - 83-mile range). However, the cost per round is 10x to 150x higher than the current HE rounds. Vulcano and Excalibur are \$70,000 - \$150,000 per round but

compatible with existing 5” Naval Guns. LRAP was specialized for the ZUMWALT class Advanced Gunnery System, estimated at \$800,000 per round, a high cost that led to the cancellation of the entire system.⁸ No modern navy presently uses any of the described advanced projectiles despite their advantages, likely due to cost.

There are other options; General Atomics is developing a Long-Range Maneuvering Projectile, aiming for a 155 mm/5” gun-compatible round able to reach targets out to 93 miles on non-ballistic trajectories, making it hard to counter. The round has many features taken directly from UAS and missile technology. It has wings, navigation, and a modular payload capability to tailor the effect to the target, including Electronic Warfare. The round is not yet in production, and costs are unknown.⁹ Boeing and Nammo have partnered to develop a new 155mm and 5” compatible round with a small Ramjet to extend Artillery (possibly Naval Guns) firing range significantly, extending 155mm artillery range from 15-40 miles up to 90 miles.¹⁰

Finally, there is the option to replace chemical propellant and existing guns with electromagnetic Rail Guns, capable of firing a solid metallic projectile well beyond 100 miles, reaching speeds up to Mach 10. The technology is maturing, yet the complex ship power generation, expensive integration, and operational reliability issues must be overcome. Currently, the development of Railguns is being led by the United States and China. The U.S. has canceled its Railgun program in favor of hypersonic missile development, and China outfitted a landing ship with a Railgun in 2021 to test their prototype at sea, although more needs to be understood about its actual capability. No operational railgun is anticipated until at least the mid-2030s.¹¹

Conclusions

The limitations of traditional naval guns in range, accuracy, trajectory, and lack of data collection capabilities are potentially surmountable, and the attack speed, once fired against a

target, is faster than the alternatives. But as their capability increases, costs rise by an order of magnitude and negate the cost-effective argument in favor of using Naval Gunnery.

Even when used for naval bombardment, the system's primary role, the operational effects are questionable. Naval guns also require a significant commitment of ship space, weight, power, human capital, and training to have operational effect and contribute to Joint Fires. During the 1991 Persian Gulf War, even though the USN utilized their 16-inch guns of the IOWA Class Battleships for bombardment at an average of 18 miles inland (5-inch guns did not have sufficient range), a key takeaway was the success of their UAVs used for spotting, targeting, damage assessment and reconnaissance. Had their UAVs been more sophisticated and capable of strike missions, it is questionable whether the battleships would have been put inshore due to the high threat posed by Iraqi drifting mines and shore-based artillery.¹²

All modern navies still design and build escort ships, destroyers, frigates, and cruisers with main guns. Yet their use cases continue to shrink (shore bombardment, surface warfare, and anti-air). Attempts to replace main guns previously failed for simple reasons; the right capability balance wasn't found. Specialist warships (Anti-Submarine, Area Air Defense) have little use for gunnery because it contributes nothing to the primary role. However, general-purpose ships designed for constabulary tasks close to shore still have a valid use case, and the visual deterrent effect of having a main caliber gun should not be undervalued, e.g., in counter-piracy operations.

However, the superior stand-off range, modularity, precision, and data acquisition attributes of missiles and UAS offer a compelling alternative for contemporary maritime arsenals. As naval warfare continues its evolution towards more network-centric and data-driven outcomes, and amphibious forces demand longer-range air power options or more control of the capabilities they require, the relevance of traditional naval guns appears to be diminishing.

Chapter 7: Back to the Future - an opportunity for change with existing infrastructure

Today's proliferation rate of Maritime UAS is challenged by limited access to highly prized flight-deck space as they compete with high-cost and exquisite crewed aircraft. An alternative could be to replace an existing capability such as Naval Gunnery, re-using the space, weight, power, and human resources to bet on the versatility of smaller UAS technology integrated into escort warships, and in war, logistic ships and ships taken up from trade. This significantly increases the overall aerial mass available to the Joint Force commander.

If the cost per unit can be kept reasonable, and reliable recovery and re-flight, a dispersed launch of UAS swarms from many ships delivers wide-area effects that could surpass traditional fleet capabilities with reduced mission costs and ease operational pressure on missile stockpiles. This trend echoes the evolution of maritime aviation as it began to supplant the battleship; UAS offer much greater operational value than Naval Guns for most modern operations.¹

A simple estimate with conservative UAS performance can demonstrate the operational value of non-carrier launched UAS. Suppose a single escort ship has its main gun replaced with the ability to launch UAS sorties. The ship can still perform all its normal escort duties. However, it can now launch 50 UAS. The UAS (RN Vampire) will be used to demonstrate their potential. The Vampire can achieve speeds up to 460mph and a one-way range of 400 miles, delivering lethal and non-lethal effect payloads up to 20kg. It launched 24 UAS to conduct an autonomous attack on two S400 Surface-to-air missile systems from 200 miles away. The UAS can behave as a swarm, dispersed and unpredictable in transit, conducting reconnaissance and targeting before concentrating on a precision attack formation designed to defeat the specific targets. The swarm might seduce the S400s into firing all eight missiles against it or attempt to

destroy both launchers. The swarm's uncrewed mass, maneuverability, and low cost make it effective.

Importantly it provides options to protect stockpiles of missiles such as TLAM. Any UAS surviving the attack can continue to conduct ISR and targeting before self-destructing if beyond recovery. In this case, and multiplied by combining additional UAS ships, existing maritime and

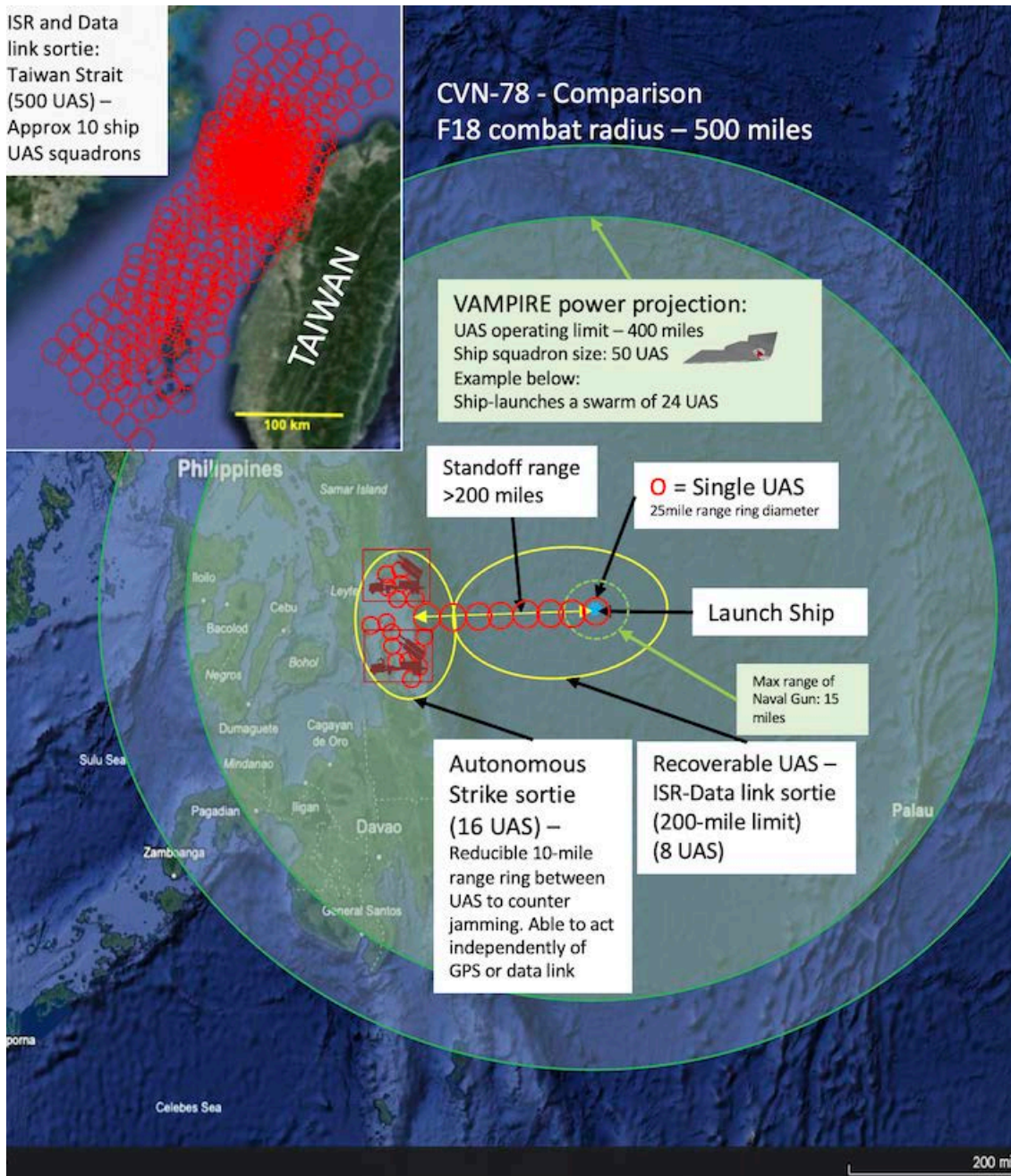


Figure 12: Example scenario for RN Vampire UAS operational radius

shore-based air defense systems would be unable to defeat such a coordinated swarm threat.² A single ship example is below; more examples are at Appendix B:

The figure below highlights the risk inherent in conducting NGS; for a target 10 miles inland, a \$1B+ ship with all 300 sailors needs to be at least within 5 miles of the shore, providing an incredibly small amount of time to react and defend against an anti-ship missile attack. This threat is very real, and recently, examples such as the Houthi attacks against ships in the Red Sea and Bab Al Mandab prove that Chinese/Iranian/Russian anti-ship missiles and UAS are being readily supplied to non-state groups for use against Western maritime forces.

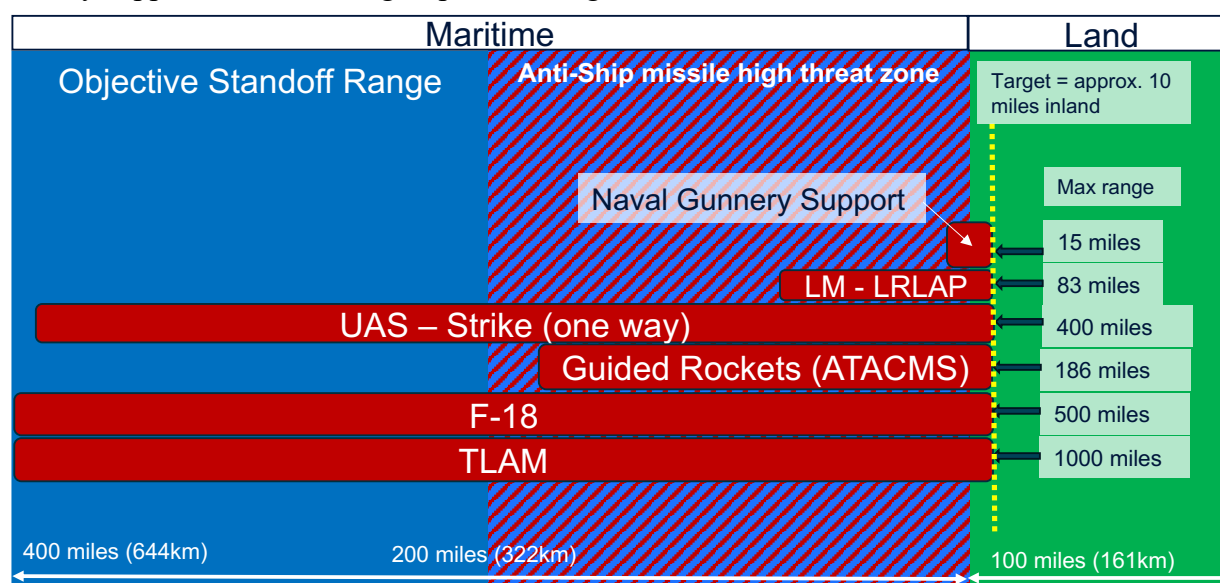


Figure 13: Indicative standoff ranges for key weapons to target 5 miles inland

Designing a recovery system onboard or offboard for the UAS post mission or to automatically refuel (Vampire uses standard aviation fuel) and relaunch opens several pathways. It quickly reduces cost per mission, a UAS conducting its 10th mission before a one-way strike makes that final mission far less costly. Being multi-mission capable increases their lifetime utility for reconnaissance, Anti-Submarine, communications, and logistics transfer tasks.

The ship can deploy UAS to gather targeting information for Joint Forces ashore or even transfer command of the UAS swarm, allowing forces ashore to prosecute targets directly, a

long-time practice of Special Forces with TLAM. Ships would carry larger UAS than forces ashore and could transfer UAS to bolster their combat mass and protect limited stockpiles.

Logistical re-supply in theatre of modular UAS would also be possible due to the UAS not being pre-fueled or pre-armed. Currently, replenishing missiles and large munitions at sea is not practiced due to the risk to life and the complexity of transferring sensitive explosive contents while underway. With UAS, replacement airframes would be inert, fuel already available onboard receiving vessels, and their at-sea replenishment practices already in place. UAS warheads would be modular, separate, and more compact, making transfer simpler.

The problems of recovery and re-launch are already solved for crewed flight and UAS. If the launch/recovery system for smaller UAS can be kept agnostic of the platform and not bespoke, then it can be developed without consuming valuable in-service warship availability. Since a UAS has no human element onboard, the risk to life can also be reduced to almost zero during all phases of development.

The USAF and DARPA have made shown with the GREMLIN project that re-arming and launching UAS swarms from larger transport aircraft is possible in flight and could translate to the maritime with larger platforms. The USN has proven in-flight autonomous re-fueling with the MQ-25; it could potentially be modified to re-fuel a UAS swarm if the requirement for extended range were made.

With the latest USN RFI and evidence of PLAN UAS/USV teaming, there appears to be interest in solving recovery/relaunch in the maritime from warships other than dedicated aircraft carriers.³ However, to achieve sortie rates equivalent to or exceeding existing aircraft carriers and contribute meaningful mass, more space must be allocated to UAS operations than the existing flight decks.

Make space for robotic carriers by removing the main Naval Gun

Replacing naval gunnery with the ability to launch and recover multi-mission UAS will enable a paradigm shift in the power projection capability of the whole maritime force. Naval guns are too short-ranged (10x less than UAS) and lack any data collection capability, contributing little to the modern precision strike complex or enabling Algorithmic Warfare.

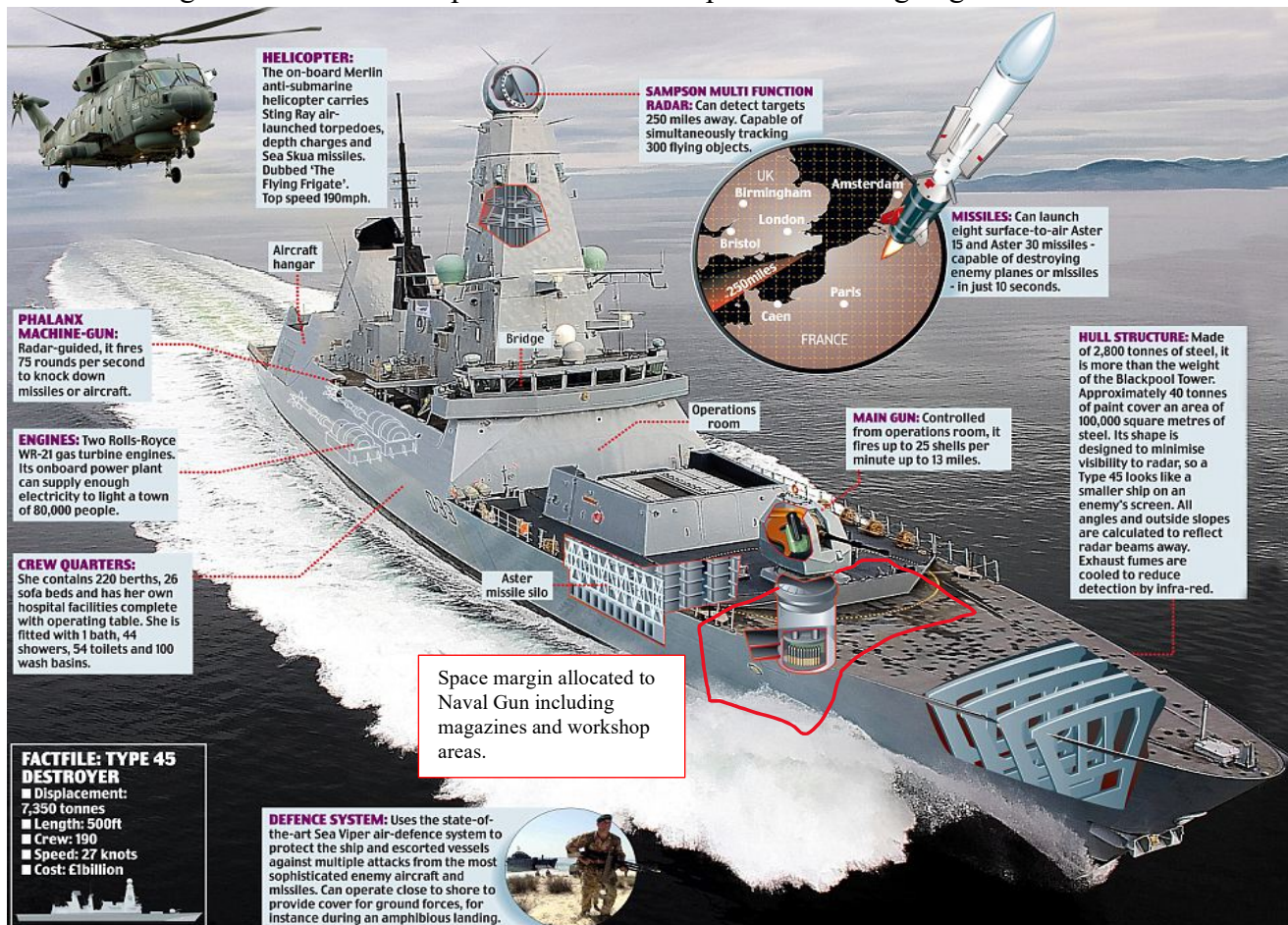


Figure 14: Type 45 Destroyer - Space margin used by current Naval Gun System. Matt Hunter, Britain's new fleet of Type 45 Destroyers, Daily Mail, 2016.

The launch area, magazines, and below-deck support compartments are large and well-armored. Able to sustain UAS operations within the space, weight, and power envelope vacated by removing the main gun. Naval Guns are mostly situated at the fo'c'sle, at the front of the ship, providing good wind-over-deck to aid UAS in the launch phase. In my experience with Type 45

Destroyers, a 10-12 team of operators and engineers are trained to operate and maintain a Naval Gun. They could be cross-trained for UAS operations without affecting other capabilities.

UAS Launch systems can range from containerized models for rapidly launching multiple UAS in quick succession to catapult launch systems which are smaller. UAS movement between decks (a hoist is used to move large 38kg+ bullets) is a simple requirement. The new USS Gerald Ford Carrier utilizes an Electromagnetic Assisted Launch System (EMALS), due to its significant saving in space and weight over traditional steam catapults. EMALS has already been miniaturized for UAS launch by General Atomics and Chinese researchers.⁴

Refuel and repair requirements are already managed for crewed flight systems onboard most warships. Only minor modifications will likely be required for this, and once operational experience is gained, compartments and fuel supplies can be modified to increase sortie rates.

The most challenging element is the recovery method, although operations could clearly begin before this final stage is solved as it mostly provides economic and sustainability benefits.

Recovery of traditional aircraft requires a runway to dissipate its speed as it transitions from flight to a stop. Typically, this is done by arresting wires slowing aircraft within the limits of human biology, leading to the size of aircraft carriers being determined by their deck length.

However, the potential solutions for recovering UAS are far broader because they don't have human limitations. DARPA and Dinetics demonstrated in-air recovery was possible for their X-



Figure 15: UAS net recovery and arrestor wire concepts, Boeing, 2022.

61A Gremlin, aiming to re-use the X-61A up to 20 times. Several UAS recovery systems have shown that a runway is unnecessary, typically using nets, arrestor wires, or parachuting into the sea (wet recovery), but there are challenges scaling to higher sortie rates with these methods.⁵

A method commonly used by amateur radio-controlled plane pilots is the vertical deep-stall landing, and could apply to fixed wing UAS such as Vampire. A 2021 article in the Journal of Intelligent Robotic Systems captures the method well. It describes how it could be adapted to military UAS operations in the maritime environment: *“To be able to recover a fixed-wing unmanned aerial vehicle (UAV) on a small space like a boat deck or a glade in the forest, a steep and precise descent is needed. One way to reduce the speed of the UAV during landing is by performing a deep-stall landing maneuver, where the lift of the UAV is decreased until it is unable to keep the UAV level, at the same time as the drag is increased to minimize the speed of the UAV”* Bristol University is exploring the technique combined with bird-like ‘flexible wings’ to aid the deep stall maneuver and a cooperative recovery system.⁶

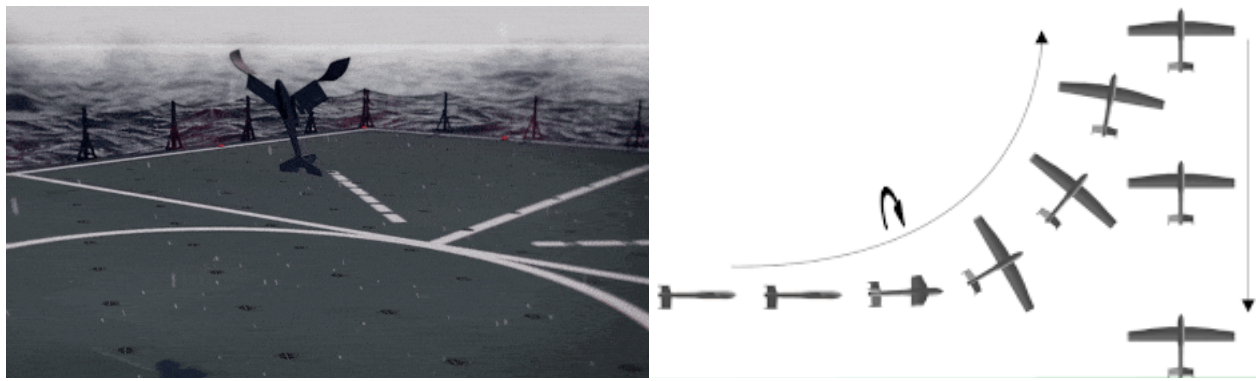


Figure 16: Deep Stall Landing concept, University of Bristol, 2018.

A solution for warships without dedicated runways and to avoid the need to impact crewed flights or introduce onboard risk could be to recover UAS offboard. Autonomous sea boats are already mature technology and compatible with existing warships; removing humans from the recovery phase broadens the potential options for recovering UAS offboard. By installing a transponder to link the UAS and the sea boats, there may be potential to recover in



Figure 17: AP24, BAE Systems, 2023. MAST Scarab autonomous sea boat, L3 Harris, 2023

highly demanding sea states. The recovery will be technologically challenging, but software-controlled landing methods between the UAS and Seaboat can iterate landing options inaccessible to crewed aviation but with no risk to life. Post recovery, the sea boat can return to the warship (or any nearby compatible ship) to offload the UAS for refueling, repair, reloading, and relaunching. This could enable a rapid iteration test platform for scalable UAS recovery options. Future autonomous boats can then be better designed to meet the requirements for increasing sortie rates or launching further into high-risk areas.

Integrating UAS to increase overall Combat Mass

Using the conservative estimate that approx. 50 UAS (Such as the RN Vampire) could be stored, maintained, and launched from escort ships; a comparison can be made with the existing missile capacity of current and future ships of the USN and RN. An example concept for how to enable high UAS sortie rates from escort ships is at Annex C. Fig 18 and 19 focus on Strike to demonstrate the additional combat mass, however strike is one of several Surface Warfare missions UAS can contribute to. It is also important to note that this is a numerical comparison only. UAS cannot be directly compared to missiles, which are specialist single-use systems.⁷

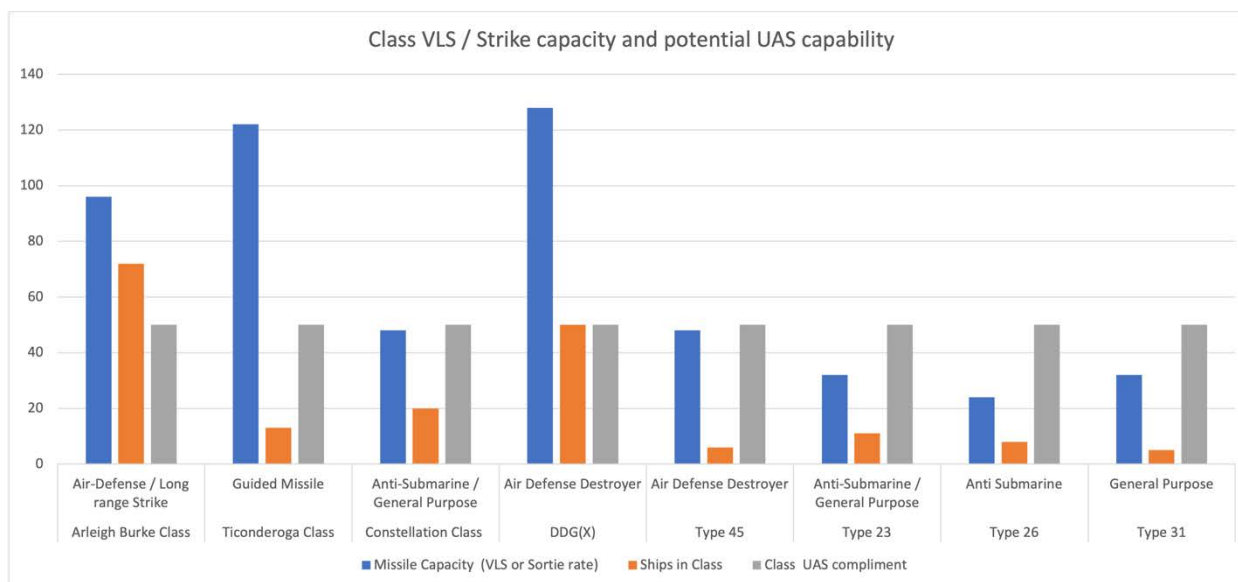


Figure 19: Comparison of existing strike capacity by ship class and potential UAS capacity



Figure 18: Strike capacity comparison by Ship and by Class (USN only)

Table four demonstrates the broad utility offered by integrating UAS into the escort fleet. This additional combat mass, shown in the previous graphs, can offer far superior utility for a maritime force and could support a greater mission portfolio because UAS can be designed to deliver modular payloads.

Domain	Mission	Existing Naval Gunnery	UAS (with enabling payload)
General Purpose	Intelligence, Surveillance, Reconnaissance (ISR)		x
	Over the Horizon Targeting (OHT)		x

	Mapping and weather data		x
	Data Link Network extension (repeater)		x
	Disaster Relief support		x
	Search and Rescue		x
	Logistics (Last mile delivery)		x
Surface Warfare (SuW)	Visible deterrent	x	x
	Illumination / Flare	x	x
	Coastal Bombardment	x	Precision Strike only
	Controllable by forces ashore (handover)		x
	Strike/Fires (15 miles)	x	x
	Strike/Fires (50 miles)		x
	Strike/Fires (300+ miles)		x
Anti-Submarine Warfare (ASW)	Detection		x
	Sonobuoy/Hydrophone drop		x
	Lightweight Torpedo / Depth Charge		x
Anti-Air Warfare (AAW)	Self-Defense	x	x
	Early detection		x
	Distraction payload (Chaff)		x
Electronic Warfare (EW)	Active Electronic measures		x
	Passive Electronic signal detection		x
	Long range decoy / deception		x
Mine Warfare	Overflight and Payload delivery		x

Table 4: Mission spectrum comparison: Naval Gunnery vs UAS

This is important from an industry perspective since the modular payload can offer a design envelope with known standards to integrate their technologies. The UAS vehicles and launch/recovery infrastructure, which is complex, will not then need investment by the industry partner developing a payload, reducing access barriers to new operational capability. T

his methodology has worked well in the Space industry for small satellites, especially Cube-Sats, which, through payload standardization, unlocked space access for a much broader spectrum of private industry, especially small start-up businesses. ⁸

Chapter 8: Conclusions and Recommendations

Maritime forces deploying AI-enabled UAS in sufficient numbers will have a significant operational advantage. Dispersed UAS launch and recovery capabilities across as many Ships/Submarines as possible will complement, not challenge, the exquisite capability of the Aircraft Carrier nor dilute its valued sortie generation capacity. It also provides insurance to a carrier being taken off task, with a fallback to alternate UAS air power from escorts.

Naval Gunnery is not obsolete when considered in niche scenarios, but the risk involved in placing warships close to shore to use it effectively outweighs and precludes many of the perceived benefits. Modern anti-ship missiles and UAS out-range Naval Gunnery by an order of magnitude and have been used by many non-state actors to attack ships too close to shore. On balance, the cost in lives and capital combined with the risk of attack by increasingly available anti-ship missiles make Naval Gunnery an unattractive option if it were not the status quo.

Surface maritime forces should replace existing Naval Gunnery with longer-range capabilities that support the primary role of the warship. This means that maritime forces should prioritize replacing it where the case for Naval Gunnery is very thin, such as in Anti-Submarine or Area Air Defense warships. But some roles such as constabulary operations for lower cost general purpose warships and patrol vessels will still find value in the deterrence effect of a Naval Gun. Other options that could be integrated into warships include long-range (100km+) guided rockets, such as the U.S.-produced Army Tactical Missile System (ATACMS), but they suffer the same limitations as VLS missiles: single-use, high cost, and difficult to replenish in theatre due to their high-explosive contents.

Battle Management Systems are rapidly integrating AI and ML at the heart of operational capability. They need data to be effective, and increasing the mass of sensors available will

increase their potency. Networked UAS providing a sensor network into an AI-driven battle management system like the JADC2 will revolutionize maritime warfare. Such a system could manage UAS in real-time, optimizing their roles based on the evolving battle scenario and available intelligence. This networked approach enhances data fed back to the central Battle Management Systems. Improving situational awareness, decision-making, and Joint Force coordination to use military means more efficiently in theatre.

Furthermore, integrating artificial intelligence (AI) and machine learning (ML) into UAS enhances their decision-making and autonomous operational capabilities. AI and ML facilitate real-time data analysis and enable UAS to adapt to changing battlefield conditions. Most important is the reduction of time required to conduct targeting cycles. The augmentation of AI and UAS to artillery in Ukraine is proving effective.¹ Maritime Forces can learn lessons from the integration practices seen in Ukraine. Although artillery fires are not as relevant in the maritime context due to their short range, the operational art developed around integrating hundreds of UAS sensors to accelerate over the horizon targeting and some of those UAS quickly switching from ISR to precision strike certainly is.²

The war in Ukraine has highlighted the importance of carefully managing the attritional pressure on high-value capability stockpiles; introducing a ‘mid-tier’ capability to provide alternatives to the missiles within the VLS or exquisite crewed aircraft might make the difference when at the limits of operational reach. There is a need to field capability in mass and at far lower cost/complexity than the high-end aircraft and missiles centric in today’s increasingly expensive maritime forces. The answer cannot just be to build new, bespoke UAS ships. The holistic challenge of crewing and sustaining an entirely new class may take a decade to refine, just like the original aircraft carriers. Re-using existing people, space and infrastructure to

establish a UAS carrier capability from escort ships could unlock the potential of UAS in maritime operations much quicker. The existing fleet is expensive and must be part of the solution rather than attempting to offload autonomous UAS capabilities to future platforms yet to be built or forcing UAS to compete with already congested flight decks.

There are trade-offs to be made; the Naval Gun has a long history, and all modern escort-style warship concepts are being designed with them. I believe that they serve an increasingly niche purpose for the Joint Force. Just as the aircraft carrier supplanted the battleship due to its advantages in aircraft range, broader mission utility, lower overall operational risk, and development potential, history will repeat itself for main guns. The challenge now is to reassess the military value of existing capabilities and create space in the existing fleet infrastructure to provide uncontested access for UAS and realize their potential ahead of our adversaries.

Recommendations:

1. Introduce the escort UAS carrier concept into fleet wargaming problems to explore the operational value of dispersed UAS aerial mass to Joint forces and concepts of operations.
2. Expand the NAVAIR RFI to seek proposals that include an option to replace existing capability if there is an opportunity to increase combat mass without reducing the primary mission of the identified warship.
3. Explore industry interest in a UAS payload standardization akin to the Cubesat model; a low barrier to entry marketplace for military payload development and deployment within the common maritime UAS launch/recovery systems.

Forward look

Battle management systems are emerging that permit human-machine teaming at scale, and joint military networks to enable their use in the real world are being created. Upon this

digital fabric, autonomy will reveal its potential and further evolve the character of war. The United States has the advantage because of its innovation culture and migration of Silicon Valley-style entrepreneurship into the defense sector, combined with the mass production capability of defense industry primes.

However, ethics in either the military or civilian industry can falter and change depending upon the perception of whether their products are being used for a just cause. The culture leading the investment choice and prioritization of each military service may take a generation to see the potential of Algorithmic Warfare despite it being revealed and proven in conflict. The PLA may have realized this potential, and with its tight control over civilian and military industry combined with an alternative view of military ethics and risk, it would fit in with its strategy for seeking asymmetric advantages over the West.

Swarm algorithms, autonomous navigation, super/hyper sonic engines, stealth technology, advanced reactive material warheads, and even a standardized payload marketplace represent obvious evolutionary steps for military UAS technology. Enhanced battlefield autonomy, driven by AI and ML, will underpin swarms of UAS capable of reactive, on-the-fly maneuver warfare, mission planning, targeting, and strike with ever-reducing human oversight. The PRC may win an advantage if it can progress UAS technology faster by releasing it from the regulating pressure placed upon UAS by a pilot-led aviation culture.

The trends of shrinking yet increasingly capable robotics and accelerating AI capabilities are robust; it is time to create space for them to co-exist and augment, not compete, with existing aviation. The maritime domain is already being impacted by adversarial UAS posing a high cost on our defense against them. It is time to turn the table by significantly increasing the number of low cost, multi-role and ultimately sacrificial UAS we can deploy to a broad operational theatre.

**APPENDIX A: REQUEST FOR INFORMATION N68335-23-RFI-0327 - SOURCES
SOUGHT FOR COMMON AIRCRAFT LAUNCH AND RECOVERY TECHNOLOGIES
FOR GROUP 3-5 ATTRITABLE UNMANNED AERIAL VEHICLES (UAVs)
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION, LAKEHURST, NJ**

Notice Type: Request for Information: Sep 26, 2023 04:28 pm EDT

THIS IS A REQUEST FOR INFORMATION (RFI) ONLY. It is not a Request for Proposal, a Request for Quotation, an Invitation for Bids, a solicitation, or an indication that Naval Air Systems Command (NAVAIR) or the Office of Naval Research (ONR) will contract for the items contained in this RFI. This RFI is issued solely for information and planning purposes.

This RFI does not commit the Navy to contract for any supply or service whatsoever.

Furthermore, the Navy is not seeking proposals at this time. Responders are advised the U.S.

Navy will not pay for any information or administrative costs incurred in response to this RFI; all costs associated with responding to this RFI will be solely at the interested party's expense.

Interested parties are responsible for adequately marking proprietary or competition sensitive information contained in their response. The Navy will not be liable for or suffer any consequential damages for any proprietary information not properly identified. Proprietary information will be safeguarded in accordance with the applicable Navy regulations.

INTRODUCTION

The Naval Air Warfare Center Aircraft Division, Lakehurst, New Jersey and the Office of Naval Research (ONR) Code 35 are seeking sources to fulfill a proposed acquisition requirement for common Aircraft Launch and Recovery Equipment (ALRE) suitable for Group 3-5 Unmanned Aerial Vehicles (UAVs). The UAVs are expected to be fixed wing, low-cost, and reusable/attritable, and would operate off of non-carrier vessel (CV) sea-based platforms.

ELIGIBILITY

The PSCs for this requirement are 1710 (Aircraft Landing Equipment) and 1720 (Aircraft Launching Equipment);

Relevant NAICS codes include: 541715 (Research and Development in the Physical, Engineering, and Life Sciences), 541330 (Engineering Services), and 336411 (Aircraft Manufacturing).

REQUIREMENTS

The Navy is seeking revolutionary launch and recovery technologies to operate low-cost, attritable, fixed wing, Group 3-5 UAVs on sea-based platforms other than aircraft carriers. The ALRE technologies shall allow the Navy to deploy a high volume of low-cost aircraft to supplement the Air Wing of the Future (AWOTF), promote critical asset survivability, and improve distribution of Naval airpower.

Information is sought for concepts that minimize space required on the deck and maximize the number of compatible low cost/attritable UAVs. Concepts may utilize modularity or a family of systems to support variable aircraft weights and launch/capture velocities. Potentially relevant Air Capable Ships (ACS) include the Expeditionary Sea Base (ESB), Destroyer (DDG), Amphibious Transport Dock (also known as the Landing Platform Dock [LPD]), or a new ship class, with flight deck sizes approximately 50 - 200 feet long and 40 - 100 feet wide. Group 3-5 aircraft may weigh approximately 1,000 - 10,000 lbs. The ALRE may be portable or permanently installed for use on a single ship class or multiple ship classes. In addition, potential concepts for ALRE may also include sea-based platforms other than ships.

Respondents shall consider how to use a holistic, systems-based approach to maximize sortie rates, i.e., the Navy is seeking information about concepts that can launch/recover a large number

of UAVs in a short amount of time. Consideration should also be given to facilitation of UAV handling (preferably, automated) and storage pre and post launch and recovery. Novel approaches for flight control techniques, innovative coupling of ship/aircraft aerodynamic effects, ship/aircraft communications, and Concepts of Operations (CONOPS) are acceptable.

SUBMITTAL INFORMATION

It is requested that interested businesses submit to the contracting office a brief product information package (existing product brochures and/or datasheets acceptable) for technologies or concepts that meet the requirements summarized herein.

Documentation should address the following:

Company Name; Company Address; Cage Code; Company Business Size; and Point-of-Contact (POC) name, phone number, and e-mail address.

Technology, concept, or existing information about launch and recovery system, which might include:

Product brochures

Concept images

Written description(s) of the technology, including the methods used to interface with the aircraft and store, transmit, deliver/absorb energy for launch/recovery

Written description of the CONOPS, including how the launch system, recovery system, and aircraft(s) can work holistically in a minimal amount of space

Specifications/Datasheets or other documented/proposed capabilities of the system, e.g., launch and recovery envelope ranges, sortie rates, controllability, etc.

Interface requirements, e.g., ship power, hydraulics, cooling, communications (fiber), health monitoring, etc.

APPENDIX B: UAS MISSION ILLUSTRATION AND COMPARISON

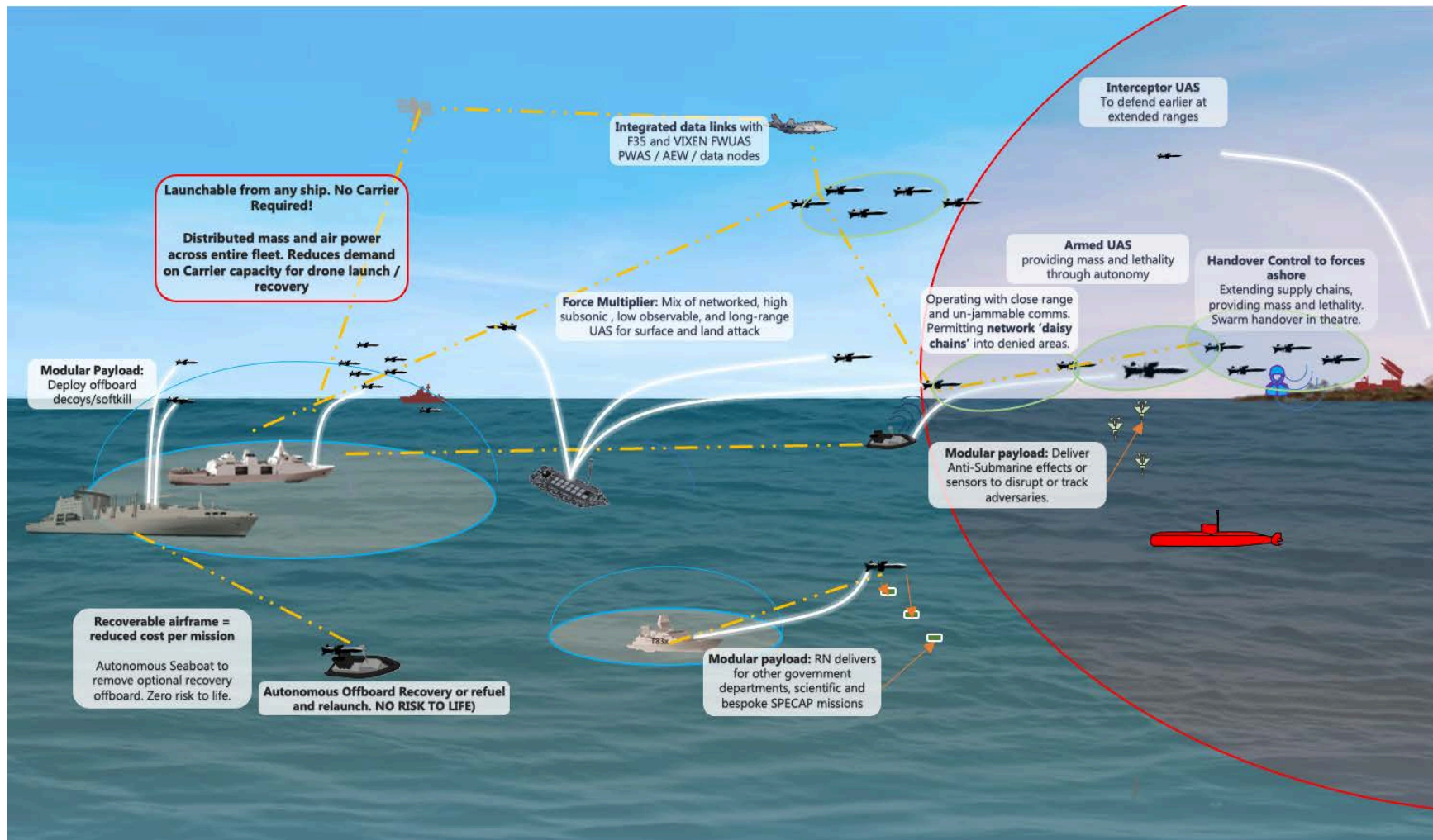


Figure 20: UAS Carrier Mission Illustration

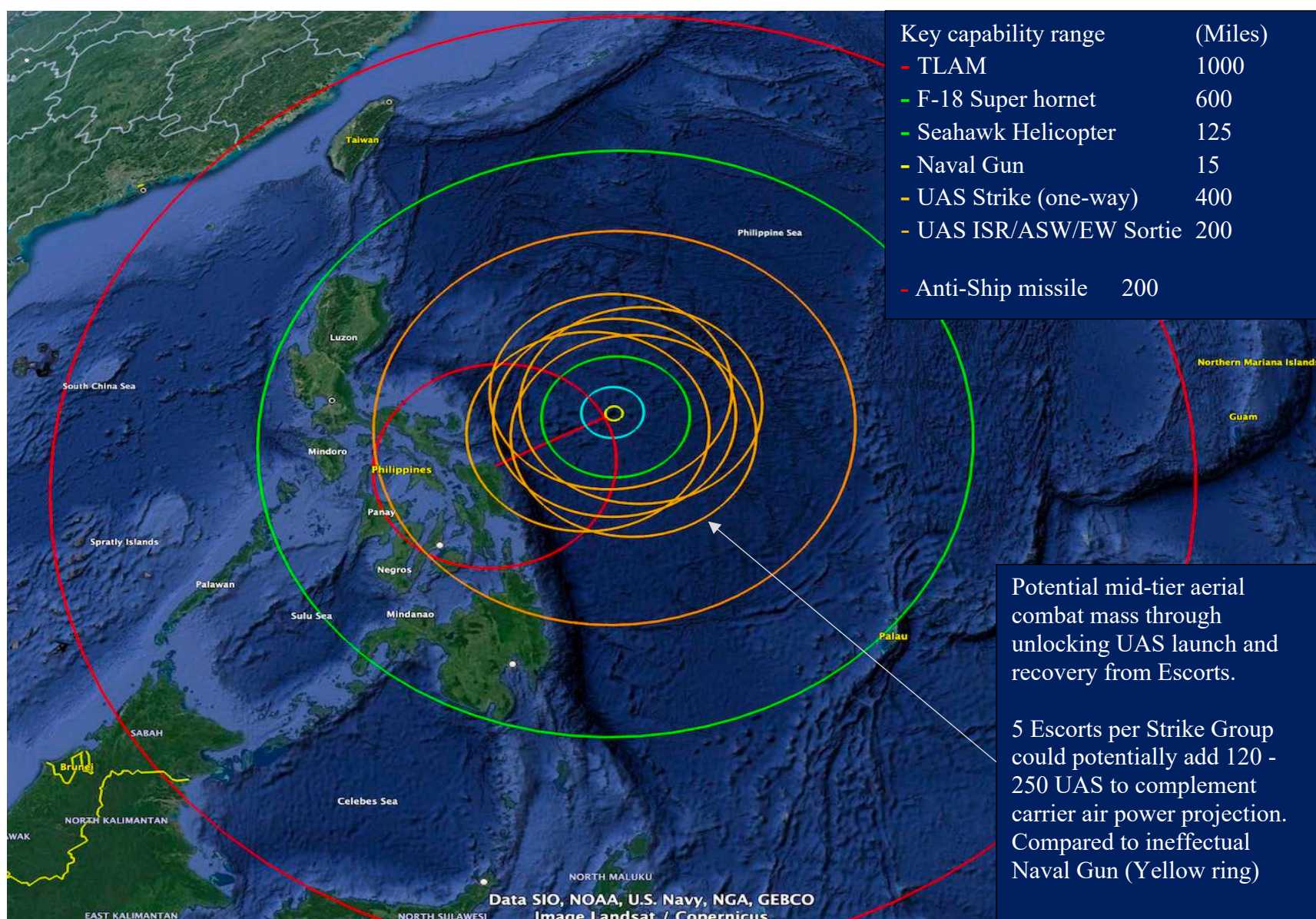


Figure 21: Carrier Strike Group: Illustration showing additional aerial mass of UAS sorties from escort warships. Note: The comparison does not include in air re-fueling ranges for either the F-18 or UAS, both could potentially have ranges extended by 50%.

APPENDIX C: DRAFT CONCEPT OF UAS INTEGRATION TO MODERN WARSHIP (TYPE 45 DESTROYER)

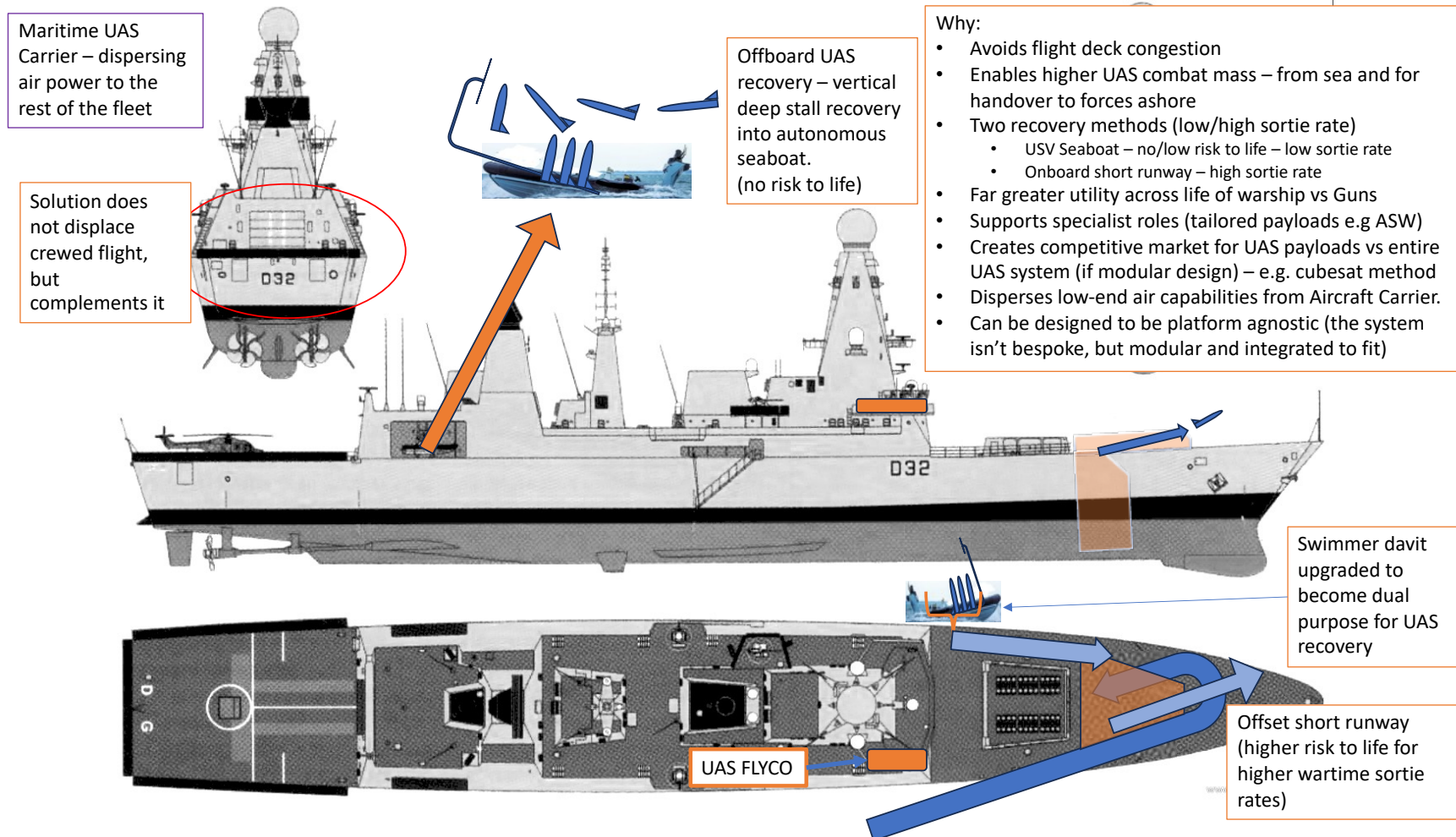


Figure 22: Type 45 to UAS carrier conversion concept

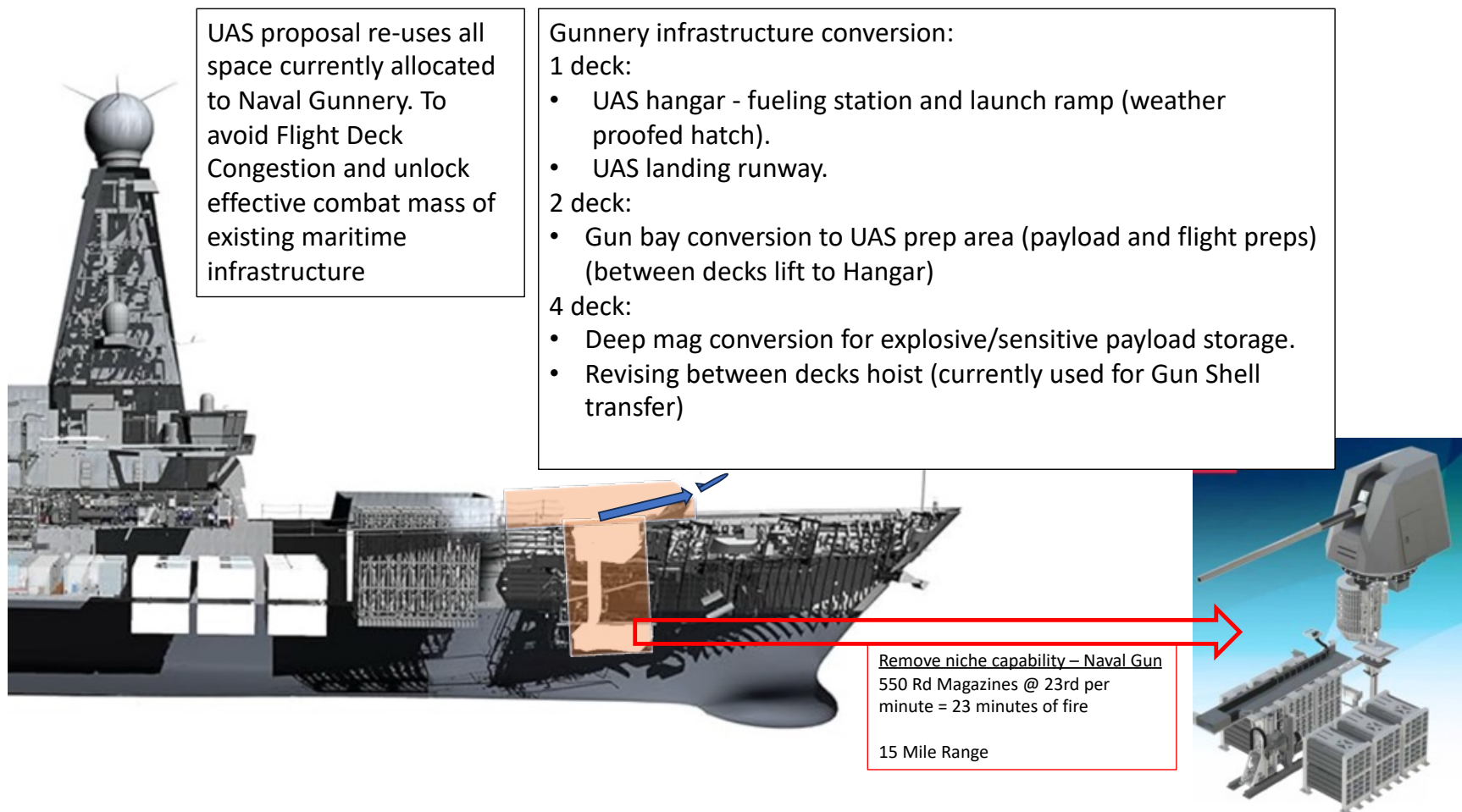
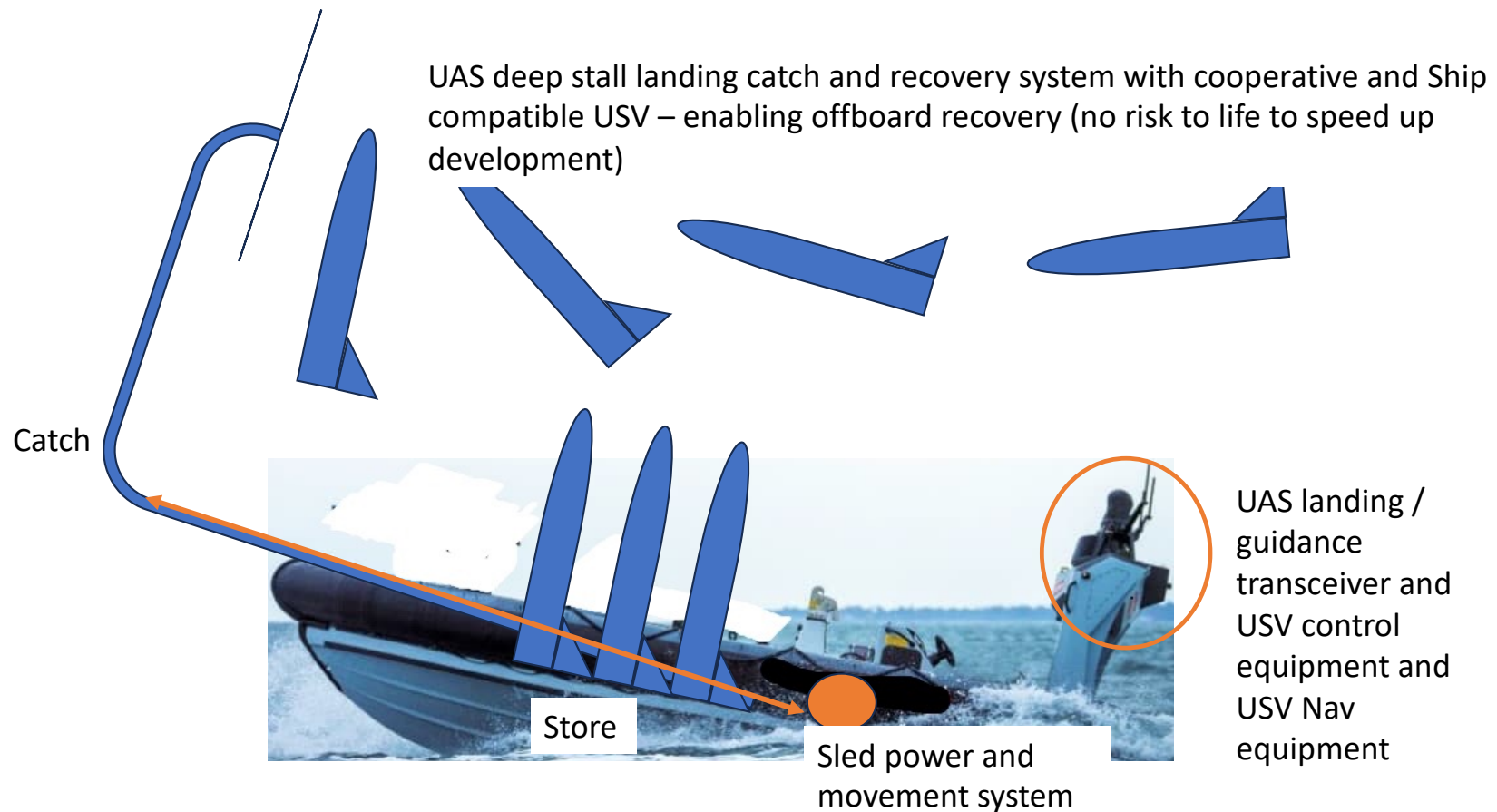


Figure 23: Type 45 to UAS Carrier Conversion concept showing usable space vacated by removing Naval Gun



Catching net integrated onto sled to move UAS from Catch area toward rear of USV for storage before return to mother ship for re-launch.

Figure 24: Autonomous Sea Boat overlaid with UAS teaming recovery concept

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Vita

Commander Steven Lovatt serves in the Royal Navy of the United Kingdom of Great Britain and Northern Ireland. He gets paid for his hobbies which include designing and executing advanced warfighting exercises, establishing international procurement projects for weapon systems, and improving the fighting capability of the UK with its allies. He has found a new hobby to pursue as a Joint Force officer and seeks to make the most of his newly acquired Joint Advanced Warfighting skills.

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