NPS-LM-25-272

ACQUISITION RESEARCH PROGRAM
SPONSORED REPORT SERIES

Unmanned Low-Profile Vessels: “Narco Subs” for Contested Logistics

September 2024

Maj Sergio A. Sierra, USAF

Thesis Advisors: Dr. Don Brutzman, Associate Professor
Dr. Mustafa Canan

Department of Defense Management

Naval Postgraduate School

The research presented in this report was supported by the Acquisition Research Program of the Department of Defense Management at the Naval Postgraduate School.

To request defense acquisition research, to become a research sponsor, or to print additional copies of reports, please contact the Acquisition Research Program (ARP) via email, arp@nps.edu or at 831-656-3793.

ABSTRACT

This research uses both qualitative secondary research and quantitative modeling and simulation to explore the concept of unmanned low-profile vessels (ULPVs) as a solution to contested logistics challenges for the U.S. military in the Indo-Pacific. ULPVs are an unmanned variation of low-profile vessels (LPV), commonly referred to as "narco subs," which are extensively used by drug trafficking organizations (DTOs) for transporting illicit goods. LPVs are effective at evading interdiction, partly due to their difficulty to detect, and are manufactured quickly with low-skilled labor and at low cost. This research uses modeling and simulation tools, including the Next Generation Threat System (NGTS), and found a significantly lower probability of detection by People's Republic of China (PRC) assets of ULPVs than other logistics vessels. This research finds ULPVs as an effective solution to enhance the U.S. military's operational capabilities in a contested environment. This research documents possible ULPV concepts of employment (CONEMPs), challenges for ULPV design, and numerous ULPV design considerations, including enterprise architecture (EA), command, control, and communications (C3), navigation, big data, and susceptibility. Finally, this research documents considerations for defense acquisition of ULPVs and informs an analysis of alternatives (AoA) for a materiel solution supporting contested logistics.

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

This research would not be possible without the guidance and support of many individuals. The scope of this research is multi-disciplinary, and it is the product of collaboration between various people who are passionate about defense of the United States and its interests.

This research benefits greatly as a sponsorship effort by the Naval Information Warfare Center Pacific as part of the NIWC Pacific fellowship between the Naval Postgraduate School and NIWC Pacific. Thank you to Michael Stuckenschneider for advising this research, being a valuable resource, and connecting me to the right people. Additionally, thank you to members of the NIWC Pacific team assisting this research's modeling and simulation efforts, especially Dr. Glenn-Iain Steinback. Much of this research would not have been possible if it weren't for your generous support. Thank you, also, to Colin Grain for helping me with troubleshooting the modeling and simulation scenario on multiple occasions.

This research is part of the NPS' Nimitz Research Group and benefits from that association. The NRG trip to U.S. Pacific Fleet in February 2023 sparked the conversations that directly led to this research effort. Thank you to VADM Phil Sawyer (Ret.) for supporting this research.

Thank you to my beautiful wife, Catarina, for always supporting and providing insight into this research over the last 2 years. I wouldn't have had the time or energy to complete this research as it now exists if it weren't for you.

Thank you to all the advisors supporting this dual-degree thesis: Dr. Don Brutzman, Dr. Jarema Didoszak, Dr. Mustafa Canan, and Professor Ray Jones. Thank you for supporting the many meetings regarding this research. In addition, I would like to extend my thanks to the following NPS faculty for supporting this effort: Dr. Sean Kragelund, Professor Christian Fitzpatrick, Professor Jeffrey Kline, Dr. David Jenn, and Dr. Timothy Shives.

Thank you to CDR Todd Greene, Matt Koch, Chris Anson, and Bill Chambers for supporting this effort by answering questions, helping me network, and granting me access to your ongoing work in support of our nation. Thank you to my friend and colleague, Lyle Bacaltos, for your contributions to the content in the Big Data section of this thesis and for entertaining countless discussions related to my interest in unmanned low-profile vessels. Also, thank you to my colleague, Lu Banchs, for your input and contributions to this research effort.

Finally, thank you to Dr. Diogenes (Dio) Placencia for always being very helpful and responsive, and pointing me to the right people to address various questions.

NPS-LM-25-272

ACQUISITION RESEARCH PROGRAM
SPONSORED REPORT SERIES

Unmanned Low-Profile Vessels: “Narco Subs” for Contested Logistics

September 2024

Maj Sergio A. Sierra, USAF

Thesis Advisors: Dr. Don Brutzman, Associate Professor
Dr. Mustafa Canan

Department of Defense Management

Naval Postgraduate School

Approved for public release; distribution is unlimited.

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access/area-denial
ACE	agile combat employment
AI	artificial intelligence
AIS	Automated Identification System
ALC	Autonomous Littoral Connector
ALPV	autonomous low-profile vessel
AoA	analysis of alternatives
AOR	area of responsibility
AUV	autonomous underwater vehicle
AVCL	autonomous vehicle command language
BLOS	beyond line-of-sight
C2	command and control
C3	command, control, and communications
C5ISRT	command, control, communications, computers, combat systems, intelligence, surveillance, reconnaissance, targeting
CLD	causal loop diagram
CLF	combat logistics force
CONEMP	concept of employment
COTS	commercial-off-the-shelf
CPU	central processing unit
DDIL	denied, degraded, intermittent, and limited
DEA	Drug Enforcement Agency
DMO	distributed maritime operations
DoD	Department of Defense
DON	Department of Navy
DoS	denial of service
DTO	drug trafficking organization
EA	enterprise architecture
EAB	expeditionary advanced base
EABO	expeditionary advanced base operations

EM	electromagnetic
EO	electro-optical
ESB	expeditionary sea base
FSO	free-space optical
FSV	fully submersible vessel
ft	foot (feet)
Gbps	gigabytes per second
GNSS	global navigation satellite system
GPS	Global Positioning System
GPU	graphics processing unit
HAT	height above terrain
helo	helicopter
HF	high frequency
HM&E	hull, mechanical, and electrical
IaaS	infrastructure as a service
IMO	International Maritime Organization
INS	Inertial Navigation System
IoT	internet of things
IP	internet protocol
IR	infrared
IRCS	infrared cross-section
IRST	infrared search and track
ISR	intelligence, surveillance, and reconnaissance
IVO	in vicinity of
JADC2	joint all-domain command and control
JLTV	joint light tactical vehicle
JWCC	Joint Warfighting Cloud Capability
km	kilometer(s)
kt	knot
lb	pound
LCAC	landing craft air cushion
LCM	landing craft, mechanized

LCU	landing craft, utility
LCVP	landing craft, vehicle, personnel
LEA	law enforcement agency
LEO	low earth orbit
LIDAR	light detection and ranging
LOS	line-of-sight
LPD	low probability of detection
LPV	low-profile vessel
LSM	landing ship, medium
LT	long ton(s)
LVC	live, virtual, constructive
m	meter(s)
M	million(s)
MARFORPAC	Marine Corps Forces, Pacific
Mbps	megabytes per second
MCDP	Marine Corps Doctrinal Publication
MCWP	Marine Corps Warfighting Publication
MDO	multi-domain operations
MEU	marine expeditionary unit
MHE	material handling equipment
mi	mile(s)
ML	machine learning
MOLA	marine operations logistics asset
MOSA	modular open systems approach
MOVES	Modeling Virtual Environments and Simulation
MSL	mean sea level
MTVR	medium tactical vehicle replacement
MVP	minimally viable product
NAVAIR	Naval Air Systems Command
NGTS	next generation threat system
NIWC	Naval Information Warfare Center
NM	nautical mile

NPS	Naval Postgraduate School
NRT	near real time
OODA	observe, orient, decide, act
OSINT	open-source intelligence
OV-1	operational view-1
PaaS	platform as a service
PACFLT	Pacific Fleet
P_d	probability of detection
PNT	positioning, navigation, and timing
PRC	People’s Republic of China
RADAR	radio detection and ranging
RCS	radar cross-section
RF	radio frequency
RORO	roll-on/roll-off
RWR	radar warning receiver
SaaS	software as a service
SAR	synthetic aperture radar
SCS	sonar cross-section
SIF	stand-in-forces
SOF	special operations forces
SOUTHCOM	Southern Command
SPSS	self-propelled semi-submersible
sr	Steradian
SSV	semi-submersible vessel
SWaP	size, weight, and power
tn	short ton
U.S.	United States
ULPV	unmanned low-profile vessel
UNREP	underway replenishment
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps

USN	United States Navy
USNA	United States Naval Academy
USSOCOM	United States Special Forces Command
USTRANSCOM	United States Transportation Command
VHF	very high frequency
VST	virtual sand table
W	watt(s)
WEZ	weapon engagement zone
WWII	World War II
X3D	extensible 3-dimensional

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Parts of sections A, B, and C of this chapter were previously published by the Acquisition Research Program at the Naval Postgraduate School (NPS) (Sierra, 2024).

The prevalent use of low-profile vessels (LPVs), also known as semi-submersible vessels (SSVs), commonly referred to as "narco subs," by drug trafficking organizations (DTOs), highlights a potentially advantageous and largely untapped model for United States (U.S.) military capability. LPVs provide drug traffickers an affordable and effective means to move illicit material around the world, crossing vast distances of open ocean and evading some of the most sophisticated drug interdiction efforts aimed specifically at preventing the successful transit of narco subs. The fundamental nature of LPVs to float minimally above the free surface has contributed to their effectiveness, while the simplicity of their construction and use of commercial-off-the-shelf (COTS) technology has contributed to their affordability (Ramirez & Bunker, 2015). Drug traffickers continually fabricate LPVs in the jungles and villages of South America to move their goods affordably and effectively throughout the world (Ramirez & Bunker, 2015). The DTOs of South America have proven that LPVs are an effective and repeatable model, one that can be adapted to meet U.S. military requirements.

The use cases for LPVs in the U.S. military are likely many. An unmanned low-profile vessel (ULPV) may be an ideally suited materiel solution to address contested logistics challenges faced by the joint force. The simplistic nature of LPV construction means that they can be produced by a large portion of the U.S. and partner nation industrial bases, as opposed to only large defense industry shipyards. This large pool of potential manufacturers may result in innovation and competition, further driving down material costs and introducing the ability to scale said production higher than current U.S. shipbuilding capability. In this era of insufficient national shipbuilding capacity (Eckstein, 2024) and naval maintenance and repair backlogs (Government Accountability Office [GAO], 2023), the ability to use alternative industrial sources is an essential requirement for any new approach.

Understanding how ULPVs can support contested logistics will benefit all Department of Defense (DoD) services as each branch looks for options to maintain a sufficient logistics capability in a contested environment. Additionally, understanding the technical and design considerations necessary for a ULPV to meet the requirements of the contested logistics mission, while also remaining affordable and simple enough to support high rates of production, will help inform the design of a desirable ULPV materiel solution to the DoD.

A. PROBLEM

In the context of a hypothetical conflict with the People's Republic of China (PRC) in the Indo-Pacific area of responsibility (AOR), there is a shortfall of logistics vessels to accomplish intra-theater logistics (Martin & Pernin, 2023). In addition to this shortfall, current logistics vessels are vulnerable against threats and are likely to be unescorted in a future large conflict (Larter, 2018), thereby negatively impacting projected success rates for vessels to deliver supply at their intended destinations. This capability gap is summarized as a lack of viable intra-theater logistics vessels, assuming an area denial, anti-access (A2/AD) threat environment present from various weapon engagement zones (WEZs) from PRC weapons systems deployed on land, air, and sea.

The foundation of any military to conduct operations hinges on successful logistics that provide the means. Failure to address this capability gap will likely lead to a significant decrement in both the capacity and effectiveness of U.S. military operations, resulting in loss to U.S. persons, materiel, and objectives in the AOR.

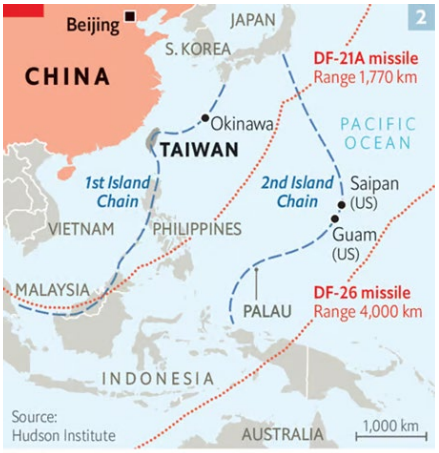
The existence of an intra-theater logistics capability gap is of particular significance because it undermines U.S. ability to deter military aggression or conflict escalation in the AOR. Rectifying the U.S. military's ability to confidently provide logistical support in a contested environment, such as the Indo-Pacific, is a critical aspect of increasing its capacity for deterrence.

B. PURPOSE

The purpose of this research is to inform the design and employment of ULPVs to support military logistics operations in a contested environment like the Indo-Pacific. This research intends to inform the acquisition of ULPVs by documenting design considerations for ULPVs that improve the DoD's ability to leverage the U.S. industrial base, and potentially that of partner nations, to manufacture and field ULPVs affordably and at scale to meet military requirements. The final written deliverable of this research effort is intended to provide the DoD with a consolidated product to inform decision making on questions regarding military use, design, and acquisition of ULPVs.

C. SCENARIO TO BOUND RESEARCH SCOPE: CONTESTED LOGISTICS IN THE INDO-PACIFIC

The overarching scope of this research is intentionally bound by a scenario that assumes a need for ULPVs to conduct logistics missions during a state of conflict between nation states in the Indo-Pacific. The geographic area of interest for this research begins at mainland China and extends to the expected maximum range of the DF-26B anti-ship ballistic missile WEZ, approximately 4,000 kilometers (km) from the coast of mainland China, as depicted in Figure 1. This area contains the places of interest and the relevant distances therein for intra-theater logistics in the Indo-Pacific.



Source: Hudson Institute

The Economist

Figure 1. Indo-Pacific Area of Interest and People's Republic of China Range Rings. Source: "America and China," (2023).

Each of the services' operational models in the Indo-Pacific are expected to be expeditionary in nature, thereby emphasizing forces that are mobile, agile, geographically distributed, and capable of various military operations within contested or potentially contested locations that may be austere or temporary in nature. The expected supply categories and their respective quantities anticipated for U.S. forces to conduct expeditionary operations in the Indo-Pacific lay the foundation for the intra-theater logistical requirements. These logistical requirements inform the design of ULPVs intended to fill the AOR's intra-theater logistics capability gap.

Of the six logistics functions described by Marine Corps Doctrinal Publication (MCDP) 4 (United States Marine Corps [USMC], 2023a, p. 215), as shown in Figure 2, this research bounds ULPV operations to focus on the logistics function of transportation. This research assumes that ULPVs supporting logistics missions can complete these functions for any unit of the U.S. military, regardless of service branch affiliation. This research also assumes that supply will need to be moved as break-bulk cargo and possibly include the use of shipping containers and containers with similar form factors and material handling equipment (MHE) interfaces of shipping containers (i.e., tank containers) to move supply.

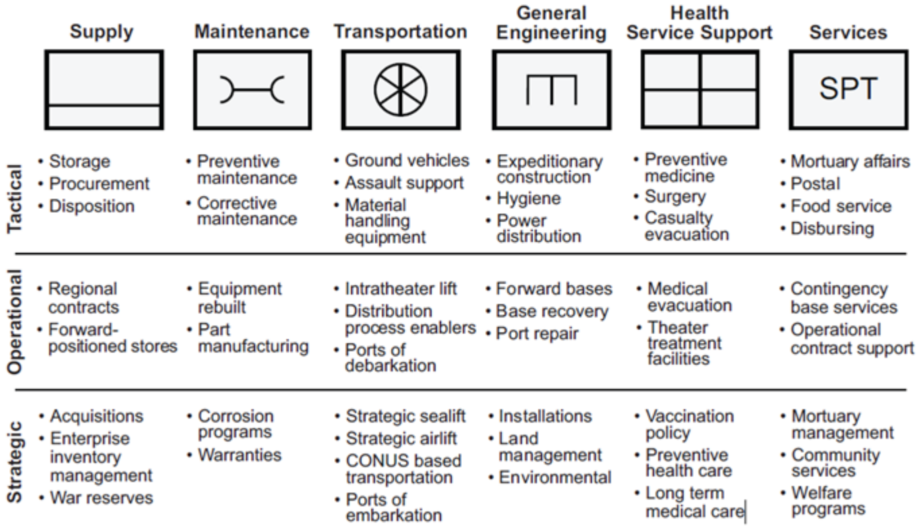
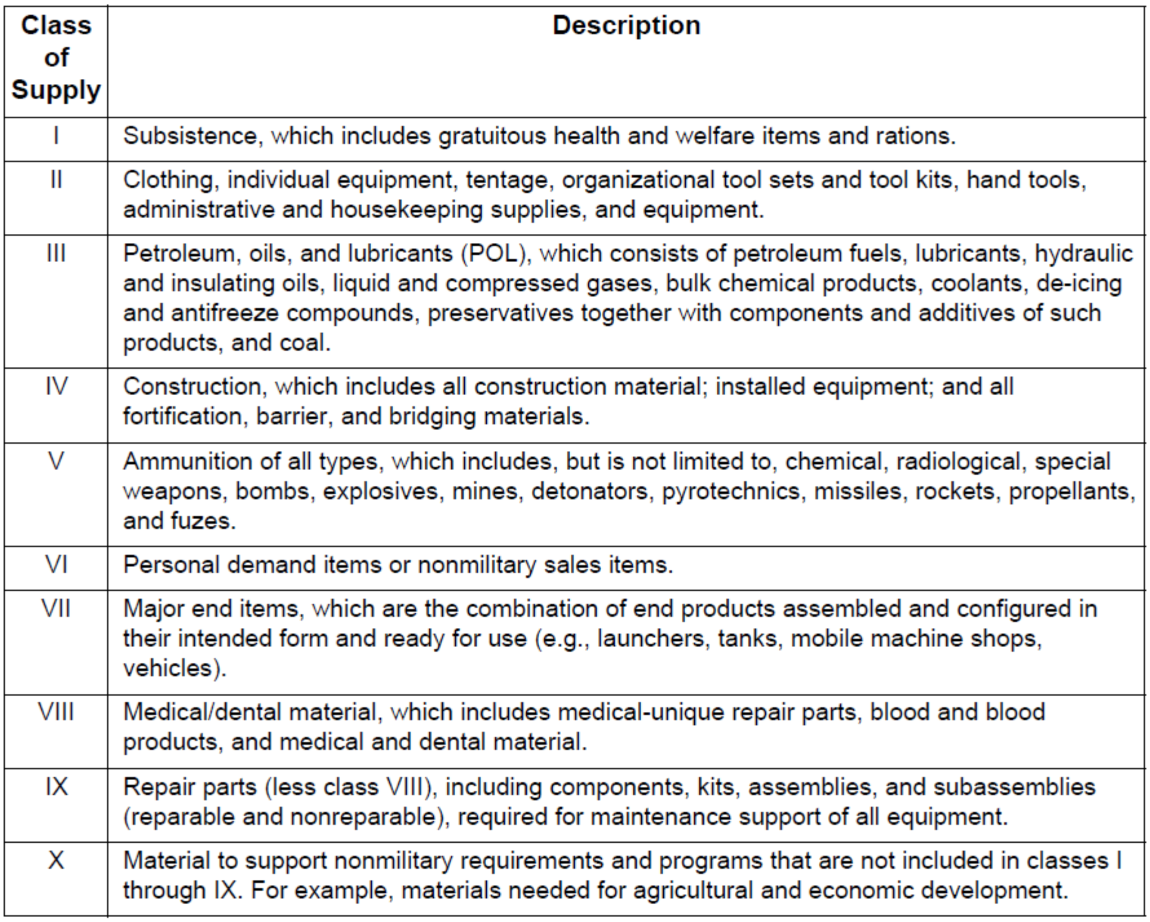


Figure 2. Logistics Functions at Each Level of Warfare. Source: United States Marine Corps (2023a, pp. 2–15).

This study assumes that ULPVs may be designed to move any class of supply except for some specific Class VII supply (major end items) that are anticipated to be too large and/or heavy for transport by ULPVs. As is the case with any vessel, the ability of a ULPV to carry any given type and quantity of supply is inherently constrained by the design of the vessel. Table 1 outlines the classes of supply.

Table 1. Classes of Supply. Source: United States Marine Corps (2023b).



Class of Supply	Description
I	Subsistence, which includes gratuitous health and welfare items and rations.
II	Clothing, individual equipment, tentage, organizational tool sets and tool kits, hand tools, administrative and housekeeping supplies, and equipment.
III	Petroleum, oils, and lubricants (POL), which consists of petroleum fuels, lubricants, hydraulic and insulating oils, liquid and compressed gases, bulk chemical products, coolants, de-icing and antifreeze compounds, preservatives together with components and additives of such products, and coal.
IV	Construction, which includes all construction material; installed equipment; and all fortification, barrier, and bridging materials.
V	Ammunition of all types, which includes, but is not limited to, chemical, radiological, special weapons, bombs, explosives, mines, detonators, pyrotechnics, missiles, rockets, propellants, and fuzes.
VI	Personal demand items or nonmilitary sales items.
VII	Major end items, which are the combination of end products assembled and configured in their intended form and ready for use (e.g., launchers, tanks, mobile machine shops, vehicles).
VIII	Medical/dental material, which includes medical-unique repair parts, blood and blood products, and medical and dental material.
IX	Repair parts (less class VIII), including components, kits, assemblies, and subassemblies (reparable and nonreparable), required for maintenance support of all equipment.
X	Material to support nonmilitary requirements and programs that are not included in classes I through IX. For example, materials needed for agricultural and economic development.

In addition, this research assumes that ULPVs will need to be able to transit distances of at least 1,900 nautical miles (NMs), or the approximate distance required to transit from the edge of the DF-26B WEZ to the first island chain (depicted in Figure 1). It is assumed that ULPVs will need to be able to operate within and navigate all oceanic conditions associated with this geographic area. It is also assumed that ULPVs will contend with variables that challenge their desired operation, to include interdiction by enemy assets, attack by enemy assets, and degradation or denial of communication and navigation capabilities.

D. RESEARCH METHODOLOGY

This research uses a combination of quantitative and qualitative approaches to address the effort’s research questions. This includes performing secondary research with a review of available open-source literature to capture key findings relevant to the design, employment, and acquisition of ULPVs to support contested logistics. These key findings are then brought together in the context of ULPV design, employment, and acquisition to create qualitative evidence in the form of key considerations for ULPVs to support contested logistics. The methodology also includes the use of documented observations, or “field work,” to inform considerations for ULPV design and operations. Conceptual use cases of ULPVs for contested logistics are utilized and analyzed to generate ULPV concepts of employments and other key design and operational considerations. Modeling and simulation are also used to create empirical data related to logistic vessel performance and to test the validity of some generated key considerations, most specifically, susceptibility variables of vessel design such as radar cross-section (RCS), infrared cross-section (IRCS), and vessel speed. The scope of this research results in documented findings of key considerations relevant to the design, employment, and acquisition of ULPVs to fill a contested logistics role in a hypothetical conflict involving the PRC in the Indo-Pacific.

II. BACKGROUND INFORMATION

This chapter was previously published by the Acquisition Research Program at NPS (Sierra, 2024).

A. NARCO SUBS: A TOOL FOR DRUG TRAFFICKING

DTOs use various methods to traffic drugs by air, land, and sea. DTOs have historically innovated new means to traffic drugs as some prove more successful than others, and as law enforcement agencies (LEAs) become more aware of and more effective at interdicting trafficking methods. One such innovative method used by DTOs is the use of "narco subs" to traffic drugs by sea. According to Ramirez & Bunker (2015), "narco sub" is a term used to describe the three main categories of narco-vessels:

1. LPVs or self-propelled semi-submersibles (SPSSs),
2. submersibles or fully submersible vessels (FSVs), and
3. "narco torpedoes" (the towed variety).

Most seized drug smuggling vessels to date are LPVs (Ramirez & Bunker, 2015) and the focus of this research effort is on LPVs. LPVs cost DTOs approximately $1 M to manufacture and are built throughout Colombia and other parts of South America, in makeshift jungle boatyards (Figure 3), in 30 to 45 days' time (VICE, 2011).

Figure 3. Low-Profile Vessel Boatyard in Colombian Jungle. Source: JaySea Archaeology (2020).

LPVs can carry up to 10 short tons (tns) of drugs (Ramirez & Bunker, 2015) and can travel between 3,000 and 3,500 NMs (VICE, 2011). In 2019, the first known trans-Atlantic crossing of a narco sub occurred when a 70 feet (ft) LPV, carrying nearly 7,000 pounds (lbs) of cocaine, made the 3,500 miles (mi) journey from Brazil to Spain (Figure 4) over a 27 day period (Jones, 2022). These vessels usually carry four crew members who make their voyage in very poor conditions, typically in a small aft space of the vessel that is hot, poorly ventilated, without a bathroom, and with makeshift bunking space (such as on top of fuel tanks) (VICE, 2011).

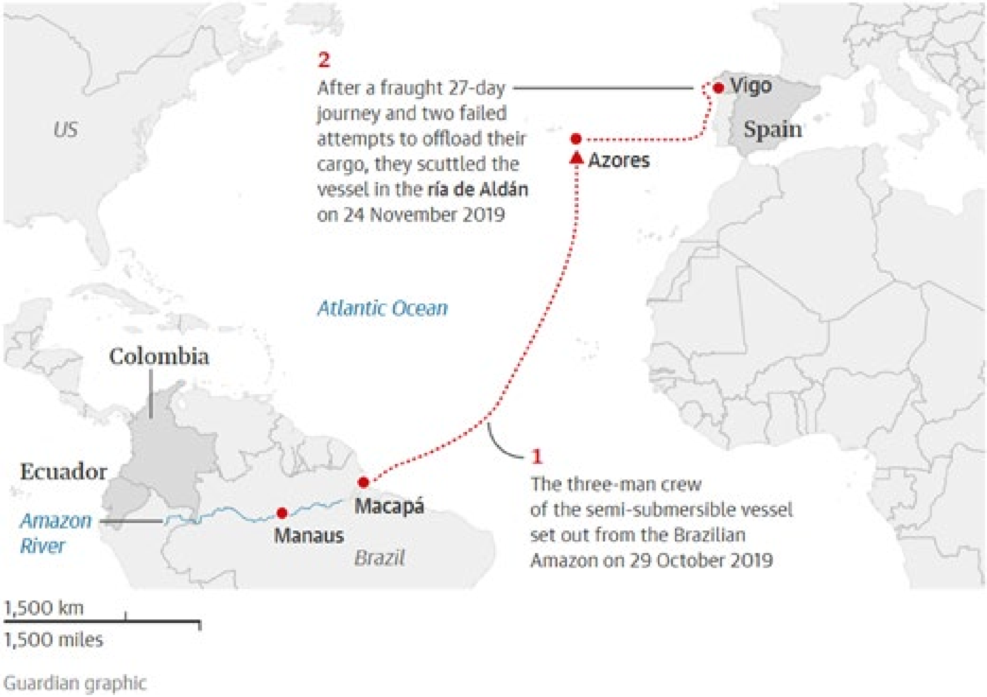


Figure 4. Trans-Atlantic Narco-Sub Journey. Source: Jones (2022).

Generally, LPVs are difficult to detect as they are nearly impossible to spot from the horizon and further difficult to detect by radar (VICE, 2011). The low observable attribute of LPVs results from various design features such as the vessel: having minimal features on the deck, being hydrodynamic in shape, riding low in the water (minimal freeboard), using thermal shielding, being built of fiberglass, and being painted in a dark color that blends with the ocean surface (Figure 5) (VICE, 2011).

Figure 5. View of Low-Profile Vessel Operating. Source: Sutton (2021b).

According to the Colombian Navy, however, one relatively easy method of detecting LPVs, despite their lack of visible wake, is by spotting them from the air with an aircraft (VICE, 2011). A 2014 account by United States Navy (USN) CAPT Mark F. Morris supported the need for aircraft utilization to achieve favorable LPV detection probability, stating:

> American operations analysis shows that given good intelligence of a drug event and a patrol box of a certain length and width, a surface vessel operating alone has only a 5% probability of detecting (PD) that event. A surface vessel with an embarked helicopter increases the PD to 30%, and by adding a Maritime Patrol Aircraft to the mix, the PD goes up to 70%. Analysis by the Colombian Navy shows that adding one of their submarines to the mix raises the PD to 90%. (Ramirez and Bunker, 2015, p. 47)

The U.S. Drug Enforcement Administration (DEA) has considered that only about 20% of narco subs are intercepted (Ramirez & Bunker, 2015). In a 2014 testimony to Congress, U.S. Southern Command (SOUTHCOM) reported that low interdiction rates were due to asset shortfalls (Ramirez & Bunker, 2015), presumably resulting in an inadequate number of vessels and aircraft able to conduct maritime interdiction missions against LPVs. Most narco subs have been found in the SOUTHCOM AOR, with 78% being found in the Pacific (in waters near South and Central America) and 20% being found in the Caribbean (Ramirez & Bunker, 2015). As a result, most LPV interdiction data exists in an environment where LEAs are under resourced, according to the 2014 SOUTHCOM testimony to Congress, resulting in uncertainty at how effective LPVs are at avoiding detection and interdiction in an environment where they are hunted with more numerous resources.

For DTOs, the business model of LPV fabrication and operation is the result of a cost-benefit analysis where the yielded benefits are far superior to the costs associated with building and operating LPVs (Ramirez & Bunker, 2015). A 10 tns cargo of narcotics may be worth approximately $200 M (Ramirez & Bunker, 2015), minus the $1 M construction cost of the LPV, leaves a $199 M profit per successful LPV voyage. Factoring in a loss rate of 20%, based on the previously mentioned LPV interdiction rate, results in an average profit per LPV voyage of approximately $159 M. This calculation assumes a full 10 tns cargo on every LPV voyage as well as a constant interdiction rate of 20%, however, it serves to highlight the superior benefit over the cost of LPV fabrication and operation, resulting in the continued DTO use of LPVs for drug trafficking.

B. APPEAL OF LOW-PROFILE VESSELS FOR CONTESTED LOGISTICS

In a foreword to *Beans, Bullets, and Black Oil*, former Secretary of the Navy, Dan A. Kimball, highlighted the criticality of logistics to the fight against the Japanese Empire in World War II (WWII), saying:

> Victory is won or lost in battle, but all military history shows that adequate logistic support is essential to the winning of battles. In World War II, logistic support of the fleet in the Pacific became a problem of such magnitude and diversity, as well as vital necessity, that all operations against Japan hinged upon it. (Carter, 1998, Foreword)

Given the success that DTOs experience trafficking drugs with LPVs, it is fair to question if a vessel like a LPV could be used in a military logistics role for the U.S. DoD. This question exists at a time when the U.S. prepares for a possible conflict in the Indo-Pacific between China and Taiwan, at a time when the commander of the U.S. Pacific Fleet (PACFLT) warned of an insufficient Combat Logistics Force (CLF) (Katz, 2024).

Wargames indicate that U.S. logistics vessels will be sought after by any adversary (Katz, 2024) and past exchanges with Chinese naval leadership indicate that these vessels will be primary targets in a U.S.–China conflict (Suciu, 2020). This environment, "one in which the armed forces engage in conflict with an adversary that presents challenges in all domains and directly targets logistics operations, facilities, and activities", is known as a contested logistics environment (Defense Acquisition University [DAU], n.d.).

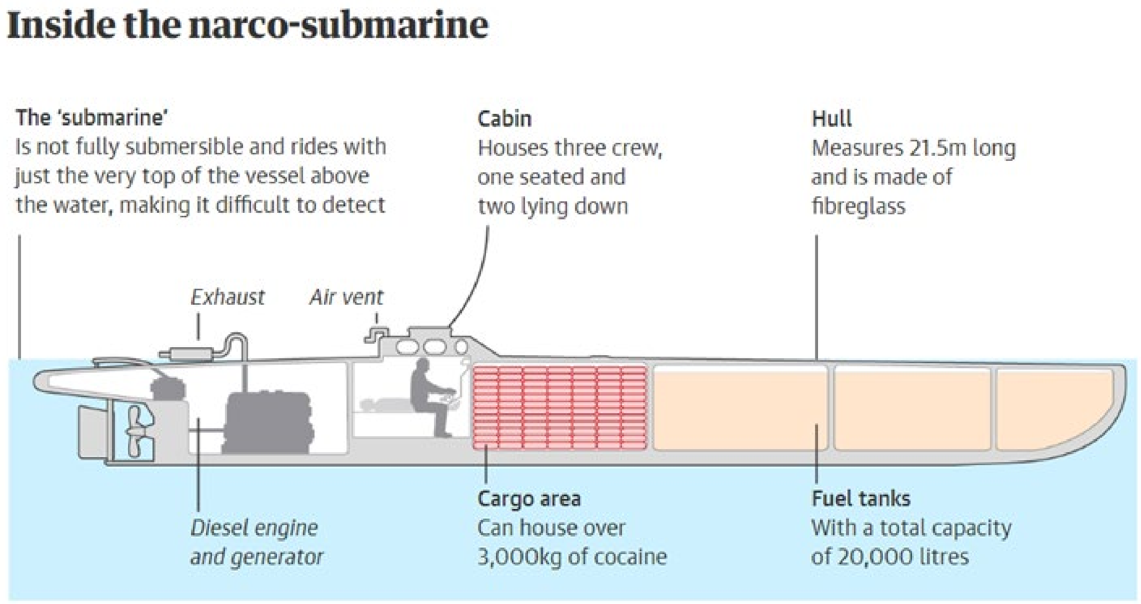
U.S. Joint Forces will require sustainment to effectively fight a war in the Indo-Pacific, and that sustainment must ensure support that flows from the U.S. to the point where United States Transportation Command (USTRANSCOM) delivers supplies, and further to the point where frontline forces receive supplies (Martin & Pernin, 2023). The logistics supply chain in this case spans the geographic distances between factories within the continental U.S. to military forces staged throughout the Indo-Pacific. Martin and Pernin highlight that the most particularly concerning stretch of the logistics map from the U.S. to the frontlines of the Indo-Pacific is the part known as intra-theater lift, "the portion of the transportation chain that delivers materiel from a port of debarkation to the point of use by an operational unit" (Martin & Pernin, 2022).

Although individual services have capabilities to meet a portion of their intra-theater transportation demands, when combined, they do not meet all needs of the joint force (Martin & Pernin, 2023). In addition to the sheer quantity of supply that would need to be transported across large distances over water, a fight in the Indo-Pacific would leave U.S. logistics vessels to contend with growing A2/AD capabilities of the PRC. These PRC capabilities span air, land, and sea, and leverage various missiles of growing quantity and capability intend to impose maximum attrition to slow and impede any adversarial military operations (Joshi, 2019). PRC A2/AD capabilities would envelop the entirety of what will be the intra-theater logistics operating area for a U.S. military operation in the Indo-Pacific (Joshi, 2019). Because logistics operations are expected to take place in contested environments, and because the DoD lacks the logistics forces to support a large military campaign in the Indo-Pacific, the need for new materiel solutions to accomplish contested logistics missions has arisen (Mills & Limpaecher, 2020).

One thought to help address the capability gap in intra-theater contested logistics is to apply the DTO model of LPVs to U.S. military logistics, perhaps even in an unmanned capacity (Mills & Limpaecher, 2020). Narco-sub-like vessels such as LPVs are thought of as a prospective materiel solution to provide logistics support to the United States Marine Corps' (USMC) expeditionary advanced base operations (EABO) (Mills et al., 2020) or to Taiwan in the event of a Taiwan conflict (Griffin, 2024). A U.S. unmanned low-profile vessel (ULPV) may be able to leverage the low observable benefits that make DTO operated LPVs difficult to detect and interdict but without the need of a crew and subjecting that crew to the conditions and risks associated with a LPV operating in the waters of the Indo-Pacific under the PRC's A2/AD threat bubble.

C. DRUG TRAFFICKING ORGANIZATION LOW-PROFILE VESSEL DESIGN THEMES

There are a few key design themes that arise from DTO LPVs that are foundational to the success of the drug trafficking LPV model. These design themes are design simplicity, design for mission needs, and design for asset attrit-ability. Narco subs evolved over decades beginning in the early 1990s with experimentation, through the early 2000s with prototyping, and continuing from 2007 to the present with design standardization and maturation (Ramirez & Bunker, 2015). One similarity among photos of all captured or interdicted narco subs is the simplicity of design that they all share (Ramirez & Bunker, 2015). Shaping wood and fiberglass into a functional LPV within 30 to 45 days, using local unskilled labor (VICE, 2011), in the jungles of Colombia is possible because of simple vessel design. Perhaps assisting the rapid LPV manufacture timeline is what Ramirez & Bunker (2015) indicate, that DTOs use readily available COTS components for the engines, navigation systems, and communications systems for their LPVs. The interiors of these LPVs further highlight their design simplicity, with little to no accommodations made for the crew and the sole focus on mission needs like cargo carrying capacity (large cargo holds) and vessel range (large fuel tanks), with neither compromised to carve out space for the crew (Figure 6). In a sense, DTOs have created a minimal viable product (MVP) to accomplish maritime drug trafficking at the lowest possible cost and highest possible benefit.



Guardian graphic. Source: La Voz de Galicia

Figure 6. Cutaway of Low-Profile Vehicle Highlighting Crew, Cargo, Engine, and Fuel Spaces. Source: Jones (2022).

In addition to design simplicity, LPVs appear tailor designed for their mission needs. As LPVs have evolved over time, their design has become more hydrodynamic, they have less piping on the hull, they run awash or with less freeboard, they incorporate lead shielding, and they use seawater to cool exhaust gases; all to decrease the probability of detection (P_d) by counter-drug operation by LEAs (VICE, 2011). While the hulls have become more hydrodynamic and larger in size, their shapes continue to remain like a sealed "go-fast" boat with a deep V-shaped hull, sufficient for the sea states they operate in (Ramirez & Bunker, 2015). Within the confines of this hull design, maximum space is afforded for cargo and fuel capacity. Loading and unloading the LPVs is accomplished through a simple single hatch on the vessel, by hand, and either at dock or at sea (VICE, 2011).

One additional theme to highlight is the inherent attritable nature of LPVs manufactured and operated by DTOs. These LPVs include a scuttle valve that floods the hull if activated by the crew (VICE, 2011) and it is used often in LPV interdictions to prevent LEAs from obtaining criminal evidence (Ramirez & Bunker, 2015). Even if the

LPV reaches its destination and successfully unloads its cargo, LPVs are typically scuttled rather than reused (VICE, 2011). Since LPVs are typically only valued at 2–3% the value of the cargo they carry, they are considered expendable (VICE, 2011).

It is also worth noting that DTO LPV designs are unbounded by regulations on maritime transport, such as those governed by the International Maritime Organization (IMO) (International Maritime Organization [IMO], n.d.b). The IMO sets standards for the safety, security, and environmental performance of international shipping (IMO, n.d.b) and it is likely that the acquisition process for any sort of LPV or ULPV by the DoD would need to comply with maritime specifications, standards, and laws for vessel design, construction, and operation; all factors which are not concerning to DTOs.

III. LITERATURE REVIEW AND RELATED WORK

Ramirez and Bunker (2015) published a collection of numerous papers on DTO narco subs. This work documents many aspects of narco subs, such as how they are built, where they are built, their reported interdiction rates, and methods of narco sub design by DTOs to prevent interdiction. In addition, this publication outlines themes of narco sub design and employment over decades of activity, highlighting the changes since inception of narco subs to present day design and operations. While narco sub designs have become more complicated over time, their designs are still relatively simple and utilize commercially available technologies and components to ensure that they can remain rapidly and affordably built in the jungles of South America by low-skilled labor.

Dougherty et al. (2020) documented various considerations for logistics vessels operating in the contested environment and uses modeling and simulation to assess the susceptibility of various logistics vessels. Vessel RCS, noise, and speed are among the characteristics utilized to determine logistics vessel susceptibility and a variety of adversary threat types are used to determine performance metrics related to expected logistic vessel performance against threats. This report also documents various considerations for logistics vessel design regarding delivery of supply and onboard systems. Recommendations are made within this report on methods to improve logistic vessel survivability by means of RCS and noise reduction, as well as the use of convoys for defense.

Sung et al. (2023) published a technical paper that looked at the idea of unmanned semi-submersible vessels to operate in a military logistics concept. The paper acknowledges the current limited guidance to inform the concept-level design of these hulls and studies the design parameters related to them. In this study, a parametric analysis is presented relating the hull form coefficients, immersions, and operation speeds of both early era submarines designed to operate mainly at the surface and modern narcotics smuggling vessels. This study makes use of illustrative histograms of hull parameters to show the significance of various LPV hull design considerations, such as the slenderness ratio, Froude number, and prismatic coefficient, which are all terms related to the wave-making resistance.

USMC (2023a) published MCDP 4 as a foundational document within the USMC that outlines the principles, concepts, and guidelines for logistics operations in support of USMC missions. It covers a wide range of logistical aspects, including sustainment, distribution, transportation, maintenance, and supply chain management. MCDP 4 emphasizes the importance of expeditionary logistics, the ability to rapidly deploy and sustain Marine forces in austere and often challenging environments. This publication provides a framework for commanders, planners, and logisticians to understand and effectively execute logistics operations, ensuring that Marines are properly equipped, fueled, and supported to achieve mission success in various operational scenarios.

IV. UNMANNED LOW-PROFILE VESSEL OPERATIONS CONSIDERATIONS

It should be considered the types of military operations which ULPVs may be able to support directly or indirectly. In addition, it is important to consider the way ULPVs support those operations by how they are employed and how the vessels are deployed for use in theater.

A. POSSIBLE SUPPORTED OPERATIONS

ULPVs may be utilized in various operations prior to or during conflict in the Indo-Pacific. The focus on this research is on ULPVs to support contested logistics in the Indo-Pacific such as by transporting supplies to support the sustainment of expeditionary units. Each service intends its own type of expeditionary operations construct for use in the Indo-Pacific. USMC has EABO, USN has distributed mission operations (DMO), the United States Air Force (USAF) has agile combat employment (ACE), and the United States Army (USA) has multi-domain operations (MDO) (Staff, 2024).

One plan for the defense of Taiwan against a potential PRC attack or invasion, termed “Hellscape” by ADM Paparo in a Washington Post interview, involves the use of thousands of unmanned systems to combat PRC assets in the Taiwan Strait (Rogin, 2024). ULPVs in this context might be used to transport and deploy other unmanned systems that can be used in the reported Hellscape operation. Alternatively, ULPVs might be used to deliver arms, munitions, or medical supplies to defending Taiwanese units on the shores of Taiwan. Another possible Taiwan scenario, a full blockade of Taiwan by the PRC, as shown in Figure 7, may benefit from the use of ULPVs to transport supplies through the blockade. This might be accomplished by using a ULPV’s low signature to sneak through undetected or by using so many ULPVs that targeting and interdicting all vessels becomes exceedingly difficult.

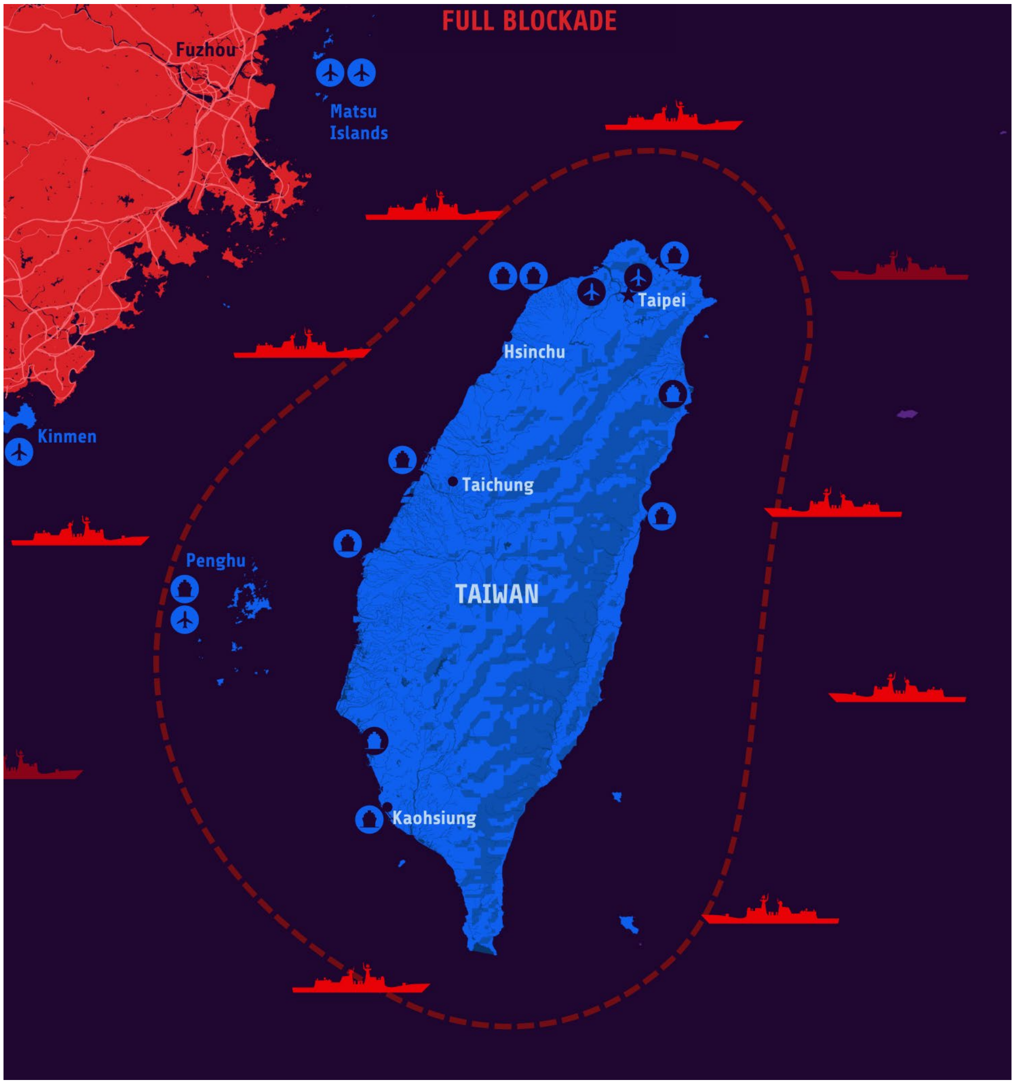


Figure 7. Possible Unmanned Low-Profile Vessel Supporting Operation: Taiwan Blockade by People's Republic of China. Source: Lague & Murray (2021).

In a conflict in the Indo-Pacific, forward operating forces will likely require sustainment to maintain a level of supply to maintain combat capability, with needs ranging from the warfighter's personal needs of food, fresh water, and personal equipment to a weapon system's needs for fuel, bombs, missiles, and repair parts. Marines operating on expeditionary advanced bases (EABs) as well as Airmen operating from forward bases under ACE could utilize ULPVs to deliver the various classes of supply required for their operations. USMC LtCol Donlon (2023) outlines the underpinning criticality of logistical capabilities for concepts like stand-in-forces (SIF) and EABO to succeed and make Force Design 2030 viable. Special operations forces (SOF) units, too, could benefit from ULPV supply deliveries and SOF units may be especially suited for support by ULPVs if a ULPV's design constrains its cargo carrying capacity to a smaller quantity than ideal for conventional units, but perhaps better suited to support SOF. A ULPV's smaller detectable signature, assuming its design maintains the difficult-to-detect characteristics of DTO LPVs, would also lend credibility to supporting SOF, which typically take great effort to minimize their own detectable signatures.

The role of decoys may be another operational role for ULPVs, though not the focus of this research effort. A ULPV intended to act as a decoy might have a design that allows it to change its detectable signature, thereby appearing as something that it is not. In the context of contested logistics, a ULPV might use means to appear a recreational vessel, much like some DTO LPVs that have disguised as recreational craft (Sutton, H I., 2021a).

B. CONCEPTS OF EMPLOYMENT

1. Swarms

One often mentioned concept of employment for unmanned systems is the idea of a "swarm," or the employment of many unmanned systems to collaborate towards a common goal, often with the intent to overwhelm the adversary by the sheer number of unmanned systems employed in the swarm. The swarm concept of employment (CONEMP) inherently assumes that the unmanned system is very low-cost, and therefore, possible to be employed in large numbers, often with an assumption that many of the unmanned systems will be lost during mission execution. In other words, a ULPV will need to be so low cost that it is considered attritable, as in reusable but expendable, to be realistically considered for use in a swarm CONEMP. Figure 8, from a Naval Postgraduate School presentation in the IS3460 course on Networked Autonomous and Unmanned Systems in 2023, shows an operational view 1 (OV-1) of a theoretical swarm of ULPVs attempting to deliver supplies through a PRC blockade of Taiwan. In the figure, two swarms of ULPVs originate from two general areas in the Indo-Pacific, a U.S. theater logistics hub and partner nations.

Figure 8. Unmanned Low-Profile Vessel Swarm Concept of Employment. Source: Bacaltos et al. (2023).

Assuming an attritable ULPV design, a swarm of ULPVs may only have a certain number of ULPVs loaded with supplies, with the remaining empty and serving as decoy targets.

2. Loitering Logistics: "Logistics on Demand"

ULPVs might also support expeditionary operations by transporting various sustainment supplies most of the distance across the theater but stopping just short of the intended destination and awaiting final tasking, or "summoning," by the supported unit for the delivery of supplies. In the likely event that supply consumption at an expeditionary base is not exactly as anticipated, a supported unit may desire to request additional ULPV resupply support, sooner than originally anticipated. Conversely, a supported unit may desire to delay ULPV resupply support. In either case, the ability for a ULPV to loiter relatively near the supported unit and receive an updated tasking to adjust resupply timing may be very useful for expeditionary operations. One risk with this approach, however, may result from increasing the amount of time that a supply-laden ULPV spends in the contested environment. This time spent loitering essentially increases the amount of time a ULPV spends in transit, thereby increasing the opportunities that may occur for it to be detected and ultimately interdicted or attacked. Design consideration must also be given to a ULPV to carry enough fuel to ensure it can loiter long enough to support this employment method. The "Logistics on Demand" employment method is credited to a USMC officer serving at U.S. Marine Forces, Pacific (MARFORPAC) (Anonymous, personal communication, February 2023).

3. Supply Cache Positioning

USMC (2023c) calls out both the ashore and afloat prepositioning of supplies as critical to improve expeditionary readiness and enable regenerative combat power. ULPVs could support logistics prepositioning by either:

1. Supporting the sustainment of supply levels at an ashore or afloat prepositioning location by delivering supplies to these locations.
2. Acting as a type of afloat prepositioned supply cache by arriving to a desired preposition supply location and dropping anchor, running aground, or submerging (either the vessel entirely or just the supplies that would presumably be prepared for undersea storage as a subsurface supply cache).

A ULPV designated to support supply cache prepositioning as described in the latter manner likely requires various design considerations that would not be necessary for a ULPV only intended to support supply cache prepositioning as described in the former manner.

4. Surface Vessel Resupply (Unmanned Low-Profile Vessel Resupply Tracks)

USAF aerial refueling typically takes place along a preestablished, coordinated air refueling track where the tanker flies a racetrack pattern within a defined airspace while waiting for receiving aircraft to arrive and receive fuel (United States Air Force [USAF], 2019). A ULPV or several ULPVs could also operate under pre-established resupply tracks where surface vessels or embarked helicopters (helos) could rendezvous to onload needed supplies from waiting ULPVs. One consideration for this CONEMP, however, is that ULPV cruise speed is likely to be much slower than that of large combatant ships of the USN. DTO LPVs, for example, typically operate at or below 10 knots (kts) (Ramirez &

Bunker, 2015). If ULPV resupply tracks exist within the WEZ of PRC anti-ship missile systems, it is presumable that U.S. Navy vessels will not risk operating at such slow speeds, as doing so would increase the vessel's time spent inside the adversary WEZ, thereby increasing risk to their survivability. In this case, a USN vessel with an embarked helo may be best suited to retrieve supplies from a ULPV resupply track, assuming the ULPV is designed in a manner which allows a helo to approach and lift supply from the vessel, perhaps by way of topside accessible hatches on the ULPV that can open to reveal containers ready for helo rigging. The faster helo could retrieve the supplies from the ULPV resupply track and return them to the ship, all while the ship continues its normal course and speed. This CONEMP is illustrated in Figure 9.

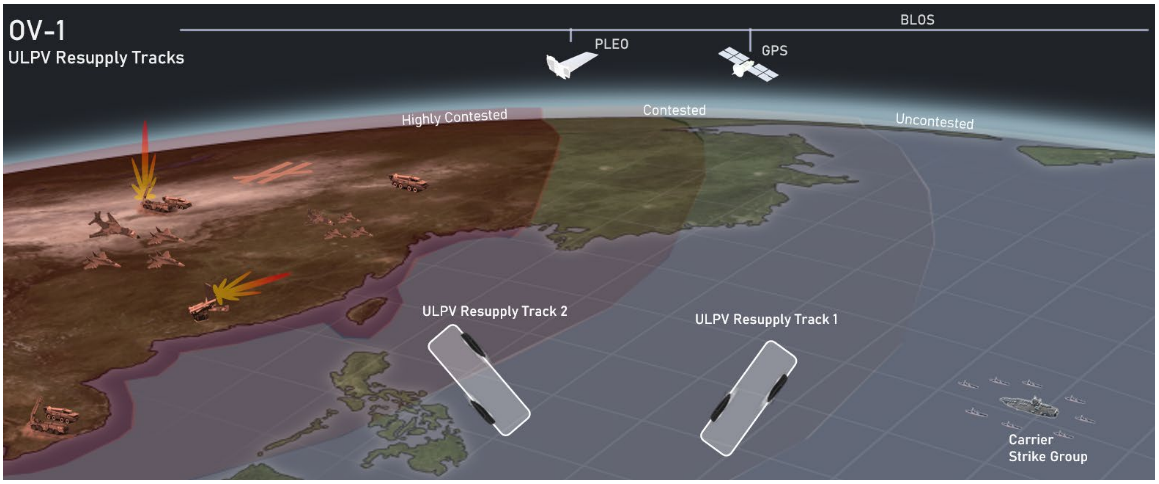


Figure 9. Unmanned Low-Profile Vessel Resupply Track Concept of Employment. Source: Bacaltos et al. (2023).

5. Steady Flow

One other method of ULPV employment may be the simplest, which is called here, steady flow. Steady flow employment assumes the most basic operating logic of a ULPV where it operates with a mission to transit to a destination and deliver its cargo, regardless of the needs of the supported unit at the destination. This method might be analogous to a subscription service for a product that arrives weekly to a user's door and does not stop delivery just because the user is not necessarily ready for the next delivery and does not deliver early just because the user needs another delivery sooner than expected. The steady flow CONEMP requires the least amount of communication to and from a ULPV due to the assumption that the ULPV will not be re-tasked mid-journey. This CONEMP may have advantages to reducing a ULPV's electromagnetic (EM) signature by reducing the amount of time the ULPV transmits data to any logistics command and control (C2) function. The simplicity of this CONEMP may also reduce system requirements in ULPV design, given the reduced need for external communications and connectivity, thereby reducing vessel cost. However, this CONEMP risks inadequate or surplus supply levels at the supported unit. This CONEMP may also increase the risk of wasted supply or harm to supported units if mid-route tasking updates are not available to redirect supplies to meet changing needs among supported units.

6. Supply Composition Consideration: Tailored vs. Generalized Packages

While various concepts exist for ULPV employment, the types and quantities of supplies that compose a ULPV's cargo should be considered with the recipient in mind. If a ULPV is to be employed in a manner that ensures its cargo will be delivered to a specific unit or a specific type of unit, then the types and quantities of supplies it carries to that unit can be tailored to the needs of that supported unit. For example, if a fires EAB is dangerously low on missile stock for its weapon systems, ULPVs dispatched to resupply the unit might carry only missiles. However, if the intended CONEMP for ULPVs is that of "loitering logistics," for example, the composition of the ULPV's cargo might be a general mix of all supply categories so that the ULPV may deliver supply of use to whichever nearby supported unit requests a resupply. Alternatively, "loitering logistics" could be accomplished with many ULPVs, each carrying a type of cargo composition, where a request for resupply by a nearby supported unit might summon one or multiple ULPVs whose combined cargos sum to meet the need of the supported unit. It should be noted, however, that any CONEMP requiring coordination between ULPVs, especially differentiating which ULPVs have which cargo composition, and accurately coordinating the actions of multiple ULPVs will require a greater level of C2 between ULPVs and the supported unit, presumably increasing the complexity of ULPV design.

C. GETTING AN UNMANNED LOW-PROFILE VESSEL TO THEATER

If the need for new materiel solutions suited for contested logistics exists on the premise that existing fielded logistics vessels are not survivable in the contested environment, then the value of a ULPV over currently fielded logistics vessels begins where those fielded vessels become vulnerable to threats of the contested environment. That said, for the basis of this research, the maximum range of the PRC DF-26B is used as the border that separates the permissive environment (where traditional logistics vessels can operate) from the contested environment (where ULPVs are envisioned to operate). Of course, a ULPV could operate outside of a contested environment, but its design may be optimized to perform within the shorter distances and unique demands of intra-theater logistics within the contested environment of the Indo-Pacific. Surely, a ULPV could be designed with enough fuel capacity to be capable of transit from the coast of California to the first island chain, effectively completing both inter-theater and intra-theater logistics. Increasing fuel capacity, however, leads to a higher vessel weight which in turn requires more power to maintain speed, resulting in a potentially much larger vessel (J. Didoszak, personal communication, August 28, 2024). There are likely more efficient manners to move supplies across most of the Pacific Ocean for inter-theater logistics, up until the point where the environment becomes contested, and when ULPVs can then receive the supplies for intra-theater logistics transportation. This line of thinking ultimately results in the presumption that ULPVs will be designed for intra-theater logistics and concepts will need to be explored for getting ULPVs to the theater of the Indo-Pacific, where they can be used in their unique role of supporting contested logistics. In addition, considering ULPV operations as originating from the edge of the DF-26B WEZ increases analysis on more demanding transit distances for ULPV operations in the Indo-Pacific, compared to transits which assume intra-theater logistics launching from established places at shorter transit distances to the first island chain, such as from Guam, Palau, the Philippines, or Japan.

1. Motherships

One advantage of focusing the analysis of ULPV transit distances to the maximum range of the DF-26B enables the idea of larger vessels (motherships), possibly with heavy lift capability, to be utilized for transporting a ULPV into theater. Motherships are assumed to be large enough to act as the "parent" vessel, capable of carrying a "child" or "children," which are multiple smaller vessels such as ULPVs and/ or other vessels to the edge of an A2/AD area. Prior to entering the A2/AD area, also considered the contested area, the mothership would stop, and the smaller vessels would disembark from the mothership to begin their mission(s). While a mothership is generally assumed to be quite large, perhaps on the order of thousands of tons, it is possible that a mothership may only need to be just slightly larger than the child it carries, using its own fuel and propulsion system to bring its carried ULPV(s) to the launch point, thereby conserving a ULPV or other vessel's fuel. Figure 10 depicts one example of a very large mothership capable of carrying and launching several smaller vessels. The larger, red deck vessel in Figure 10 is utilizing a ballast system to lower itself in the ocean for launching its carried vessels.

Figure 10. Mothership Example. Source: Alexander et al. (2019).

The mothership concept might also make use of shipping containers if ULPVs fit into shipping containers, either as fully built vessels or as prefabricated pieces requiring some final assembly. A ULPV capable of transit within shipping containers may enable the DoD to utilize commercial shipping vessels designed to handle shipping containers for the inter-theater transport of ULPVs, as a means for transporting ULPVs to the edge of a contested environment. Figure 11 shows a concept unmanned vessel capable of fitting inside a shipping container for transportation into theater.

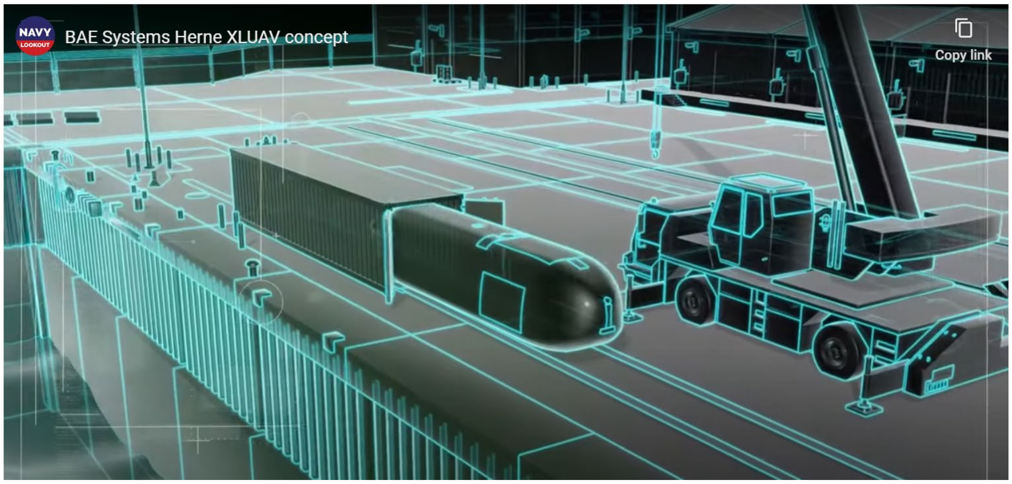


Figure 11. BAE Systems Herne Transportation within Shipping Container. Source: Navy Lookout (2023).

A ULPV made up of pieces spread between a few shipping containers might undergo final assembly onboard a vessel carrying containers of ULPVs, and then lower the completed vessel into the ocean to begin its mission. If the supplies intended for the ULPV to carry are also located onboard this vessel, the ULPV could undergo final assembly, be loaded with its supply payload, be lowered into the water, and then begin its mission; all from the same mothership. If the ULPV fits within a shipping container fully assembled, then the same could be accomplished on the mothership but without the need for any final ULPV assembly prior to supply loading, lowering, and launch. Designing a vessel within the dimensions of a shipping container can have advantages for transportation and concealment, as shown in Figure 12, which shows the concealment of drug-trafficking vessels within semi-trailers for transportation.

Figure 12. Covered Truck Transport of Drug Trafficking Organization Vessels. Source: The Mob Reporter (2021).

2. Full Build in Theater (Build from Scratch)

Just as DTOs build their LPVs in the jungles of South America, it may be advantageous for ULPVs to be built within the Indo-Pacific. Building ULPVs in theater would likely decrease the distance needed for a ULPV to transit and provide intra-theater logistics support to expeditionary units. Decreased transit distances for ULPVs would result in shorter times required to reach destinations and return for a new load of supply and new tasking. A shorter time required for ULPV mission completion likely means that each ULPV will be able to complete more resupply missions over any given period, resulting in fewer total operating ULPVs required to maintain desired supply levels at expeditionary bases in the Indo-Pacific. Fewer required ULPVs results in cost savings from less vessels necessary for theater sustainment operations. Building ULPVs in theater may also decrease overall logistics operational costs by means of fuel savings from shorter transit distances to and from expeditionary bases. As one example, ULPVs may be built at several locations throughout the Philippines, such as at bases depicted in Figure 13.


US forces will have access to 9 bases

STRAITS TIMES GRAPHICS

Figure 13. Philippine Bases with Planned United States Access. Source: Cepeda (2023).

3. Prefabrication Kits (Finish a Partially Completed Vessel)

Like a full build in theater, a prefabrication kit of a partially completed ULPV that is delivered to a location in theater may enable final assembly to occur in locations with little to no need for infrastructure, skilled labor, or specialized tools. Surely, the degree to which any of those aspects are required for final assembly would depend on the ULPV design and what is required for final assembly. As mentioned in the mothership section above, prefabricated sections of a ULPV could be delivered in shipping containers, along with whatever tools, materials, and instructions are required to complete final assembly. In theory, prefabrication kits could enable final assembly of ULPVs wherever enough labor and space exist to complete final assembly, such as on large ships near the Indo-Pacific or on partner nation land. ULPVs in prefabricated kits might even undergo final assembled in the large hangar spaces of aircraft carriers (L. Banchs, personal communication, May 7, 2024) or the large spaces of an expeditionary sea base (ESB) ship (United States Navy [USN], 2024). Figure 14 shows the large spaces on an ESB that could be leveraged for forward final assembly of prefabricated ULPV kits. These kits might hold key components for the ULPV, such as its engines, control systems, and communications systems to install in a hull (J. Didoszak, personal communication, September 3, 2024), or these kits may contain entirely completed sections of a ULPV that simply require final connecting, fastening, or welding, as well as wiring prior to being ready to disembark.

Figure 14. Side Aspect of an Expeditionary Sea Base Ship. Source: United States Navy (2024).

4. End-to-End Design (Self Deliverable)

A ULPV that can launch in any body of water and complete transit over the inter-theater transit distance would be considered a ULPV that is self-deliverable, or an end-to-end design. A ULPV capable of self-delivery to the theater may need to be designed for larger fuel capacities and it should be considered the relatively low transit speeds that ULPVs may operate at, lengthening the time required for ULPV arrival in theater.

5. Air Delivery

One option to bring a ULPV to the theater might be to use a military cargo aircraft or helo. Hypothetically, depending on the ULPV size and weight, a C-130, C-17, or C-5 might be able to transport a ULPV to the edge of the contested area and deliver the ULPV directly into the water (Figure 15). Similarly, a ULPV might be delivered to the contested area by a helo sling load or other carrying device.

Figure 15. Airdropping Unmanned Vessels by Military Cargo Aircraft. Source: Staff (2024).

Air delivery may be infeasible, however, because LPVs tend to be very heavy—a characteristic that contributes to their typically minimal freeboard. For example, the ULPV concept by CDR Todd Greene, NightTrain (Greene, 2023), is estimated to weigh 90–100 long tons (LT) (180,000–200,000 lbs) before including the weight of cargo (T. Greene, personal communication, August 9, 2024). An already heavy ULPV, when laden with supplies, would presumably be very heavy. A C-130 is capable of airdropping loads up to 42,000 lbs (USAF, n.d.). The C-17 has successfully airdropped a payload as heavy as 77,000 lbs (Thuloweit, 2010). The much larger C-5 can airdrop up to 60,000 lbs per drop, with one recorded C-5 airdrop consisting of four tanks and many troops for a combined total airdrop weight of 190,493 lbs (Aviation Zone, 2022). Of note, in the case of the 77,000 lbs payload airdropped from a C-17, a specialized, larger set of parachutes was used

(Thuloweit, 2010). Any ULPV approaching this amount of weight may need its own specialized parachutes rated for handling an airdrop load that may exceed more widely used airdrop systems designed for lesser loads.

Air delivery of a ULPV by a helo would be limited to a ULPV weighing under 36,000 lbs, the maximum external lift capacity for the CH-53K (Fair Lifts, 2024). However, it should be noted that a CH-53 carrying near the limit of its external carrying capacity results in a carrying range limited to 50 mi before the helo must return to base (Naval Air Systems Command [NAVAIR], n.d.). Utilizing helos to carry ULPVs along the journey in 50 mi segments is theoretically possible, assuming enough CH-53 helos are available and staged in a manner to conduct such "leapfrogging," but the practice may be an inefficient use of resources.

6. Towed Delivery

Towing a ULPV behind another vessel to transport the ULPV is another possible method to get a ULPV to the Indo-Pacific. This is similar in a sense to the manner which DTOs use for some "narco torpedos" that are towed underwater and behind vessels that appear like vessels engaged in standard unsuspicious activity like fishing (Bunker & Ramirez, 2015). It may be possible for multiple ULPVs to be towed in series, one behind the other, to complete the inter-theater transit of the vessels. However, a vessel being towed, or a series of vessels being towed, would likely introduce a lot of hydrodynamic drag and require much stronger engines on the lead vessel conducting the towing (J. Didoszak, personal communication, September 3, 2024).

7. Prepositioned Unmanned Low-Profile Vessels

Prepositioning ULPVs may reduce the challenges of getting ULPVs into theater during conflict by ensuring that ULPVs are within theater in advance of conflict. If ULPVs have low operating speeds, decreasing their transit distance to resupply expeditionary units by prepositioning in theater negates a need to transit from Hawaii, CONUS, or other locations outside the Indo-Pacific. Brutzman et al. (2024) found various locations for ULPV prepositioning in the Indo-Pacific, all within various PRC WEZs, as depicted in Figure 16. According to USN LCDR David Hamilton, prepositioned ULPVs may be fully built, operational vessels or prefabricated kits requiring final assembly or integration and these ULPVs may be staged in or at warehouses, factories, pier facilities, or docks (Brutzman et al., 2024).

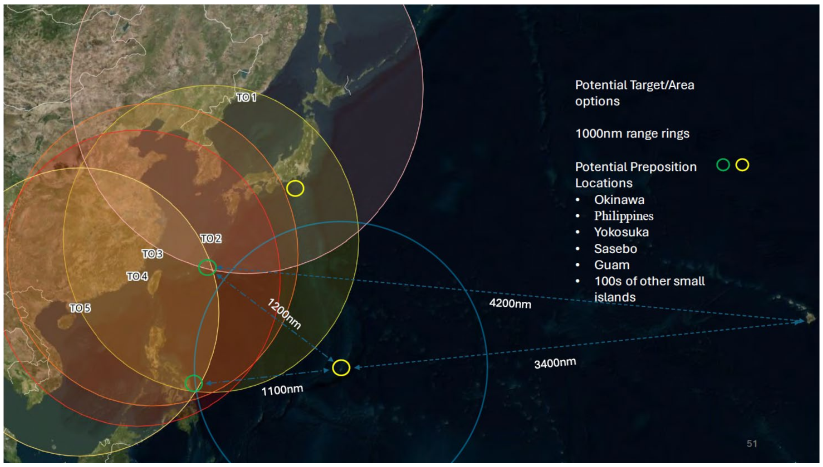
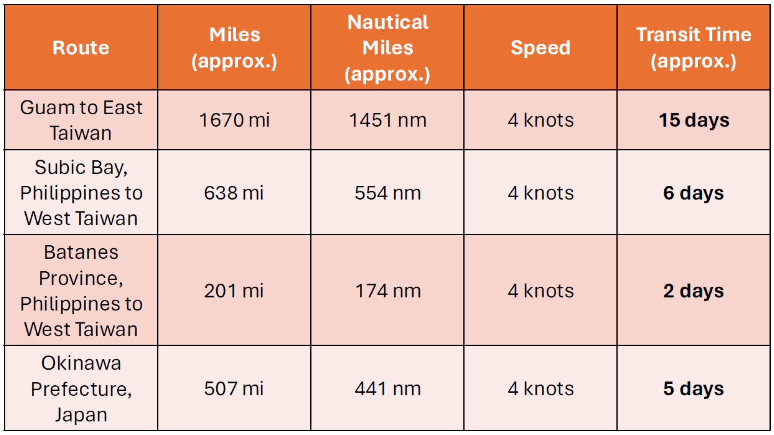


Figure 16. Prepositioned Unmanned Low-Profile Vessels Map. Source: Brutzman et al. (2024).

LCDR Hamilton calculated approximate transit times between some locations relevant to prepositioned stocks, assuming a ULPV operational speed of 4 kts, and those calculations are in Figure 17.



Route	Miles (approx.)	Nautical Miles (approx.)	Speed	Transit Time (approx.)
Guam to East Taiwan	1670 mi	1451 nm	4 knots	**15 days**
Subic Bay, Philippines to West Taiwan	638 mi	554 nm	4 knots	**6 days**
Batanes Province, Philippines to West Taiwan	201 mi	174 nm	4 knots	**2 days**
Okinawa Prefecture, Japan	507 mi	441 nm	4 knots	**5 days**

Figure 17. Unmanned Low-Profile Vessel Prepositioned Stock Points of Interest: Transit Distances and Times (4 Knots Speed). Source: Brutzman et al. (2024).

V. UNMANNED LOW-PROFILE VESSEL DESIGN CONSIDERATIONS

Parts of section A and B of this chapter were previously published by the Acquisition Research Program at NPS (Sierra, 2024).

A. SEAKEEPING: FROM THE HIGH SEAS TO THE "LAST TACTICAL MILE"

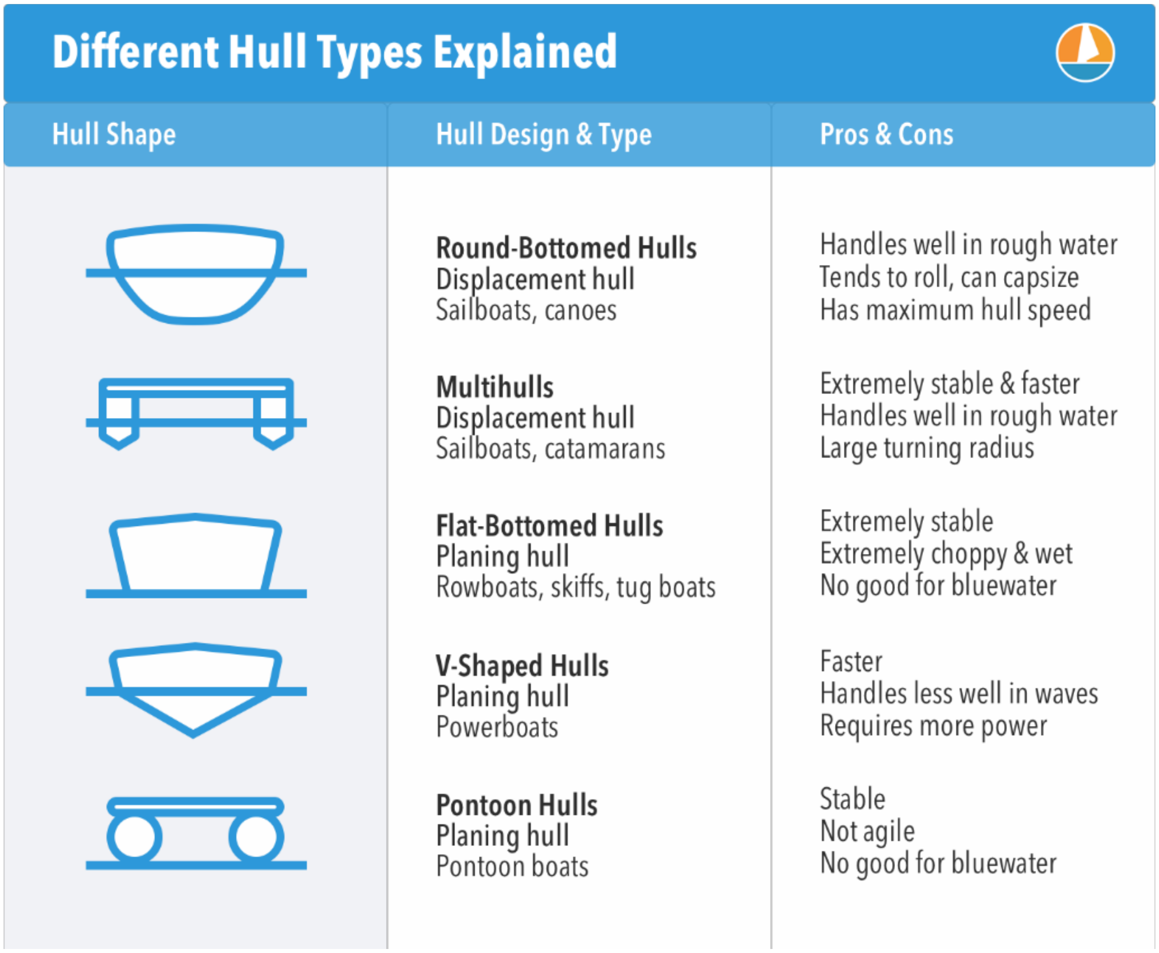
LPVs are immersed more than standard surface vessels, however, maintaining a minimal freeboard and proximity to the free-surface allows LPVs to use low-cost combustion engines while also negating the need for costly pressure vessels, submarine control surfaces, and other mechanisms necessary for a vessel that operates fully submerged (Sung et al., 2022). Initial analysis indicates that LPVs have increased stability with more slender hull shapes (Sung et al., 2022) and a review of DTO LPVs shows a trend toward increasingly slender vessels over time (Sutton, 2020).

It is important to consider the differences in sea conditions, or sea states, that exist between the waters where DTOs operate versus the waters of the Indo-Pacific. As there is little to no data on how LPVs would perform in the sea states of the Indo-Pacific, some initial research has been done on semi-submersible vessels (SSVs) which can be applied to LPVs. Initial research at the United States. Naval Academy (USNA) indicates that LPV hydrodynamic performance would be very sensitive to the forces of surface waves and that more extensive testing is needed (Sung et al., 2023). Further findings include increased resistance, due to increased hydrodynamic drag, experienced with a hull operating more immersed (Sung et al., 2023), likely equating to a need for greater power requirements than traditional surface vessels to attain a similar operating speed.

One of the greatest challenges to design ULPVs for contested logistics in the Indo-Pacific is choice of hull shape. This is due to the wide range of environmental conditions that a ULPV should expect to encounter. Just as narco-subs are purpose built to serve a specific mission in a specific threat environment, ULPVs intended to support the contested logistics mission should be designed to meet the needs of that specific mission and threat environment of the expected operational area. It is assumed that ULPVs will need to transit vast distances of deep, open ocean, also referred to as the “high seas” or “blue water.” In addition, it is assumed that ULPVs, either directly or by interaction with another asset, will need to land supplies on a beach for receipt by an expeditionary unit. The task of completing beach landings and bringing supplies from offshore vessels, known as ship-to-shore operations, is typically completed by shallow draft (often flat bottomed) vessels called “connectors.” Transiting this so called last tactical mile involves navigating shallow surf zones, often characterized in the Indo-Pacific by varying beach gradients, the presence of rocks, coral, sand bars, and lava beds. The last tactical mile may also include strong currents and changing tides.

With each U.S. military service planning for expeditionary operations in the Indo-Pacific, the ability of ULPVs to sustain expeditionary forces will depend on a ULPV designed to support the unique requirements of expeditionary operations. According to USMC (2018) MCDP 3, the term “expeditionary” implies austere conditions and support, often with limited infrastructure, partly due to the temporary nature of expeditionary operations (pp. 2-9). Limited infrastructure at the destination for ULPV loading or unloading should be assumed and accounted for in ULPV design.

A vessel’s hull shape is chosen based on the environment the vessel is intended to operate in. In addition, the amount of cargo to be carried, the required vessel speed, and stability of the vessel are considerations that contribute to hull shape choice (J. Didoszak, personal communication, September 3, 2024). There are generally five types of boat hulls, each with its own advantages and disadvantages, depicted in Figure 17. The challenge with designing a ULPV that is capable of seakeeping in the waters of both the “high seas” as well as the “last tactical mile,” two very different environments that generally require different hull types optimized for one or the other. If a ULPV is intended to conduct beach landings, for example, it will likely require a capability to decrease its draft to a minimal acceptable level for beach landings, while also being capable of maintaining acceptable seakeeping while in transit over parts of ocean with much greater depth and different environmental considerations. Of note however, as a vessel’s draft is reduced, the risk of capsizing can increase.



Different Hull Types Explained

Hull Shape	Hull Design & Type	Pros & Cons
	Round-Bottomed Hulls Displacement hull Sailboats, canoes	Handles well in rough water Tends to roll, can capsize Has maximum hull speed
	Multihulls Displacement hull Sailboats, catamarans	Extremely stable & faster Handles well in rough water Large turning radius
	Flat-Bottomed Hulls Planing hull Rowboats, skiffs, tug boats	Extremely stable Extremely choppy & wet No good for bluewater
	V-Shaped Hulls Planing hull Powerboats	Faster Handles less well in waves Requires more power
	Pontoon Hulls Planing hull Pontoon boats	Stable Not agile No good for bluewater

Figure 18. Hull Types, Pros, and Cons Overview. Source: Buckles (n.d.).

According to the USMC (2023d) manual for EABO, in reference to the Medium Landing Ship (LSM), shallow draft and beaching capabilities are keys to providing the volume and agility to maneuver required capabilities to key maritime terrain (pp. 6–16). The use of a ballast system to raise or lower a ULPV's draft depending on the environment may be an appropriate design approach to account for some of this challenge, albeit, at the additional cost of incorporating the components and ballast tanks required for an active ballast system. One example of a fielded operational vessel with hull design elements and a ballast system that may be worth consideration for ULPV is the SEALION, employed by United States Special Forces Command (USSOCOM) (Sutton, 2017). Figure 19 provides a simplified cutaway of the SEALION hull and ballast system, which allows the vessel to change its freeboard and draft to meet mission requirements.

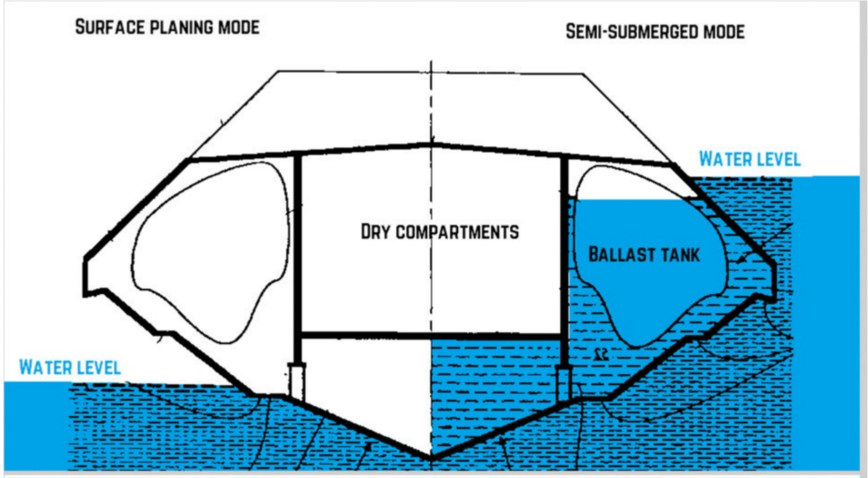


Figure 19. Cutaway of SEALION Semi-Submersible Vessel. Source: Sutton (2017).

Currently, many DTO LPVs typically utilize a type of displacement hull. For a good example of DTO LPV hull shape, see Figure 43, which shows the deep draft displacement hull typical of DTO LPVs that sit low in the water with minimal freeboard (Toledano, 2023). Displacement hulls lie in the water instead of on top of it and are well suited to handle rough ocean conditions (Buckles, n.d.). Displacement hulls are generally very heavy, with the weight adding stability assuming that the weight is in a low part of the vessel, thus lowering the center of gravity. These hulls do not need a lot of power to propel, are generally fuel efficient, and are great for carrying cargo (Buckles, n.d.). One negative aspect concerning displacement hulls, however, is their tendency to roll, increasing the risk of capsizing. One method to reduce roll and capsize risk involves adding a keel. Adding a keel, however, increases the depth of the vessel's draft. Increasing a vessel's draft is no concern for DTO LPVs that load and unload their cargo pier side or at sea (VICE, 2011). However, for a ULPV needing to navigate the hazards of the last tactical mile, a deep draft hull may result in the vessel running aground or striking an obstacle before reaching the beach where, for example, U.S. Marines may stand ready to receive a delivery of any number of critical supplies like food, water, munitions, of fuel. A displacement hull is naturally partially submerged (Buckles, n.d.) and a ULPV utilizing this sort of hull presumably be designed so that most of the hull is submerged to reduce vessel freeboard, up to the point of operating awash.

B. CHOICE OF VESSEL MATERIAL

In addition to hydrodynamic considerations, most of which requiring further research for DoD adoption of SSVs (and LPVs) (Sung et al., 2023), LPV design should also consider the material choice for fabrication as well as the complexity of the vessel design. As previously discussed, drug trafficking LPVs are typically made of wood and fiberglass. These materials are more affordable and easier to build with compared to metal, requiring less skilled labor or specialized machinery. In addition, these materials are harder to detect with radar than metal. In the context of military conflict, these materials may be advantageous to help defeat threats that ULPVs encounter in the waters of the Indo-Pacific. Maintaining a vessel design that is simple and with as few extra features or building steps as possible will allow the DoD to follow the DTO LPV model of minimal cost, thereby driving towards a design that is both affordable and able to be rapidly built, increasing the chance of the ULPV being considered attritable.

Material choice plays a role in ULPV susceptibility. One aspect of ULPV susceptibility is related to its infrared (IR) signature. The magnitude of the contributing part of a ULPV's IR signature that comes from solar radiation reflected off the vessel's body can be informed by consulting the emissivity of various material. Emissivity is a measure of the efficiency in which a surface emits thermal energy (ThermoWorks, n.d.). Table 2 shows the emissivity of some materials, where a material with an emissivity value of 0 is considered a perfect thermal mirror (ThermoWorks, n.d.). Therefore, a material with a lower value would result in a lower contribution to an IR signature.

Table 2. Infrared Emissivity Table. Adapted from (ThermoWorks, n.d.).

Material	Emissivity Value
Aluminum: polished	0.05
Steel: rolled freshly	0.24
Steel: galvanized	0.28
Stainless plate	0.34
Stainless steel	0.59
Fiberglass	0.75

Material	Emissivity Value
Aluminum: anodized	0.77
Plywood: commercial, smooth finish, dry	0.82
Plywood: untreated	0.83
Plywood	0.83–0.98
Rubber	0.95
Water: distilled	0.95

The materials listed in Table 2 with low emissivity values may have large contributions to reduce RCS and material choice should consider all contributions to a vessel's signature. Material choice will also impact the ULPV's RCS as some materials reflect energy more naturally than others (D. Jenn, personal communication, May 20, 2024). ULPV design should account for the relative permittivity value of the vessel materials and their expected impact to ULPV RCS against the frequency range(s) of radar systems most likely to be used to find or track ULPVs. More information on ULPV susceptibility can be found in Chapter VII. Unmanned Low-Profile Vessel Susceptibility.

C. LOADING AND UNLOADING

ULPV design should keep in mind how the vessel is intended to be loaded, unloaded, and interfaced with by people and other vessels or equipment. For a vessel with the primary mission of transporting supply for logistics, it is paramount that the vessel be designed with the operational environment in mind. For example, if the ULPV needs to resupply Marines operating on EABs in the Indo-Pacific, and the island EAB location does not have a pier, then it should be considered if the ULPV needs to be able to beach, or if the Marines will have to retrieve the supply by other means. If the ULPV needs to be able to beach, it must be able to make its way through the shallow, and often reef and rock strewn, water of islands in the Indo-Pacific. This requires a vessel with a shallow draft, a hull attribute poorly suited for transiting rough sea states over large distances. DTO LPVs do not have a shallow draft hull. Then again, DTO LPVs typically load and unload at sea or pier side. It should be considered how supply will be loaded on and off the ULPV, either by crane, roll-on/roll-off (RORO), manually by hand, or otherwise.

This study assumes five destinations that ULPVs may be expected to load or unload their supplies at. This study also assumes six primary means for loading or unloading supplies from a ULPV. Table 3 summarizes the assumed compatibility of each method at each destination.

Table 3. General Methods for Supply Loading and Unloading by Destination

		Load/Unload Methods					
		RORO	Crane	Winch	Manual	Helo	Deployable Cargo**
Load/Unload Destinations	Austere Beach	Y	N	Y	Y	Y	Y
	Pier	Y	Y	Y	Y	Y	Y
	Well Deck	Y	Y	Y	Y	N	Y
	Alongside Vessel	N*	Y	N*	Y	Y	Y
	IVO Vessel	N	N	Y	N	Y	Y

*Unless alongside lighter.
**Deployable Cargo is a concept for ULPV cargo interface at the load/unload destinations and requires the use of at least one other load/unload method for supplies to reach the end user.
IVO: In vicinity of

1. Load/Unload Destinations

a. Austere Beach

An austere beach is defined as a beach with no existing infrastructure to support loading or unloading vessels. The approach to an austere beach from the sea includes shallow waters with multiple obstacles such as rocks and coral, limiting landing to shallow draft vessels, perhaps only during certain times of the day when tide levels permit beach landing.

A ULPV may be designed to land on a beach like a traditional landing craft, with its deck remaining level when connected to the beach. Another option may be for a ULPV that is designed to land in a manner such as the beached DTO LPVs in Figures 20 and 21.

This design may be of interest if the ULPV hull is designed for the high seas, yet its draft is shallow enough to make it to the beach (perhaps during high tide). This design may also be of interest if the vessel cost is intended to be as low as possible and/or the ULPV is designed for single use. Extraction of supply from the beached ULPV laying on its side or upright might occur manually through a hatch, or by means of removing a panel or cutting through designated points in the hull to reveal an area designed for supply offload.

Figure 20. Leaning Beached Drug Trafficking Organization Low-Profile Vessel. Source: Ramirez & Bunker (2015).

Figure 21. Upright Beached Drug Trafficking Organization Low-Profile Vessel. Source: Muñoz (2011).

b. Pier

A pier is defined as a large stable surface running from the land over the sea to some distance from land that provides adequate depth and protection to prevent docking vessels running aground. A pier is assumed to have at least one crane capable of conducting loading and unloading of a vessel.

c. Well Deck

A well deck is defined as the area aft of some ships that can flood with water for the launch and recovery of smaller vessels.

d. Alongside Vessel

Loading or unloading alongside vessel is defined as two vessels oriented in parallel to each other, close enough to move trade supply by means of pulley systems or hoses, and either stationary or in motion at the same speed and heading, such as in the case of underway replenishment (UNREP).

e. In Vicinity of Vessel

Loading or unloading IVO vessel is defined as vessels that are not operating in a manner or in close enough proximity to trade supply by means of a pulley system or hoses but are still near enough to trade supply with each other by rotary aircraft or lighter vessel.

2. Load/Unload Methods

a. Roll-On/Roll-Off

RORO is defined as the ability for supply to slide or roll on and off the ULPV and the destination surface. This may be possible with a ULPV that utilizes a deep cargo storage area below the free surface if the ULPV has its own means of lifting cargo to a higher point of the vessel that is capable of RORO loading and unloading. The RORO method is an assumed compatible loading and unloading method at austere beaches, piers, and well decks. However, the RORO method is assumed only possible with an alongside vessel if that vessel operates at a level of similar freeboard, such as in the case with a lighter vessel. Figure 22 illustrates one concept ULPV, the Marine Operations Logistics Asset (MOLA), which featured retractable ramps on the bow that would allow supply containers to be rolled to or from the vessel and lowered or lifted inside the vessel's scissor lift system (Alexander et al., 2019).

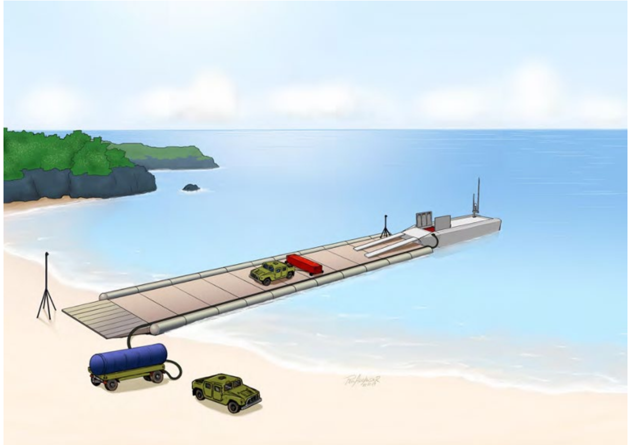


Figure 22. Roll-On/Roll Off Load/Unload. Source: Alexander et al. (2019).

b. Crane

A crane (Figure 23) is defined as a mechanical system mounted to a ship, pier, or inside a well deck for the purpose of moving supply in and out of a vessel like a ULPV. It is assumed that an austere beach will not have a crane available for supply loading and unloading.

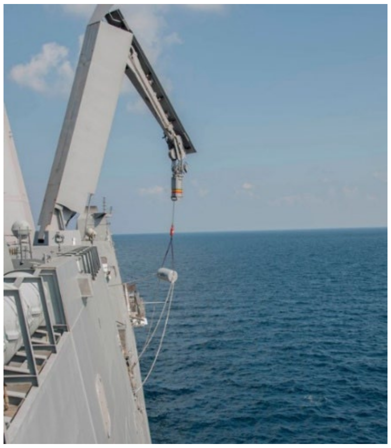


Figure 23. Crane Load/Unload. Source: Reynolds (2015).

c. Winch

A winch (Figure 24) is defined as a mechanical system mounted to a vehicle, vessel, or rotary aircraft to load or unload supply. It is assumed that a vehicle mounted, or portable winch, will be available to personnel on an austere beach. It is assumed that a winch is only available in an alongside vessel loading/unloading scenario in the vessel has similar freeboard to that of a ULPV, such as a lighter vessel.

Figure 24. Winch Load/Unload. Source: OpenAI (2024).

d. Helicopter

A helo (Figure 25) is a rotary wing aircraft that can move supplies by lifting supplies at the origin, carrying them below the helo, and lowering them at the destination. A helo may use any number of systems to move supplies such as winches, hooks, fasteners, etc.

Figure 25. Helicopter Load/Unload. Source: Greene (2023).

e. Manual

Manual loading and unloading (Figure 26) are defined as the use of physical lifting and moving supplies by personnel and hand carried equipment. Manual loading and unloading also encompasses the use of hoses that run from one vessel to another to move fluids such as water or fuel.

Figure 26. Manual Load/Unload. Source: DeFilippis (2008).

3. Prospective Design: Deployable Cargo

Deployable cargo refers to the ability of a vessel to move its carried cargo by its own means into the water. Presumably the deployed cargo would float and be maneuvered to the next destination, whether that be a ship's well deck, a beach, alongside another vessel, or onto another vessel. Maneuver of the deployed cargo may be possible under its own power, for example, if deployed cargo rested on a floating platform with a small propulsion and navigation system. Alternatively, deployed cargo may be maneuvered by tow from a small (presumably manned) vessel that was waiting nearby for the ULPV to deploy the cargo. Brutzman et al. (2024) found that supply delivery by this method could also be used to intentionally submerse a prepositioned stock.

A ULPV capable of releasing supply at sea in a manner where the supply floats or is maintained afloat on something that functions as lighterage appears inherently advantageous compared to a ULPV that must be able to interface with all possible loading/ unloading scenarios. Incorporating a supply delivery method into the ULPV that does not require the ULPV to beach for cargo delivery to a shore lacking infrastructure means the ULPV hull can maintain a design optimized for stability and efficiency over long distances of deep-sea conditions. A deployable cargo design may make use of smaller vessels within the larger vessel to complete a final stage of delivering cargo. A ULPV design for deployable cargo may have supply rest on platform that is stored within the ULPV, where the ULPV can release the floating platform (and the supply secured to it) to transit the last tactical mile to the beach of an expeditionary base. In essence, the idea of lighters and barges with shallow draft and supply secured atop may be a plausible method to deliver supply where a deep draft ULPV, designed for the open sea, cannot go. This approach is like the approaches used in the second world war, with shallow draft landing craft being launched by a larger vessel, prior to the surf zone, to transit the last tactical mile to the beach. The difference with a ULPV, however, is that a deployable cargo system that functions as a landing craft with supplies would have to be nested within the design of the ULPV so that the ULPV still maintains its minimal freeboard while in transit.

One ULPV design that incorporates a deployable cargo design comes from CDR Todd Greene (2023) at the USNA and is called the NightTrain. NightTrain is an innovative ULPV concept with a unique design to ferry shipping containers across large distances, proposing to move supply from the factory to the frontlines (Greene, 2023). The NightTrain approach has the shipping containers flooded and afloat by means of their natural buoyancy, yet still contained within the structure of the ULPV that transports them to the destination (Greene, 2023). Upon arrival at the destination, the shipping containers are released from the NightTrain and may be retrieved. Alternatively, the containers may finish the journey of the “last-tactical mile” to an island by self-propelled attachments to the containers, such as wedges that provide propulsion and additional buoyancy (see Figure 27) (Greene, 2023).

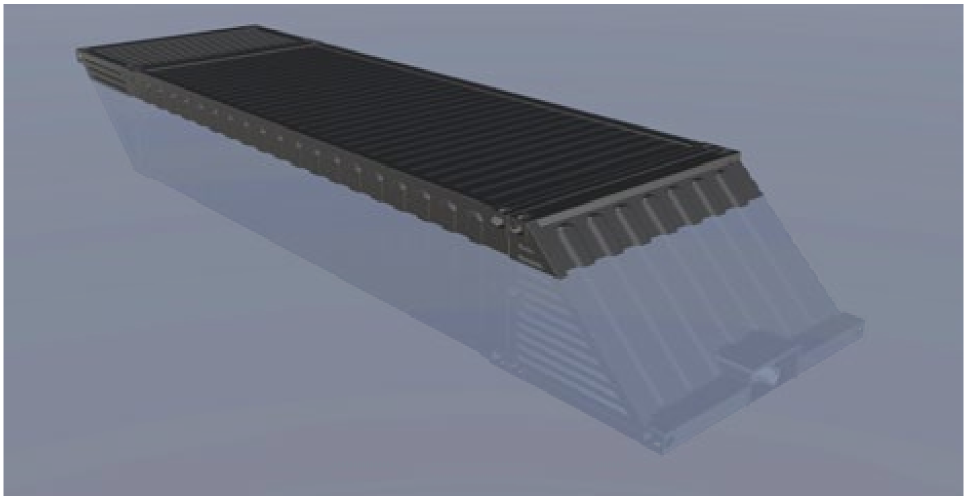


Figure 27. Deployable Cargo Example: NightTrain and Self-Propelled Shipping Container. Source: Greene (2023).

To navigate from the ULPV, through the surf zone, and land on the beach, the ‘deployed’ cargo would essentially need to function as a connector. Deployable cargo solutions intended to function as connectors, bringing supplies from an offshore ULPV to a beach, may leverage work done by the USMC on an autonomous navigation kit under the Autonomous Littoral Connector (ALC) system. Landing craft, utility (LCU) and landing craft, mechanized (LCM) 8 vessels, traditionally manned connectors, were modified with the ALC system and successfully navigated the last tactical-mile and completed beach landings (Katz, 2023).

4. Other Considerations

a. Well Deck Considerations

ULPVs capable of entering a well deck might be able to make use of any cranes or winches within a well deck for supply loading or unloading, assuming the capabilities and limitations of well decks and the equipment within USN ships with well decks are considered during the ULPV design process. In addition, RORO designs might be possible for ULPV load/unload within a well deck. However, it should be considered that depending on the hull shape of a ULPV, the use of a cradle might be necessary to keep the ULPV upright and stable if the well deck is drained.

b. *Intermodal Shipping Containers*

Moving supply by means of an intermodal shipping container is advantageous to logistics operations due to standardized interfaces that exist on each container, allowing them to be loaded onto ships, trains, trucks, and aircraft with highly efficient processes and widely available equipment (Greene, 2023). Designing a ULPV around the dimensions and interfaces of the intermodal shipping container increases its flexibility to support contested logistics by taking advantage of a shipping system that is widely proliferated, with many military systems and supplies already designed for movement in containers, and with millions of containers in use around the world (Greene, 2023). The ULPV design concept, marine operations logistics asset (MOLA), envisioned the use of "cargo pods" that would store various supply types and be lowered into or lifted from the vessel's cargo hold (Figure 28). Any ULPV could be designed to accommodate the dimensions of standardized intermodal shipping containers.

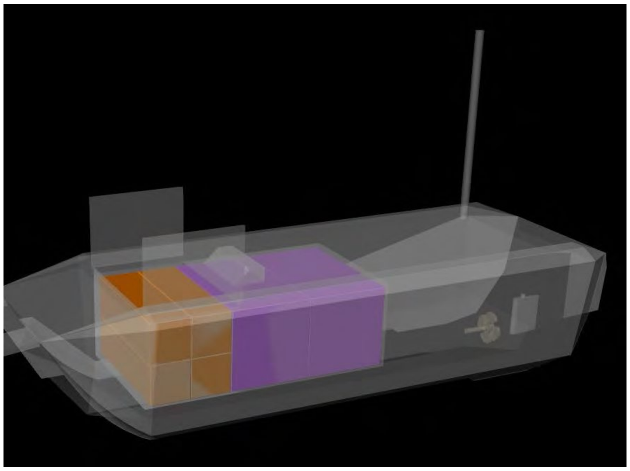


Figure 28. Cargo Pods within the Marine Operations Logistics Asset. Source: Alexander et al. (2019).

c. *Mooring, Beaching, Anchoring, Submerging*

Upon ULPV arrival at a destination for loading or unloading, USN LCDR Alan Gutburlet outlined the ideas of mooring, beaching, anchoring, and submerging as various options that a ULPV design may consider for behavior before or during loading or unloading activity occurs (Brutzman et al., 2024). ULPV mooring appears to be the most basic, most likely activity that a ULPV may be designed for when loading or unloading supply. The mooring of a ULPV most likely supports its ability to interface with a piling, pier, well deck, and alongside another vessel. A ULPV maintaining an ability to beach increases its compatibility with loading and offloading activities on austere beaches. A ULPV capable of anchoring may increase its ability to indirectly interface with an austere beach, if the expeditionary unit ashore has a vessel capable of reaching the anchored ULPV and that the supplies within the ULPV are easily moved from it to the expeditionary unit's vessel. A ULPV capable of anchoring may also be a desirable design consideration if a loitering CONEMP is used, as anchoring may reduce the fuel consumption needed for the ULPV to maintain a stationary position. The ability to submerge was another capability listed by Gutburlet and one that was conceptualized for use prior to delivery (Brutzman et al., 2024). Like loitering while anchored, a ULPV would submerge near the destination and wait until signaled to surface and complete the final transit and loading or offloading activity. Presumably, the vessel would complete this submersion at a very shallow depth to avoid the need of a pressure vessel in the hull, and a retractable snorkel may also be necessary if the ULPV propulsion system requires access to surface air.

D. DESIGN IDEAS FOR CONSIDERATION

The following are ideas that are brainstormed unconventional design ideas that might serve to inform a design for a ULPV that can perform as an end-to-end materiel solution and navigate both conditions of the high seas as well as the last tactical mile. Some of these ideas have not undergone any level of engineering analysis to determine their actual feasibility. The MOLA did undergo initial engineering design studies at NPS (Alexander et al., 2019). It should also be noted that increasing the complexity of the ULPV design is likely to increase the per-unit acquisition cost, thereby reducing any attritable characteristic of the vessel. Increasing design complexity may also negatively affect where the ULPV can be built, regarding the number and types of vendors capable of fabricating the vessel, as well as where in the world the vessel can be fabricated. A DTO LPV is so quickly built with low-skilled labor in the jungles of South America due in large part to the simplicity of vessel design.

- **Idea 1: Nesting Doll**. Consider a ULPV hull with the traditionally deep draft that enables satisfactory performance on the high seas. Now consider that the ULPV is large enough, both wide and deep, to contain within it a shallow draft vessel laden with logistics supplies. This design idea is like the Deployable Cargo design mentioned in this chapter, where the deployable cargo is the internally carried shallow draft vessel used to transit the last tactical mile, navigate through the surf zone, and land on the beach.

- **Idea 2: Use of Low-Mounted Ballast Saddle Tanks.** Consider the ballast saddle tanks used on submarines in WWII. Similar saddle tanks might be considered for attaching to the hull of a ULPV to increase its capability to increase or decrease freeboard and draft. Attaching the saddle tanks to a low part of the hull might provide the greatest capacity to decrease vessel draft when the saddle tanks are fully emptied of ballast water.
- **Idea 3: Inspiration from WWII Landing Boat Designs**. Consider the landing craft, vehicle, personnel (LCVP) or other similar "Higgins Boat" landing craft from WWII. These craft were made from plywood and served as adequate materiel solutions to bring men, supplies, and vehicles from ships to the beaches of many islands throughout the Indo-Pacific (Carter, 1998). Consider taking the hull shape of a LCVP and incorporating a sealed top, a sealed bow ramp/ door, making the vessel unmanned, and ensuring it operates with minimal freeboard (presumably with an internal or saddle mounted ballast system). This conceptual design might also be scaled slightly larger to fit the dimensions of modern cargo. This might look quite like the MOLA concept design, shown in Figure 29, which uses a shallow draft, somewhat flat-bottomed hull and with squared dimensions designed to hold rectangular cargo containers.

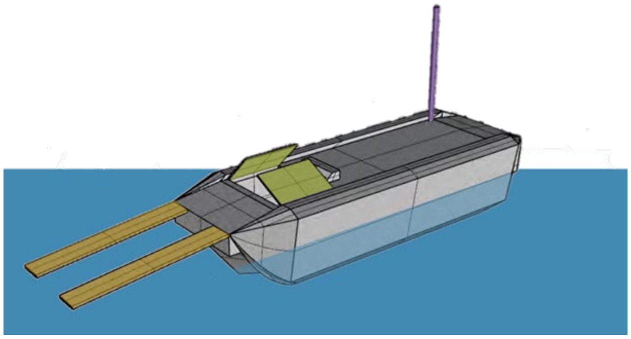


Figure 29. Marine Operations Logistics Asset Unmanned Low-Profile Vessel Design Concept. Source: Alexander et al. (2019).

- **Idea 4: Expendable Deep Draft Hull "Shoe."** Consider an external shell, or "shoe" that is a hull which a ULPV connects into. The external "shoe" is optimized for deep ocean voyages, and the rest of the ULPV connected to the external shell is optimized for the last tactical mile with a shallow draft and capable of beach landing. Upon the ULPV arriving at the last tactical mile, it disconnects from the deep draft exterior hull and completes the last part of its journey, landing on a beach for supply unload.
- **Idea 5: Expendable Keel.** Consider a shallow draft ULPV that is optimized for the last tactical mile and capable of beach landings, but a detachable keel is attached to the bottom of the ULPV to provide seakeeping stability during the vessel's transit over the "high seas." Upon arrival at the last tactical mile, the ULPV drops its keel and completes its journey. Expending the keel would also serve to remove weight from the vessel, likely decreasing the ULPV's draft, something helpful during the last tactical mile transit.
- **Idea 6: Inflatable Pontoons or Balloons.** Consider the use of inflatable pontoons or balloons on the exterior of a ULPV hull that are inflated only during final transit through the last tactical mile to decrease vessel draft enough to navigate the surf zone and successfully complete a beach landing. This is like the use of ship salvage airbags (Figure 30) to raise or move ships that are sunken or beached. These airbags are very small in size when deflated and are lightweight as well (Blue Ocean Marine Equipment, n.d.).

Figure 30. Ship Salvage Airbags. Source: Blue Ocean Marine Equipment (n.d.).

VI. UNMANNED LOW-PROFILE VESSEL TECHNICAL AND SYSTEMS CONSIDERATIONS

As in any unmanned system, a ULPV is a system of systems and there are a number of technical considerations that must be accounted for in the design of a ULPV. The first technical consideration to consider is the enterprise architecture of the vessel. A Modular Open Systems Approach (MOSA) should also be considered for the systems onboard a ULPV. In addition, external connectivity systems, navigation systems, and the sensors that enable ULPV system functions should also be considered during ULPV design. Finally, the way ULPVs are commanded and controlled, the level of autonomy designed into the system, and the role that big data plays are some final technical and systems considerations for ULPV design.

A. ENTERPRISE ARCHITECTURE

The contested logistics environment is marked by the expected loss of reliable communications capabilities due to jamming, spoofing, or other kinetic and non-kinetic attacks that would result in a denied, degraded, intermittent, and limited (DDIL) communications environment. While ULPVs have inherent design aspects that make them a natural choice for vessels with increased survivability in the contested environment, it is this DDIL communications environment that complicates the functionality of unmanned systems in general, most of which have historically required reliable communications links or access to the Global Positioning System (GPS) to accomplish their tasks.

The rise in popularity of cloud computing naturally poses the question, “Is cloud computing compatible with implementation in the enterprise architecture of ULPVs?” Similarly, one can ask if edge computing can be considered for the needs of ULPVs. Implemented alone, neither cloud nor edge computing is likely to address the enterprise architecture (EA) needs of ULPVs, but implemented together, cloud and edge computing models can serve in an EA to address the unique challenges that unmanned vessels will face in the DDIL communications environment.

1. Background: Cloud and Edge Computing

Cloud computing capabilities can benefit many EAs, and the DoD plans to leverage the cloud through the Joint Warfighting Cloud Capability (JWCC) and the various cloud services that are available (Evans, 2022). The cloud may be implemented through various approaches, consisting of three main service approaches and three main deployment approaches. The service models are infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS), whereas the deployment models are public clouds, private clouds, and hybrid clouds (Mahmood & Hill, 2011). While there are various benefits to each of the cloud computing approaches, the key tenets are that cloud servers are centralized, generally have high processing capability and storage capacity, and are cyber secure. However, the main drawback of cloud computing is that it requires internet connectivity between the end device and the cloud, and any such connections are likely to experience latency and bandwidth constraints (Goundar, 2023).

To address the challenges that accompany cloud computing, edge computing has emerged to bring "computational power and data storage closer to the source of data generation, enabling real-time processing and analysis at the edge of the network" (Goundar, 2023, p. XIII). Further, "edge computing enhances efficiency, reduces latency, and mitigates the strain on cloud infrastructure by distributing tasks across a network of edge devices, such as routers, gateways, and Internet of Things (IoT) devices" (such as ULPVs, in this case; (Goundar, 2023, p. XIII).

2. The Cloud in Unmanned Low-Profile Vessels

The nature of logistics in wartime requires careful tracking of the movement of wartime materials throughout an AOR to ensure that correct supplies arrive at the right unit, at the right time, and in the right location. Failure to accurately track shipments would likely have detrimental results, such as units running out of fuel, ammunition, food, water, medical supplies, or other items that the war effort depends on. The coordination of such logistical activity likely requires centralized coordination to move limited quantities of supplies by limited means of transport. Such centralized coordination may benefit from the use of data science (perhaps enabled by some form of artificial intelligence) to provide predictive analysis to optimize logistics movements throughout an AOR.

While centralizing logistical data appears beneficial, for ULPVs to play the role of suppliers within a centralized system that orchestrates logistics, it is expected that ULPVs should need to communicate various metrics to a centralized logistic coordination construct. These metrics would include those previously mentioned, such as the vessel's location, systems status, remaining fuel load, heading, and speed. However, these metrics need not be relayed constantly, as logistical coordination is unlikely to require updates with such periodicity.

Communication of these updates from ULPVs and a centralized implementation of logistics coordination may fit nicely with the integration of cloud-based computing and associated applications that enable the coordination of logistic activity throughout an AOR. The method of connecting to the cloud by a ULPV may vary depending on several factors; however, periodic status updates from a ULPV to the cloud would align with natural limitations expected with the cloud, those being small bandwidth, the presence of latency, and the need for connectivity to utilize the cloud. Given the nature of ULPVs operating in the DDIL communications environment, the centralized logistical coordination system in the cloud would receive updates from ULPVs at a potentially unpredictable rate, likely leading to the uncertainty of a vessel's fate. A military leader may ask, "Did the vessel make it to its destination?" when a ULPV goes some time without establishing connectivity to the cloud. Perhaps, in this case, the vessel did complete its mission but was not yet able to make a connection to the cloud by any beyond line-of-sight (BLOS) or line-of-sight (LOS) methods at its disposal. Or perhaps, the vessel was lost at sea for some unknown reason. One strength of placing logistics coordination in the cloud, in this case, may be the ability to leverage powerful cloud computing resources to aid decision-making via analytic tools that leverage data compiled throughout the military conflict in the AOR. Said tools may help assess the likelihood that the vessel was lost due to enemy action, weather, or terrain collision and compare that outcome against the likelihood that the vessel is simply still within an area where it is unable to connect to the cloud and provide an update. Ultimately, this would help decision-makers decide if another logistics asset should be launched to backfill the mission of the out-of-communication ULPV. As a result, wasted resources could be minimized with an approach that centralizes resources in the cloud and leverages cloud computing.

3. Edge Computing in Unmanned Low-Profile Vessels

As previously stated, the benefits of cloud computing could enable the ULPV enterprise architecture necessary to coordinate the movement of supplies in a contested logistics environment among a multitude of vessels in an AOR. In addition, the shortfalls of cloud computing with ULPVs can be addressed by also implementing edge computing. Edge computing may provide the onboard computing necessary for the ULPV's point-to-point navigation, obstacle avoidance, networking with other ULPVs that are within LOS communications, and any so called "last tactical mile" coordination necessary for a ULPV to deliver its supplies to the end user. Edge processing will enable the fusion and packetization of key data for dissemination to the cloud once cloud connectivity resumes. Information *roll-ups*, a summarization of noteworthy updates, to include a historical breadcrumb trail of the ULPV's route, observations or incidents of significance, high priority system issues, as well as current statuses (fuel, position, systems health, and planned mission route, to name a few) would be provided to the centralized logistics or ULPV coordination application in the cloud through cloud connectivity as network conditions to the cloud permit.

4. Caution Regarding Cloud and Edge Computing

Though cloud computing is widely advertised as more secure than on-premises computing, DoD cybersecurity professionals could face unique limitations when trying to provide cybersecurity support to the cloud when said cloud is being managed by any other organization than the DoD, such as any of the cloud hyper-scalers, those large cloud service providers with extensive resources. This is due to most cloud providers using the so-called "shared responsibility model" toward security, resulting in providers claiming responsibility for security in their cloud environment while clients must ensure the security of access to that cloud environment (Hazdun, 2023). The hyper-scalers involved in the DoD's JWCC include at least Amazon, Google, Microsoft, and Oracle (DoD, 2022), and the DoD may be given little to no authority to take actions affecting cybersecurity within the infrastructure of any of these companies' cloud environments. As a result, DoD data within the cloud will likely rely on the cybersecurity capability of cloud providers. Implementing the cloud into the EA for ULPVs, or any centralized logistics coordination capability, could force the DoD to entrust the cybersecurity of such an EA to outside organizations and personnel.

As with all aspects of designing a new information technology system, especially one intended to be a "low-cost" materiel solution like the ULPV, special consideration is needed toward maintaining the simplicity and availability of components. Edge computing processors and related hardware used in the ULPV design should be widely available, perhaps in use across various product lines throughout differing industries. Central processing units (CPUs) and graphics processing units (GPUs) that are widely available in the commercial market should be chosen for implementation as edge processing methods to ensure the availability of these components in ULPV production, thereby reducing the risk of supply chain issues that custom computing solutions can experience. Leveraging COTS technology to achieve edge processing for the ULPV is also more likely to ensure that these components do not drive costs higher than necessary for the level of computational power that a ULPV would need to accomplish its edge processing requirements.

5. Enterprise Architecture Summary

The anticipated operating environment of the ULPV in the contested logistics environment results in an added complexity of DDIL communications. This complexity creates a challenge for an unmanned system like a ULPV and its respective enterprise architecture. On their own, cloud and edge computing are helpful but likely insufficient to meet the needs of a ULPV. An enterprise architecture designed around seamless interoperability between edge and cloud computing, however, would best enable a ULPV and the coordination of logistics in a contested logistics environment.

B. MODULAR OPEN SYSTEMS APPROACH

The DoD’s open systems strategy is termed MOSA. MOSA is described as a technical and business strategy for designing an affordable and adaptable system. MOSA is being implemented in most defense acquisition programs, and the DoD expects MOSA to bring increased innovation and deliver faster, more affordable, and more frequent system updates (Davendralingam et al., 2018, p. 390). Further, MOSA is expected to improve interoperability between the DoD services’ systems to a level closer to that needed for the DoD to realize its Joint All-Domain Command and Control (JADC2) strategy (Real-Time Innovations, Inc., 2022, p. 4).

Incorporating MOSA into ULPV design will likely be required due to implementation requirements signed into law (Government Publishing Office, 2016, pp. 2252–2268) and service specific mandates by the Air Force, Army, and Navy secretaries mandating MOSA implementation “to the maximum extent possible” (Spencer et al., 2019). The end goal is for those implementations to enable seamless data sharing across the DoD. This level of interoperability is described as both foundational for and the overarching vision of JADC2 (Department of Defense [DoD], 2022, p. 1). Building MOSA into any ULPV design will help ensure that a ULPV is capable of data-sharing with other fielded and future systems. Maximizing data paths for data to and from a ULPV is presumed to positively impact a ULPV’s enterprise architecture, increasing the number of paths that data may take to and from a ULPV. MOSA implementation may also increase the ease and flexibility of changing a ULPV’s systems when updates are necessary.

One disadvantage of incorporating MOSA in ULPV design, however, is that such an approach can lead to duplicative “support subsystems that are required to ensure interoperability,” thus leading to increased size, weight, and power (SWaP) in complex systems (Davendralingam et al., 2018, p. 393). Duplicative support subsystems may increase not only the SWaP of systems onboard a ULPV but also the overall cost of a ULPV.

C. EXTERNAL CONNECTIVITY (COMMUNICATIONS)

For ULPV communications at distances BLOS, satellite services are an option. Provided the necessary equipment is onboard, ULPVs will presumably have access to the resources of satellites intended for U.S. military use. However, various options exist for commercially provided satellite communication services. Inmarsat is one such provider, with Inmarsat Fleet Xpress providing service to over 10,000 ships in 2019 with speeds up to 330 megabytes per second (Mbps) (Wright, 2020). The positioning of thousands of small satellites in low earth orbit (LEO) has created communications networks capable of providing ubiquitous broadband coverage worldwide, with data exchanges exhibiting very low latency rates due to the short distance between LEO and the user (Wright, 2020). One popular LEO satellite communications provider, Starlink (n.d.b), uses terminals that utilize an electronic phased array for the antenna. An electronic phased array is considered to maintain low probability of detection (LPD) characteristics regarding its radio frequency (RF) emissions. LPD communications are presumed to be of great importance to a ULPV to minimize its P_d in a contested environment, thereby increasing its chance of mission success. The Starlink constellation is highly populated and now covers most of the globe, including the Indo-Pacific, as seen in a snapshot of real-time Starlink satellite positions in orbit (Figure 31).

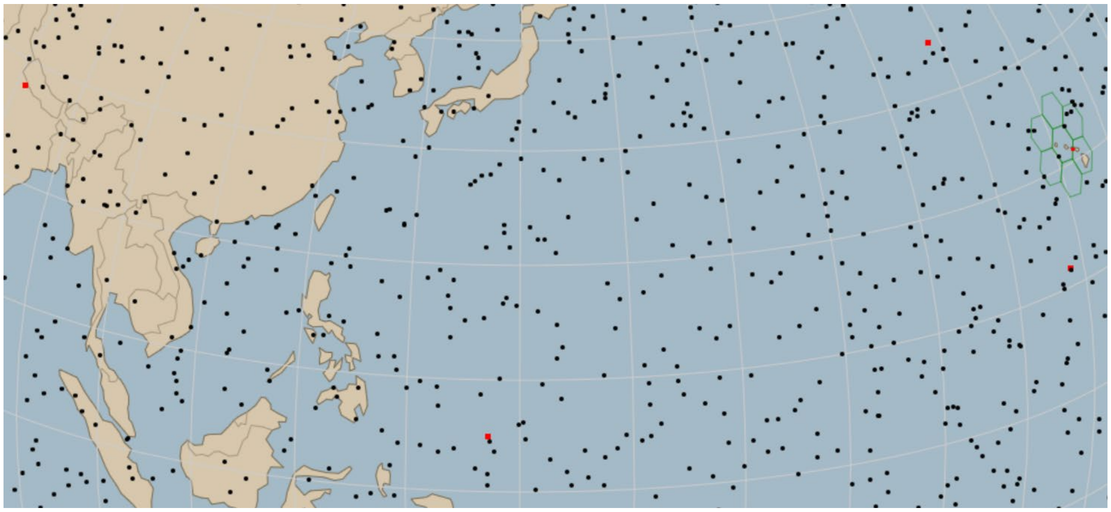


Figure 31. Snapshot of Starlink Satellites in Orbit over the Indo-Pacific. Source: Starlink (n.d.a).

High frequency (HF) communications are another option for BLOS communications in ULPVs. Internet protocol (IP) over HF is a capability that exists for low-bandwidth communication (Jodalen et al., 2003) and could be used by ULPVs to send and receive small amounts of data for C2. While a Starlink antenna would likely need to be mounted atop a ULPV hull, much like any mounted HF loop antenna, a long-wire HF antenna might be able to be installed within the upper part of the hull, running the length of the vessel (L. Banchs, personal communication, May 8, 2024).

In addition to BLOS communications, it is also important to consider the requirements for any final coordinating communications between a supported unit at an expeditionary location and an arriving ULPV. Presumably, these communications will involve the ULPV alerting the supported unit of its presence and either warning the supported unit of its planned activities or alerting the supported unit that it is awaiting final instruction before proceeding with further behavior. The communications that take place may or may not need to be LPD, depending on the level of the supported unit's desire to control EM signatures. In the event LPD communications are needed, free-space optical (FSO) communication may be an option during the ULPV's last tactical mile transit. With FSO, data is transmitted via laser technology with data rates up to 2.5 gigabytes per second (Gbps) to support data, voice, and video through the air at distances up to 4 km (Sadiku et al., 2016). Zhao et al. (2019) found that FSO communications are possible at distances between 1 km and 10 km. One important consideration, however, is that the supported unit would need to have FSO communications equipment in hand, and expeditionary units may not currently deploy with FSO communications systems like they do with radios. Figure 32 shows several FSO products commercially available from one vendor, Torrey Pines Logic (n.d.).

L20

Small, portable, simple to use LED based Light Gun for signaling. Operates on Harris and Brentronics standard batteries or external power. Lightweight - <1kg, fits into a pocket! Can be used to transmit Morse code or color light signals. 12 hours of continuous ON operation/illumination on one charge.

L30

In addition to all L20 functionality, LightSpeed optical communications provide clear voice link between L30 units at distances over 1km.

R36

The LightSpeed™ R36 unit is the latest generation of the Optical Communication system providing IP based Ethernet network and voice connection between vehicles. Each communication node utilizes an array of IR LEDs and an omnidirectional receiver capable of providing a 360° communication link.

R50

The eye-safe IR LED allows non-visible communication between units at distance up to 6km. Provides full-duplex voice communication and functions as an Ethernet link to a remote computing device or to another system via a standard Ethernet connection.

R55

The eye- safe IR source (Class 1) used by R55 allows non-visible communications between units at distances at extended range. Using the supplied headsets, R55 provides full- duplex voice communication. The units also function as an Ethernet link to a remote computing device or to another system via a standard Ethernet connection.

U10

The eye-safe blue light LED used by U10 allows communications between units at distances up to 300 meters. The units function as an Ethernet link to a remote computing device or to another system via a standard Ethernet connection.

Figure 32. Example of FSO Communications Products. Source: Torrey Pines Logic (n.d.).

D. NAVIGATION

The ability to conduct successful navigation is perhaps the most important capability for a ULPV intended for contested logistics. If the ULPV cannot reach the intended destination with the intended supplies and within the desired timeframe, its malperformance may leave the warfighter emptyhanded in a time of need, ultimately resulting in loss of life. A ULPV must be capable of maintaining not only awareness of its location on the globe for transit over long distance but also its immediate surrounding to avoidance collisions. It may be advantageous for a ULPV design to incorporate multiple navigation systems, ranging from active to passive systems, to provide redundancy for a ULPV competency as important as navigation. Active navigation systems radiate energy to support navigation functionality, and passive navigation systems do not radiate energy to support navigation functionality.

In a NPS C2 capstone course, USN LCDR Gerred Olona and LCDR Ken Stout found that a ULPV might benefit from the use of both active and passive navigation systems (Brutzman et al., 2024). Sonar, GPS, and celestial navigation were the primary means for navigation systems used by the capstone course, with compass, gyrocompass, and dead reckoning supplementing the primary navigation methods (Brutzman et al., 2024). Olona and Stout's layered approach highlights redundancy when designing a ULPV, with various navigation inputs complementing each other and providing the overall navigation system with failover navigation options should any fail or become faulty or untrustworthy, such as in the case of cyberattack, spoofing, or jamming. Table 4 summarizes various navigation means that should be considered for ULPV design.

Table 4. Possible Unmanned Low-Profile Vessel Navigation Methods.
Adapted from Brutzman et al. (2024).

Navigation Method	Active or Passive System
Global Navigation Satellite System	Passive
Inertial Navigation System	Passive
Dead Reckoning	Passive
Radar Navigation	Active
Celestial Navigation	Passive
Radio Navigation	Passive

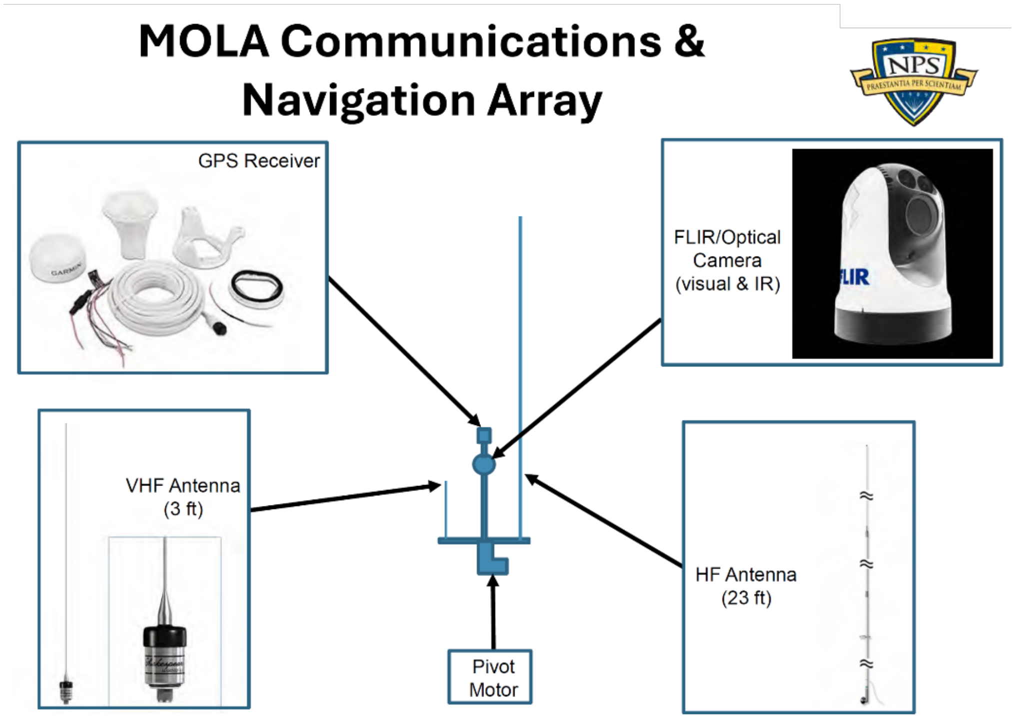
Global Navigation Satellite System (GNSS), made up predominantly of GPS, Glonass, and Galileo (Brutzman et al., 2024), can provide a ULPV with a passive means of accurate navigation over long distances. A ULPV navigation system might consider the use of dead reckoning supported by an Inertial Navigation System (INS) and updates provided by GNSS to ensure location accuracy and prevent location *drift*, which can result if location error culminates over long periods of time or distance. Corrections to a vessel's accuracy might also be possible over BLOS communications if the ULPV is being tracked by friendly airborne or spaceborne assets. Similarly, if a friendly asset has GNSS connectivity but the ULPV does not, the concept of differential GPS can be used to increase the ULPV's location accuracy.

In the event of jamming or spoofing, GPS signals may be unreliable, unavailable, or untrustworthy for ULPV navigation. Recent research indicates that Starlink is a viable alternative to GPS as a source of positioning, navigation, and timing (PNT) data (Hansen, 2023; Stock et al., 2023). Incorporating a Starlink antenna in the design of a ULPV may be advantageous, as doing so can enable both BLOS communications as well as a PNT fallback option from GPS.

Collision avoidance is another aspect of ULPV navigation that should be considered. While previous navigation considerations focus on the long distances that a ULPV must accurately navigate to arrive at the right destination, the capability to avoid other vessels or unforeseen obstacles along the transit is equally important. Floating debris, a stationary fishing vessel, a transiting cargo ship, or an unexpected sandbar are all examples of the hazards a ULPV needs to detect and avoid. Sonar is one method a ULPV can use to determine ocean depth and take evasive action if the vessel encounters unexpectedly shallow waters or subsurface objects that pose a risk. As for avoiding surface hazards, a ULPV may utilize a radio detection and ranging (RADAR) or a light detection and ranging (LIDAR) system to search for and avoid objects; however, these are active systems that have implications for vessel susceptibility if their emanated signals are detected. The MOLA concept also proposed the use of an automated information system (AIS) in a receive-only mode to help avoid collisions with other vessels (Alexander et al., 2019), which would only work if the other vessel were transmitting on AIS. Object avoidance by passive systems, such as sensors mounted atop the ULPV, could prove a better method to avoid collision with surface hazards while also radiating minimal energy to maintain the lowest possible EM signature and improve vessel susceptibility. This is discussed further in Chapter VII. One final consideration on ULPV mounted sensors for object avoidance, however, is that the low freeboard of a ULPV inherently limits where sensors can be mounted. This is discussed in greater detail in the following section.

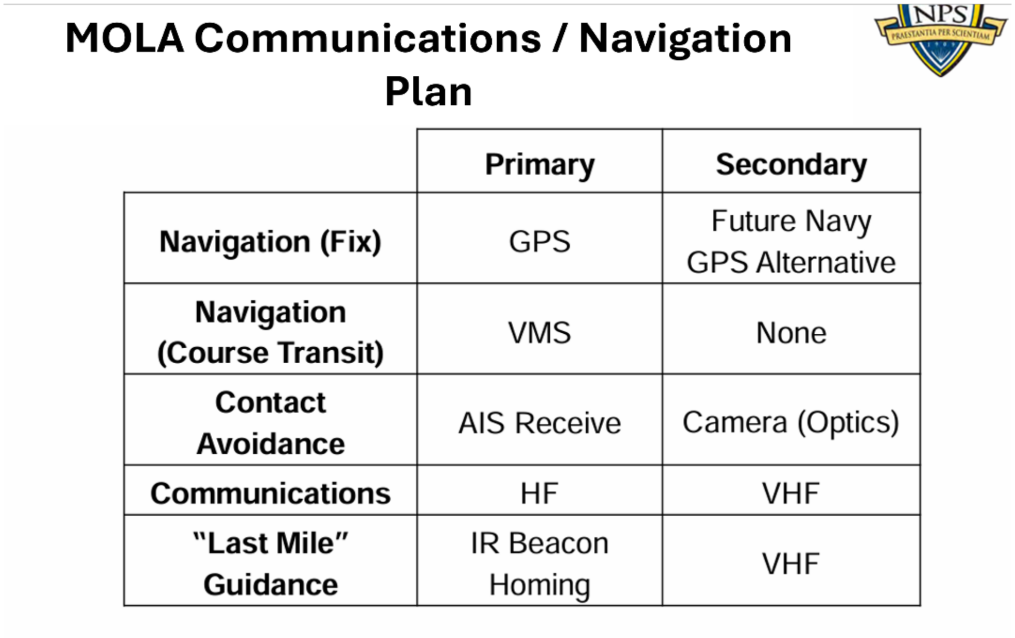
E. SENSORS

Sensors mounted on a ULPV, like most unmanned systems, will provide data input to enable the vessel to complete its mission. One consideration, however, is the very limited height above terrain (HAT) where these sensors can be mounted on a ULPV due to the vessel's low freeboard and desire to maintain minimal detectability. Adding a large mast or structure for sensor-mounting likely defeats the purpose of exploring a ULPV as a materiel choice, namely, the vessel's ability to avoid detection. ULPV design may be forced to accept the trade-off of UPLV sensors' more limited line of sight for the benefit of decreased detectable signatures and, therefore, decreased detectability. The types of sensors that a ULPV might incorporate are many, but it is presumed that electro-optical (EO)/IR and bathymetry sensors will be used to achieve basic object avoidance and support final navigation during the ULPV's transit of the last tactical mile. A radar warning receiver (RWR) might also be installed on a ULPV to provide a passive means for a ULPV to better understand if it is being detected or targeted and take evasive actions (D. Brutzman, personal communication, August 14, 2024). Figure 33 illustrates a sample of sensors and communications gear that were conceptualized for the array on the ULPV concept, MOLA (Alexander et al., 2019). Figure 34 shows a communications and navigation plan created for the MOLA, and while very high frequency (VHF) communications are certainly an option for ULPVs, the resulting increase to the ULPV's RF signature from using VHF should be considered. The detectability concerns from using VHF, and many other frequency bands, may be alleviated if a directional antenna, vice an omnidirectional one, is used for transmissions.



MOLA Communications & Navigation Array

Figure 33. Example Communications and Navigation Array. Source: Alexander et al. (2019).



MOLA Communications / Navigation Plan

	Primary	Secondary
Navigation (Fix)	GPS	Future Navy GPS Alternative
Navigation (Course Transit)	VMS	None
Contact Avoidance	AIS Receive	Camera (Optics)
Communications	HF	VHF
“Last Mile” Guidance	IR Beacon Homing	VHF

Figure 34. Example Communications and Navigation Plan. Source: Alexander et al. (2019).

F. COMMAND AND CONTROL AND AUTONOMY

According to Scharre (2018), the autonomy of an unmanned system "encompasses three distinct concepts: the type of task the machine is performing, the relationship of the human to the machine when the machine is performing that task, and the sophistication of the machine's decision making when performing that task" (p. 31). The manner in which a ULPV operates can span a spectrum of intelligence ranging from simple automatic intelligence to sophisticated autonomous intelligence, as described by Scharre (2018) and adopted by Brutzman (2022), shown in Figure 35.

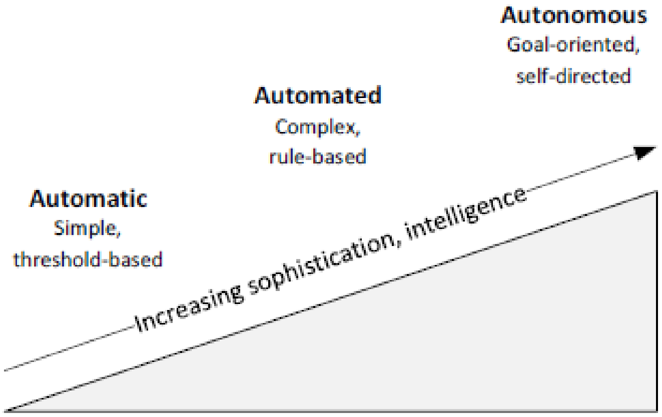


Figure 35. Scharre Spectrum of Intelligence in Machines. Source: Scharre (2018).

Regardless of the level of intelligence in a ULPV, however, the vessel will presumably follow a decision-making process like that used by humans, which, according to Boyd (Coram, 2002), is the observe, orient, decide, act (OODA) loop. Brutzman (2022) provides a general comparison of continuous control loops that may be utilized by ULPVs, shown in Figure 36. A ULPV might make use of decision-making loops at any point, such as during transit to adapt to changing sea states, maintain course toward the destination, and avoid collisions along the way. In a NPS C2 capstone course, it was reported that simple decision-making loops will have application to ULPVs in status reporting, payload delivery, and determinations to scuttle or return to base (Brutzman et al., 2024).

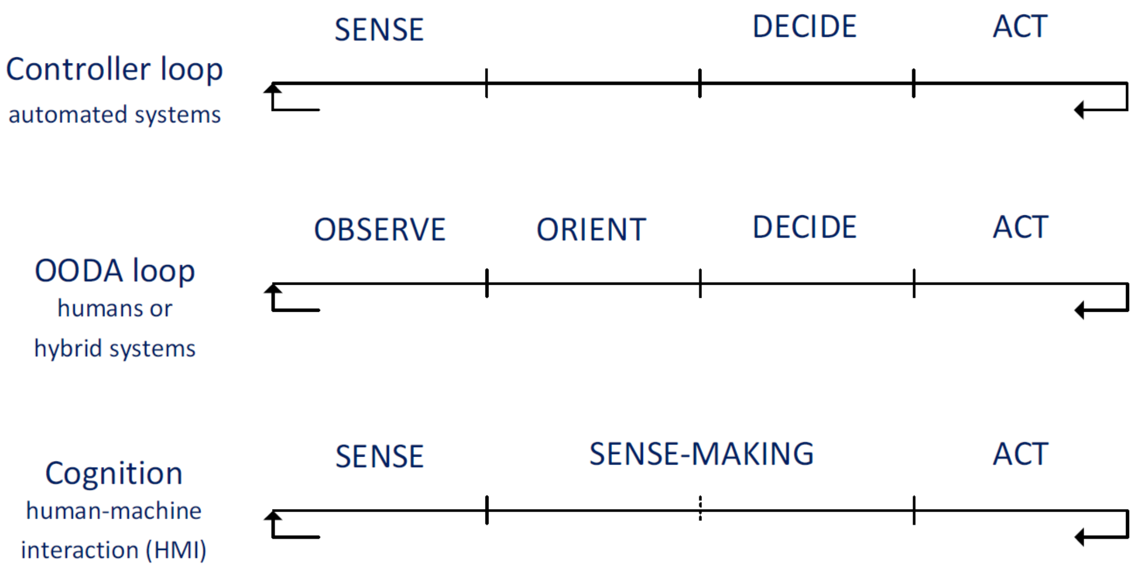


Figure 36. Continuous Control Comparisons. Source: Brutzman (2022).

The amount of human involvement required in an unmanned system's operation can be generally described by one of three levels, as depicted in Figure 37. A ULPV might operate as a semi-autonomous system whenever communications are assured and a logistics C2 hub is able to maintain a communications link with the ULPV. In this case, an operator might be continuously watching the near-real-time (NRT) activity of the ULPV and providing control inputs to the vessel. The ULPV at this level requires human input for operation. This scenario describes ULPV operations with a human in the loop. Similarly, if communications are assured, a human may instead be monitoring one, several, or dozens of ULPVs transiting the Indo-Pacific, and while this person can step in to provide input to any of the vessels at any given time, the vessels operate autonomously under human supervision. The ULPV does not require human input to operate, but a human can intervene and provide input to the ULPV as desired. This scenario describes ULPV operations with a human on the loop.

If communications with a ULPV are severed or unavailable, a ULPV that is capable of full autonomy can continue its mission without the need for human intervention. This scenario most closely describes operations with a human out of the loop, which presumes that the human still has some ability to control the unmanned system, though that ability may not be in a timely or convenient manner.

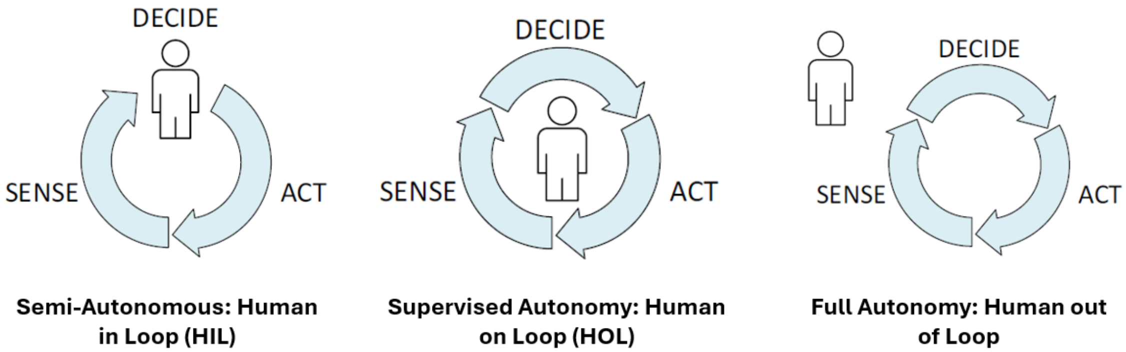


Figure 37. Levels of Human Involvement and Autonomy. Adapted from Scharre (2018).

ULPV design should consider the level of autonomous operation that a ULPV is capable of and the resulting implications for C2 of the vessel, enterprise architecture requirements, communications system requirements, complexity of software, and the costs associated with these factors in ULPV acquisition. A photo of the USMC autonomous low-profile vessel (ALPV) effort (Figure 38) shows a Marine operating an ALPV with a remote control, indicating that this ULPV maintains at least the capability for semi-autonomous, human in-the-loop control. Figure 39, from the Department of the Navy's (DON) Unmanned Campaign Framework, provides another useful illustration on the spectrum of autonomy and human dependence.

Figure 38. Autonomous Low-Profile Vessel Remote Control, Human-in-Loop Option. Source: King (2024).

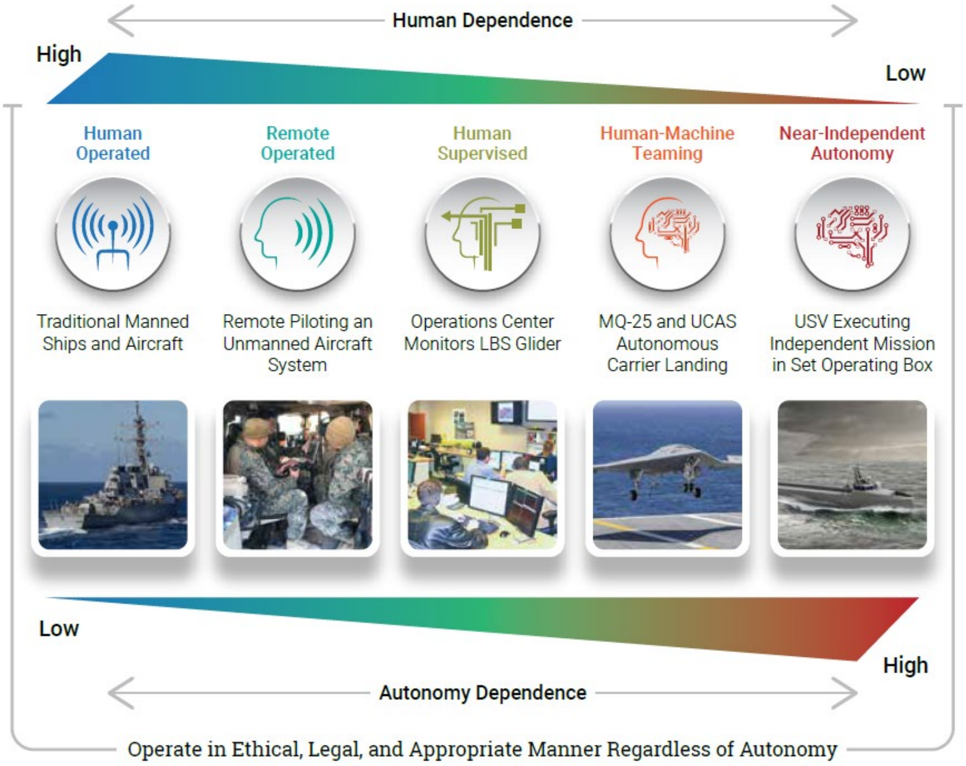


Figure 39. United States Navy Spectrum of Autonomy and Human Dependence. Source: Department of the Navy (n.d.).

G. BIG DATA

For vessels like ULPVs, big data can be leveraged with machine learning (ML) techniques to increase the vessels' operational effectiveness. However, while there are benefits of leveraging big data on ULPVs, one must also consider some of the challenges associated with doing so. There is limited experience of USN unmanned vessels experiencing combat or hostile interactions, and as a result, a ULPV operating in a contested environment may benefit from the ability to learn from its own experiences and those of other unmanned systems in the area. In 2022, the USN experienced hostile action against two of its unmanned surface vessels when Iran temporarily captured two Navy Saildrone vessels operating in the Middle East (Figure 40) (Shelbourne, 2022). This event introduces the idea of a useful use case for a ML algorithm designed for ULPVs to identify when they are being engaged by an adversary and take evasive maneuvers as appropriate.

Figure 40. Saildrone Vessels Captured by Iranian Ship Source: Helfrich (2022).

1. Possible Machine Learning Applications

While many existing applications of ML for unmanned vessels focus on collision avoidance, it is important for unmanned vessels operating in a contested environment to understand the intention of other nearby vessels to take action to not only avoid collision but also escape the threat of interference from a hostile vessel (Song et al., 2022). In this case, the vessel uses ML to actively adapt to escape from active interference by an adversary. ML can also be used to create an algorithm for assessing the effectiveness of the vessel's evasive maneuvers based on the recorded vessel sensor data from hostile interactions. For ULPVs, this data should flow freely between the ULPV and the node where the ML algorithm is hosted, which may be housed in a location outside of the threat area. Ideally, data from one ULPV's interactions would feed the ML algorithm, enabling learning and updated behavioral responses for other ULPVs in future hostile interactions, even if those other ULPVs have not yet had their own interaction with a hostile vessel from which to learn. Further, to leverage an advantage of big data (the ability to utilize heterogeneous data), the ML algorithm can become more effective by utilizing data from other vessels, systems, or sensors collecting data on the contested area. All of this additional data can be utilized, along with that of the unmanned vessels, to help the ML algorithm improve and communicate more effective behavioral adaptations to ULPVs.

In addition to benefiting an unmanned vessel's behaviors, ML techniques can be used to assist with the broader issue of making use of the vast data quantities that unmanned systems will provide. Information collected from intelligence, surveillance, and reconnaissance (ISR) assets in the USN has grown to great quantities, while the capacity of intelligence analysts is so small in comparison that only 5% of data collected by ISR assets reach USN analysts (Porche et al., 2014). With the USN's increased use of unmanned vessels, there will be an even greater number of sensors, like those found on ISR assets, that will be able to provide data of use to intelligence assets. This will only increase the gap between available data and intelligence analyst capacity, resulting in untold quantities of missed intelligence value. In this case, big data analytics and ML algorithms may be able to help the USN improve its ability to analyze data. One use of ML algorithms might complete an initial screening of ISR data, like a full-motion video, tagging specific parts of the video that have possible intelligence value. A recent RAND report highlighted ways for the USN to improve its ISR processes by fixing the inefficient transmission of useless data, such as hours of video staring at an open ocean (Porche et al., 2014). If an ML algorithm can run through data on a ULPV as that data is being collected from the vessel's sensors, the algorithm might be able to identify timeframes when the data is potentially of intelligence value. That identified data could then be transmitted back to intelligence analysts, preserving both limited network bandwidth and analysis capacity.

2. Physical Component Challenges

The incorporation of big data analytics into ULPVs offers substantial benefits, including improved autonomy, enhanced decision-making, and increased situational awareness. However, the additional hardware and power requirements for data processing and management necessitate careful consideration of SWaP constraints (Oruç, 2022). Addressing these considerations is crucial for maintaining the vehicle's low-profile nature and operational efficiency.

The physical integration of computational hardware and data processing units into ULPVs may pose a challenge due to space constraints. Advanced computational systems must be compact yet powerful enough to handle large volumes of data. Moreover, the integration of advanced sensors and communication systems for data acquisition and transmission must be optimized for space efficiency. A modular design approach can offer flexibility, allowing for the scalable integration of big data components based on mission requirements (Oruç, 2022).

The addition of Big Data hardware may also increase the overall weight of a ULPV, affecting its mobility and payload capacity (Oruç 2022). It may be necessary to select lightweight materials and components without compromising system performance. Additionally, the power supply system may need enhancements to support increased energy demands, further influencing the vehicle's weight. Balancing these aspects is crucial to maintaining the vehicle's agility and operational range.

Big Data processing is inherently power-intensive, necessitating efficient energy management strategies. ULPVs performing any computationally intensive big data processes must be equipped with power systems capable of sustaining prolonged data processing while maintaining adequate reserves for mobility and other essential functions (Oruç, 2022). Energy-efficient processors and optimized data processing algorithms can reduce power consumption. Alternative energy sources, such as solar panels mounted on the deck of a ULPV hull, might be able to provide auxiliary energy to support data operations and minimize the impact on the vehicle's primary power system. However, if the ULPV is designed to operate awash, this may not be a viable option. It should also be considered if the cost of such a system is worth its expected benefit, especially if the vessel is intended to be attritable.

3. Security Concerns and Challenges

Integrating big data into ULPVs in military environments introduces several security concerns that must be meticulously addressed to safeguard sensitive information and ensure the integrity of military operations. The vast volumes of data collected, processed, and transmitted by ULPVs can include critical operational details, personnel information, and strategic intelligence, making security a paramount concern. One primary security concern is data confidentiality. Ensuring that sensitive information collected and transmitted by ULPVs is not accessible to unauthorized parties is crucial (Oruç, 2022).

This includes implementing robust encryption protocols for data at rest and in transit, ensuring that even if data is intercepted, it remains protected (Oruç, 2022). Additionally, securing communication channels to prevent eavesdropping or data interception is vital, particularly when ULPVs communicate over potentially insecure networks. Data integrity is another concern. The data collected and processed by ULPVs must be accurate and reliable, as any manipulation or tampering could lead to incorrect decisions or assessments (Oruç, 2022). Implementing mechanisms to detect and prevent unauthorized data modification is essential, ensuring that the information remains trustworthy for decision-making processes.

The availability of data is another critical security aspect. If a ULPV relies on continuous access to big data for its operations, any disruption in data availability, such as through denial of service (DoS) attacks, can impair its functionality (Oruç, 2022). Ensuring redundant systems and robust network defenses to maintain data availability may be crucial for the uninterrupted operation of ULPVs, especially those designed to rely on somewhat consistent connectivity to operate as desired, such as with an enterprise architecture that depends entirely on cloud computing.

The physical security of a ULPV is another concern. If an enemy were to capture a ULPV, they could potentially access its data storage, possibly leading to a significant security breach. Implementing secure hardware measures, such as data encryption and self-destruct mechanisms for sensitive data, can mitigate these risks (Oruç, 2022).

4. Cloud-Based Big Data Integration

Integrating big data with cloud-based artificial intelligence (AI)/ML processing significantly enhances the capabilities of ULPVs, offering advanced analytical and decision-making tools. The cloud’s computational prowess allows for the efficient handling of vast datasets from ULPVs, facilitating sophisticated data processing and analysis that surpass the limitations of onboard systems (Shrader, 2023). This integration is pivotal for ULPVs, enabling real-time data processing, predictive analytics, and enhanced decision-making, all of which are crucial for the vessels’ varied missions. The deployment of advanced AI/ML models via cloud platforms significantly augments the intelligence and autonomy of ULPVs (Shrader, 2023). These models, which are more complex and capable than those the ULPVs might host themselves, offer improved accuracy and insights, facilitating better operational outcomes (Shrader, 2023). Moreover, the cloud's scalable resources allow for the continuous improvement of these AI models, ensuring that ULPVs benefit from the latest advancements in AI/ML, thereby continuously enhancing their operational efficiency and effectiveness. Moreover, cloud-based processing fosters enhanced collaboration and data sharing among ULPVs, enabling shared intelligence and collective learning, which are instrumental in amplifying the individual and collective capabilities of ULPV fleets (Shrader, 2023). Centralized control facilitated by cloud platforms also enables synchronized fleet operations, providing strategic oversight and coordination. Additionally, the cloud ensures secure data handling and compliance with stringent data privacy regulations, addressing potential security concerns associated with Big Data processing.

The synergy of big data and cloud-based AI/ML processing offers a transformative approach for ULPVs, significantly boosting the vessels' operational capabilities, autonomy, and strategic value in various missions. This integration not only enhances data processing and decision-making capabilities but also ensures scalability, security, and cost-efficiency, marking a significant step forward in the operational dynamics of ULPVs in modern and future landscapes.

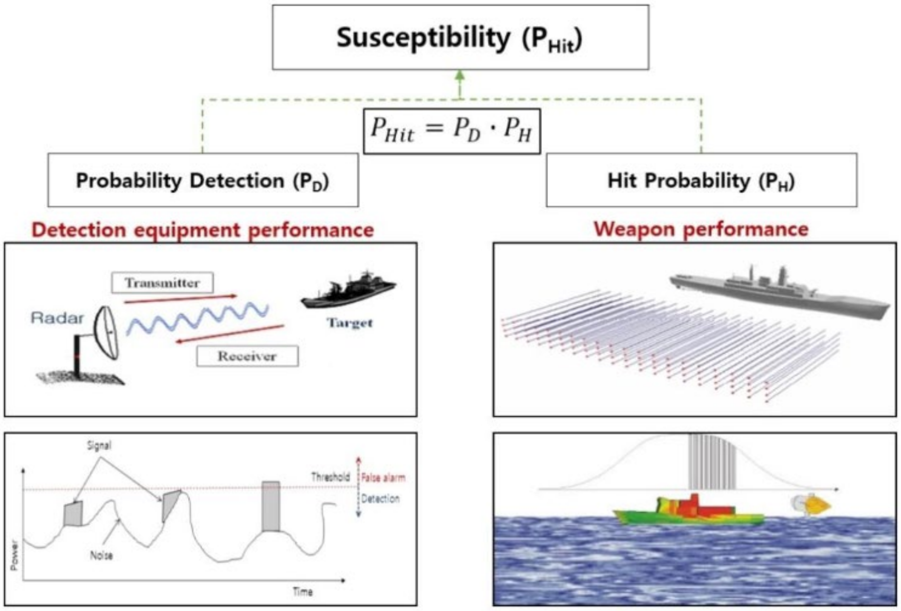
5. Big Data Summary

The role that big data can play in ULPV operations is real, and consideration should be given to possible big data applications. However, incorporating big data into ULPV operations likely has implications for the SWaP of systems onboard a ULPV that support big data analytics. Further, big data may require a level of BLOS communications connectivity that needs to be understood given the anticipated DDIL communications environment in a contested environment. The cost of incorporating big data into ULPV design should also be weighed against the anticipated gain(s) of big data applications.

VII. UNMANNED LOW-PROFILE VESSEL SUSCEPTIBILITY

According to Kim et al. (2014), “the survivability of a ship is evaluated by three types of indicators: its susceptibility, vulnerability, and recoverability”. The most fundamental way to improve vessel survivability involves decreasing susceptibility, a vessel’s probability of being hit by a weapon after being detected, as much as possible (Kim et al., 2014). Ball defines susceptibility “as the inability of a ship to avoid the sensors, weapons and weapons effects of that man-made hostile environment” (Ball & Calvano, 1994).

Figure 41 illustrates how P_d and hit probability contribute to a vessel’s susceptibility. It should be noted that this research assumes that if a ULPV is attacked, it will have little to no capability to defend itself (making itself vulnerable). This research also assumes a ULPV has little to no capability to recover itself since it is unmanned.



Note: These diagrams illustrate the relationship between susceptibility, P_d, and probability of hit. Note that definitions for P_Hit and P_H are nonstandard and somewhat confusing.

Figure 41. Vessel Susceptibility Equation. Source: Kim et al. (2014).

Various methods of detecting a ULPV, like any vessel, exist. A ULPV will have a "signature" that exists along various points of the EM spectrum and a receiver capable of receiving and exploiting that signature will be able to positively contribute toward a greater P_d and hit probability against a ULPV. Figure 42 illustrates various types of signatures that a surface vessel can have.

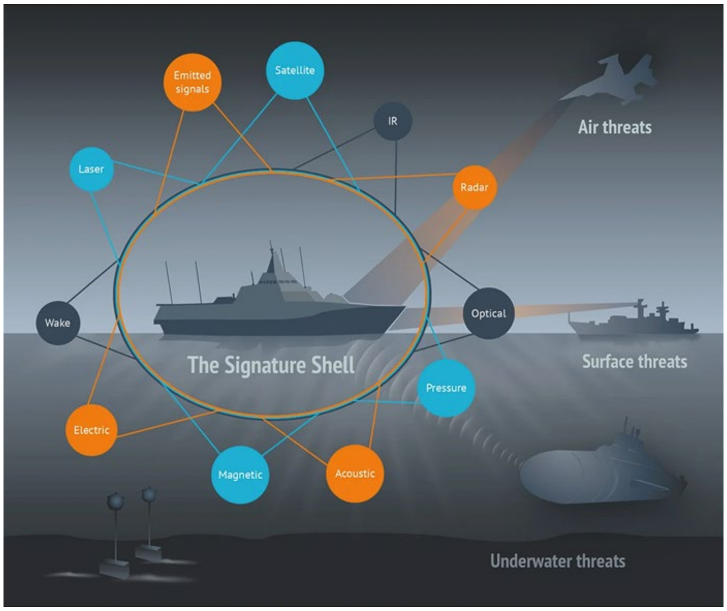


Figure 42. Signatures of a Surface Vessel. Source: Naval Signature Measurement (n.d.).

A receiver may be a sensor in a missile, the antenna of radar system, the eyes or ears of a person, or the supercooled sensor in an infrared camera system. A receiver capable of receiving and exploiting a ULPV signature may be embedded in a weapon, such as in the "seeker" of a missile. A weapon may be capable of guidance toward a ULPV based on a signature received from the ULPV, and in this case, a ULPV's signature may impact weapon performance and the probability that a ULPV may be hit by a weapon. Other factors, such as how much of the ULPV is physically above the water, likely also contributes to hit probability as a weapon's performance may be degraded if it was designed for a target with different characteristics and signatures. Figure 43 shows the typical areas of a DTO LPV that are visible above the surface.

Figure 43. Drug Trafficking Organization Low-Profile Vessel as Viewed from Above. Source: Toledano (2023).

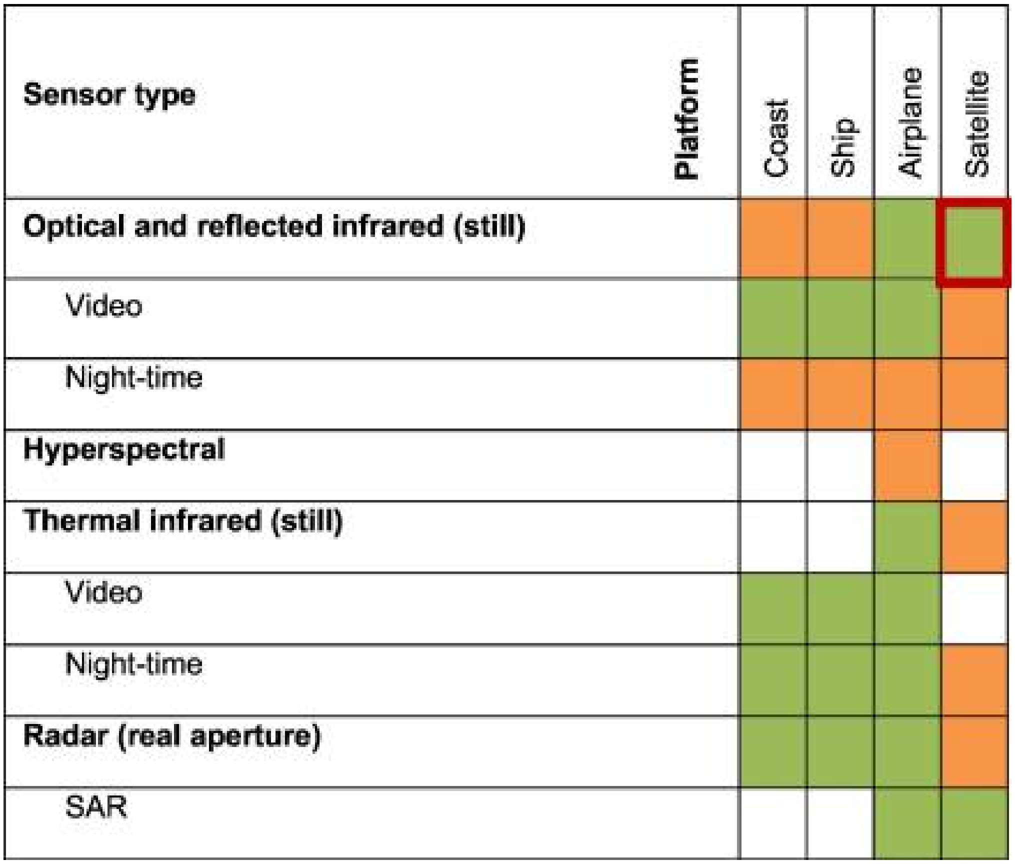
A ULPV will have a signature that is detectable by radar, known as its RCS. A ULPV will have a visible signature that allows it to be seen by the human eye as well as EO sensors, as well as an infrared signature that allows it to be seen by IR sensors. Imaging a ULPV with a specialized multispectral or hyperspectral sensor will reveal yet another signature. An operating ULPV will likely create additional detectable signatures such as noise from operation, wake from disturbed water, or magnetic signature from the presence of certain metals on the vessel. Underwater, a ULPV will have a signature that is detectable by sonar, known as its sonar cross-section (SCS). Figure 44 provides a look at sub-surface area of a DTO LPV, given its hull shape, which likely implications for SCS. A ULPV will also have an acoustic signature, due to the sounds resulting from engine operation or any other onboard systems, such as pumps or cooling fans. Finally, an unmanned vessel like a ULPV is assumed to utilize systems that propagate RF energy, which can also be received by certain sensors, and contribute to a ULPV's RF signature.

Figure 44. Drug Trafficking Organization Low-Profile Vessel Full Hull Image. Source: Bender (2016.).

Figure 45 shows how the USMC prototype of a ULPV, the ALPV, may appear to other nearby surface vessels, from a broadside aspect, due to its small amount of freeboard. A ULPV with so little freeboard will likely have lower radar, optical, and infrared signatures compared to vessels with more freeboard, resulting in lower susceptibility.

Figure 45. United States Marine Corps Autonomous Low-Profile Vessel Horizon Perspective. Source: King (2024).

According to Kanjir et al. (2018), airplanes are commonly used with EO, reflected IR, thermal IR, and radar sensors to conduct maritime surveillance and vessel detection, with hyperspectral sensors also used occasionally by aircraft for these means. Satellites most commonly use EO, reflected IR, and synthetic aperture radar (SAR) to conduct maritime surveillance and vessel detection, while only occasionally using thermal IR and not typically using hyperspectral sensors for this purpose (Kanjir et al., 2018). Kanjir et al. (2018) found that ships and coastal platforms generally rely on the same sensor types for maritime surveillance and vessel detection, namely radar, EO/IR video, and night-time thermal IR stills. These findings are depicted in Figure 46.



Sensor type Platform	Coast	Ship	Airplane	Satellite
Optical and reflected infrared (still)	🟧	🟧	🟩	🟩
Video	🟩	🟩	🟩	🟧
Night-time	🟧	🟧	🟧	🟧
Hyperspectral			🟧	
Thermal infrared (still)			🟩	🟧
Video	🟩	🟩	🟩	
Night-time	🟩	🟩	🟩	🟧
Radar (real aperture)	🟩	🟩	🟩	🟧
SAR			🟩	🟩

This figure shows a "combinations of imaging sensors and platforms that are used for vessel detection and maritime surveillance. A green field means the combination is very suitable and/or frequently used for vessel detection, whereas an orange field means it is only occasionally used for vessel detection. A white colour in the field means the sensor-platform combination is not generally used for detecting vessels" (Kanjir et al., 2018). The red border marks the area of focus by Kanjir et al. (2018).

Figure 46. Sensor Types. Source: Kanjir et al. (2018).

A. RADAR CROSS-SECTION

Current designs of DTO LPVs, as well as designs of ULPVs for contested logistics, tend to have similar general geometries. These geometries are summarized by hulls that are minimally visible broadside, due to their low freeboard, and a mostly flat deck as viewed from above (as shown previously in Figure 43). While some DTO LPV designs use sloped sides on the topside of the vessel, some appear to use rather flat contours with sharp angles throughout the hull.

Stoyanov (1987) highlights that the RCS for a vessel is the result of multiple contributing factors, to include the geometry of the vessel, multiple reflections of electromagnetic energy involving the vessel and the sea, and the wake created by the vessel's movement through the water (p.10). Figure 47 illustrates a textbook example of the various paths that radar energy may take to detect a vessel. As this figure illustrates the effect of electromagnetic energy being reflected off the side of a ship, it underscores the role of a vessel's freeboard as a contributor to a vessel's RCS. In the case of a ULPV, minimal or no freeboard (in the case of a vessel that runs awash), that part of the vessel above the surface, is presumed to result in fewer opportunities for vessel detection along the radar paths illustrated in Figure 47, therefore resulting in a low RCS.

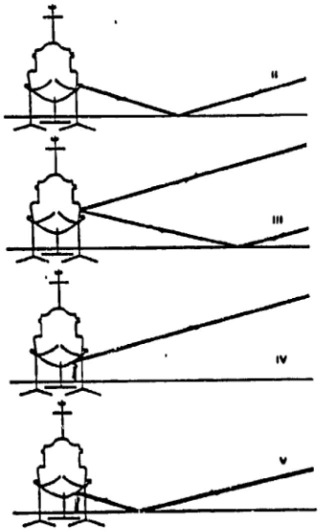


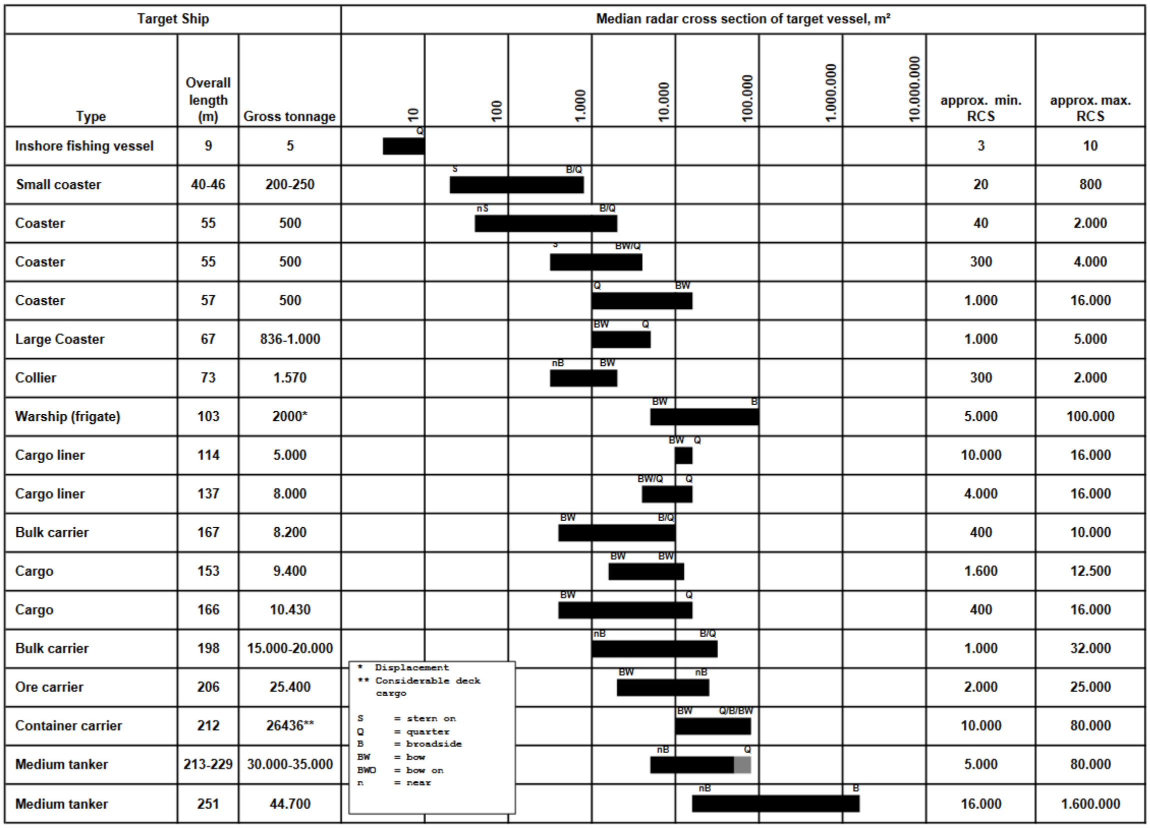
Figure 47. Examples Radar Paths for Vessel Detection. Source: Stoyanov (1987, p.12).

A vessel with little to no freeboard may have a low RCS against radar paths originating from stern, bow, or broadside, however it is still important to consider the RCS of the vessel against radar paths originating from above. A ULPV with any relatively flat aspects of its hull is likely to result in a greatly increased RCS for the ULPV, as according to Stoyanov,

> The most important point to be made about RCS is that a small, efficient reflector – such as a flat plate, normal to the radar beam – can reflect as much energy as a considerably larger sphere, and thus have a large RCS (1987).

This point is especially pertinent to ULPV design as a vessel with so little freeboard and a relatively flat deck should expect its greatest RCS signature to exist when viewed by a receiver above the vessel. Radar paths that originate from above a vessel may come from helos, airplanes, or satellites. In the case of DTO LPVs, the relatively flat top of the vessel hull is a probable contributor to an increased RCS when that radar energy originates from above. This vessel geometry and resulting higher RCS from a top-down aspect is presumably related to the reported dramatic increase in P_d DTO LPVs when helos or maritime patrol aircraft are added to a search for a DTO LPV (Ramirez and Bunker, 2015). According to Ramirez and Bunker, adding an embarked helo to a surface vessel's search for a DTO LPV increased the P_d that DTO LPV from 5% to 30%, and adding a Maritime Patrol Aircraft to the mix increased the P_d the DTO LPV to 70% (2015).

Figure 48 provides estimated median RCS values for vessels based on vessel type, length, and gross tonnage. This reference was utilized to inform the assumed RCS values assigned to the "blue" logistics vessels tested in this effort's modeling and simulation work described in Chapter XIII.



Type	Overall length (m)	Gross tonnage	approx. min. RCS	approx. max. RCS
Inshore fishing vessel	9	5	3	10
Small coaster	40-46	200-250	20	800
Coaster	55	500	40	2.000
Coaster	55	500	300	4.000
Coaster	57	500	1.000	16.000
Large Coaster	67	836-1.000	1.000	5.000
Collier	73	1.570	300	2.000
Warship (frigate)	103	2000*	5.000	100.000
Cargo liner	114	5.000	10.000	16.000
Cargo liner	137	8.000	4.000	16.000
Bulk carrier	167	8.200	400	10.000
Cargo	153	9.400	1.600	12.500
Cargo	166	10.430	400	16.000
Bulk carrier	198	15.000-20.000	1.000	32.000
Ore carrier	206	25.400	2.000	25.000
Container carrier	212	26436**	10.000	80.000
Medium tanker	213-229	30.000-35.000	5.000	80.000
Medium tanker	251	44.700	16.000	1.600.000

* Displacement
** Considerable deck cargo

S = stern on
Q = quarter
B = broadside
BW = bow
BWO = bow on
n = near

Figure 48. Radar Cross-Section Approximations for Vessels. Source: Williams et al. (1978).

One final note regarding RCS concerns SAR. SAR is a type of radar used to detect vessels and is probably the best available sensor for vessel detection by aircraft or satellites because it can image relatively wide areas at constant resolution and can function independent of cloud cover or daylight (Kanjir et al., 2018). For this reason, the RCS of a ULPV as viewed from airborne and spaceborne assets should be heavily considered and accounted for in ULPV design. If the vessel is made of metal and its hull contains any sharp edges or surfaces that reflect radar energy intensively, and the vessel is operating in open waters, then the vessel will appear as bright dots and edges (Kanjir et al., 2018). In the case of ULPV design, reducing susceptibility requires a vessel design that does not reflect radar energy back toward airborne or spaceborne sensors, with a mind toward geometry and fabrication material choice.

B. INFRARED SIGNATURE

How a ULPV appears to a receiver capable of "seeing" in the infrared spectrum is a ULPV's infrared signature. As viewed from above, a ULPV infrared signature may be significant, as demonstrated by one DTO LPV in Figure 49, due to the differences in infrared energy returned by the vessel compared to that returned by the water surrounding the vessel. A ULPV's overall IR signature is contributed by three parts, according to Ball (1985): IR radiation from the engine hot parts and exhaust hot parts, the plume IR signature from hot engine exhaust gas, and the solar radiation reflected off the body of the vessel.

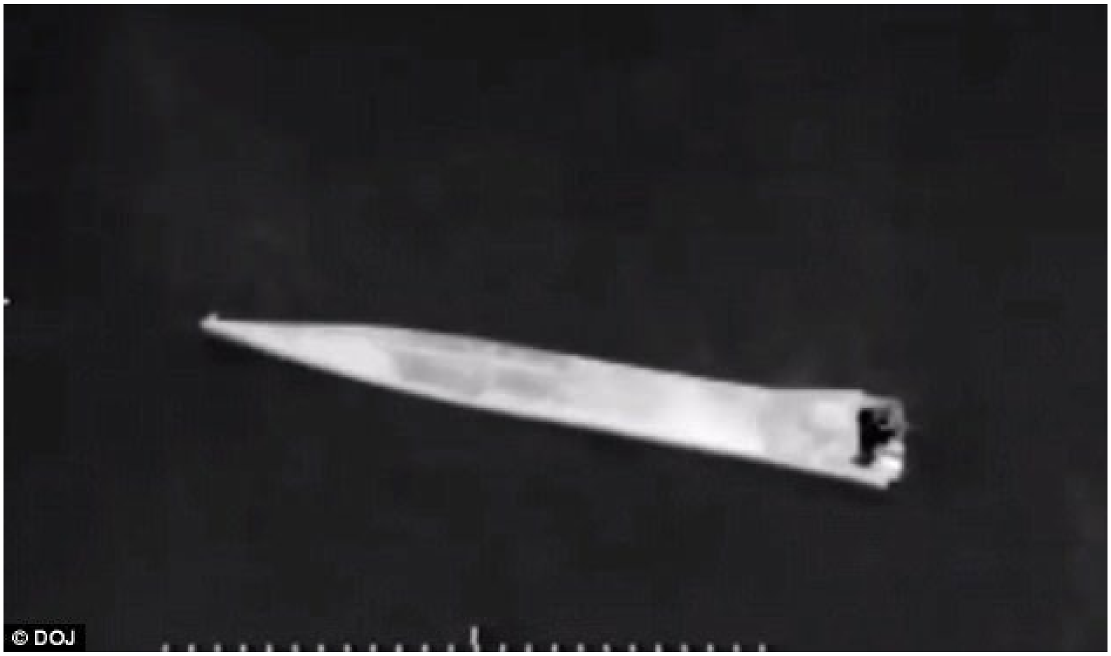


Figure 49. Infrared Image 1 of a Narco Sub. Source: Gordon (2017).

In the case of a vessel that runs awash, where the water surrounding the vessel runs over the top of its hull, the IR signature of that vessel is expected to decrease. Figure 50 shows a DTO LPV running awash, with waves running over the top of its hull. The result appears to be a much lower contrast between the IR energy returned by the vessel and that of the water surrounding the vessel, resulting in a much lower IR signature for the vessel. A ULPV should be designed to consider the impact of its design, resulting IR signature, and the implications of that signature on its overall susceptibility.

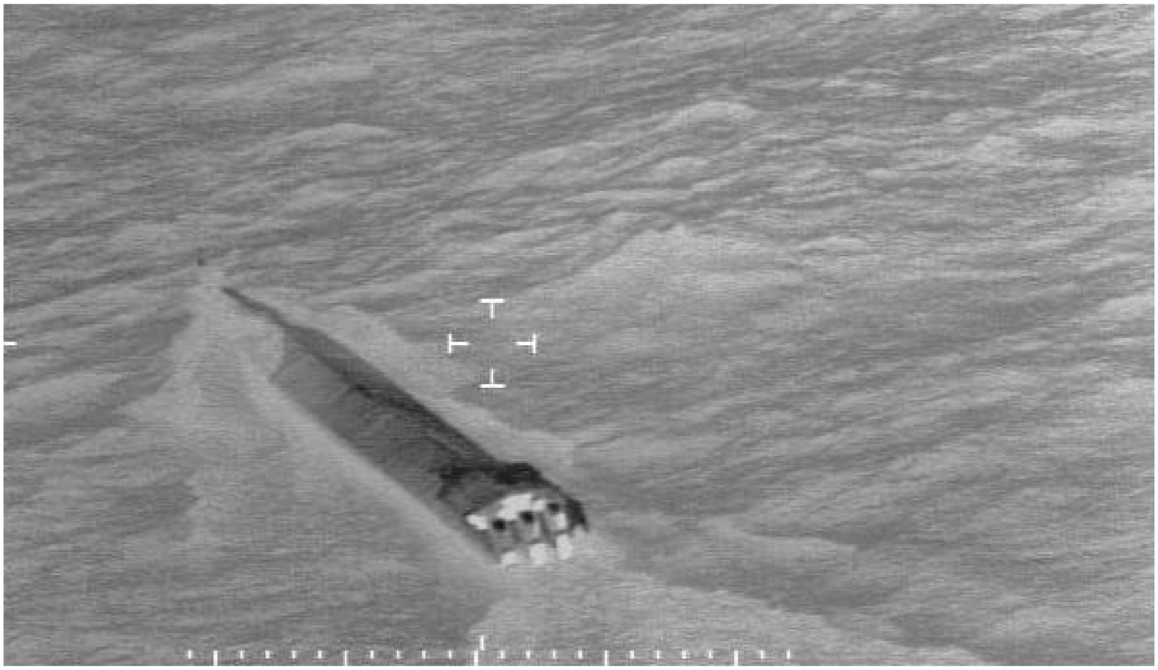


Figure 50. Infrared Image 2 of a Narco Sub. Source: Customs and Border Protection (2018).

C. WAKE DETECTION

Ship wake generated by vessels moving through water is another signature that can be detected to increase a vessel's susceptibility. Wake can make a vessel more detectable as the disturbed water trailing the vessel is often white in appearance and wake creates its own RCS signature. A small ship moving at high speed, for example, might create a wake that is large enough in height and length that a radar scattering from the wake may return a signal strong enough for detection (Stoyanov, 1987, p.10). Some weapons, like wake-homing torpedoes, are guided by sensors that detect the presence of persistent turbulence of a surface ship's wake (Peláez & Sevilla, 2013). DTO LPVs generally operate at speeds at or below 10kts and generate almost no wake (Ramirez & Bunker, 2015) and a ULPV with a design that creates little to no wake will decrease that vessel's susceptibility. Figure 51 shows a DTO LPV operating at high speed, presumably attempting to evade interdiction, and creating significant wake.

Figure 51. Wake Generated by a Fleeing Narco Sub. Source: Global Security (n.d.).

Peláez & Sevilla (2013) highlighted that wake may also create infrared implications for a vessel's signature, especially in the case when the vessel operates in warm waters. Known as "thermal scarring," this phenomenon occurs when a moving vessel disturbs the warmest water at the surface and creates thermal contrast in the sea surface (Peláez & Sevilla, 2013). As seen in Figure 52, this results in a long-lasting thermal streak behind the vessel, as viewed from an infrared sensor.

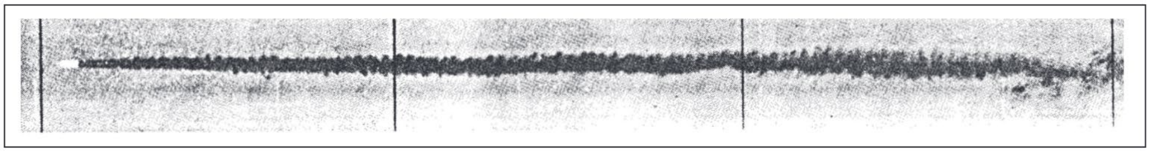


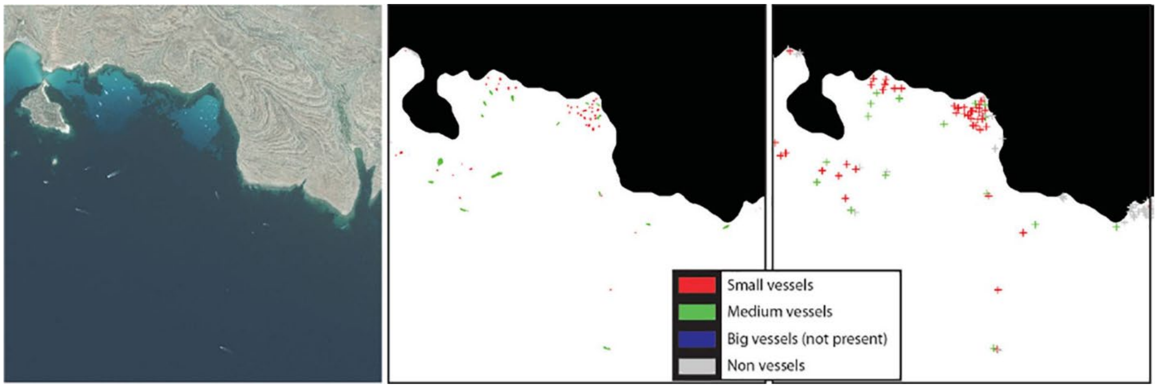
Figure 52. Thermal Scar and Wake Signature Behind Vessel. Source: Voropayev et al. (2011).

D. OPTICAL

Kanjir et al. (2018) highlights that the most common vessel detection technique in optical imagery exploits how vessels are often brighter than their immediate surroundings. Therefore, ULPVs can decrease their susceptibility against optical receivers by utilizing a paint scheme that contrasts the least with the waters it operates in. As shown in Figure 53, DTOs occasionally paint their LPVs to decrease their vessel's susceptibility.

Figure 53. Blue Painted Narco Sub. Source: Sutton (2020).

Many studies on optical detection of vessels from space sensors indicate a relatively high success rate for vessel detection, however, most results seemed to use a small number of images for testing and those images were usually of vessels in calm sea states (Kanjir et al., 2018). Figure 54 shows an example vessel detection and classification by a space based optical sensor. However, even if detected, a vessel smaller than 10m in length is very difficult to classify, though this may change as space-based optical sensors become more numerous and capture images with increasingly higher resolutions (Kanjir et al., 2018).



"Left: input image. Middle: classified segments with the land removed. Right: classified targets marked with crosses. Small (red) vessels represent detected segments smaller than 20 m, medium (green) between 20 m and 100 m, and big (blue) vessels are the ones measuring more than 100 m." Kanjir et al. (2018).

Figure 54. Vessel Classification on a GeoEye-1 Image Based Vessel Size. Source: Kanjir et al. (2018).

E. UNMANNED LOW-PROFILE VESSEL SUSCEPTIBILITY SUMMARY

Despite its low-profile nature and minimal freeboard, ULPVs will have various signatures that will be detectable to various receivers. Reducing those signatures will decrease the susceptibility of a ULPV. Upon visual analysis of most LPV and ULPV designs, it appears that the area which contributes greatest to this vessel type's susceptibility is the top of the vessel, or its deck, which is generally flat and most detectable by airborne or spaceborne receivers. This is especially true regarding optical systems if the vessel appears to contrast significantly from the color of the waters surrounding it. Detection of a ULPV from above may occur after a sensor capable of observing a large area, such as a radar or optical satellite sensor, detects the presence of the vessel and cues a different sensor, such as an infrared sensor, to scan a specified area and classify the vessel type. Specialized paint schemes or low-observable coatings may be considerable methods of decreasing ULPV signatures; however, these methods were not explored in this research. It may also be possible to incorporate ULPV behaviors and capabilities that can further decrease susceptibility. For example, a ULPV might be designed with the ability to stop its engines and increase ballast to the point of becoming completely submerged just below the water for a limited time when the situation necessitates such a maneuver.

THIS PAGE INTENTIONALLY LEFT BLANK

VIII. MODELING AND SIMULATION: UNMANNED LOW-PROFILE VESSEL CONTESTED LOGISTICS

Parts of section E of this chapter were previously published by the Acquisition Research Program at NPS (Sierra, 2024).

A. OVERVIEW AND ASSUMPTIONS

Part of this research uses modeling and simulation to inform relatively unknown aspects concerning the idea of ULPVs for contested logistics. One analysis, using the NGTS, seeks to understand the P_d and susceptibility of ULPVs operating in the Indo-Pacific against some threats from the PRC. Another analysis seeks to better understand the impact of ULPVs on maintaining a steady level of supply for expeditionary units, such as Marines operating on EABs during a conflict with the PRC.

Some environmental conditions are assumed for the contested logistics modeling and simulation efforts in this research. Table 5 outlines the transit distances assumed necessary for blue vessels to transit, as well as the weather conditions assumed during transit and the arrival conditions assumed necessary for a beach landing at the destination.

Table 5. Contested Logistics Scenario Environmental Assumptions: Long Distance Transit with Beach Landing Destination

Transit Distance (departure to arrival)	Approximately 1,920 NM (see Figure 55) 16° 15’ 49.572911”N, 154° 47’ 29.532522”E (Edge of DF-26B WEZ) to 23° 30’ 50.160180”N, 121° 27’ 11.373609”E (Eastern Shore of Taiwan)
Weather and Sea States (during transit)	Within operating limits of all vessels
Object Avoidance (in transit)	All blue vessels are assumed to avoid obstacles during transit, including vessels, islands, or sandbars.
Beach Landing and Obstacle Avoidance (at destination)	Beach landings are required, and all blue vessels will be capable of conducting beach landings and obstacle avoidance. Shallow draft vessels are expected as necessary to accomplish a beach landing due to the assumed presence of coral, rocks, lava beds, and shallow waters when approaching the beach.

Figure 55. Map of Transit for Contested Logistics Scenario: DF-26B WEZ Boundary to First Island Chain

B. NEXT GENERATION THREAT SYSTEM: CONTESTED LOGISTICS SIMULATION

From a journal on defense modeling and simulation, Tryhorn et al. described NGTS with the following:

> NGTS is a military simulation environment produced by the Naval Air Warfare Center Aircraft Division (NAWCAD) that provides real-time military scenario simulations. NGTS models threat and friendly aircraft, ground, surface, subsurface platforms, corresponding weapons and subsystems, and interactions in a theater environment. (2023)

NGTS modeling and simulation work in this research is a collaborative effort between the NPS and the Naval Information Warfare Center (NIWC) Pacific, specifically Dr. Glenn-Ian Steinback who is the modeling and simulation lead for the live, virtual, constructive (LVC) team at NIWC Pacific at the time of this research.

As stated by Kim et al. (2014), decreasing a vessel's P_d as much as possible is the most fundamental way to decrease the vessel's susceptibility, therefore increasing the likelihood of survival against enemy forces. This research uses NGTS to inform the susceptibility of a ULPV against threats from the PRC, in particular, the probability that a ULPV will be detected by a surface vessel or airborne asset.

NGTS was used to simulate a ULPV, and other logistics vessels, transiting a contested environment, specifically, a body of water shared by various types of PRC surface and airborne assets. The outcome of each NGTS simulation occurrence provided data on if a logistics vessel was detected or remained undetected during transit. Being detected, in the context of this research, is defined as the presence of the blue asset being noticed and the identity of the blue asset being known. ULPVs and other logistics vessels are assumed to be unarmed and vulnerable, therefore, it is assumed that maximizing a logistics vessel's chance of successfully completing logistics missions in a contested battlespace depends on remaining undetected.

1. Scenario and Behavior

The NGTS scenario used to analyze ULPV P_d encompasses a 120 NM-by-120 NM maritime space in the simulation environment. Depicted in Figure 56, the right edge of the simulation area marks the "start" line for the blue (friendly) asset and the left edge of the simulation area marks the "finish" line for the blue asset. Upon simulation start, the blue asset materializes at a random point along the start line and maintains a direct, straight-line course toward the finish line at a constant speed. The blue asset does not exhibit any other behavior.

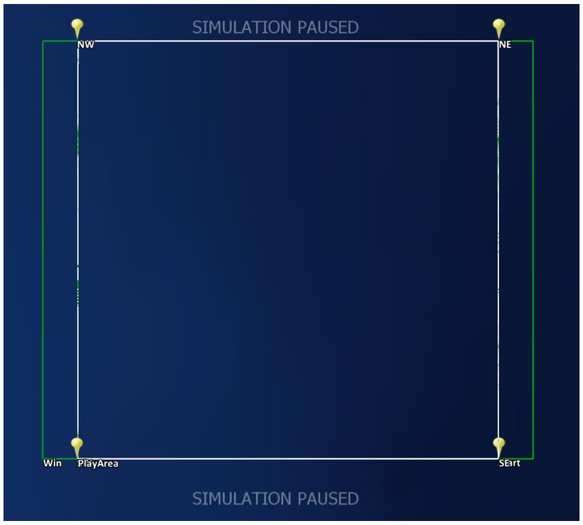


Figure 56. Screenshot of Unmanned Low-Profile Vessel Research Simulation Area

Upon simulation start, if the red asset is a surface vessel, it materializes at a random point within the simulation area and chooses a random point to navigate toward within the simulation area, and then, after reaching that point, continues navigating in the same heading through the boundary of the simulation area. Figure 57 shows a screenshot of the simulation at the start of a run with a red surface vessel. NGTS displays assets for improved visibility, and as a result, all blue and red assets on screenshots are not displayed to scale.

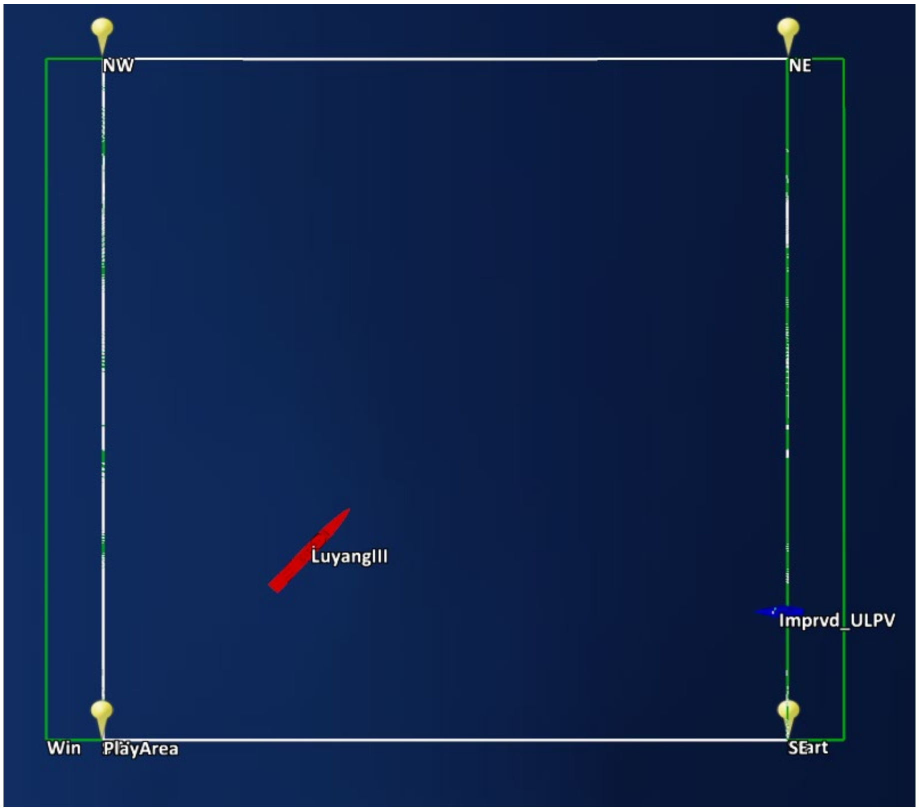


Figure 57. Screenshot at Point of Simulation Start with Red Surface Vessel

In the case that the red asset is a fixed-wing aircraft, upon simulation start, the red fixed-wing aircraft materializes at a random point outside of the simulation environment and chooses a random point within the simulation area to navigate toward, and then, after reaching that point, continues navigating in the same heading through the boundary of the simulation area. Figure 58 shows a screenshot of the simulation at the start of a run with red fixed-wing aircraft.

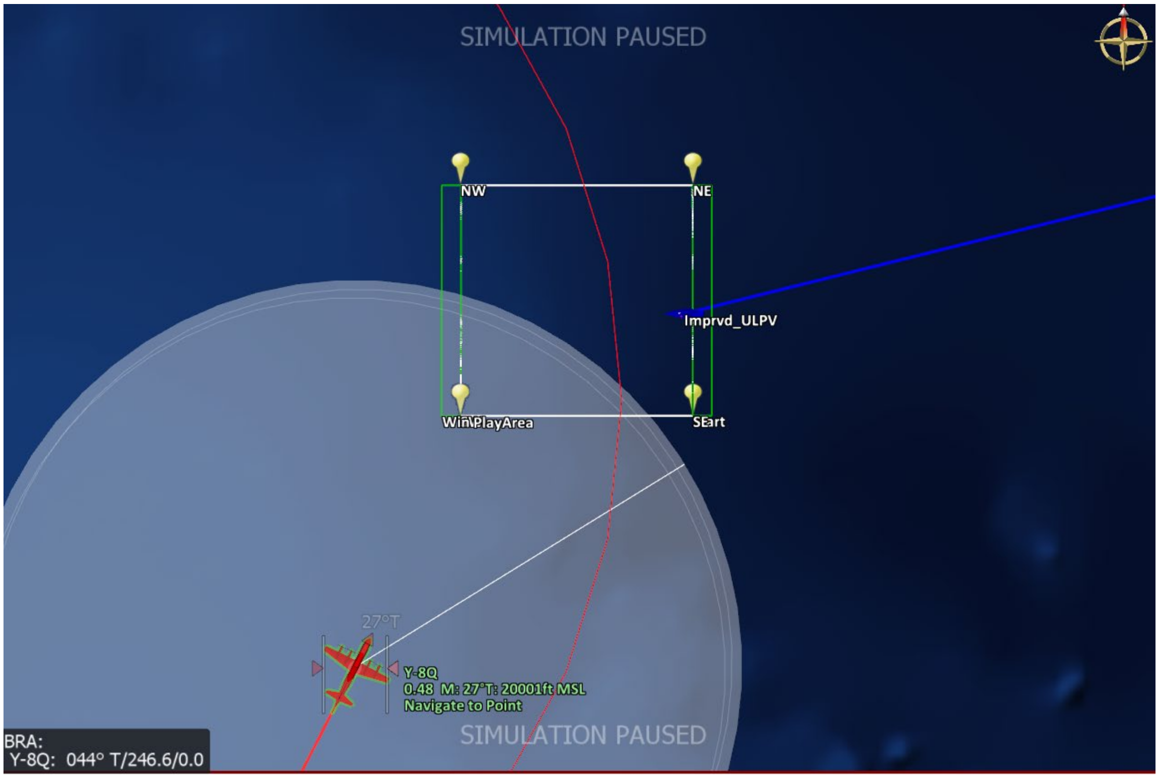


Figure 58. Screenshot at Point of Simulation Start with Red Fixed-Wing Aircraft

Throughout all times of the simulation, the red asset uses its sensors to search for any blue asset in the area of interest. The types of sensors equipped on a red asset and the corresponding capabilities of those sensors are modeled according to openly available unclassified data originating from Janes Information Services (Janes, n.d.), as delivered by NIWC Pacific within the NGTS scenario file. If a red surface vessel carries a helo, it launches that helo throughout every three hours of simulation time and that helo searches the area of interest for any blue asset. A helo launched by a red surface vessel remains airborne for one hour and orbits the red surface vessel approximately 20 NM from the red surface vessel.

Table 6 highlights general operational characteristics of the red assets used in the NGTS simulations. Table 7 highlights the general operational characteristics of the blue assets used in the NGTS simulations, as well as design characteristics that impact their physical signature.

Table 6. Red Assets

	LuyangIII	Ka-27 (Enbarked on LuyangIII)	Y-8Q*
Type	Surface Vessel	Helo	Fixed-Wing Aircraft
Speed	19 kts	0.27 Mach	0.48 Mach
Altitude (ft MSL†)	0	5,000	20,000
Sensor 1	Eyeball	Eyes	Eyeball
Sensor 2	Knife Rest	Optics	Generic IRST‡
Sensor 3	Dragon Eye	OSMINOG	APS-504
Sensor 4	Active Sonar	Ros-V Sonar	
Sensor 5	Sea Gull C (Type 364)		
Sensor 6	Type 345 MR35		

*No magnetic anomaly detector equipped on Y-8Q in NGTS
†Mean sea level (MSL)
‡Infrared search and track (IRST)

Table 7. Blue Assets

	DTO LPV	Improved ULPV	LCU-1610 Class	LCAC†
Length (ft)	70	100	135	92
Beam (ft)	10	14	30	48
Height (freeboard) (ft)	1	0.5	10	16.41
IRCS (W‡/sr*)	53.34	106.67	1,234.38	1,345.93
RCS (m²)**	1	0.1	150	100
Speed (kts)	10	10	11	20

†Landing craft air cushion (LCAC)
‡Watt (W)
*Steradian (sr)
** Meter(s) (m)

2. Assumptions and Limitations

Some assumptions and limitations are made in the NGTS simulation.

- Data used to create the performance parameters for all red (PRC) assets is based on unclassified, open-source information.

- In the case of two blue assets, the LCU-1610 Class and the LCAC, open-source information is used to model these vessels' length, beam, height, and speed.
- For all blue asset RCS values, an estimate was made based on RCS approximation data from Williams et al. (1978), as shown in Figure 48 (found in Chapter VII), with consideration for vessel size, freeboard, geometry, and vessel material type. For example, in the case of the DTO LPV, fiberglass as a vessel material type decreased its RCS value and a low amount of freeboard also decreased its RCS value.
- For all blue asset IRCS values, an estimate was made based on an estimate of the surface area of the vessel as viewed from above, by multiplying the beam and length of each vessel. After calculating the estimated vessel surface area, the value was either halved if the vessel had low freeboard during operation (freeboard less than or equal to 2 ft) or quartered if the vessel ran awash during operation.
- The P_d of blue vessels by red submarines was not included in the NGTS simulations.
- Detection of blue vessels was only simulated by those red assets listed in Table 6 (Red Assets). No other red assets capable of detecting blue assets in the air, land, sea, space, or cyberspace domains were included in the NGTS simulations.
- The threat of destruction by naval mines was not included in the NGTS simulations.
- Electromagnetic signatures of blue assets were assumed nonexistent in the NGTS simulations, and should these signatures be present on a blue asset, their ability to change a blue vessel's P_d was not simulated.
- Weather is not included as a variable in the NGTS simulations.
- No fuel constraints existed for any assets in the NGTS simulations. However, the helo operating from the LuyangIII exhibited flight times consistent with fuel limitations before recovering to the LuyangIII.
- All assets operated at constant speeds and those speeds are defined in Table 6 and Table 7.

- Assumed no interference of red asset sensors by weather or geography to introduce radar clutter or shadowing.

3. Data and Findings

The average detection range of each blue vessel by each red vessel was determined by averaging three measurements of distance when a red asset's radar detected the blue asset. The detection range of each red asset was influenced by the radar horizon, illustrated in Figure 59, where the distance a red asset's radar could detect the blue asset at would be influenced by the height of the red asset's radar sensor and the height of the blue vessel. As the red asset radar heights never changed, because red asset characteristics were fixed in all simulation runs, the difference in vessel height between blue vessels likely influenced radar detection ranges. In addition to blue vessel height, the blue vessel's RCS played a role.

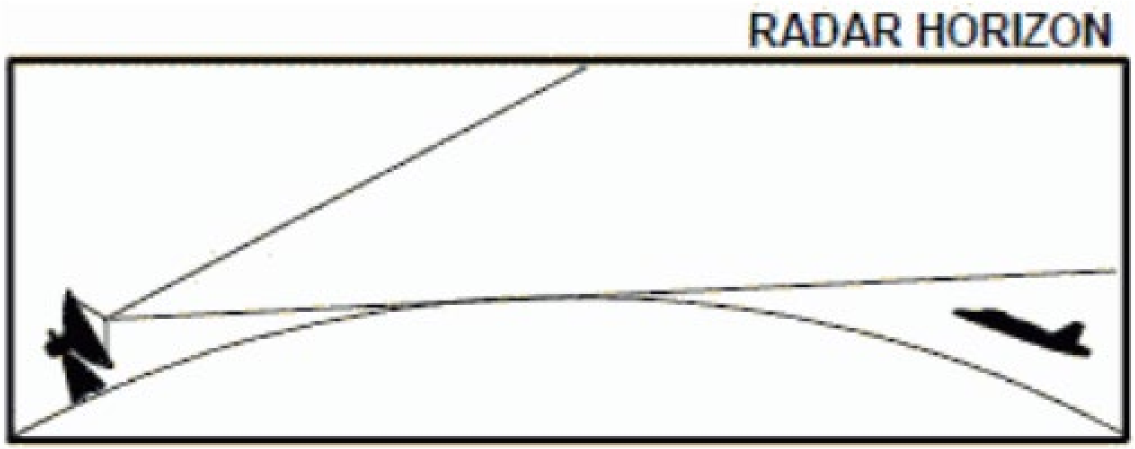


Figure 59. Radar Horizon Illustration. Source: Naval Air Warfare Center (1999).

The LuyangIII's surface search radar within NGTS performed capable enough to detect practically anything between it and the horizon. For example, the Improved ULPV with an RCS of 0.1 m^2 was detected by the LuyangIII at a range of 11.20 NM, on average. The LuyangIII detected the LCU-1610 Class vessel, with its RCS of 150 m^2, at 13.30 NM, on average. The LCAC was detected at 15.50 NM, on average, likely due to the vessel's higher vessel height despite having a smaller RCS than the LCU-1610 Class. Table 8 displays the average detection ranges of each blue vessel by each red asset and Figure 60 depicts the same data in a bar chart.

Table 8. Average Radar Detection Ranges of Blue Vessels by Red Assets

	NGTS: Average Radar Detection Ranges (in NM)			
	LCAC	**LCU-1610 Class**	**DTO LPV**	**Improved ULPV**
LuyangIII	15.50	13.30	11.40	11.20
Ka-27	15.93	15.87	15.97	15.90
Y-8Q	180.43	179.07	83.87	50.60

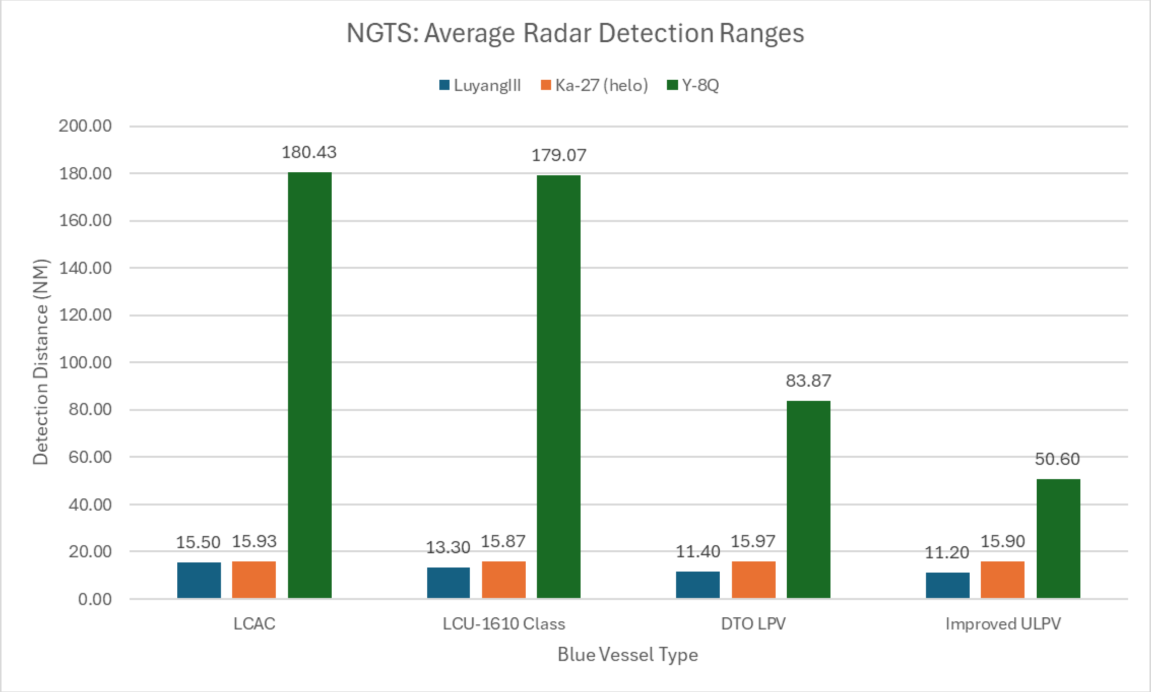


Figure 60. Average Radar Detection Ranges of Blue Vessels by Red Assets

The following figures, Figures 61 and 62, show the raw number outcomes and corresponding percentages for the DTO LPV detections in the NGTS simulation runs.

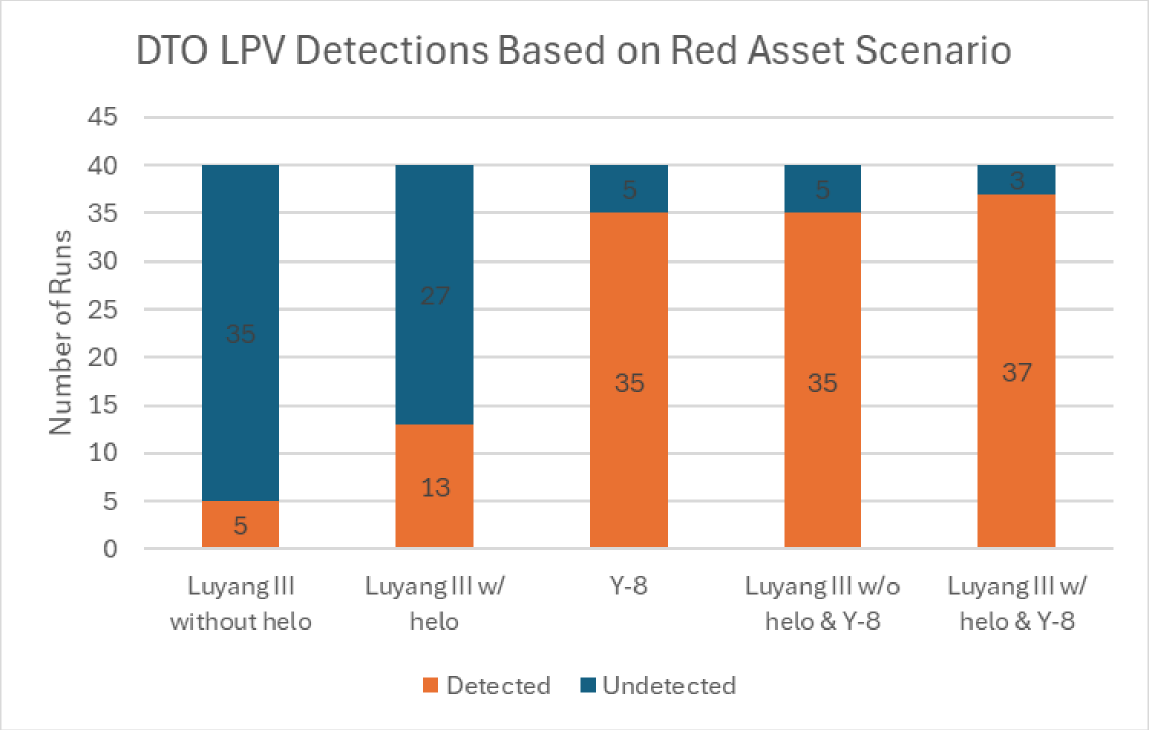


Figure 61. Drug Trafficking Organization Low-Profile Vessel Detections Based on Red Asset Scenario

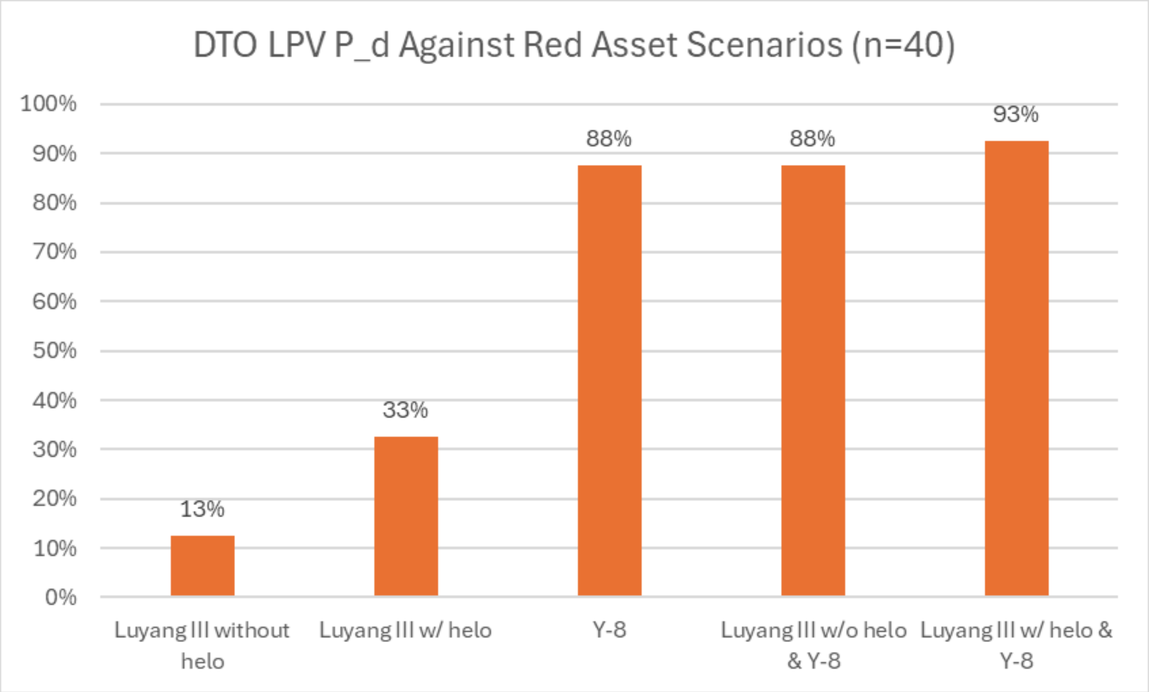


Figure 62. Drug Trafficking Organization Low-Profile Vessel Probability of Detection Against Red Asset Scenarios

The following figures, Figures 63 and 64, show the raw number outcomes and corresponding percentages for the LCU-1610 Class detections in the NGTS simulation runs.

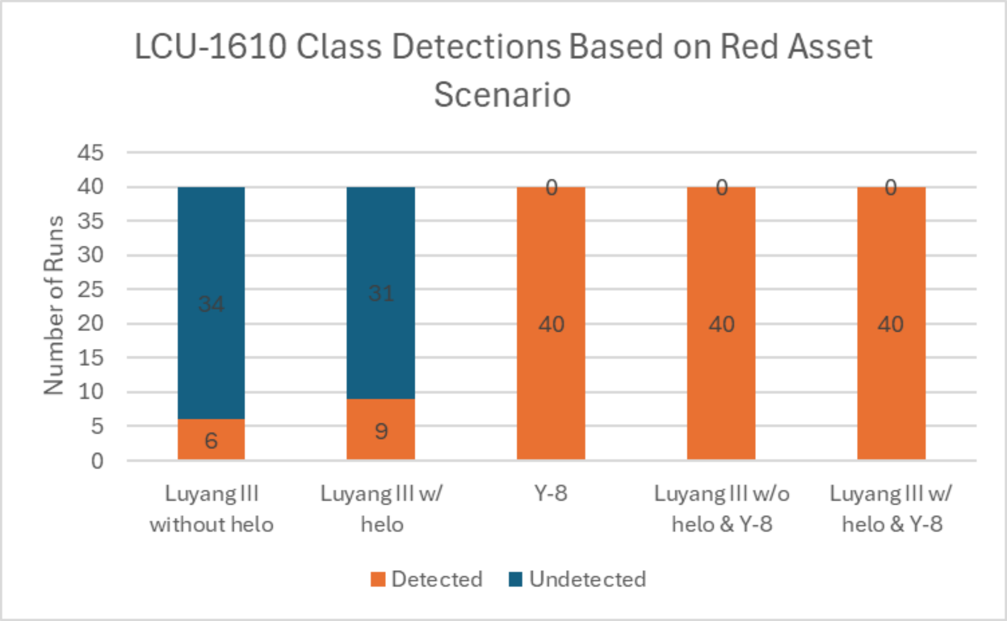


Figure 63. LCU-1610 Class Detections Based on Red Asset Scenario

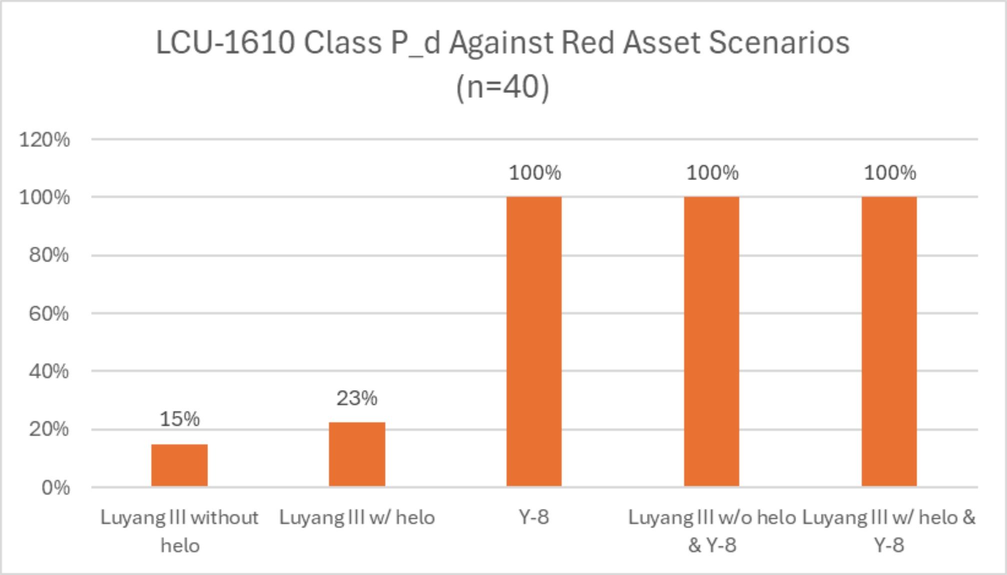


Figure 64. LCU-1610 Class Probability of Detection Against Red Asset Scenarios

The following figures, Figures 65 and 66, show the raw number outcomes and corresponding percentages for the LCAC detections in the NGTS simulation runs.

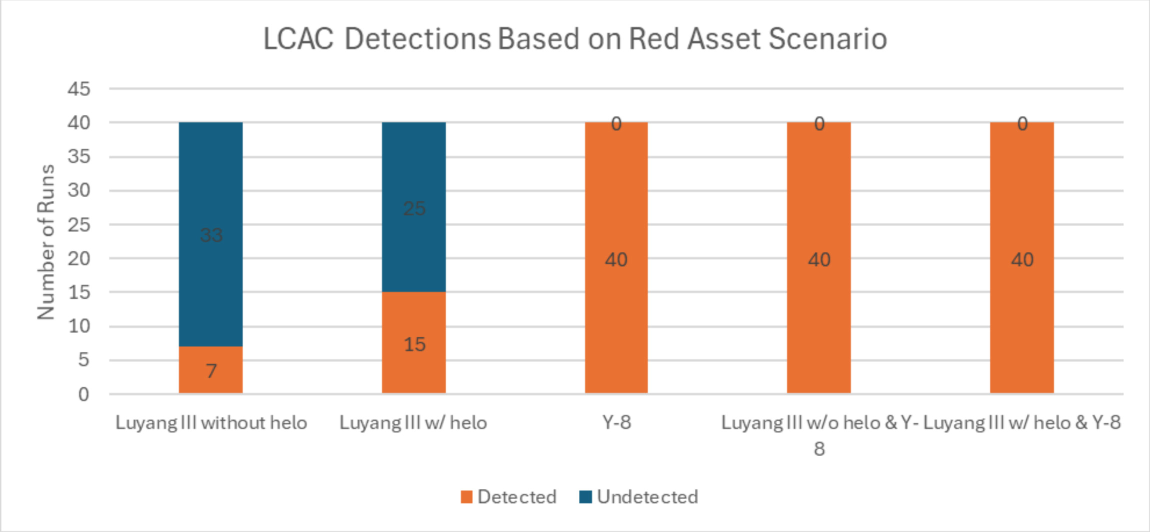


Figure 65. Landing Craft Air Cushion Detections Based on Red Asset Scenario

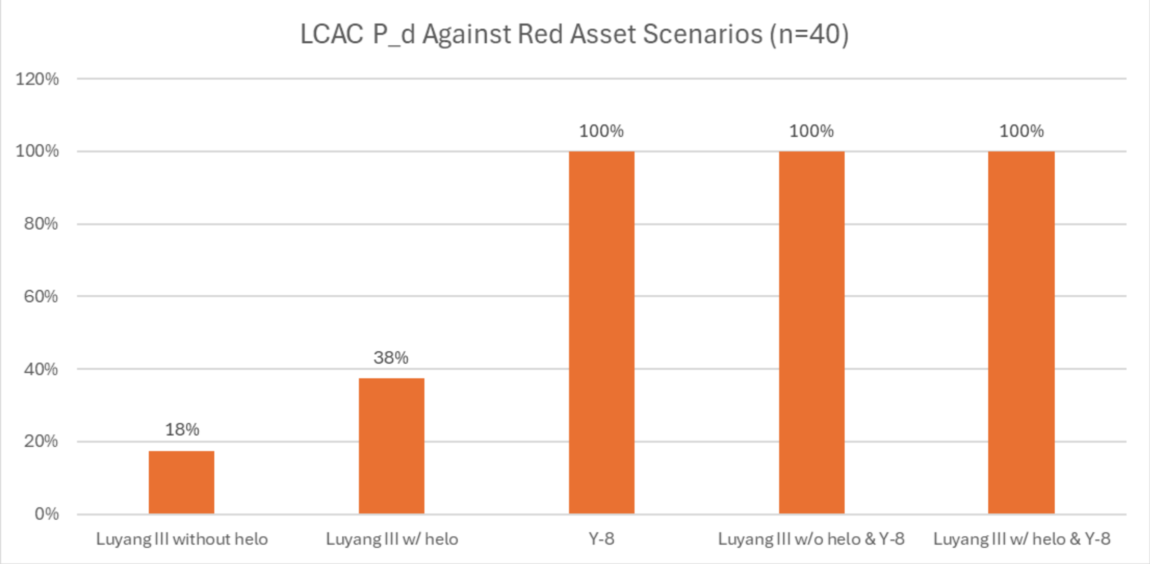


Figure 66. Landing Craft Air Cushion Probability of Detection Against Red Asset Scenarios

The following figures, Figures 67 and 68, show the raw number outcomes and corresponding percentages for the Improved ULPV detections in the NGTS simulation runs.

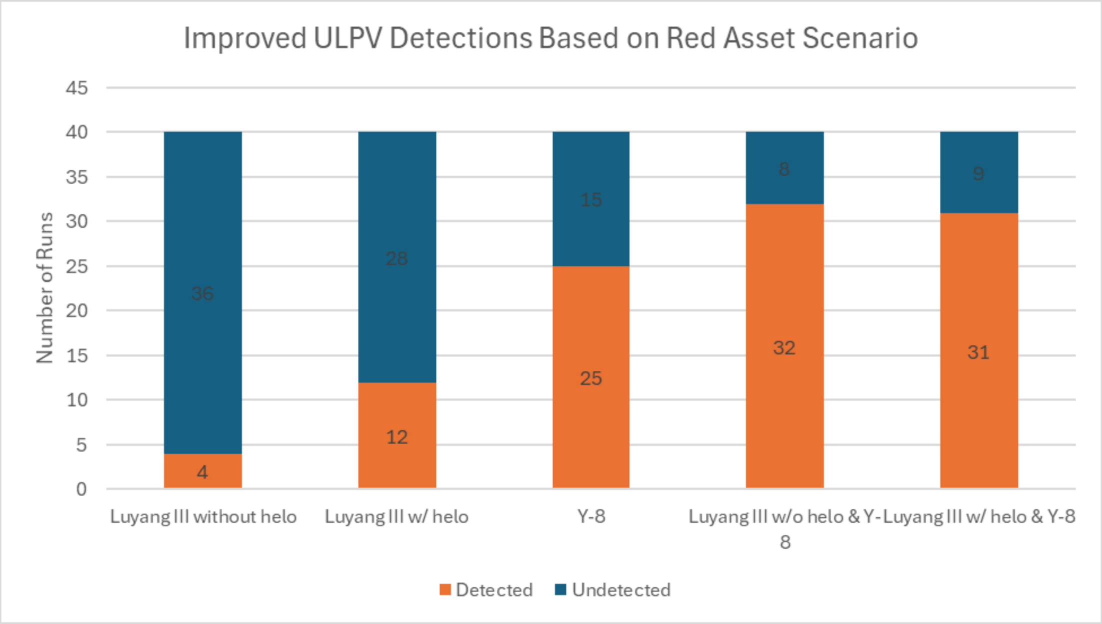


Figure 67. Improved Unmanned Low-Profile Vessel Detections Based on Red Asset Scenario

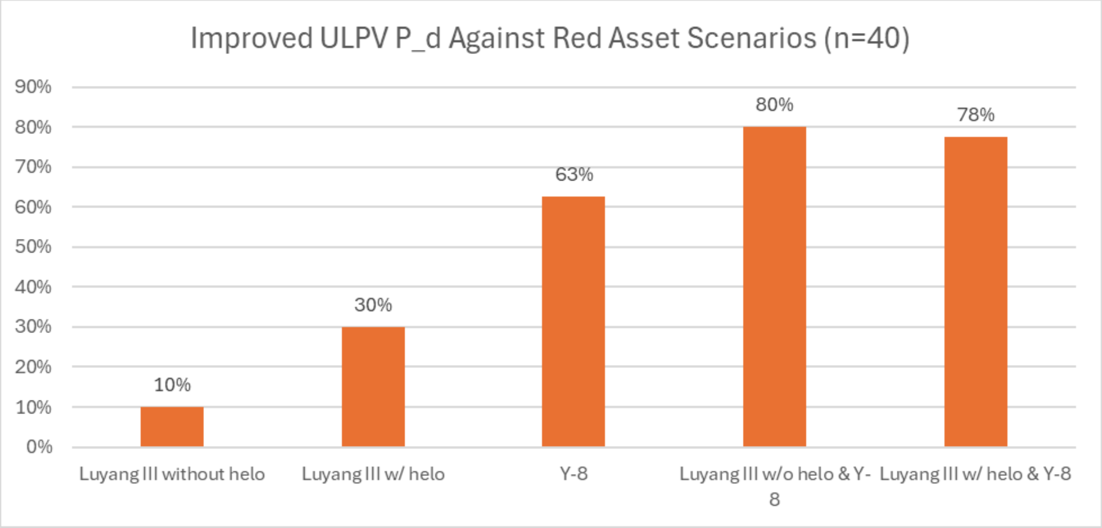


Figure 68. Improved Unmanned Low-Profile Vessel Probability of Detection Against Red Asset Scenarios

C. APPLICATION OF NEXT GENERATION THREAT SYSTEM FINDINGS

The outputs from the NGTS simulation runs provided the data on a given blue vessel's P_d against one of five scenarios of red asset(s) that are assumed to be present within the same 120 NM-by-120 NM space as the blue vessel. However, the presence of any red asset within the same space as a blue vessel must be given a probability of occurring since a blue vessel in transit along the 1,920 NM journey to the first island chain does not have a 100% chance of encountering a PRC asset along the way. To account for this, as shown in Figure 69, the 1,920 NM journey is broken into 16 individual points, to reflect a vessel needing to transit 16 individual 120-by-120 NM spaces to accumulate the total 1,920 NM distance.

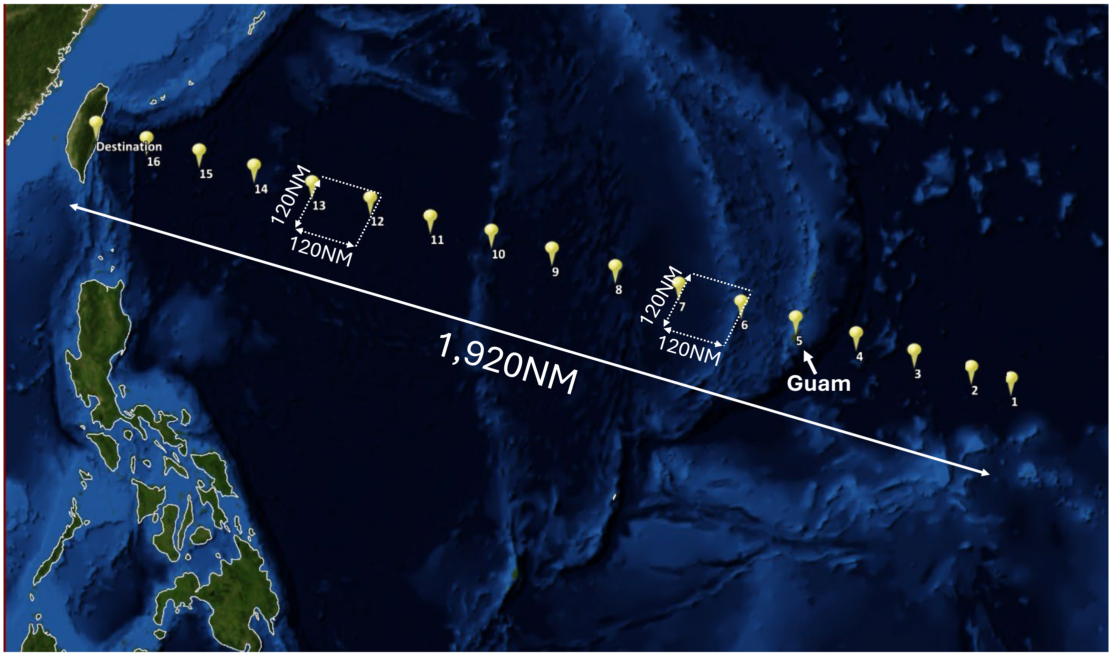


Figure 69. Blue Vessel Transit Visualization, 1,920 Nautical Miles from Edge of DF-26B Weapon Engagement Zone to First Island Chain

At each of the 16 points, a probability was assigned for the chance a red asset is present at that point, with an equation used to continually increase the probability of a red asset being preset as the blue vessel approached the destination. Two equations were used to calculate the probability of a red asset being present. While both equations used a "step value” to increase the probability of a red asset being present as the distance point increased, the first equation (termed “Lower Risk of Red Presence”) used a lower step value than the second equation (termed “Higher Risk of Red Presence”).

The Lower Risk of Red Presence equation, used to calculate the probability of a red asset being present at a given point, is given as

$$P_r = 0.1 + \left((0.015 + (0.025 - 0.015)) * Rand(\square)\right) * p \qquad (1)$$

In Equation 1 P_r is the probability of a red asset being present at any point of interest; 0.1 is a constant representing the assumed minimum probability of red being present, 0.015 and 0.025 are constants representing the range of the random probability change, Rand() is the function to generate a random number value from a uniform distribution between 0 and 1. p in Equation 1 is the distance point (ranging from 1 to 16). Multiplying by p increased the P_r output when the vessel is closer to the destination, operating off the assumption that a blue vessel would have a higher probability of encountering red assets the closer it gets to mainland China. The reason for using a random number generator in equation is to account for the aleatory uncertainty in the operational environment. Since the location and behavior of red assets cannot be known, by using random number generators in simulation, a distribution instead of a point estimate is used.

The Higher Risk of Red Presence equation, Equation 2, used to calculate the probability of a red asset being present at a given point, is given as:

$$P_r = 0.1 + \left((0.025 + (0.055 - 0.025)) * Rand(\square)\right) * p \qquad (2)$$

In Equation 2 P_r is the probability of a red asset being present at any point of interest. 0.025 and 0.055 are constants representing the range of the random probability change while all other aspects of Equation 2 remain the same as Equation 1. In Equation 2, the higher values used for the range of random probability change results in higher P_r outputs from Equation 2 compared to Equation 1, which is the reason Equation 2 is named Higher Risk of Red Presence.

The probability of red asset being present at point $p = 1$ is assumed as a constant of 0.1, (10%). When $p = 1$, neither Equation 1 nor Equation 2 is used to calculate P_r.

Further, the type and quantity of PRC asset that a blue vessel encounters in transit, assuming any PRC (red) asset is present within the same space as the blue vessel, would presumably have different probabilities of occurring based on the distance that the blue vessel is from mainland China. To account for the changing probabilities of red asset composition that may exist at various points along the blue vessel's transit to the destination, the 1,920 NM journey was broken into 3 distinct distance categories, D1, D2, and D3. As shown in Figure 70, D1 encompasses the first 6 points of transit (P1–P6), D2 encompasses the next 6 points of transit (P7–P12), and D3 encompasses the final 4 points of transit (D13–D16).

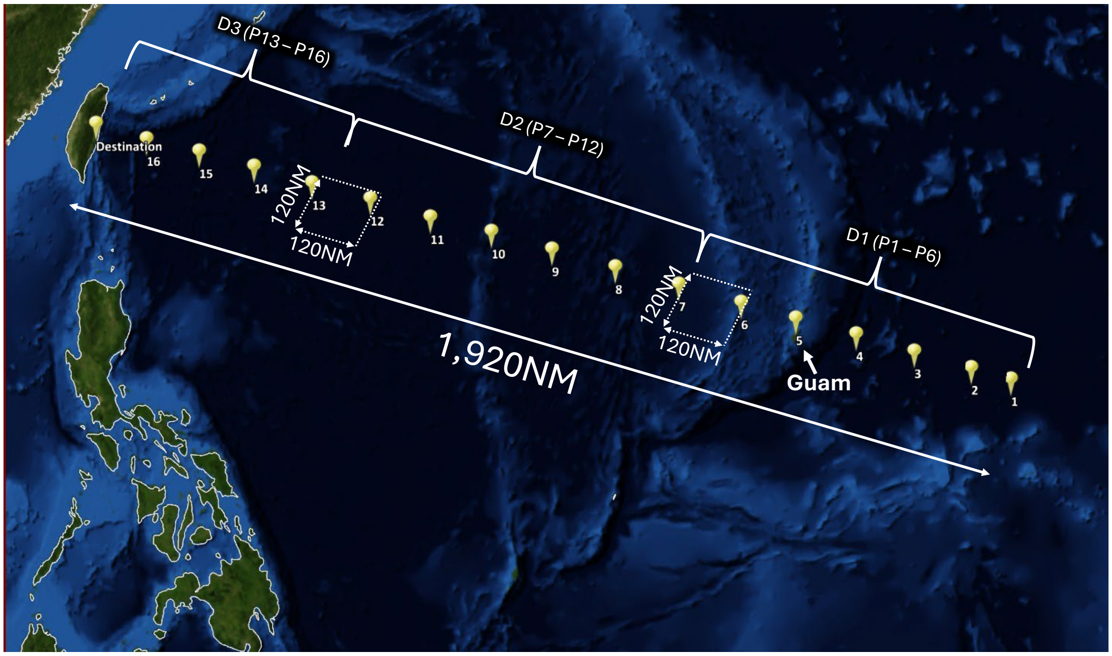


Figure 70. Breakdown of Transit Distances for Changes to Probabilities of Red Presence and Scenario

The assumed probabilities for each type of red asset composition occurring, assuming red asset presence and assuming a given distance point (and corresponding distance category), is provided in Table 9.

Table 9. Assumed Values for Red Asset Scenario Occurring

	Probability of Red Asset Composition, Assuming Red Asset(s) Present				
	Only LuyangIII with helo	Only Y-8Q	Only LuyangIII without helo	Y-8Q & LuyangIII with helo	Y-8Q & LuyangIII without helo
D1 (P1–P6)	0.6	0.05	0.3	0.025	0.025
D2 (P7–P12)	0.4	0.3	0.2	0.05	0.05
D3 (P13–P16)	0.35	0.25	0.15	0.15	0.1

Figure 71 provides a graphical representation of the probability tree, the method used to calculate the total P_d for a blue vessel at a given distance through its journey, transiting the 1,920 NM journey from the departure point to the destination.

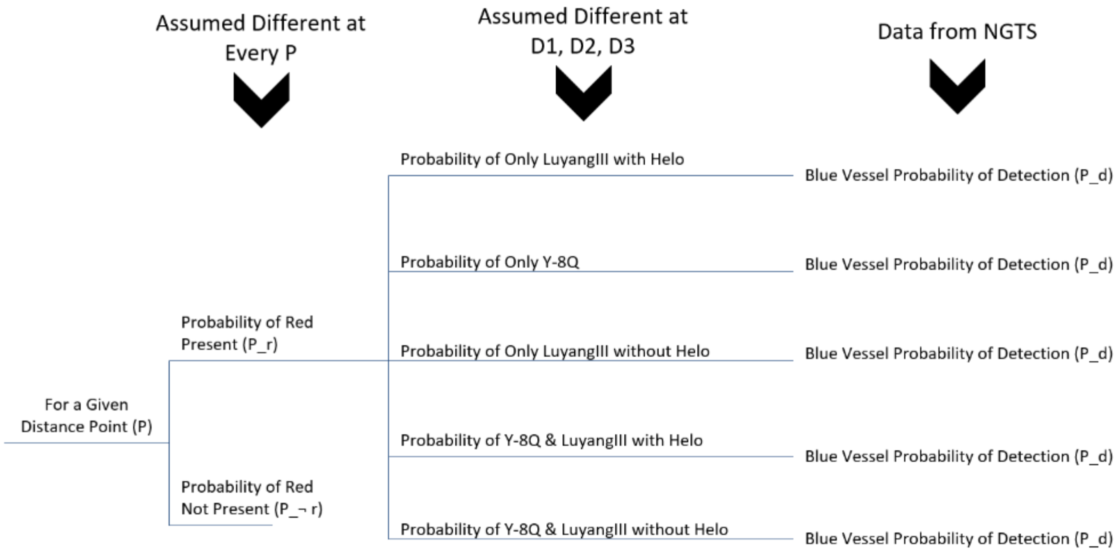


Figure 71. Probability Tree: Conceptual Method for Calculating Probability of Detection at a Given Distance Point

Monte Carlo simulations were conducted for each blue vessel at each distance point to incorporate Equations 1 and 2, the probability of red present, as well as the values found in Table 9, the probability of each red asset composition occurring, and the blue vessel P_d values found in Figures 62, 64, 66, and 68. Each blue vessel was tested in 100 simulation runs at each distance point which resulted in data to inform the likelihood a blue vessel experiences specified levels of P_d at various points of its transit along distance points P1–P16. Assuming a Lower Risk of Red Presence, Figure 72 shows the blue vessel risk of experiencing a P_d that is greater than or equal to 10% at each distance point, while Figure 73 shows the blue vessel risk of experiencing a P_d that is greater than or equal to 20% at each distance point. There were no instances of any blue vessels experiencing a P_d greater than or equal to 30% at any distance point when using the assumed values of the Lower Risk of Red Presence equation. Figure 72 shows a spike in probability of occurrences around distance point 6 that remains elevated for the following distance points. This is assessed to result from the assumed increased probability of a Y-8Q existing in any red asset compositions from distance point 6 and higher. Figure 73 shows a similar spike in probability of occurrences around distance point 12 and this is assessed to result from the assumed increased probability of multiple red assets existing in any red asset compositions from distance point 12 and higher

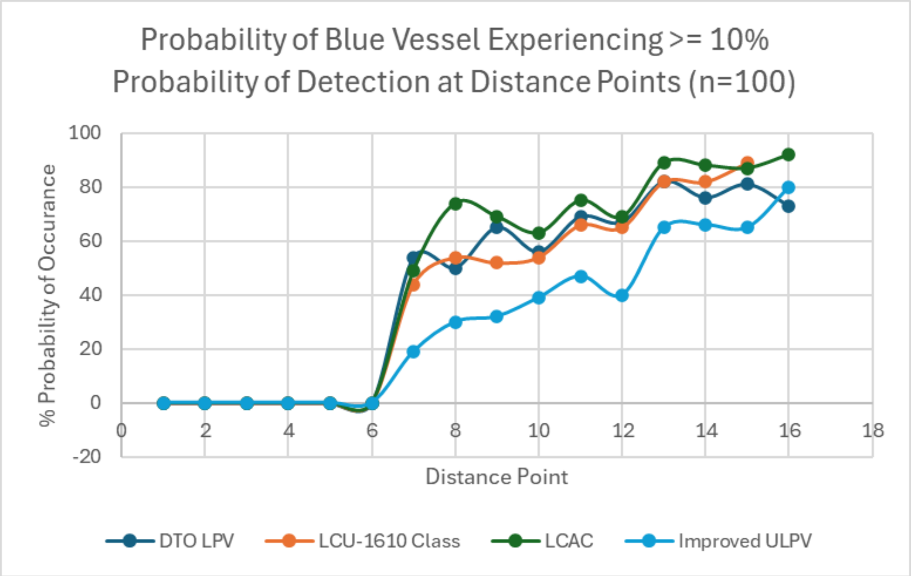


Figure 72. Blue Vessel Detection Risk (>= 10%) at Distance Point (Assuming Lower Risk of Red Presence)

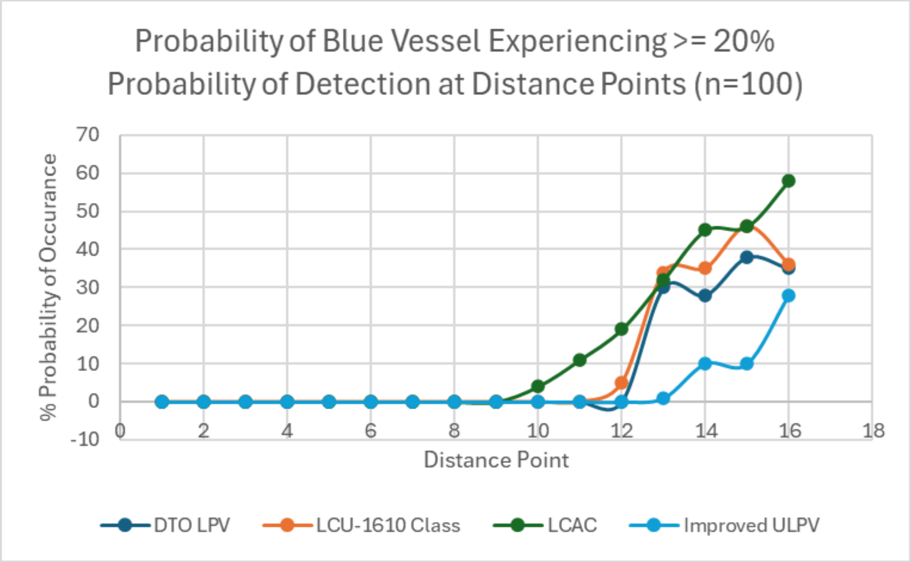


Figure 73. Blue Vessel Detection Risk (>= 20%) at Distance Point (Assuming Lower Risk of Red Presence)

Assuming a Higher Risk of Red Presence, Figure 74 shows the blue vessel risk of experiencing a P_d that is greater than or equal to 10% at each distance point, while Figure 75 shows the blue vessel risk of experiencing a P_d that is greater than or equal to 20% at each distance point. Figure 76 shows the blue vessel risk of experiencing a P_d that is greater than or equal to 30% at each distance point when using the assumed values of the Higher Risk of Red Presence equation. When compared to the Monte Carlo results in Figures 72 and 73, which used the Lower Risk of Red Presence equation, the Monte Carlo results found in Figures 74, 75, and 76 that used the Higher Risk of Red Presence equation show noticeable increases in the probability of occurrences and at earlier distance points. Figure 74, for example, shows an uptick in occurrences as early as distance point 4 and with most vessels experiencing an occurrence rate above 80% after distance point 7, when using a greater than or equal to 10% threshold. This is significant when compared to Figure 72 where most blue vessels did not start to experience an occurrence rate above 80% until distance point 13. A similar theme is witnessed in Figure 75, where the probabilities of occurrence appear higher and at earlier distance point when compared to Figure 73. Figure 76 highlights the result of a higher probability of red assets being present because while no occurrences of the blue vessel experiencing a P_d greater than or equal to 30% were present while using the Lower Risk of Red Presence equation, there were occurrences of this as early as distance point 8 while using the Higher Risk of Red Presence equation.

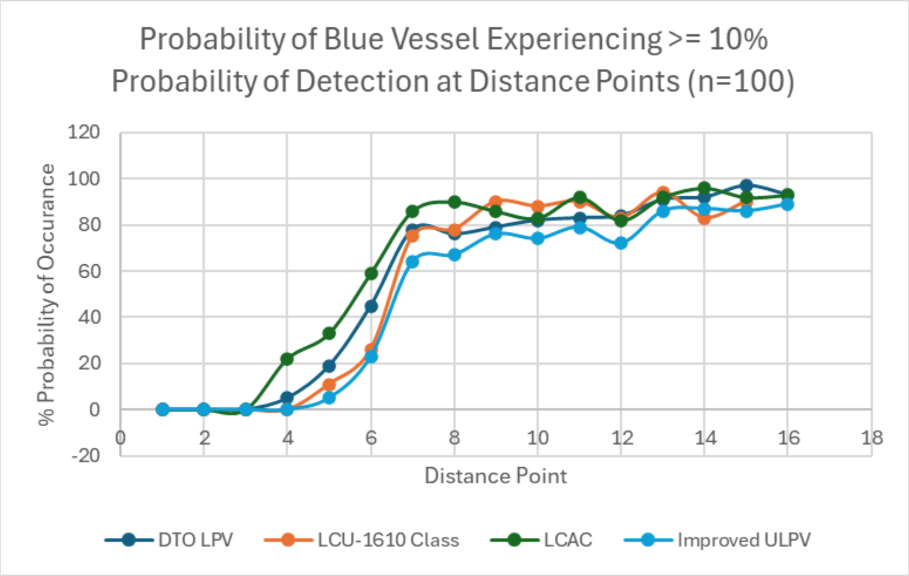


Figure 74. Blue Vessel Detection Risk (>= 10%) at Distance Point (Assuming Higher Risk of Red Presence)

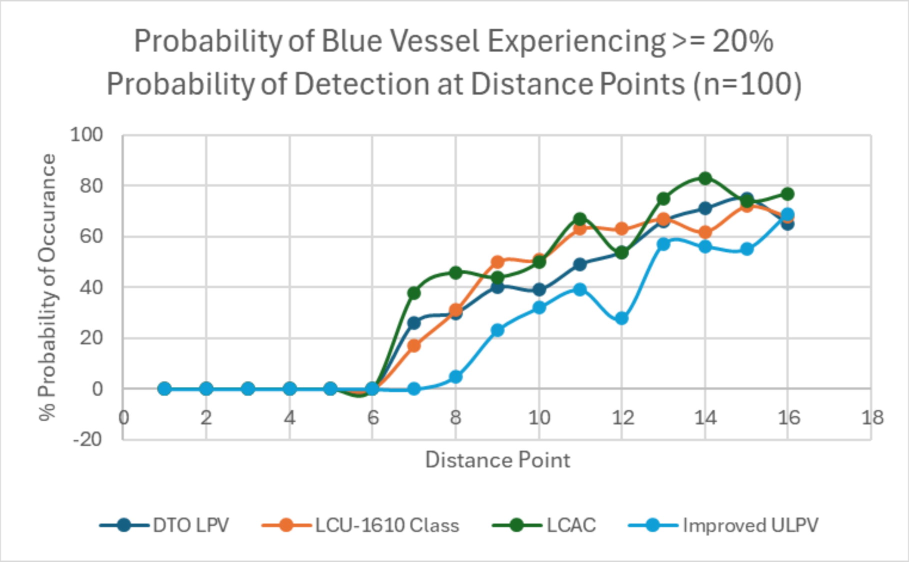


Figure 75. Blue Vessel Detection Risk (>= 20%) at Distance Point (Assuming Higher Risk of Red Presence)

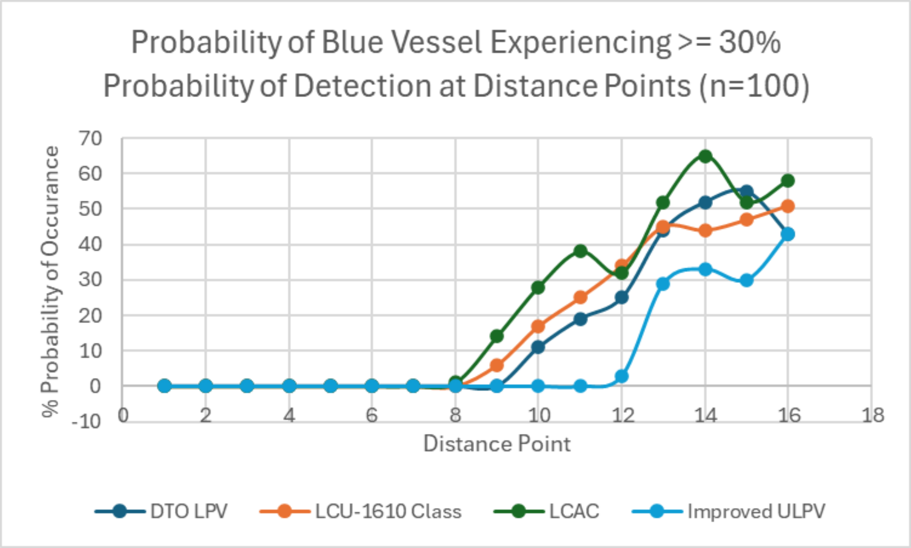


Figure 76. Blue Vessel Detection Risk (>= 30%) at Distance Point (Assuming Higher Risk of Red Presence)

D. CONSIDERING EXPEDITIONARY UNIT SUPPLY CONSUMPTION RATE AND BLUE VESSEL SUPPLY CAPACITIES

This effort's modeling and simulation scenario assumes that logistic vessels will be tasked to sustain USMC operating on EABs, during a state of conflict, at locations within the first island chain. These EABs are assumed to be "fires" EABs, equipped with the personnel, vehicles, equipment, munitions, and other related supplies necessary to execute kinetic strikes from the EAB. According to Katzman (2022), a fires EAB requires 90 personnel, 18 joint light tactical vehicle (JLTV) like vehicles, and 12 medium tactical vehicle replacement (MTVR). This would result in a daily sustainment requirement of 5,400 lbs of sustenance and 9,956 lbs of fuel (Katzman, 2022). In addition, each 8-missile salvo requires a resupply totaling 7,048 lbs and this research assumes an average missile consumption rate of 8 missiles per day by a fires EAB. In total, for a fires EAB with 90 Marines, the daily required sustainment rate is summed to 22,404 lbs which is equivalent to 248.93 lbs per Marine per day.

A capstone report by Dougherty et al. (2020) offered data on sustaining USMC, and that data was considered for use in this research's modeling and simulation scenario (p.191). Dougherty et al. found a daily sustainment need of 164.01 tns to support 2,095.06 Marines which equates to 156.57 lbs per Marine per day. As the sustainment data used in Dougherty et al. (2020) was related to USMC operating in a marine expeditionary unit (MEU), this research instead uses the sustainment figures provided by Katzman (2022) as they are specific to EABO, the type of Marine Corps operational construct assumed in this research's scenario.

This modeling and simulation effort assumes the need to sustain 1,000 Marines operating across numerous fires EABs within the first island chain. Multiplying the daily sustainment requirement for a Marine (248.93 lbs) by 1,000 Marines results in a daily sustainment requirement of 248,933.33 lbs, or 124.47 tns, worth of all supply for EAB operations in the AOR. Figure 77 depicts the calculations used for the supply consumption assumptions in this modeling and simulation scenario. Table 10 highlights the types of missions and tasks for EABO, as described in the Tentative Manual for EABO, that drive EABO sustainment requirements.

Table 10. United States Marine Corps Activities Driving EABO Sustainment Requirements. Source: Adapted from United States Marine Corps (2023d, p. 1–3)

EABO Missions	**EABO Tasks**
Support sea control operations	Conduct surveillance and reconnaissance
Conduct sea denial operations within the littorals	Generate, preserve, deny, and/or project information
	Conduct screen/guard/cover operations
Contribute to maritime domain awareness	Deny or control key maritime terrain
Provide forward-C5ISRT[†] and counter-C5ISRT capability	Conduct surface warfare operations
	Conduct air and missile defense
Provide forward sustainment to support and enable the joint force, and partners and allies	Conduct strike operations
	Conduct anti-submarine warfare
	Conduct sustainment operations
	Conduct forward arming and refueling point operations
	Conduct security cooperation
	Conduct irregular warfare

[†] Command, control, communications, computers, combat systems, intelligence, surveillance, reconnaissance, targeting (C5ISRT)

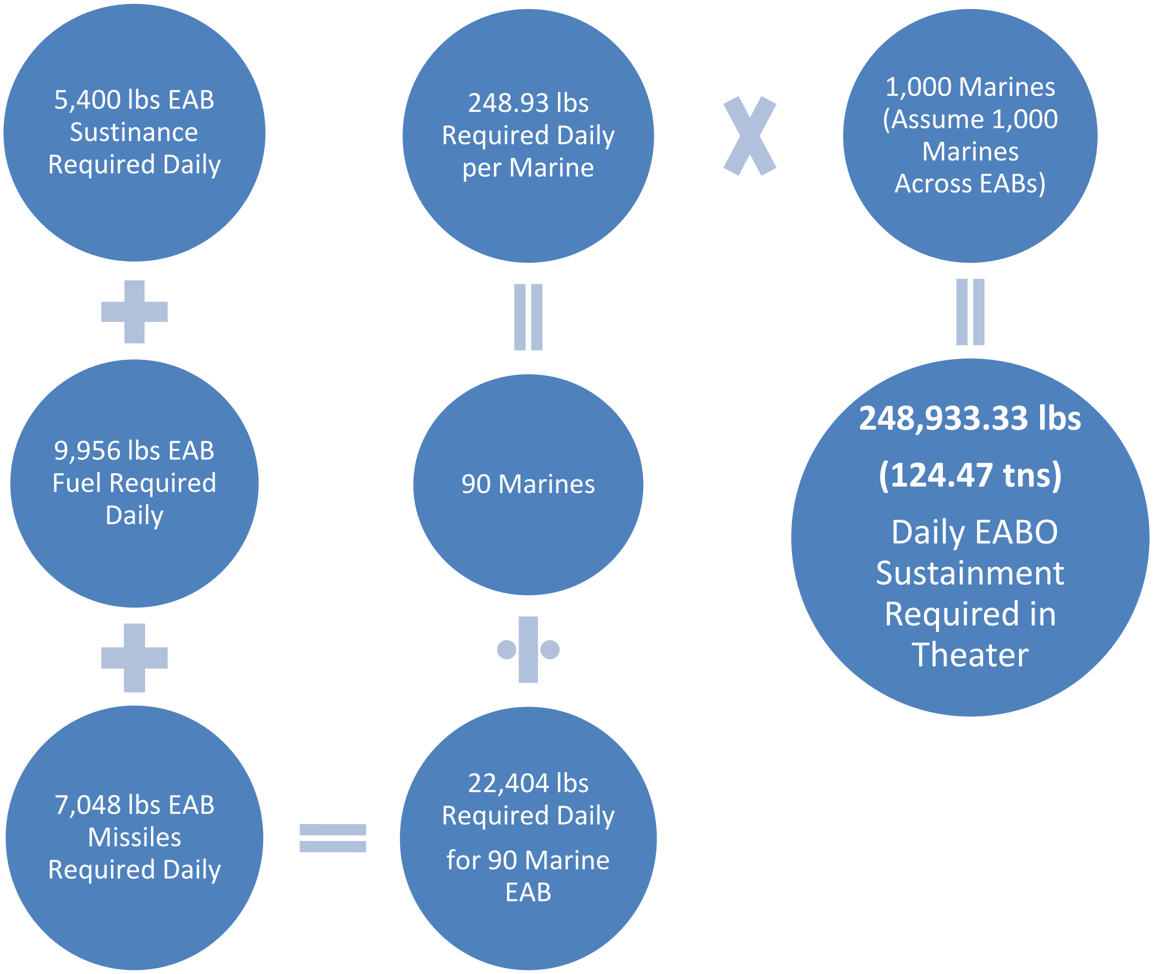


Figure 77. Calculating Required Daily Sustainment Quantity for United States Marine Corps Expeditionary Advanced Base Operations in Contested Logistics Scenario

While vessel P_d was the primary focus of this effort's modeling and simulation work, the supply capacity for a given logistics vessel is another important factor for sustaining expeditionary operations such as EABO. Table 11 provides supply capacity limits for the blue vessels analyzed in this effort, with a theoretical capacity used for the Improved ULPV as it is a conceptual vessel. Table 11 also shows the calculated required number of daily supply deliveries by each vessel type, assuming no attrition and perfect arrival schedules where the blue vessel never fails to arrive with exactly the amount of required supply on exactly the required day. It is also assumed that supply can only be delivered by a naval vessel.

Table 11. Theater and Expeditionary Advanced Base Sustainment Estimates by Blue Vessel Type

Blue Vessel Type	Blue Vessel Supply Capacity	Required Daily Vessel Deliveries for Daily Sustainment (Whole Theater, 124.47 T)	Required Daily Vessel Deliveries for Daily Sustainment (Per EAB, 11.202 T)
LCU-1610 Class	140 tns	0.89 Vessels	0.08 Vessels
LCAC	60 tns	2.07 Vessels	0.19 Vessels
DTO LPV	10 tns	12.45 Vessels	1.12 Vessels
Improved ULPV	20 tns	6.22 Vessels	0.56 Vessels

Note: Daily EABO theater sustainment requirement is 124.47 tns for all blue vessel types.

The numbers in Table 11 draw attention to the impact of different blue vessel supply capacities. Notably, if the LCU-1610 Class and LCAC vessels are assumed to conduct sustainment operations at maximum capacity, they can meet daily theater delivery requirements with much fewer vessels in use than the DTO LPV or Improved ULPV. However, while a single LCU-1610 class vessel has the capacity to meet the daily EABO theater sustainment requirement, it is assumed that there would be several EABs needing sustainment throughout the theater. Continuing off the assumption that there are 1,000 Marines operating across various EABs within theater, and that each fires EAB is made up of 90 Marines (Katzman, 2022), the resulting expected number of EABs within theater needing sustainment would be approximately 12 EABs (1,000 Marines divided by 90 Marines per EAB equals 11.111, which is rounded up to 12 to prevent truncating sustainment requirements of the remainder of Marines).

If logistics vessels would need to sustain 12 EABs at various locations within theater, it would be improbable for a single LCU-1610 class vessel to shuttle supply to all EABs within a day to meet each EAB's individual daily supply need of 22,404 lbs (or 11.202 tns) (Katzman, 2022). This improbability becomes especially apparent when considering the time required to transit between EABs as well as the time required to unload supply at each EAB. Therefore, while a single LCU-1610 loaded to 89% of its load limit can theoretically support the needs of 1,000 Marines conducting EABO in the Indo-Pacific, the distances between EABs likely necessitate the need for multiple vessels to conduct sustainment, and as each EAB requires only

11.202 tns of daily supply (Katzman, 2022), a fraction (8%) of the LCU-1610 class capacity, perhaps sustainment of EABs is more efficient by vessels of much lower capacity to better match the consumption rate of EABs.

Until this point in the report, sustainment has been discussed as a daily requirement. However, it is assumed that supply deliveries to EABs would not necessarily occur daily to meet daily sustainment needs, but rather, that some level of stockpiling can be done at each EAB to prevent the need for the "just in time" daily delivery of supply that meets the daily consumption rate of supply. For example, if an improved ULPV is used to sustain an EAB, with its capacity of 20Tons, an Improved ULPV would need to arrive a little more frequently than every other day to sustain an EAB. However, a fully loaded LCAC with its capacity of 60Tons would only need to arrive approximately once every five days to sustain an EAB. However, the implications of stockpiling supplies on an EAB should be considered, especially if there is an intent to minimize the observable signature of operations at the EAB. Another consideration is the amount of observable signature accompanying the loading or unloading of supplies at any EAB and the resulting consequences if a logistics vessel does so more often with smaller quantities of supply or less often with larger quantities of supply.

E. CAUSAL LOOP DIAGRAM

The NGTS modeling and simulation work informed blue vessel P_d by specific red forces. The P_d data output from the NGTS simulation runs can then be input into a causal loop diagram (CLD) to simulate the larger interaction of variables concerning different blue logistics vessels maintaining a level of supply at an expeditionary base location. Using the P_d data from NGTS can highlight tradeoffs between different blue logistics vessel types supporting contested logistics and inform how ULPVs compare to currently fielded materiel solutions for contested logistics.

"Causal loops diagrams (also known as system thinking diagrams) are used to display the behavior of cause and effect from a system's standpoint. A CLD is a causal diagram that aids in visualizing how different variables in a system are interrelated" (Barbrook-Johnson & Penn, 2022). According to Barbrook-Johnson & Penn:

> CLD are made up of connections, or edges, which represent causal influence from one node to the other; either positive (i.e., they increase or decrease together) or negative (i.e., they change in opposite directions, if one goes up, the other goes down, and vice versa). The maps always show and focus on feedback loops, both in the construction of the map and in its visualization. Loops are made conspicuous by the use of curved arrows to create circles. (2022)

Figure 78 is a CLD that was created by this effort to analyze the impact of ULPVs and other logistics vessels on maintaining a steady level of supply for expeditionary units. However, this research did not pursue work beyond the completion of the diagram in Figure 78, and as a result, there is no resulting data from any simulation runs. The CLD instead provides value as a conceptual tool to understand the interaction between variables in the contested logistics environment and serves to inform future work.

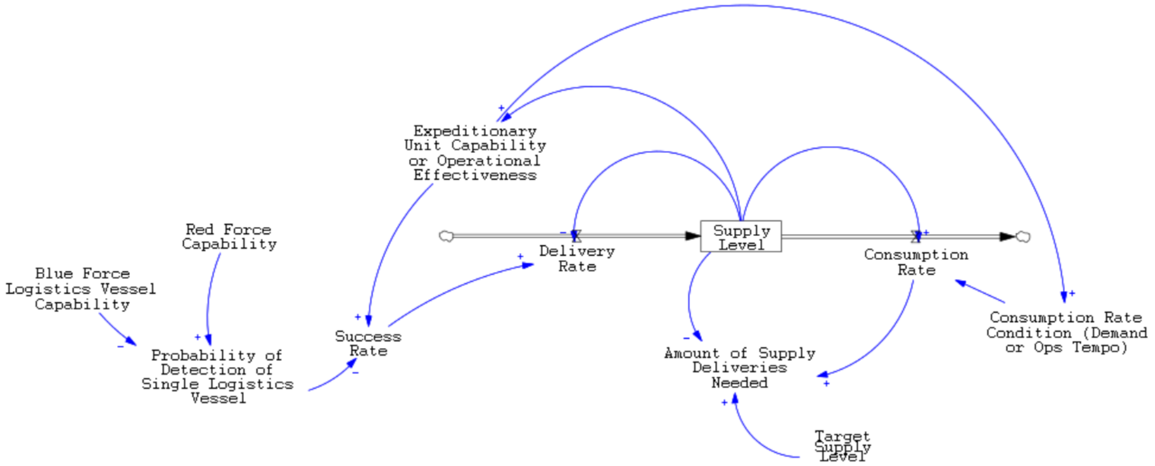


Figure 78. Causal Loop Diagram for Contested Logistics and Expeditionary Unit Resupply

1. Model Variable Definitions

Listed are definitions of the variables being utilized in this research effort's modeling and simulation:

- Blue Force Logistics Vessel Capability: The collective attributes of the blue force (US) logistics vessel in question contributing to its detectable signature.

- Red Force Capability: The collective attributes of the red force (PRC) assets (surface vessels and airborne craft) resulting from the type and quantity of red force assets attempting to detect and destroy blue force logistics vessels.
- P_d of Single Logistics Vessel: Probability that the logistics vessel in question will be detected by red force assets.
- Success Rate: Probability that the logistics vessel in question will not be detected, interdicted, or destroyed by the red force and will therefore reach its delivery destination.
- Delivery Rate: The number of deliveries per measure of time.
- Expeditionary Unit Capability or Operational Effectiveness: The ability of an expeditionary unit to support its own needs to maintain unit health, readiness, and the ability to successfully complete any tasked mission.
- Supply Level: The amount of various supply classes that must be maintained at an operational unit to support that unit’s health, readiness, and ability to successfully complete any tasked mission.
- Consumption Rate: The amount of supply consumed per measure of time.
- Consumption Rate Condition (Demand or Ops Tempo): The influence exerted on the consumption rate given the level of operational activity intensity at a point in time.
- Amount of Supply Deliveries Needed: Quantity of resupply missions required (based on supply capacity of logistics vessel in question) to replenish supply level at expeditionary unit.
- Target Supply Level: The desired level of supply.

2. Assumptions and Limitations

Some assumptions and limitations are made in this CLD. First, the logistics vessels in question will be unarmed and defenseless. Second, logistics vessels will carry supplies that are of equal type and proportional quantity necessary to maintain the total supply level stock at the expeditionary unit.

F. CONCLUSIONS FROM MODELING AND SIMULATION ANALYSIS

The NGTS results provided similar results to those quoted in Chapter II, Part A of this paper, where a surface vessel and helo resulted in a 33% P_d for DTO LPV, vice the 30% reported by Ramirez and Bunker (2015). However, the NGTS results found that adding a maritime patrol aircraft resulted in a 93% P_d of DTO LPV, compared to 70% reported by Ramirez and Bunker (2015). NGTS results also concluded that DTO LPVs are most susceptible to detection by overhead observation, as indicated by the large increase in P_d from 13% (by a surface vessel without an embarked helo) to 33% (by a surface vessel with an embarked helo) and further to 88% (by a maritime patrol aircraft and a surface vessel without an embarked helo) and finally to 93% (by a maritime patrol and a surface vessel with an embarked helo). All other blue vessels tested in the NGTS simulations experienced similar themes of increased probabilities of detection when adding a helo or maritime patrol aircraft to the red asset composition.

Initial work was completed to apply NGTS findings to a larger scenario with the intent to understand a blue vessel's P_d at various points in transit along a 1,920 NM route to a first island chain destination. This work created the framework for calculating the probability of red asset presence at a given distance point as well as the probability of a given red asset composition existing at a given distance point based on a one of three distance categories. This framework was used to calculate a blue vessel's expected P_d at any given distance point during transit. Further, Monte Carlo simulation was used to provide the probabilities that a blue vessel would experience certain probabilities of detection above specified thresholds at each given distance point.

Basic calculations were used to estimate the numbers of blue vessel deliveries would be necessary to support EABO operations in the Indo-Pacific, however, these calculations did not include many important considerations and mean to only introduce the problem. Calculating the exact number of blue vessels of any given type required to maintain EABO sustainment will require considering each blue vessel's load capacity, speed, range, susceptibility, and method of employment. The approximate locations of each EAB and accurate estimates for supply consumption rates at each EAB will be needed for the calculation as well. It may be helpful to use causal loop diagrams to inform or conduct these calculations. The causal loop diagram completed in this effort helped to conceptualize the relationship between variables in the contested logistics space, however, data and formulae were not used to run simulations in the model, and therefore, it is an area available for continued work.

THIS PAGE INTENTIONALLY LEFT BLANK

IX. INFORMATION OPERATIONS AND DECEPTION

While ULPVs are presumed to be less detectable, and therefore more survivable in the A2/AD environment than traditional logistics vessels, the proliferation of openly available data from various sensors throughout the world challenges the notion of a vessel remaining undetectable (Taylor, 2024). This reality introduces the need for alternatives to increase vessel survivability, most notably, information operations like deception. There are various ways ULPVs may support information warfare to both support U.S. military objectives in the Indo-Pacific as well as increase the probability of mission success for ULPVs conducting contested logistics. It is believed that the use of information warfare tactics will increase ULPV's probability of success in conducting logistics missions in a contested environment.

A. INFORMATION OPERATIONS BACKGROUND

The war in Ukraine illustrates the proliferation of sensors, commercially available data, and open-source intelligence (OSINT) which results in a battlefield that no longer permits any participant to be invisible to the enemy (Taylor, 2024). Instead of being undetectable, survivability in modern warfare requires appearing insignificant (Taylor, 2024). Maintaining an understanding of how the enemy receives, interprets, and acts on a received communication plays a pivotal role in the successful outcome of the communication problem (Shannon & Weaver, 1949). Properly understanding Shannon and Weaver's communication problem and applying it to information warfare operations may increase the ability for ULPVs to appear insignificant, thereby increasing their probability of success. Information operations conducted by ULPVs may also be used to leverage the innate human tendency to imitate and desire what others desire, such as described in René Girard's theory of mimetic desire (Packer, 2021). Leveraging this theory may allow ULPV operations to change the perceived value of some key terrain, as desired by U.S. information operations. Finally, DeMarree et al. (2020) found a relationship between the confidence of a person's held attitudes and the likelihood that action is taken on that attitude. Given this relationship, social media and other publicly shared information on

ULPV operations may be leveraged to decrease the confidence PRC leaders have in their attitudes against the U.S. and therefore decrease the chance of PRC actions against the U.S.

B. ADAPTING TO THE "TRANSPARENT BATTLEFIELD"

While Colombian authorities have reported on the great difficulties of detecting DTO LPVs (VICE, 2011), the proliferation of sensors and commercially available data, or open-source intelligence, increases the likelihood that ULPVs employed in an Indo-Pacific conflict may not be as easily undetectable as would be expected given the accounts by the Colombian military on DTO LPVs. USN CAPT Mark Morris's 2014 account on detecting LPVs stated how adding a helo to a surface ship patrol box of a suspected drug event would increase the P_d of LPV from 5% to 30% and adding a maritime patrol aircraft to the mix would increase that probability further to 70% (Ramirez and Bunker, 2015). However, this reporting is now ten years old, and it does not account for the modern availability of commercial satellite imagery and openly available tools that can detect and classify vessels from commercial satellite imagery with ever-increasing image resolution (Kanjir et al., 2018).

In an article from the Modern War Institute at West Point, Taylor (2024) makes observations from the war in Ukraine, highlighting the conditions of a "transparent battlefield" that the U.S. should expect in its next war. "Everything from ubiquitous commercial satellite technology to handheld drones and sensors has rendered the battlefield transparent to any competent adversary" (Taylor, 2024). Taylor (2024) goes on to describe a path to success in the transparent battlefield: "The key to survival for U.S. forces in this environment is to mask indicators that betray unique or critical capabilities. In today's battle of signatures, you can't be invisible, but you can look unimportant." Perhaps then, the question to be considered regarding ULPVs for contested logistics is not whether ULPVs will be undetectable, but rather, whether ULPVs will look unimportant.

One way for ULPVs to appear unimportant may be for the vessels to mirror the behavior of other unimportant vessels, such as cargo ships or fishing vessels. Figure 79 shows historical cargo ship routes taken in the Indo-Pacific from January through October of 2012.

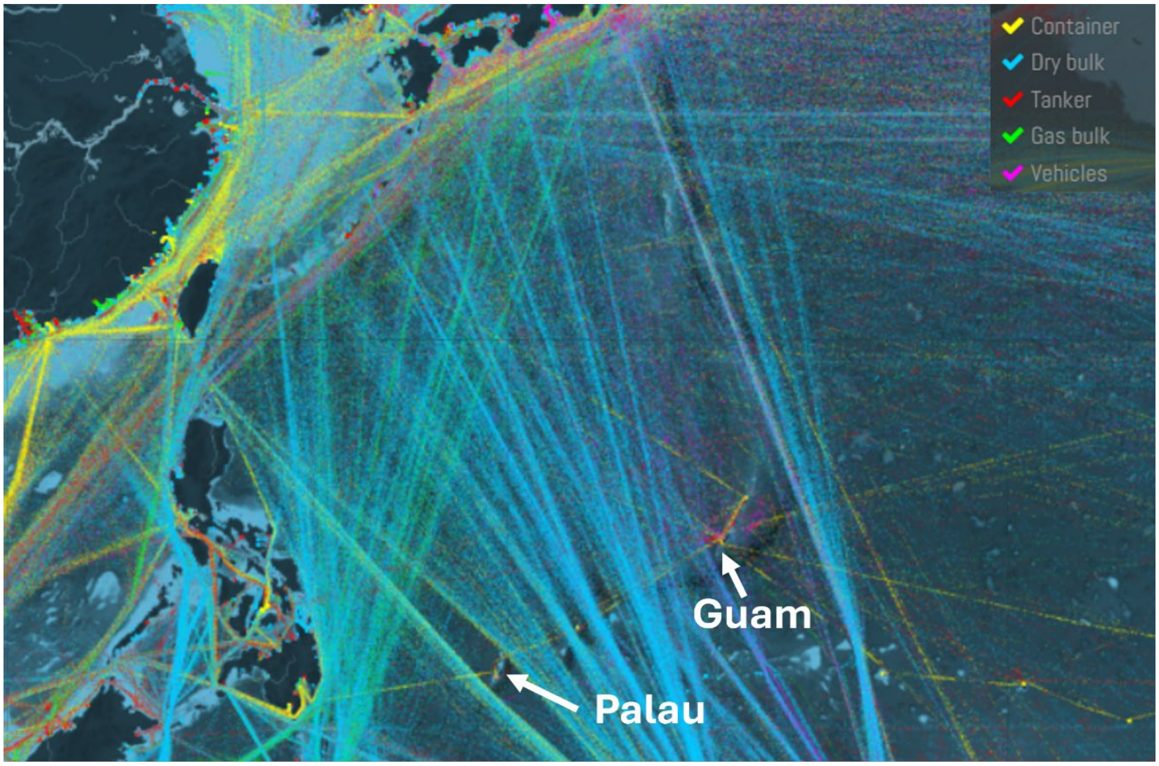


Figure 79. Pacific Cargo Ship Traffic Routes in 2012. Adapted from Plumer (2017).

However, while ULPVs may use the same routes commonly used by cargo ships, the operating speed of ULPVs, if assumed to be around 10kts or less, as in the case of DTO LPVs (Ramirez and Bunker, 2015), may be too slow to match the expected behavior and adequately blend with commercial shipping traffic as cargo ships maintain an average speed of 14 kts (Arimo, 2023). Fishing boats, however, generally have cruising speeds between 3 kts and 10 kts, with an average speed of around 6kts, although larger open-sea fishing vessels will likely operate at higher speeds (Frami, n.d.). ULPVs may be more likely to operate at the typical speed of a fishing vessel than a cargo vessel. In addition, assuming that ULPVs will be visible, like most vessels, from satellite imagery (Kanjir et al., 2018), the dimensions of a ULPV more closely match that of fishing vessels vice cargo vessels which are often hundreds of feet long.

Figure 80 shows a snapshot of the positions of various vessel types within the Indo-Pacific at a given moment. ULPV behavior intended to blend with the behavior of other vessels should consider mirroring that of fishing vessels or pleasure craft that do not necessarily follow strict point-to-point routes like that observed with cargo vessels. If ULPVs behave as cargo vessels, transiting in a straight line along typical shipping routes and toward a location within the first island chain, but are detected and classified as vessels much too small to be cargo vessels, the ULPV will unintentionally highlight its existence as something other than a cargo vessel, drawing undesired attention. Figure 81 highlights how the locations of fishing vessels appear less organized along standardized lines of movement compared to that of the cargo vessels highlighted in Figure 82. It should also be considered how cargo shipping routes might change during a time of conflict in the Indo-Pacific, and likewise, how fishing vessel activity might change, so that ULPV behavior is to have ULPVs appear as unimportant as desired.

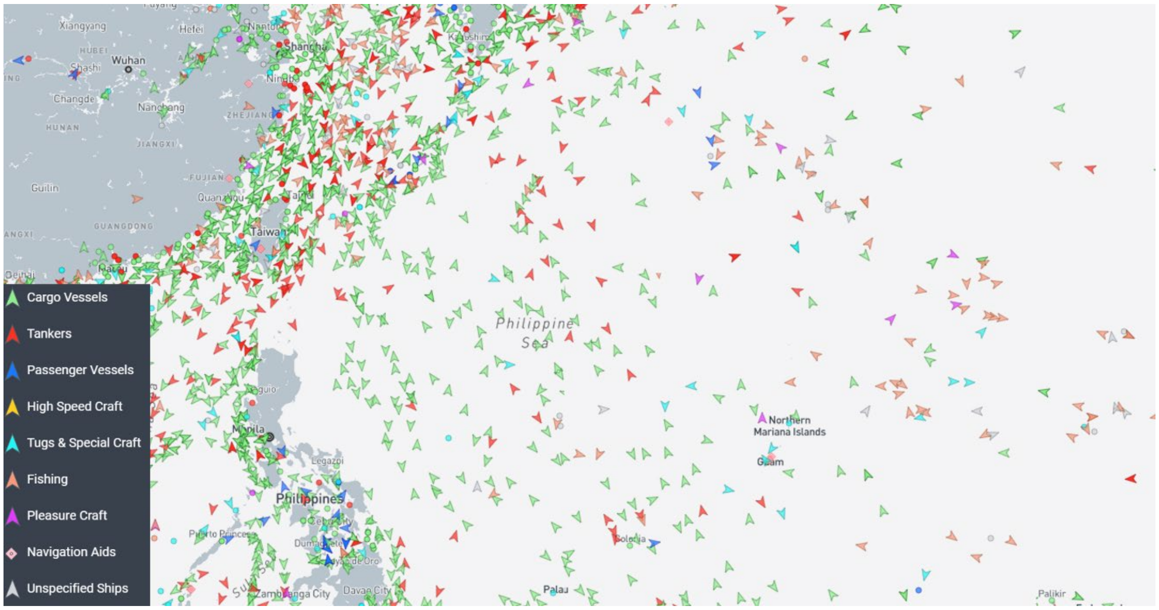


Figure 80. September 2024 Snapshot of All Vessels in the Indo-Pacific. Source: Marine Traffic (n.d.).

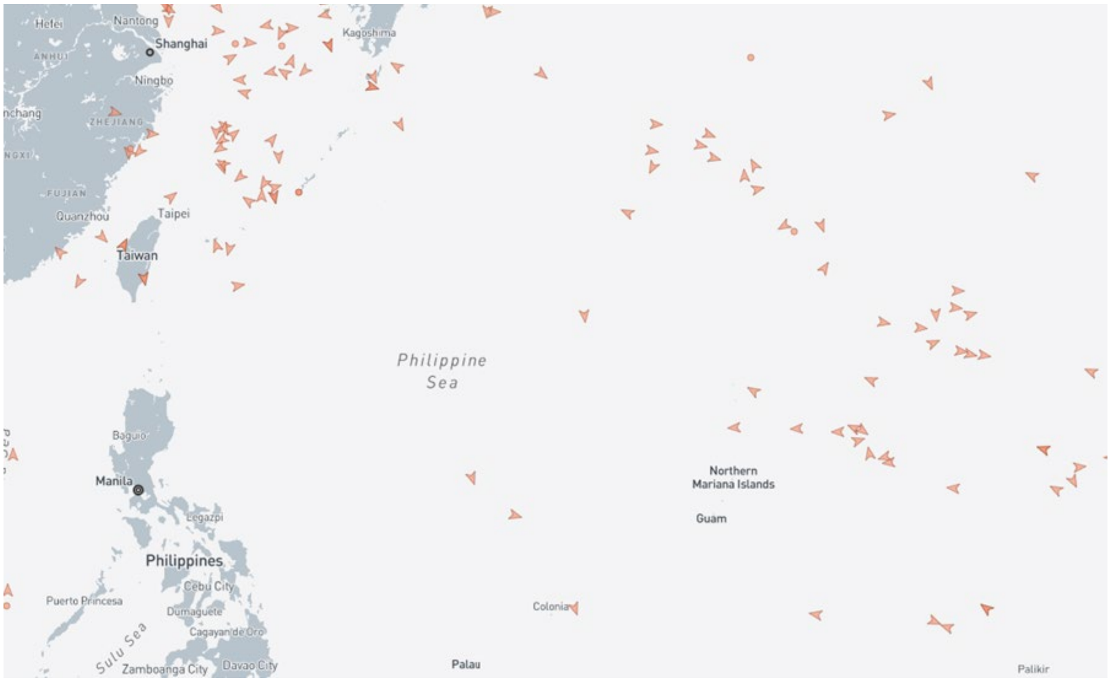


Figure 81. September 2024 Snapshot of Fishing Vessels in the Indo-Pacific. Source: Marine Traffic (n.d.).

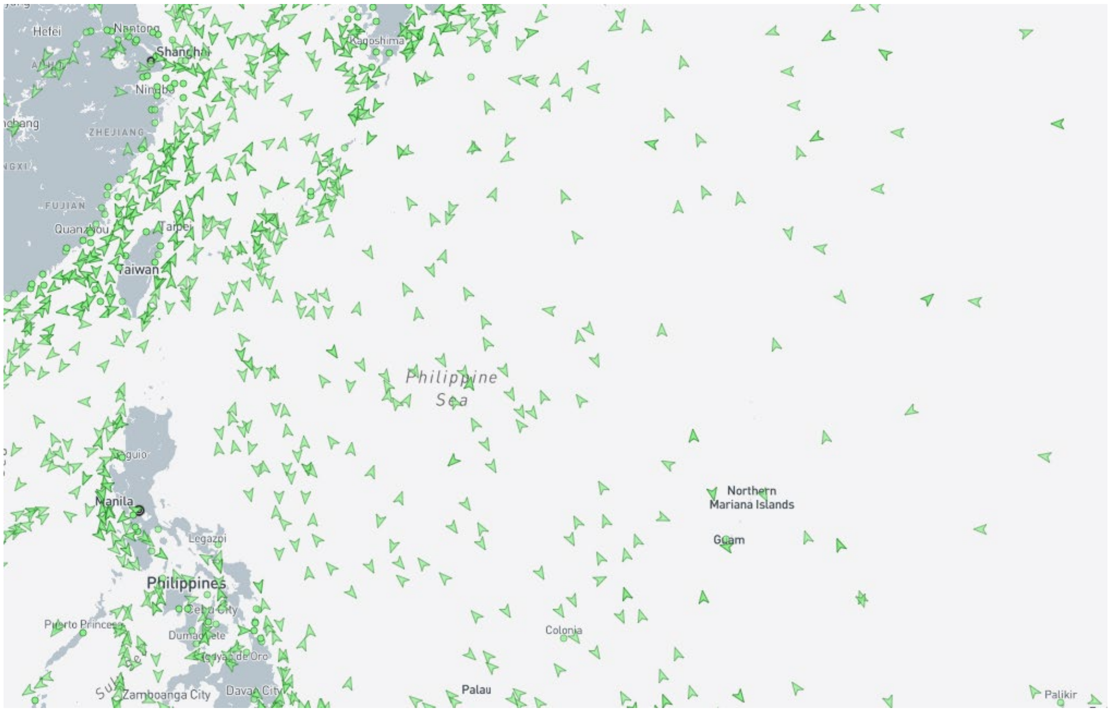


Figure 82. September 2024 Snapshot of Cargo Vessels in the Indo-Pacific. Source: Marine Traffic (n.d.).

C. DECEPTION IN COMMUNICATIONS

The AIS, a requirement for ships of 300 gross tonnage or greater (IMO, n.d.a), is one possible method that can be used to influence the type of vessel that it is classified as. While a ULPV would presumably be designed below the IMO threshold for requiring the use of AIS, the inclusion of AIS in ULPV design may increase the vessel's ability to blend with other vessel traffic and increase the ULPV's ability to appear unimportant. The use of AIS requires that the vessel provide information on its type, position, course, speed, and navigation status automatically to shore stations, ships, and aircraft (IMO, n.d.a). If it is assumed that ULPVs are to be detected, it may be advantageous to incorporate AIS into a deception strategy that masquerades the identity and purpose of ULPVs. Referring to Shannon and Weaver's 1949 publication on the communication system and its problems provides insight into how an AIS deception by ULPVs may function, as symbolized in Figure 83.

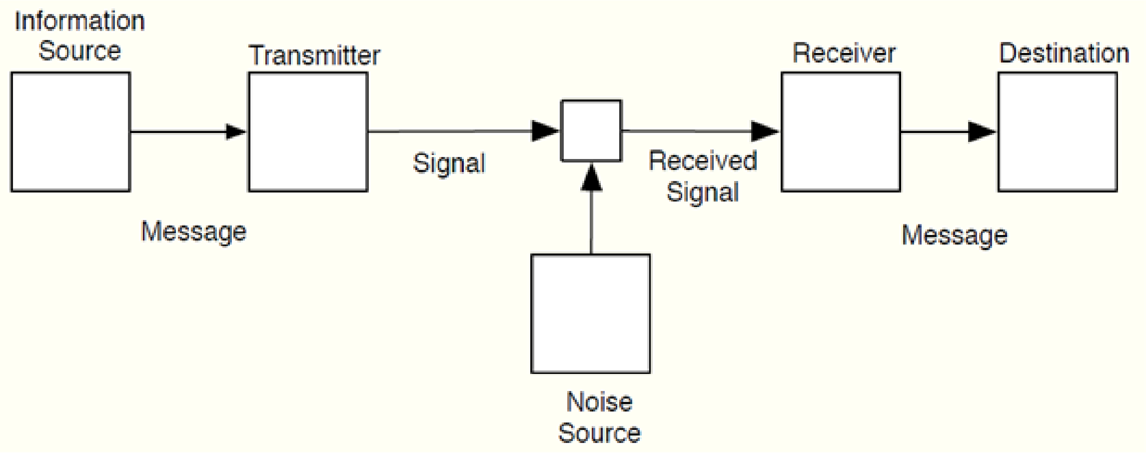


Figure 83. Communication System. Source: Shannon & Weaver (1949).

Shannon and Weaver presented that the overall effectiveness or success of any communication is, in general, the sum of the effectiveness of a communication's three fundamental levels (Shannon & Weaver, 1949, p. 2). The parts of a communication system connect the information source to the destination. The message from the information source passes through a transmitter, is changed into a signal, and is sent over the communications channel. The signal is subject to the possibility of noise, extra information added to the signal that is not intended by the information source. The signal then passes through a receiver which turns the signal back into a message and the message is passed to the destination. Shannon and Weaver's analysis indicated that a communication passing through this communication system is ultimately successful if the destination responds to the message as the information source intended, or in Shannon and Weaver's words, if the desired conduct occurred (Shannon & Weaver, 1949, p. 2). While a ULPV's AIS message may ultimately reach its intended PRC destination, Shannon and Weaver argued that the success of the communication ultimately depended on whether the sent message resulted in the intended conduct (Shannon & Weaver, 1949, p. 2). This final intention is what Shannon and Weaver termed the "effectiveness problem", where the communication was only truly successful if it could first overcome the "technical problem" (where the symbols of a transmission are accurately transmitted), then overcome the "semantic problem" (where the transmitted symbols convey the desired meaning to the receiver), and ultimately overcome the effectiveness problem (Shannon & Weaver, 1949, p. 2).

In practice, this means that the use of any AIS deception by ULPVs should understand how data should flow from the ULPV transmitter to other AIS receivers so that the ULPV's message is understood by the receiver as intended by the transmitter, and so that the meaning the ULPV's transmission conveys results in the desired behavior by the intended destination (the PRC). In this case, the desired behavior by the PRC may be disinterested in the ULPV, as the ULPV has conveyed the meaning that it is another sort of vessel, perhaps one that is of no interest to the PRC. Further, it may be worth considering ULPV AIS operations that differ between individual vessels. For example, perhaps some vessels may use false AIS transmissions, others may use no AIS transmissions, and yet others may use true AIS transmissions. If ULPVs use a mixture of AIS transmission strategies it may aid in disrupting any learnable pattern of ULPV operations, a pattern that may increase the likelihood of classifying the vessels as ULPVs among the sea of other vessels. The use of some ULPVs broadcasting AIS messages that highlight the true nature of the ULPV may also be used to impact PRC behavior, such as drawing resources toward a ULPV to interdict it or attack it. Given such an example, it may be considered that some

ULPVs may be used as decoys, and vessels used in this capacity may be loaded with worthless contents, nothing at all, or explosives armed against would-be interdiction efforts. ULPV operations might also be used to communicate other desired meanings to the PRC.

D. MIMETIC THEORY OVER KEY TERRAIN

One such meaning that can be communicated to the PRC by use of ULPVs can be the worth or value of terrain. A specific island within the first island chain that receives frequent visits by ULPVs, for example, may communicate the meaning that the island holds importance as a key terrain that supports military operations. René Girard's theory of mimetic desire holds that a person's behavior is greatly driven by imitation, where a person wants what other people want (Packer, 2021). This theory can be applied to the leaders of the PRC, where any key terrain that appears desirable by the U.S. can result in the PRC desiring the same terrain and its behavior driven by imitation. ULPV operations can take advantage of this human tendency toward imitation and deceive PRC leadership to focus military resources on terrain that the U.S. does not actually value.

ULPV operations may also be conducted to appear to resupply unoccupied locations. Similarly, ULPV operations may conduct supply deliveries to USMC expeditionary advanced bases (EABs), however, they may appear to arrive and depart the EAB at rates that indicate a greater or lesser military presence at the EAB than is real. Such operations may deceive PRC leadership as to the true value, priority, or capability of an EAB. The use of dummy supplies and equipment, as well as a small ground force to support deception operations at an expeditionary base, might be considered to further enhance the effectiveness of the deception operation. Ultimately, ULPV operations can be conducted in an observable manner to PRC receivers to support deception operations by conveying false meanings, though as intended by U.S. leadership.

E. SOCIAL MEDIA

Modern technologies like social media are known for playing a profound role in increasing the influence of mimetic desire in people's lives (Packer, 2021). Social media posts or other public news can be used with ULPV operations to support U.S. information warfare operations. For example, a picture could be taken of a ULPV landed on a beach of an empty island and that picture could be publicly shared (M. Canan, personal communication, August 28, 2024). This picture could be used as claimed proof that ULPV operations have successfully occurred undetected and undeterred right under the PRC's nose (M. Canan, personal communication, August 28, 2024), with the intent to discourage PRC confidence in their military capabilities. DeMarree et al. (2020) found a strong relationship between people with high levels of confidence in held attitudes and the tendency to act on that attitude. If ULPV information operations can decrease PRC confidence in its military capabilities, PRC leaders may be less likely to act on their attitudes against the US.

F. INFORMATION OPERATIONS AND DECEPTION SUMMARY

While ULPVs are expected to be difficult to detect compared to traditional surface vessels, their presence on the "transparent battlefield" may not be as undetectable as assumed. Due to the rise in openly available data, ULPVs conducting contested logistics operations in the Indo-Pacific may be detectable. As a result, information operations are expected to increase the chance of ULPV mission success by making ULPVs appear insignificant. In addition, ULPVs may play a critical role in theater-wide information operations through operations that leverage social media, mimetic theory, and deceptive communications.

THIS PAGE INTENTIONALLY LEFT BLANK

X. RESEARCH APPLICATION TO DEFENSE ACQUISITION

Parts of Section A of this chapter were previously published by the Acquisition Research Program at NPS (Sierra, 2024).

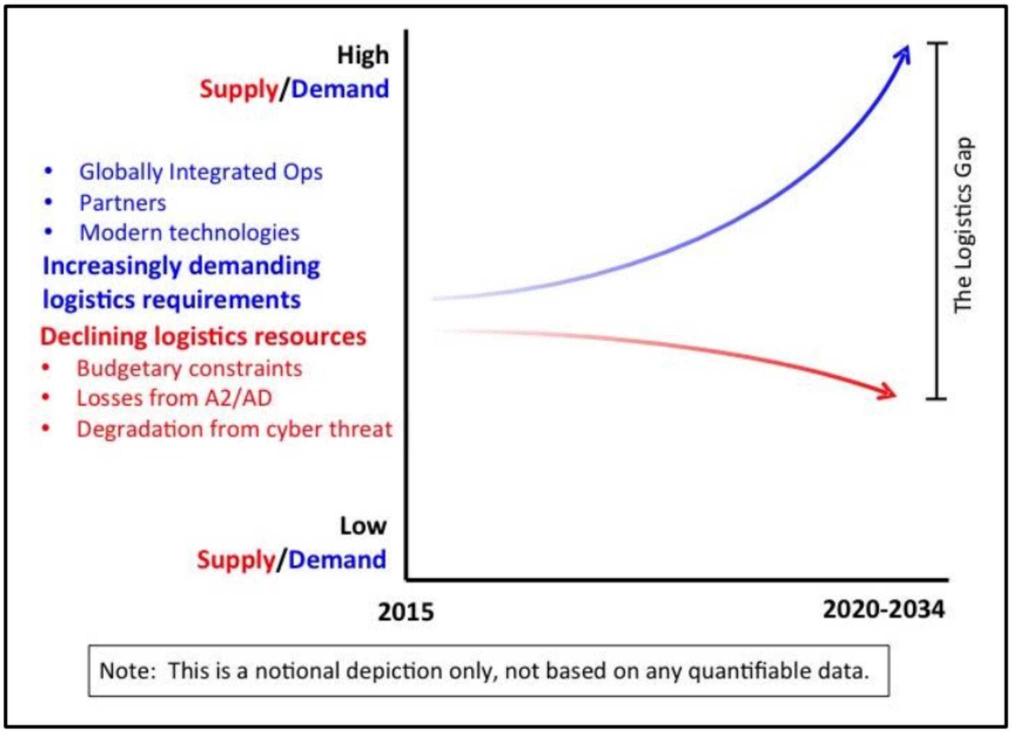
A. INTRODUCTION

Most of this paper is dedicated to a discussion of various operational and design considerations regarding ULPVs. These considerations should inform an analysis of alternatives (AoA) for contested logistics materiel solutions, including ULPVs. The documented findings of this research effort should also inform a vessel design that is sustainable and scalable by the industrial base, presumably due to advantageous design choices and data rights decisions that enable the DoD to compete a simple, affordably manufactured ULPV design between many different vendors.

A ULPV acquisition effort should consider the findings and documented design considerations in this report, especially those expected to impact vessel cost and production time, as part of an overarching need to balance a ULPV's ability to be used as a surgable, sustainable, and possibly attritable materiel solution in support of national defense responsibilities to deter, de-escalate, and defeat. One interesting consideration for ULPV production is the prospect of leveraging small businesses and boatyards throughout the United States, vice shipyards, given the insufficient national shipyard capacity (Eckstein, 2024) that may not be able to meet production demands of a new line of vessels such as ULPVs. There may exist a relationship between ship design simplicity, COTS component utilization, and material choices that result in a level of production complexity not outside the capability of many small businesses and boatyards throughout the United States. Further, ULPV designs and their respective production complexities may or may not easily support the vessels' production in host or partner nations throughout the Indo-Pacific. The ability to produce ULPVs within the theater of conflict would save the use of copious resources needed to transport these vessels into theater. This research, therefore, is intended to inform the ease with which ULPVs may be produced in the Indo-Pacific.

B. REQUIREMENTS

Requirements that justify the acquisition of new materiel solutions for contested logistics, like ULPVs, are found in various published documents. In the *Joint Concept for Logistics*, the disparity between logistics demand and logistics resources is called out as the “logistics gap” (Joint Chiefs of Staff, 2015, p. 4), as depicted in Figure 84.



Note: This is a notional depiction only, not based on any quantifiable data.

Figure 2. The Challenge: Increasingly Demanding Logistics Requirements in an Era of Constrained and Degraded Resources

Figure 84. Logistics Gap. Source: Joint Chiefs of Staff (2015).

The USMC (2021) states that any necessary sustainment of forces inside the contested area requires the development of new capabilities, to include “small and plentiful vessels capable of connecting SIF inside the contested area to distribution nodes outside the contested area” (pp. 21–22). They further call for more diversified distribution methods, nodes, and modes; that sustaining a distributed naval expeditionary force will require distribution capabilities that are interoperable, scalable, efficient, and unpredictable (USMC, 2023c, p. 6).

C. UNMANNED LOW-PROFILE VESSEL CONCEPT EXPLORATION AND OBJECTIVES ANALYSIS

This thesis research overlaps the concept exploration phase in the system life cycle, shown in the center of Figure 85. The findings of this research have two sets of outputs (Kossiakoff et al., 2020) for the ULPV system:

1. performance requirements
2. candidate system concepts.

These two outputs provide the necessary information flow and input.

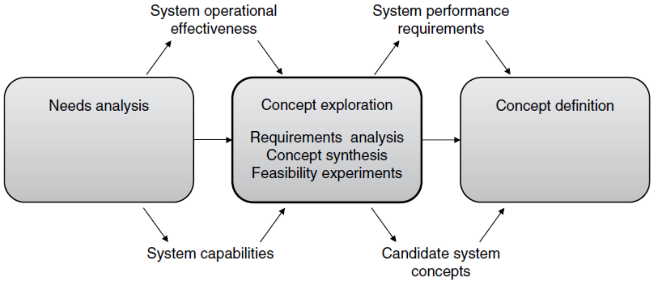


Figure 85. Concept Exploration Phase in the System Life Cycle. Source: Kossiakoff et al. (2020).

Concept explorations phase has inputs from the need analysis (Kossiakoff et al., 2020). One of the important inputs from the needs analysis that enables ULPV concept exploration and inform candidate system designs is the objective tree; a method for to conduct objectives analysis. Objective analysis is the process of developing and refining a set of objectives for a system (Kossiakoff et al., 2020). An objective tree provides a hierarchical view of a top-level objective, which is decomposed into primary and secondary objectives (Kossiakoff et al., 2020) as shown in Figure 86. Decomposition of objectives within the objective tree occurs until an objective becomes verifiable, and measurable. Being verifiable or measurable means that functions of the system that enable the objective defined and at that point the decomposition stops (Kossiakoff et al., 2020). Figure 86 provides a sample objective tree for ULPVs where the overarching objective is the successful transportation of supplies.

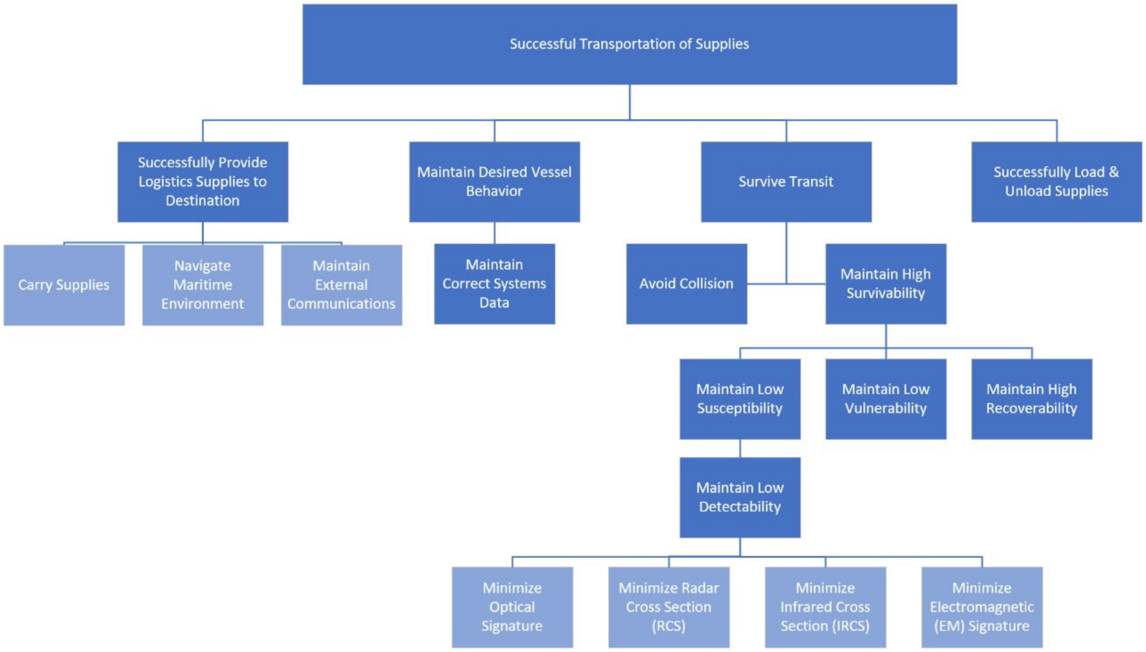


Figure 86. Sample Unmanned Low-Profile Vessel Objective Tree

D. FABRICATION CONSIDERATIONS

LCDR Banchs proposed the use of vacuum injection molding, as shown in Figure 87, as a fiberglass fabrication method for ULPV hulls to ensure consistent, durable, and high-quality construction (Brutzman et al., 2024). Another fabrication method, brushing fiberglass onto a hull mold (a.k.a., hand-laid), is a traditional way to build fiberglass boats. Either method, however, requires the use of a mold, and a ULPV mold must be standardized to ensure all vessels are built to design. A standardized manufacturing process that is available for use in both austere and exquisite fabrication facilities increases the number of locations where ULPVs can be manufactured, thereby increasing the options available for getting ULPVs into theater. Fabrication methods that can be used to build ULPVs within the Indo-Pacific presumably decrease the cost of ULPV acquisition by reducing the cost of transiting ULPVs into theater and by utilizing labor available in the Indo-Pacific.

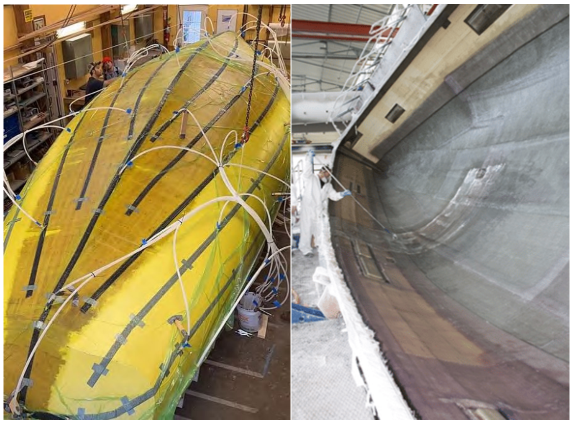


Figure 87. Vacuum Injection (Left) and Brush-On Fiberglass Molding. Sources: Artisan Boatworks (n.d.); Dufour Yachts (2016).

Fabrication of ULPVs in the United States need not be confined to existing defense contractors but rather may also include any business capable of fabricating ULPV hulls. Small boatyards throughout the United States, as well as manufacturers located in land-locked states, very likely have the facilities, equipment, and labor necessary to produce ULPVs. The historical rallying of factories, small and large, throughout the United States to produce war materiel in WWII is well documented (Herman, 2012). DTOs already demonstrate that manned LPVs can be rapidly and affordably fabricated in austere conditions with unskilled labor (VICE, 2011), and the DoD's ability to fabricate unmanned iterations of LPVs is presumably possible. However, building a ULPV, given the unmanned systems that must be integrated onboard, is inherently more complicated and costly than building the manned LPVs produced by DTOs. The integration strategy that the DoD uses for ULPV fabrication is key to ensure that ULPV costs can be minimized.

E. UNMANNED LOW-PROFILE VESSEL PREFABRICATION AND INTEGRATION STRATEGY

The method of prefabricating sections of a vessel and then joining the sections together to complete the fabrication of an overall system, thereby increasing production efficiency, speeding build time, and reducing build costs, is well documented, most notably in various WWII production lines, especially those of the Liberty Ships (Herman, 2012). The method of prefabricating sections of a vessel and then joining the sections together to complete the fabrication of an overall system, thereby increasing production efficiency, speeding build time, and reducing build costs, is well documented, most notably in various WWII production lines, especially those of the Liberty Ships.

One method of ULPV integration might break the fabrication of ULPVs into two distinct parts. The first part (Part A) would be the ULPV hull and its hull, mechanical, and electrical (HM&E) systems (hull, ballast systems, rudder, pumps, engine[s]), while the second part (Part B) would be the mission system, composed of sensors, computers, actuators, hydraulics, antennas, and any other systems used in the mission, other than HM& E. Alternatively, the hull alone could be the first part (Part A), and the rest of the ULPV system (HM&E and mission system) could be the second part (Part B). It is understood that many components making up HM&E and mission systems will be COTS, and therefore, any vendor building either part of a ULPV will need to be assured reliable access to any system components making up that part. Table 12 shows how a ULPV might be broken down into two parts for prefabrication prior to integration of the two parts.

Table 12. Notional Unmanned Low-Profile Vehicle Prefabrication and Integration Strategies

	Step 1: ULPV Prefabrication	Step 2: ULPV Integration
Vessel-and-Mission Strategy	Part A: Build HM&E system (hull, ballast, rudder, pumps, engine[s]). Part B: Build mission subsystem(s) (sensors, computers, actuators, hydraulics, antennas).	Integrate Part B into Part A.
Hull-and-"Everything Else" Strategy	Part A: Build hull. Part B: Build all ULPV subsystems(s) (ballast, rudder, pumps, engine(s), sensors, computers, actuators, hydraulics, antennas).	Integrate Part B into Part A.

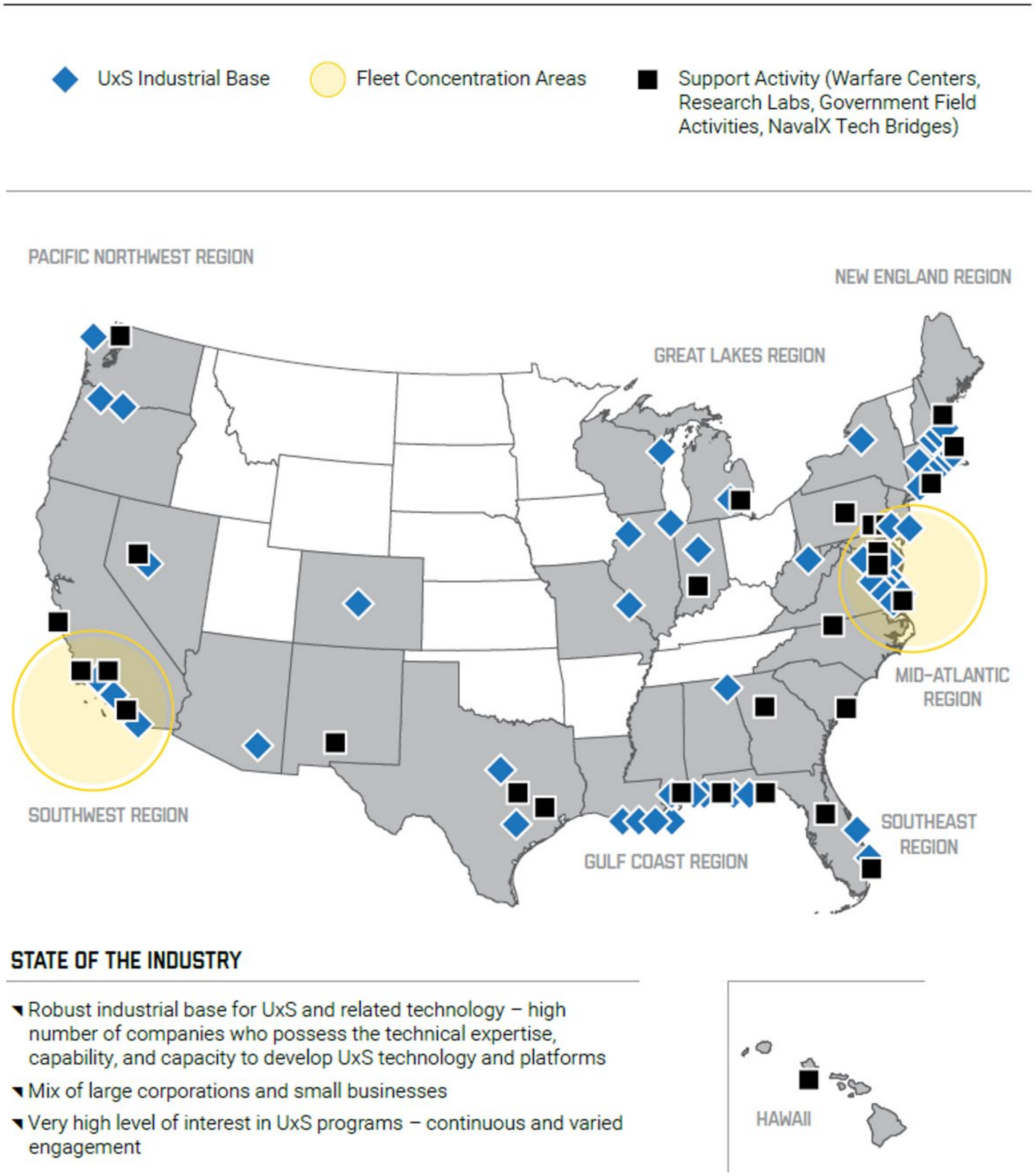
One question of integration strategy is where integration takes place. An integration strategy that utilizes integration centers would allow the DoD to accept largely COTS vessels fabricated from a small business or boatyard and then complete final modifications and installation of mission and/or HM&E systems (O'Connor, 2024). In addition, an integration strategy like this would prevent the unnecessary burden of classified or controlled work on small businesses (O’Connor, 2024). If a ULPV is prefabricated in two parts, such as in either case depicted in Table 12, the solution may be to complete integration where the hull exists, since the hull is likely the largest piece of either prefabricated part of a ULPV. For example, if the hull is fabricated in the Indo-Pacific, it would make sense to complete final integration in the Indo-Pacific, as well. However, if the hull is fabricated in the center of the United States, it may be advantageous to complete final integration somewhere closer to where the ULPV is intended to launch (such as at a coastal port in California); however, a cost comparison should be done to account for integration at a new location and the transportation costs of getting the hull to that location. To minimize transportation costs in support of ULPV integration, it may be advantageous to complete final integration at the location where the hull is fabricated.

Modular construction is one fabrication approach that could aid in reducing the costs of transporting large ULPV hulls prior to final integration. LCDR Banchs in his Naval Postgraduate School C2 capstone project highlighted that a vessel constructed in distinct sections, such as the bow (front), payload (center), and propulsion (stern/rear), could yield advantages for both transportation as well as final integration (Brutzman et al., 2024). If each ULPV section were designed to fit into standard shipping containers, either 10ft, 20ft, or 40ft in length, existing global logistics infrastructure could be leveraged to transport large, prefabricated sections of ULPVs to the point of final integration. The use of shipping containers also provides concealment of ULPV section shipments from curious observers. Obviously, designing ULPV sections to fit within shipping container dimensions may pose challenges, such as limiting vessel size or shape. Figure 88 depicts LCDR Banchs’ idea of modular construction and a modular LPV, which uses molds for fabrication and fits into shipping containers for transport (Brutzman et al., 2024).

Figure 88. Modular Low-Profile Vessel, Mold Fabrication, and Container Transport. Source: Brutzman et al. (2024).

F. USING SMALL BUSINESSES AND SMALL BOAT BUILDERS

While there already exists an industrial base to produce ULPVs, adding small businesses and small boat builders to increase the number of viable vendors for ULPV fabrication should also be considered. Figure 89, from the Navy Unmanned Campaign Framework (Department of the Navy [DON], 2021), shows a map of the existing U.S. unmanned systems industrial base, but decision-makers should consider ULPV design, fabrication, and integration strategy from a lens of leveraging a broader range of the industrial base than only that which already specializes in unmanned systems. World War II saw the United States rely on manufacturers that originally specialized in building cars or home appliances shift into building countless wartime materiel (Herman, 2012). Those manufacturers were businesses small and large, and the United States can again embrace a mix of businesses and a wider manufacturing base to manufacture unmanned vessels like ULPVs (O'Connor, 2024).



STATE OF THE INDUSTRY

- Robust industrial base for UxS and related technology – high number of companies who possess the technical expertise, capability, and capacity to develop UxS technology and platforms
- Mix of large corporations and small businesses
- Very high level of interest in UxS programs – continuous and varied engagement

Figure 89. Map of Existing United States Unmanned Systems Industrial Base. Source: Department of the Navy (2021).

THIS PAGE INTENTIONALLY LEFT BLANK

XI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Parts of sections A, B, and C were previously published by the Acquisition Research Program at NPS (Sierra, 2024).

A. CONCLUSION

This research analyzed various considerations for ULPV design and employment. The ULPV is a feasible materiel solution for contested logistics operations in the Indo-Pacific. The manner which a ULPV is designed should consider many factors, such as seakeeping, the manner of loading or unloading supplies, the locations where supplies will need to be loaded or unloaded, and the material handling equipment expected to be available to support ULPV loading or unloading at any of those locations. Further, technical considerations such as enterprise architecture, MOSA, external communications, navigation, sensory, autonomy, and big data are several areas that require attention in vessel design. This research demonstrated that ULPVs are expected to be less susceptible, and therefore more survivable, than existing logistics assets. However, ULPVs still have signatures that are detectable, and when considering the threat environment of the Indo-Pacific during a time of conflict, ULPVs may still be detected and experience attrition at levels like the P_d rates discovered in this research's modeling and simulation work. If a ULPV's ability to avoid detection isn't adequate to maintain the success rates necessary for ULPV contested logistics operations, deception or other information warfare tactics may be of use to increase the survivability of ULPVs.

ULPVs may provide the DoD long-term stabilization value during an era of grey-zone competition and military conflict. Having a contested logistics capacity to provide indefinite logistics resupply across first and second island chains in the Indo-Pacific provides paths for de-escalation back to deterrence, rather than unchecked escalation to conflict. The Liberty Ship program of WWII proved critical to the war's outcome (Herman, 2012). Liberty Ships overcame attrition by German U-Boats in the contested waters of the Atlantic. Many lessons learned from the design and production of Liberty Ships can similarly inform the design and production of ULPVs to overcome threats in the contested waters of the Indo-Pacific. Some applicable lessons learned include utilizing principles of standardization and methods of mass production (Lane, 1951, p. 31 & p. 72) as well as the use of machine tools and prefabrication (Herman, 2012). These same lessons were applied with great success by Andrew Higgins in 1942 (Lane, 1951, p. 185), resulting in the design and mass production of the "Higgins boats", tens of thousands of which were shallow-draft landing craft made of wood and steel for amphibious assaults in the Indo-Pacific (Strahan, 1994). The geography of the Indo-Pacific since World War II remains very similar today, and applying lessons learned from vessels designed, produced, and employed during World War II may prove beneficial to inform ULPV design, production, and employment for the DoD today.

B. CAUSAL LOOP DIAGRAMS

The CLD in Figure 78 illustrates the conceptual interactions between a logistics vessel, the red forces, and the expeditionary unit supply level. However, in the case of a fully unmanned system such as a ULPV, additional factors might play into the CLD to illustrate the need for the ULPV as a series of systems to perform as desired. The resulting desired system performance would then be a variable, in addition to the P_d, impacting the success rate of the vessel. In addition, a presumed reliance on external connectivity between the ULPV and any logistics command and control structure would introduce another series of variables that contribute to the desired system performance as well as the vessel's RF signature.

This research effort did not pursue simulation of a CLD specific to a ULPV. However, it is useful to see the possible interactions between variables specific to a ULPV. Figure 90 is a draft, working version of a possible ULPV CLD that was started by this effort. Future work may make use of this diagram to visualize some of the variable interactions necessary for successful ULPV operations for contested logistics.

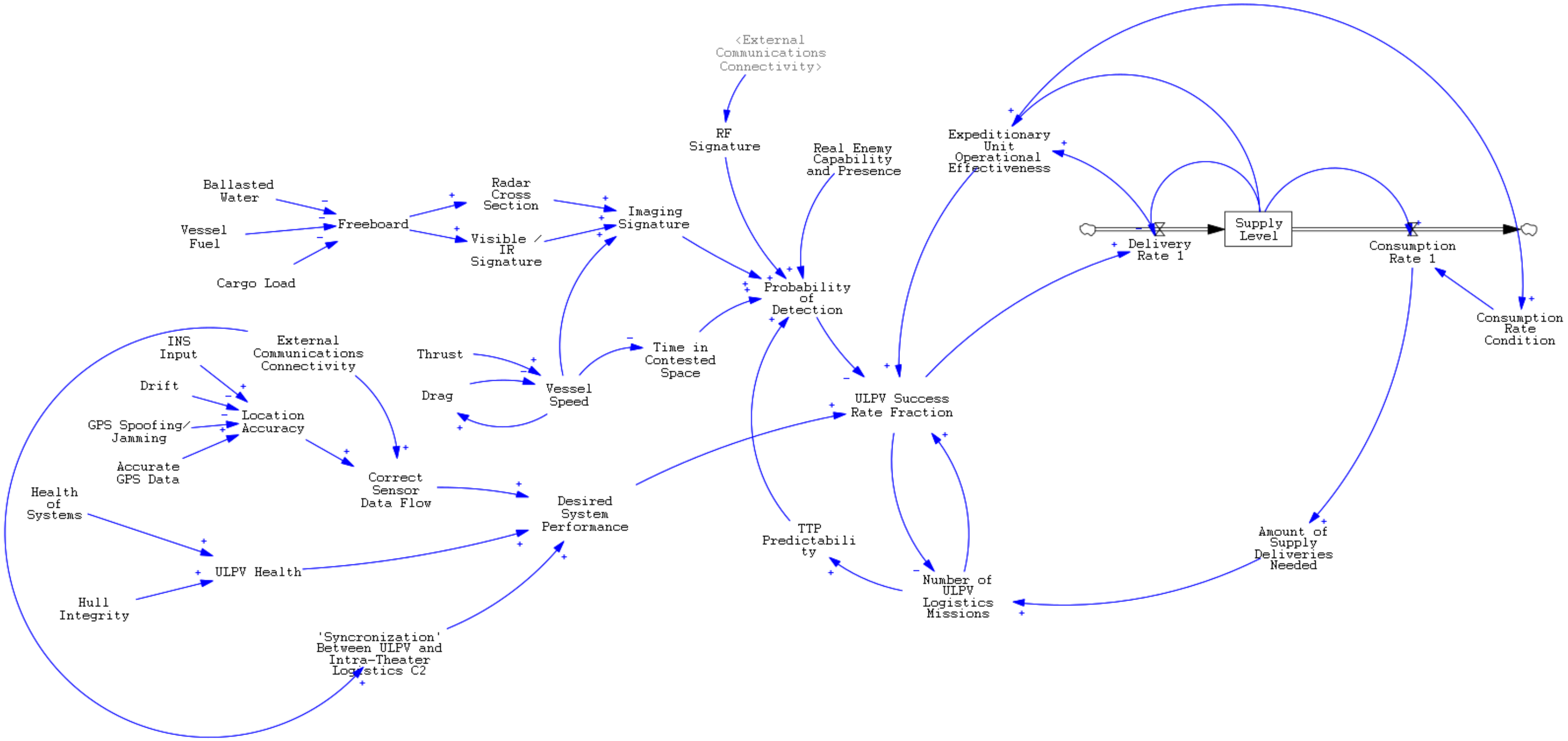


Figure 90. Unmanned Low-Profile Vessel Specific Causal Loop Diagram for Contested Logistics and Expeditionary Unit Resupply

C. VIRTUAL SANDBOXING

The Modeling Virtual Environments and Simulation (MOVES) Institute at NPS has a virtual sand table (VST) (Figure 91) that can be utilized for future work with 3D printed models of notional ULPVs to visually depict ULPV employment on real-world projected locations. This process can enable data collection to inform potentially new considerations for ULPV design and employment. 3D models used in SPIDERS3D are produced from a variety of sources, then converted (if necessary) to X3D for mashup composition and Web-based collaborative visualization. Extensible 3-dimensional (X3D) Graphics is the international standard for publishing interactive 3D models on the Web (Brutzman & Daly, 2007). More information is available at https://www.web3d.org/x3d/what-x3d.

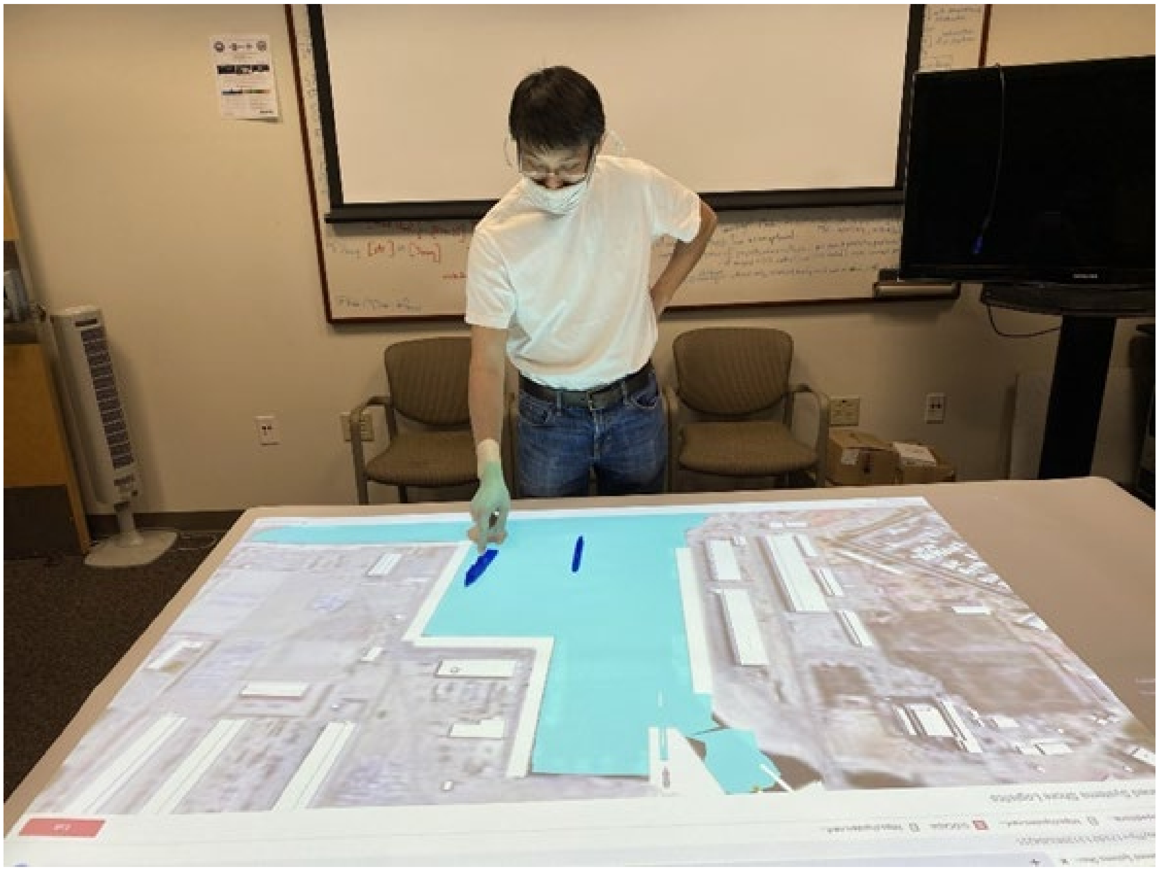


Figure 91. Demonstration of Virtual Sand Table at the Naval Postgraduate School. Source: EXWC SPIDERS3D (2021).

D. OPTIMIZATION OF UNMANNED LOW-PROFILE VESSEL DESIGN

One additional area for future work is the optimization of ULPV designs. Optimization could incorporate many design elements, such as those documented in this report, and optimize for a ULPV that maximizes a performance metric, such as probability of successful delivery or probability of remaining undetected. Similarly, optimization work could optimize for minimal cost, which would be especially insightful for ULPV designs that are intended to be expendable. Optimization could occur within given constraints such as maximum number of man hours, maximum level of design complexity, maximum cost per vessel, minimum operating range, maximum P_d, and minimum supply cargo capacity.

E. RADAR CROSS-SECTION APPROXIMATION

Another area for follow-on research is to generate radar cross-section approximations for one or multiple ULPV designs. This can be done based on the geometry of a ULPV design, using 3-dimensional computer models and computer tools designed for conducting RCS approximation. This research started initial work to approximate the RCS values associated with a DTO LPV, however, the work was abandoned to focus on the modeling and simulation aspects found in this research. Figures 92 and 93 show some of this initial work.

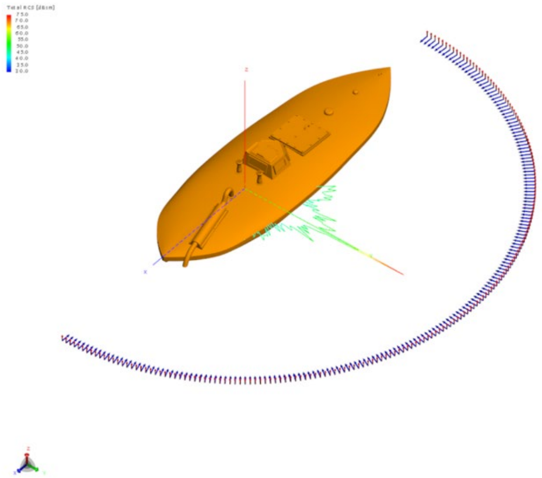


Figure 92. Radar Cross-Section Approximation Initial Work

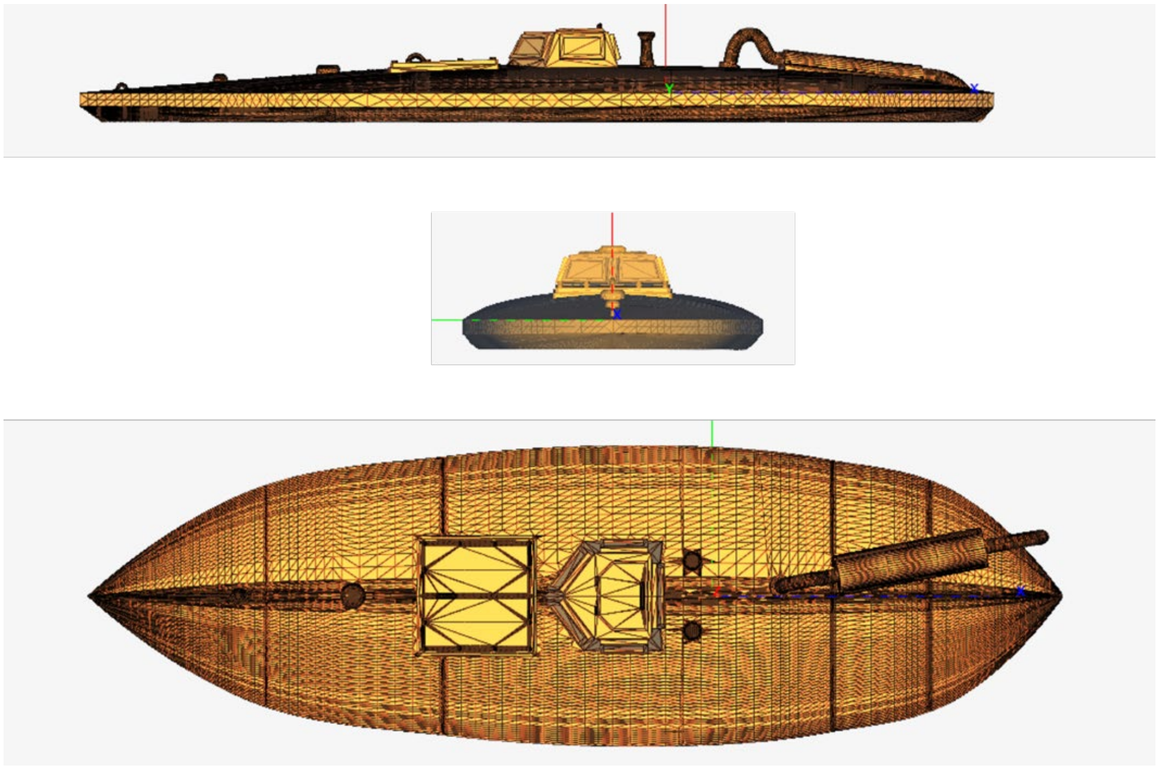


Figure 93. Drug Trafficking Organization Low Profile Vessel 3-Dimensional Model

APPENDIX A. NEXT GENERATION THREAT SYSTEM SCREENSHOTS

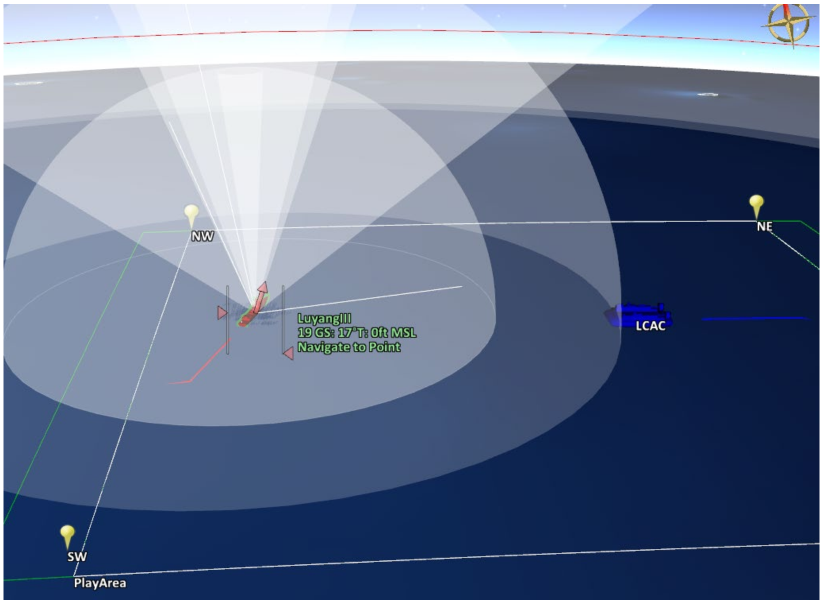


Figure 94. 3-Dimensional View of Landing Craft Air Cushion Simulation Run

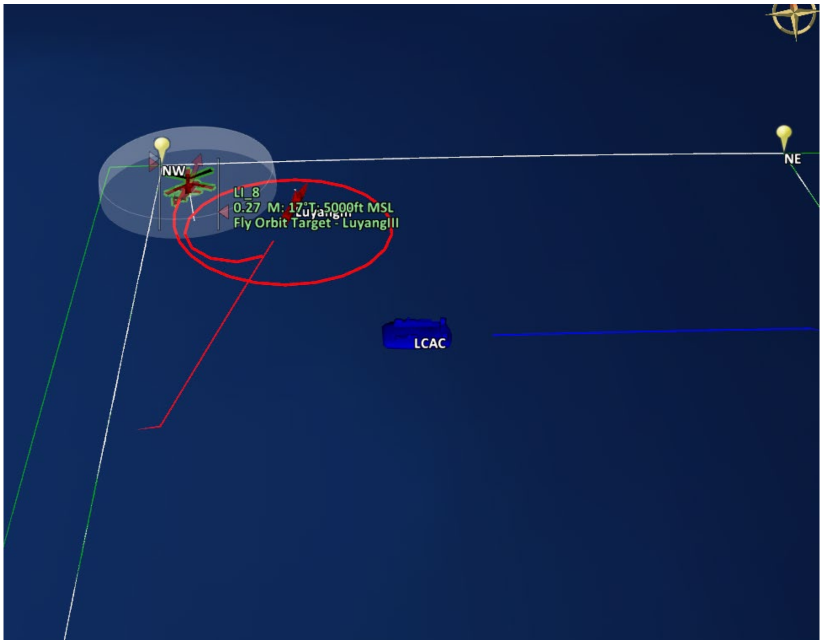


Figure 95. 3-Dimensional View of Simulation Showing Embarked Helicopter Operating

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. EXAMPLE UNMANNED LOW-PROFILE VESSEL MISSIONS

A. AUTONOMOUS VEHICLE COMMAND LANGUAGE MISSION DIAGRAMS

Autonomous vehicle command language (AVCL) is the mission command language used by the autonomous underwater vehicle (AUV) Workbench for mission planning, rehearsal and operations (Davis, n.d.).

> While numerous military and civilian uses for autonomous air, ground, surface, and undersea vehicles have been identified or proposed, and a few available products attempt to meet some of these, a critical shortcoming exists that will inhibit the implementation of systems that adequately address the majority of these potential applications. The fact of the matter is that vehicle-specific data formats and mission planning systems preclude effective coordination in multi-vehicle systems and hinder the design of such systems (even those wherein individual vehicles operate more or less independently to achieve a common goal).
>
> To date the preponderance of research into coordinated operations of multiple autonomous vehicles has assumed that the vehicles involved are inherently compatible. That is, either the multi-vehicle system consists solely of one type of vehicle, or all vehicles use the same language for mission specification and inter-vehicle communication. Unfortunately, this is unrealistic given current inventories of legacy vehicles and the parallel development of vehicles by various commercial, academic, and government entities. It is precisely this gap that a common autonomous vehicle control language (AVCL) is intended to fill.
>
> A well-defined common format for mission-specification (tasking), inter-vehicle communication, and mission-results, coupled with utilities for the automatic conversion of data in this format to and from vehicle-specific formats can serve as a bridge between dissimilar autonomous vehicles. This AVCL will facilitate coordinated operations between dissimilar vehicles and enable their human operators to provide more effective tasking for systems of dissimilar vehicles and interact with vehicles during their missions (Davis, n.d.).

Figures 96 and 97 illustrate initial work to create ULPV mission diagrams in AVCL.

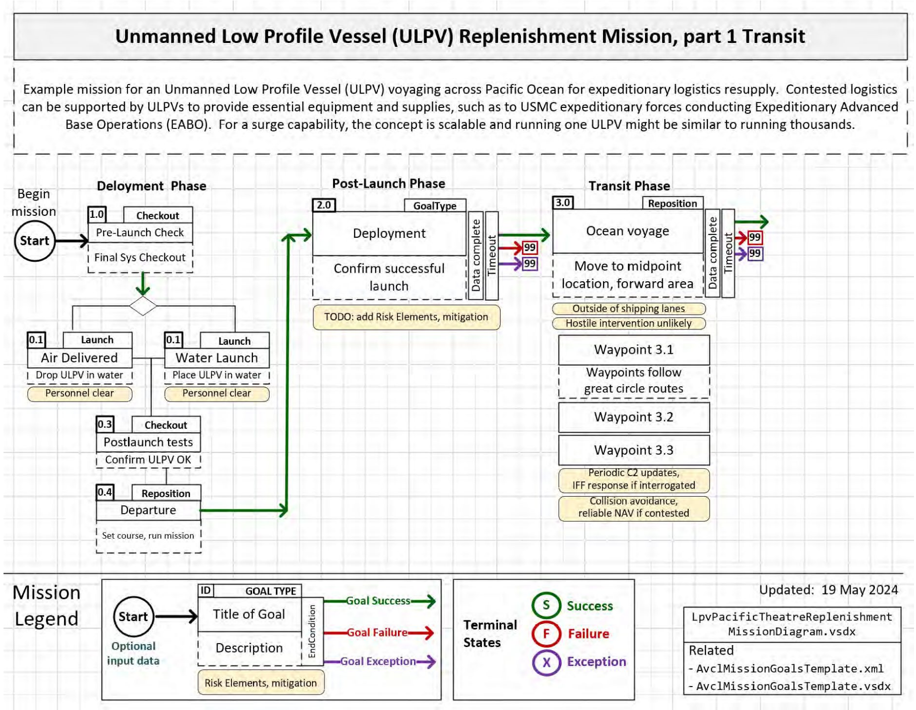


Figure 96. Sample Unmanned Low-Profile Vessel Mission Diagram, Part 1. Source: Brutzman (2024).

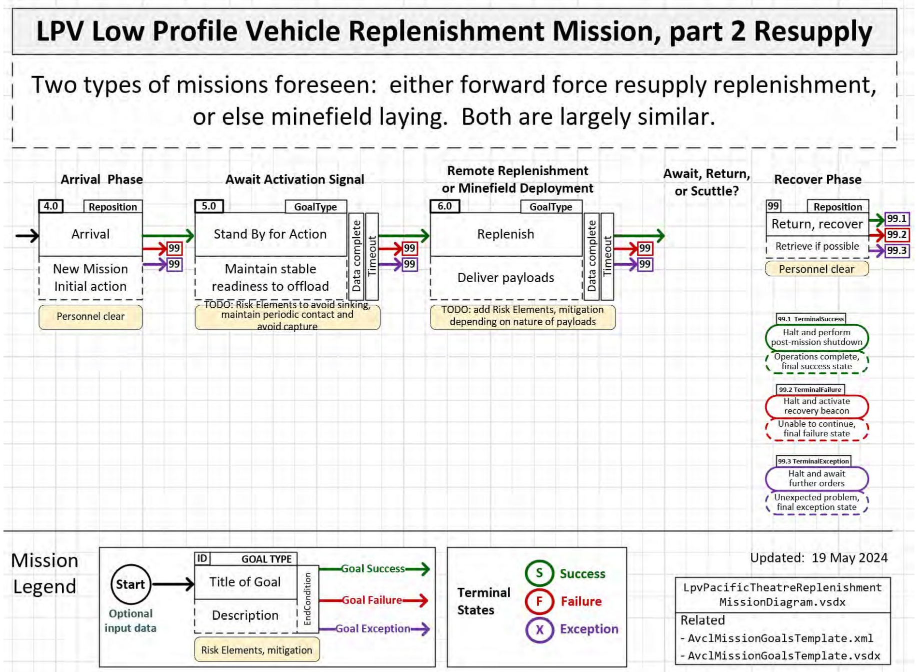


Figure 97. Sample Unmanned Low-Profile Vessel Mission Diagram, Part 2. Source: Brutzman (2024).

B. MISSION TEMPLATES

The following, named “Operation Dumbo Drop, is a set of example mission plans from LCDR Luis Banchs on notional ULPV offensive mining operations. Though LCDR Banchs’ examples are built for the offensive mining mission, most of the example’s contents are directly applicable to a ULPV conducting logistics functions.

Operation Dumbo Drop: Exercise – Notional Unmanned LPV Offensive Mining

BLUF: This unit has been tasked with a mission to execute the offensive mining of “an area” far-far away using unmanned LPVs. In order to accomplish this mission, we will utilize this six step/phase mission template to gain situational awareness of the target area and develop plans for clandestine transport, deployment, insertion, actions on objective, post-deployment surveillance and redeployment of assets. Then we will use a six-step plan to transit to/from target area and a four-step plan for the arrival and delivery of weapons to designated aim points.

Six Phase Mission Plan – The Big Picture

1. **Intelligence Collection and Surveillance:**
    - In this initial phase, intelligence is gathered about the enemy’s movements, naval assets, and potential targets. Surveillance methods include aerial reconnaissance, satellite imagery, and other intelligence sources.
    - The goal is to identify suitable areas for laying mines and to understand the adversary’s patterns and vulnerabilities.
2. **Notification of Imminent Mining:**
    - Once the decision is made to conduct offensive mining, friendly forces must be informed. This notification ensures that friendly ships avoid the mined areas.
    - Timely communication is essential to prevent accidental encounters with the minefields.
3. **Mine Laying and Deployment:**
    - During this phase, the actual minefields are laid. Mines can be deployed from ships, submarines, or aircraft.
    - The choice of mine type (contact, magnetic, acoustic, etc.) depends on the mission and the intended targets.

4. **Post-Deployment Surveillance:**
    - After laying the mines, continuous surveillance is necessary to monitor the minefields. This includes checking for drift, ensuring proper spacing, and assessing the effectiveness of the minefield.
    - Adjustments may be needed based on changing conditions.
5. **Mine Activation and Targeting:**
    - Offensive mines are activated when enemy vessels approach. Activation mechanisms vary (e.g., pressure, magnetic fields, acoustic signals).
    - The mines are strategically placed to disrupt enemy movements, protect friendly forces, and deny access to critical areas.
6. **Mine Countermeasures:**
    - The final phase involves countering enemy mine warfare efforts. This includes locating and neutralizing enemy mines.
    - Mine countermeasures teams use sonar, divers, and remotely operated vehicles to detect and remove mines.

Operation Dumbo Drop: Exercise – Notional Unmanned LPV Offensive Mining

Six Phase Plan – LPV Transit Operation to/from Target Area

1. **Pre-Mission Planning**:
    - **Objective Definition**: Clearly define the mission objectives and the specific requirements for the object drop.
    - **Route Planning**: Determine the optimal path for the vessel to reach the drop coordinates, considering maritime traffic, weather, and potential hazards.
    - **System Checks**: Ensure all vessel systems, including navigation, communication, and payload release mechanisms, are fully operational.
2. **Programming and Testing**:
    - **Autonomous System Programming**: Input the mission parameters into the vessel's autonomous navigation system.
    - **Simulation Testing**: Run simulations to test the vessel's ability to execute the mission under various scenarios.
    - **Dry Runs**: Conduct controlled trials in a safe environment to validate the vessel's performance.
3. **Deployment**:

    - **Launch**: Deploy the uncrewed vessel from its home port or launch site.
    - **Transit**: Monitor the vessel as it transits to the drop zone, ensuring it stays on course and functions as expected.
4. **Object Drop Execution**:
    - **Arrival at Coordinates**: Confirm the vessel has reached the predetermined coordinates.
    - **Payload Release**: Execute the drop sequence, releasing the objects at the designated location.
    - **Confirmation**: Use onboard sensors or external verification to confirm successful object deployment.
5. **Post-Drop Operations**:
    - **Data Collection**: Gather data from the drop for analysis and future mission refinement.
    - **Return Transit**: Navigate the vessel back to its home port or to the next mission waypoint.
    - **Mission Debrief**: Analyze the mission's success, document lessons learned, and make recommendations for future operations.
6. **Maintenance and Upgrades**:
    - **System Maintenance**: Perform routine maintenance and any necessary repairs on the vessel.
    - **Software Updates**: Update the autonomous navigation system with new software patches or enhancements.
    - **Hardware Upgrades**: Install any new hardware that may improve future mission performance.

Operation Dumbo Drop: Exercise – Notional Unmanned LPV Offensive Mining

<u>Four Phase Plan – LPV Arrival & Delivery of Weaponry to Target Area</u>

Note: Here are the phases for the arrival and delivery of objects using an uncrewed vessel in more granular detail.

1. **Approach and Arrival at Destination**:
    - **Final Course Adjustment**: As the vessel nears the drop zone, make fine adjustments to the course based on real-time environmental data and navigational inputs.
    - **Verification of Coordinates**: Use GPS and other navigational tools to verify the vessel's position relative to the predetermined coordinates.

  - **Pre-Drop Checks**: Conduct final systems check to ensure all payload release mechanisms are functional and the vessel is ready for object delivery.

2. **Delivery Execution**:
  - **Positioning Over Drop Zone**: Maneuver the vessel to be directly over the drop zone, considering any drift or current that may affect the drop accuracy.
  - **Payload Release Sequence**: Initiate the automated sequence to release the objects at the exact coordinates. This may involve opening hatches, activating release mechanisms, or other actions depending on the payload type.
  - **Confirmation of Delivery**: Use onboard sensors, cameras, or external verification methods to confirm that the objects have been successfully delivered to the intended location.
3. **Post-Delivery Procedures**:
  - **Data Logging**: Record all relevant data from the delivery, including time, location, environmental conditions, and any anomalies encountered during the operation.
  - **Departure from Drop Zone**: Once delivery is confirmed, pilot the vessel away from the drop zone to avoid any interference with the delivered objects or to prepare for subsequent delivery phases.
  - **Communication with Base**: Report the successful delivery to the command center or base of operations, providing all necessary data for mission analysis.
4. **Return Transit and Recovery**:
  - **Navigation Back to Base**: Set the course for the vessel to return to its home port or recovery location.
  - **Monitoring Return Journey**: Continuously monitor the vessel’s systems and environmental conditions to ensure a safe return transit.
  - **Recovery Operations**: Upon arrival at the recovery location, execute the procedures for securing the vessel and offloading any remaining payload or data equipment.

These phases are designed to ensure the precise delivery of objects to a remote location using an uncrewed vessel.

APPENDIX C. NEXT GENERATION THREAT SYSTEM RED ASSETS ADDITIONAL DETAILS

Figure 98. People's Republic of China Y-8Q (also known as KQ-200, GX-6, or High New 6). Source: Vavasseur (2019).

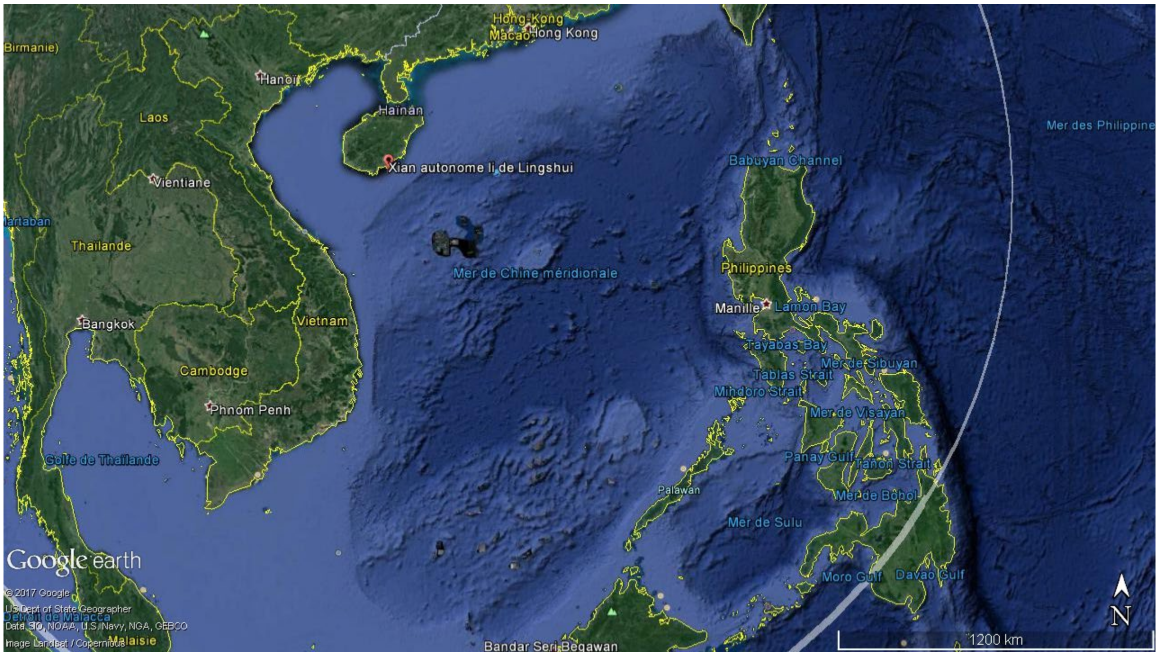


Figure 99. Y-8Q Operational Range from Lingshui Air Base, Estimated at 2,000 Kilometers. Source: Vavasseur (2019).

Figure 100. People’s Republic of China LuyangIII Class Destroyer with Helicopter. Source: Naval Technology (n.d.).

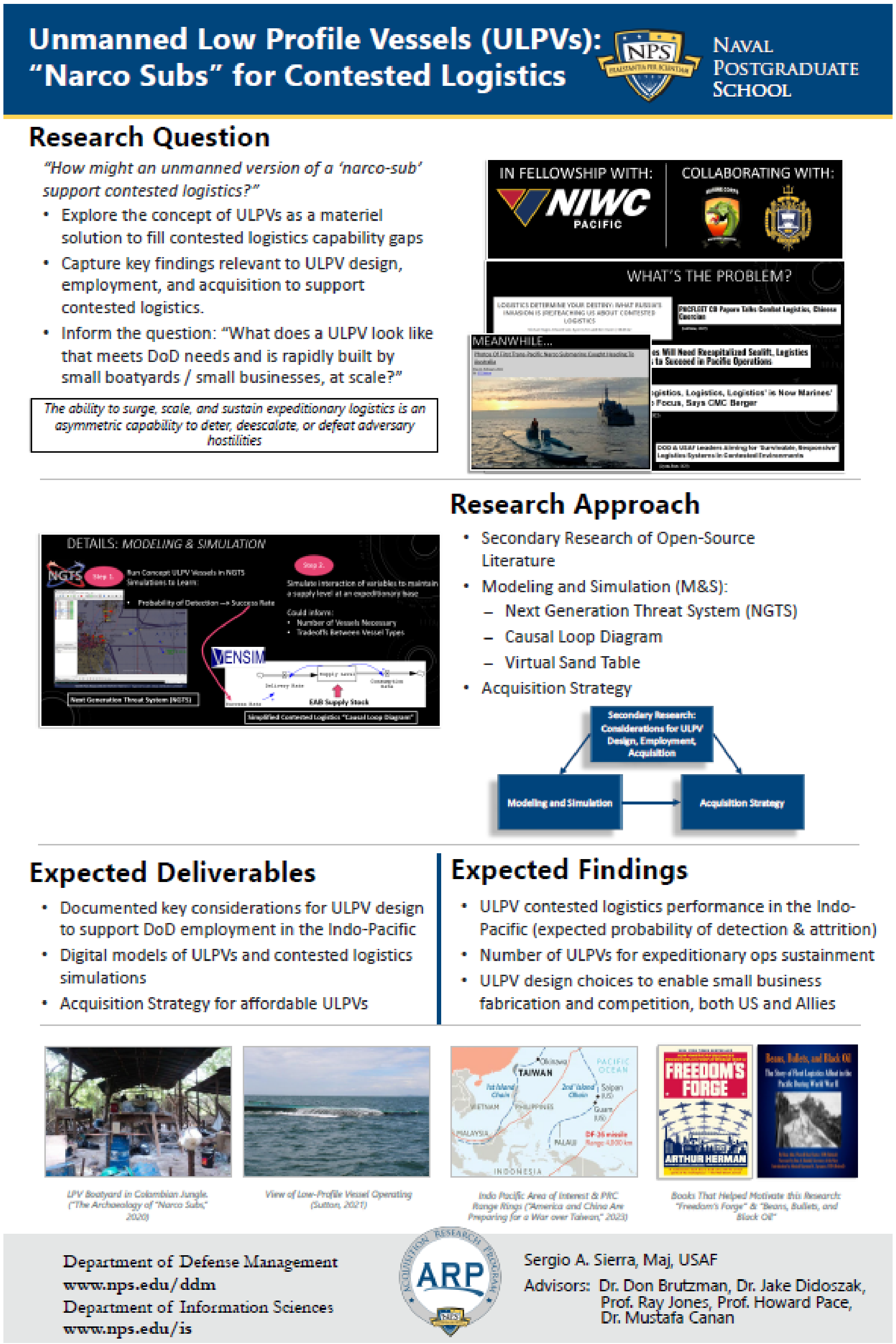
Figure 101. LuyangIII Class Destroyer Systems Callouts. Source: United States Naval Institute (2020).

Figure 102. Ka-27 Launch/Recovery from Underway Ship. Source: “Ka-27/28 and Ka-29 Helix” (n.d.).

Figure 103. Model of LuyangIII with Ka-28. Source: Chinese Type 052d Destroyer Model (n.d.).

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX D. RESEARCH RELATED PRESENTATION MATERIALS



Unmanned Low Profile Vessels (ULPVs): "Narco Subs" for Contested Logistics

NAVAL POSTGRADUATE SCHOOL

Research Question

"How might an unmanned version of a 'narco-sub' support contested logistics?"

- Explore the concept of ULPVs as a materiel solution to fill contested logistics capability gaps
- Capture key findings relevant to ULPV design, employment, and acquisition to support contested logistics.
- Inform the question: "What does a ULPV look like that meets DoD needs and is rapidly built by small boatyards / small businesses, at scale?"

The ability to surge, scale, and sustain expeditionary logistics is an asymmetric capability to deter, deescalate, or defeat adversary hostilities

Research Approach

- Secondary Research of Open-Source Literature
- Modeling and Simulation (M&S):
  - Next Generation Threat System (NGTS)
  - Causal Loop Diagram
  - Virtual Sand Table
- Acquisition Strategy

Expected Deliverables

- Documented key considerations for ULPV design to support DoD employment in the Indo-Pacific
- Digital models of ULPVs and contested logistics simulations
- Acquisition Strategy for affordable ULPVs

Expected Findings

- ULPV contested logistics performance in the Indo-Pacific (expected probability of detection & attrition)
- Number of ULPVs for expeditionary ops sustainment
- ULPV design choices to enable small business fabrication and competition, both US and Allies

LPV Boatyard in Colombian Jungle. ("The Archaeology of "Narco Subs," 2020)

View of Low-Profile Vessel Operating (Sutton, 2021)

Indo Pacific Area of Interest & PRC Range Rings ("America and China Are Preparing for a War over Taiwan," 2023)

Books That Helped Motivate this Research: "Freedom's Forge" & "Beans, Bullets, and Black Oil"

Department of Defense Management
www.nps.edu/ddm
Department of Information Sciences
www.nps.edu/is

Sergio A. Sierra, Maj, USAF

Advisors: Dr. Don Brutzman, Dr. Jake Didoszak, Prof. Ray Jones, Prof. Howard Pace, Dr. Mustafa Canan

Figure 104. Author's Research Poster Presented at the 2024 Acquisition Research Symposium.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX E. RELATED NAVAL POSTGRADUATE SCHOOL WORK

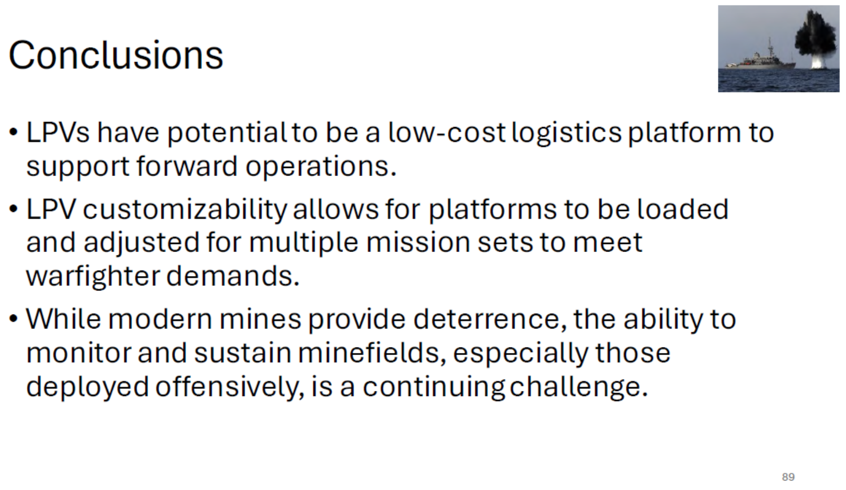
The below slides are taken from Brutzman et al. (2024) and serve as amplifying data for some concluding points regarding the concept of ULPVs in general and specific to the concept of ULPVs for mine warfare. In addition, from Brutzman et al. (2024), some slides describing challenges, termed “showstoppers”, for ULPVs are placed in this appendix.

INTERNATIONAL MINE WARFARE
TECHNOLOGY SYMPOSIUM
San Diego, CA | 21-23 May 2024 | #IMWTS24

Command and Control (C2) for Theater Mine Warfare Sustainment

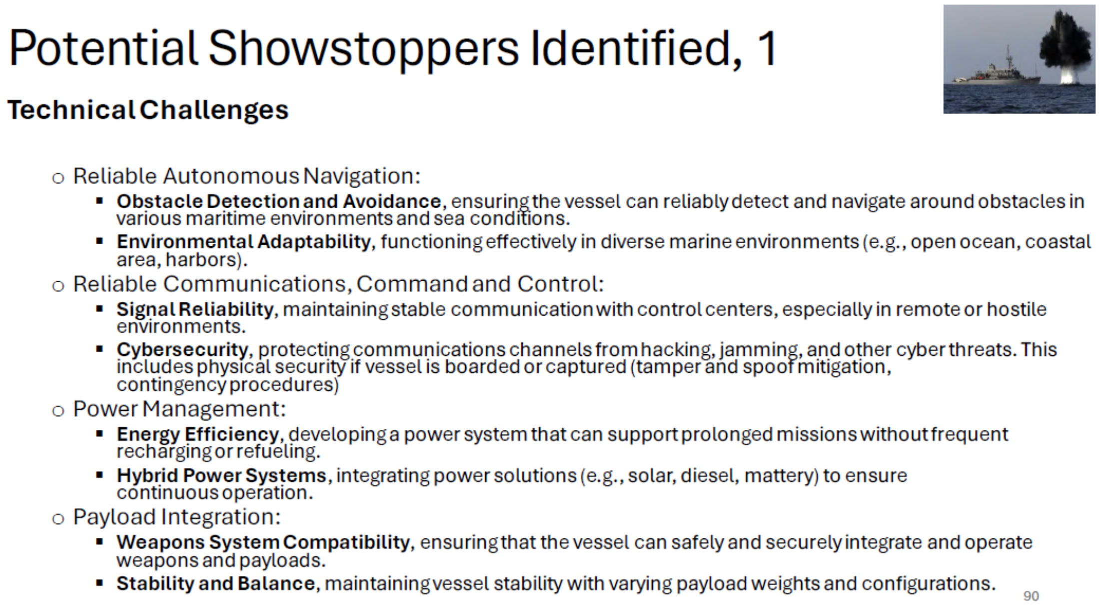
International Mine Warfare Technology Symposium

Don Brutzman, brutzman@nps.edu
CC4913 Capstone: Warfare Innovation 2045 Concept Study
Naval Postgraduate School (NPS), Monterey California USA
21 May 2024



Conclusions

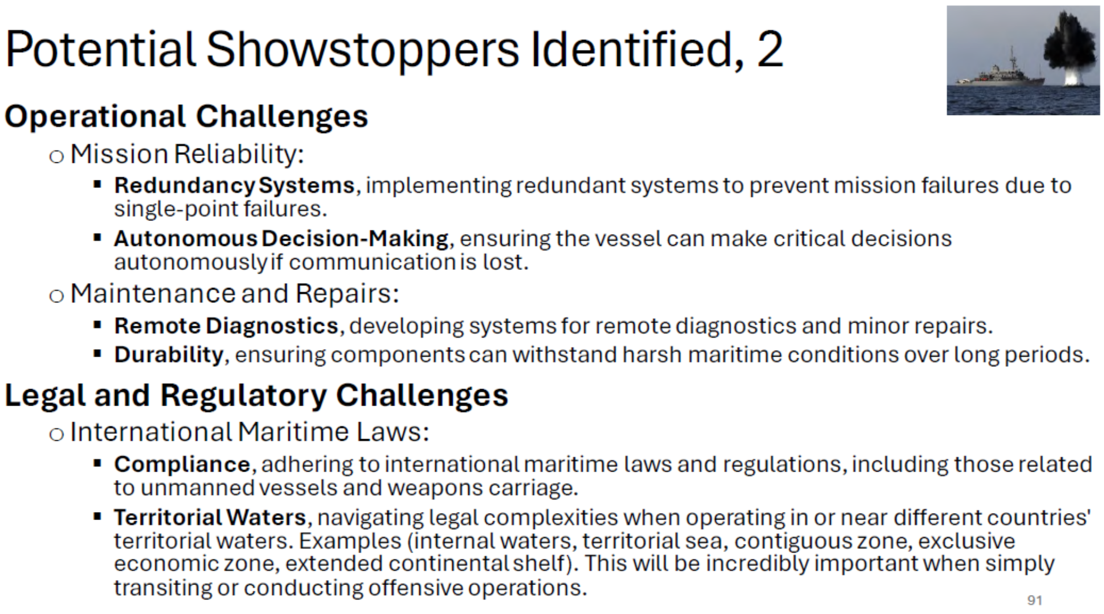
- LPVs have potential to be a low-cost logistics platform to support forward operations.
- LPV customizability allows for platforms to be loaded and adjusted for multiple mission sets to meet warfighter demands.
- While modern mines provide deterrence, the ability to monitor and sustain minefields, especially those deployed offensively, is a continuing challenge.



Potential Showstoppers Identified, 1

Technical Challenges

- Reliable Autonomous Navigation:
  - **Obstacle Detection and Avoidance**, ensuring the vessel can reliably detect and navigate around obstacles in various maritime environments and sea conditions.
  - **Environmental Adaptability**, functioning effectively in diverse marine environments (e.g., open ocean, coastal area, harbors).
- Reliable Communications, Command and Control:
  - **Signal Reliability**, maintaining stable communication with control centers, especially in remote or hostile environments.
  - **Cybersecurity**, protecting communications channels from hacking, jamming, and other cyber threats. This includes physical security if vessel is boarded or captured (tamper and spoof mitigation, contingency procedures)
- Power Management:
  - **Energy Efficiency**, developing a power system that can support prolonged missions without frequent recharging or refueling.
  - **Hybrid Power Systems**, integrating power solutions (e.g., solar, diesel, mattery) to ensure continuous operation.
- Payload Integration:
  - **Weapons System Compatibility**, ensuring that the vessel can safely and securely integrate and operate weapons and payloads.
  - **Stability and Balance**, maintaining vessel stability with varying payload weights and configurations.



Potential Showstoppers Identified, 2

Operational Challenges

- Mission Reliability:
  - **Redundancy Systems**, implementing redundant systems to prevent mission failures due to single-point failures.
  - **Autonomous Decision-Making**, ensuring the vessel can make critical decisions autonomously if communication is lost.
- Maintenance and Repairs:
  - **Remote Diagnostics**, developing systems for remote diagnostics and minor repairs.
  - **Durability**, ensuring components can withstand harsh maritime conditions over long periods.

Legal and Regulatory Challenges

- International Maritime Laws:
  - **Compliance**, adhering to international maritime laws and regulations, including those related to unmanned vessels and weapons carriage.
  - **Territorial Waters**, navigating legal complexities when operating in or near different countries' territorial waters. Examples (internal waters, territorial sea, contiguous zone, exclusive economic zone, extended continental shelf). This will be incredibly important when simply transiting or conducting offensive operations.

Potential Showstoppers Identified

Legal and Regulatory Challenges (continued)

- Arms Control Agreements:
  - **Regulatory Approvals**, securing necessary approvals for deploying an armed autonomous vessel, potentially subject to arms control treaties and regulations.
  - **Non-Proliferation**, addressing concerns related to the proliferation of autonomous weapons systems.

Ethics and Safety Challenge

- Rules of Engagement
  - **Autonomous Targeting**, developing clear rules and protocols for autonomous targeting and engagement to avoid unintended escalation or civilian harm.
  - **Human Oversight**, ensuring human oversight in the decision loop, particularly for weapons deployment.
- Public and Political Acceptance
  - **Ethical Concerns**, addressing ethical concerns surrounding the use of autonomous systems in warfare.
  - **Transparency and Accountability**, providing transparency in operational protocols and ensuring accountability for the vessel's actions.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Alexander, P., Reinhardt, D., Bailey, N., Cardin, C., Cayaban, B., Clark, J. … Martin, S. (2019). *Future EABO logistics: Marine operations logistics asset (MOLA)* [PowerPoint slides]. Naval Postgraduate School Total Ship Systems Engineering.

America and China are preparing for a war over Taiwan. (2023, March 9). *The Economist*. https://www.economist.com/briefing/2023/03/09/america-and-china-are-preparing-for-a-war-over-taiwan

Arimo. (2023, June 21). How fast do cargo ships go? *Arimo Travels*. https://arimotravels.com/how-fast-do-cargo-ships-go/

Artisan Boatworks. (2015, July 24). *12-Meter luxury daysailer being built at Artisan Boatworks* [Video]. YouTube. https://www.youtube.com/channel/UCWJ2YD2VitHdqXHKQCMaG2Q

Aviation Zone. (2022, April 3). *Lockheed C-5 Galaxy Cargo Plane Specs & History.* https://www.theaviationzone.com/lockheed-c-5-galaxy/

Bacaltos, L, Bessette, A., Eubanks, J., Phelps, N., & Sierra, S. (2023). Taiwan Blockade: Unmanned Low-Profile Vessel (ULPV) Use Case. [PowerPoint slides]. Naval Postgraduate School IS3460 Networked Autonomous Systems.

Ball, R. E. (1985). Fundamentals of Aircraft Combat Survivability: Analysis and Design. *American Institute of Aeronautics and Astronautics*. http://ebookcentral.proquest.com/lib/ebook-nps/detail.action?docID=3111478

Ball, R. E., & Calvano, C. N. (1994). Establishing the Fundamentals of a Surface Ship Survivability Design Discipline. *Naval Engineers Journal*, 106(1), 71–74. https://doi.org/10.1111/j.1559-3584.1994.tb02798.x

Barbrook-Johnson, P., & Penn, A. S. (2022). Causal Loop Diagrams. In P. Barbrook-Johnson & A. S. Penn, Systems Mapping (pp. 47–59). Springer International Publishing. https://doi.org/10.1007/978-3-031-01919-7_4

Bender, J. (2016, April 12). *Cartels are using these "narco-submarines" to move tens of thousands of pounds of drugs at a time*. Business Insider. https://www.businessinsider.com/cartel-narco-submarines-2016-4

Blue Ocean Marine Equipment. (n.d.). *Ship salvage airbags.* Blue Ocean Marine Equipment. Retrieved August 18, 2024, https://blueoceanmarineequipment.com/marine-supply-equipment/ship-salvage-airbags/

Brutzman, D. (2022, July 31). Control Loops for Autonomy: Sense Decide Act and Observe Orient Decide Act (OODA) [PowerPoint slides]. Naval Postgraduate School.

Brutzman, D. (2024, May). Unmanned Low Profile Vessel (ULPV) Replenishment Mission [PowerPoint slides]. Naval Postgraduate School.

Brutzman, D., & Daly, L. (2007, April). X3D: Extensible 3D Graphics for Web Authors. Elsevier. https://dl.acm.org/doi/book/10.5555/1214715

Brutzman, D., Sierra, S., York, T., Banchs, L., Hamilton, D., Morris, M., Gutberlet, A., Brown, C., Olona, G., Stout, K., Parker, M., & Moore, Z. (2024, May 21). *Command and Control (C2) for Theater Mine Warfare Sustainment* [Symposium Presentation]. International Mine Warfare Technology Symposium. San Diego, CA, United States.

Buckles, S. (n.d.). *The Illustrated Guide To Boat Hull Types (11 Examples)*. ImproveSailing. https://improvesailing.com/guides/boat-hull-types

Carter, W. R. (1998). *Beans, bullets, and black oil: The story of fleet logistics afloat in the Pacific during World War II*. Naval War College Press.

Cepeda, M. (2023, April 11). *Philippine military bases with U.S. access won't be used for offensive actions, says Marcos*. https://asianews.network/philippine-military-bases-with-us-access-wont-be-used-for-offensive-actions-says-marcos/

Chinese Type 052d Destroyer Model—TurboSquid 1153716. (n.d.). Retrieved September 8, 2024, from https://www.turbosquid.com/3d-models/chinese-type-052d-destroyer-model-1153716

Coram, R. (2002). *Boyd: The fighter pilot who changed the art of war* (1st ed.). Little, Brown.

Customs and Border Protection. (2018, September 5). *CBP Air Crew Leads USCG to $55M Cocaine Seizure*. https://www.cbp.gov/newsroom/local-media-release/cbp-air-crew-leads-uscg-55m-cocaine-seizure

Davendralingam, N., Guariniello, C., Tamaskar, S., DeLaurentis, D., & Kerman, M. (2018). Modularity research to guide MOSA implementation. *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, *16*(4), 389–401. https://doi.org/10.1177/1548512917749358

Davis, D. (n,d.). N*PS AUV Workbench: Autonomous Vehicle Command Language (AVCL)*. Retrieved September 6, 2024, from https://savage.nps.edu/AuvWorkbench/javahelp/Pages/AVCL.html

Defense Acquisition University. (n.d.). Contested logistics environment. In *Defense Acquisition University glossary*. Retrieved December 12, 2023, from https://www.dau.edu/glossary/contested-logistics-environment

DeFilippis, R. (2008, March 25). *U.S. Marine Corps Forces Europe/Africa*. https://www.marforeur.marines.mil/In-the-News/Photos/igphoto/180378/

DeMarree, K. G., Petty, R. E., Briñol, P., & Xia, J. (2020). Documenting individual differences in the propensity to hold attitudes with certainty. *Journal of Personality and Social Psychology*, 119(6), 1239–1265. https://doi.org/10.1037/pspa0000241

Department of Defense. (2022, March 17). Summary of the Joint All-Domain Command & Control (JADC2) Strategy. https://media.defense.gov/2022/Mar/17/2002958406/-1/-1/1/SUMMARY-OF-THE-JOINT-ALL-DOMAIN-COMMAND-AND-CONTROL-STRATEGY.PDF

Department of the Navy. (2021, March 16). *Department of the Navy unmanned campaign framework*. https://apps.dtic.mil/sti/citations/AD1125317

Donlon, B. (2023, November 1). *Logistics 2030: Foraging is not going to cut it*. U.S. Naval Institute. https://www.usni.org/magazines/proceedings/2023/november/logistics-2030-foraging-not-going-cut-it

Dougherty, S. R., Garcia, R. J., Lemenager, K. D., Nye, B. S., Rego, J., Sandridge, B. E., & Shofner, M. G. (2020, June). LOGISTICS IN CONTESTED ENVIRONMENTS.

Dufour Yachts. (2016, March 8). *How it's made: Fiberglass hulls*. Cruising World. https://www.cruisingworld.com/how-its-made-fiberglass-hulls/

Eckstein, M. (2024, March 20). Navy 30-year shipbuilding plan relies on more money, industry capacity. *Defense News*. https://www.defensenews.com/naval/2024/03/20/navy-30-year-shipbuilding-plan-relies-on-more-money-industry-capacity/

Evans, B. (2022, December 9). Pentagon Goes Multicloud! Amazon, Google, Microsoft, Oracle to Collaborate on $9B JWCC Deal. *Acceleration Economy*. https://accelerationeconomy.com/cloud-wars/pentagon-goes-multicloud-amazon-google-microsoft-oracle-to-collaborate-on-9b-jwcc-deal/

EXWC SPIDERS3D. (2021, March 14). *Virtual Sand Table*. Naval Postgraduate School. GitLab. https://gitlab.nps.edu/Savage/Spiders3dPublic/-/blob/master/videos/demonstrations/VirtualSandTable/README.md

Fair Lifts. (2024, January 5). *The Top 10 Heavy Lift Helicopters for 2024*. Fair Lifts Helicopter Services. https://www.fairlifts.com/helicopters/the-top-10-heavy-lift-helicopters-for-2024/

Frami, J. (n.d.). How fast do fishing boats go? here's what you need to know. *Boat Pursuits*. Retrieved September 3, 2024, from https://boatpursuits.com/how-fast-do-fishing-boats-go/

Global Security (n.d.). *Self-propelled semi-submersible (SPSS) watercraft*. Retrieved July 24, 2024, from https://www.globalsecurity.org/military/world/para/spss.htm

Gordon, J. (2017, September 21). Infrared video shows Coast Guard vessels catch narco submarine. *Mail Online*. http://www.dailymail.co.uk/~/article-4907114/index.html

Goundar, S. (2023). Edge Computing—Technology, Management and Integration. *IntechOpen*. https://doi.org/10.5772/intechopen.105637

Government Accountability Office. (2023). *Navy ships: Applying leading practices and transparent reporting could help reduce risks posed by nearly $1.8 billion maintenance backlog* (GAO-22-105032). Government Accountability Office. https://www.gao.gov/products/gao-22-105032

Government Publishing Office. (2016). National Defense Authorization Act for Fiscal Year 2017.

Greene, T. (2023, June 8). *The NightTrain: Unmanned Expeditionary Logistics for Sustaining Pacific Operations*. Center for International Maritime Security. https://cimsec.org/the-nighttrain-unmanned-expeditionary-logistics-for-sustaining-pacific-operations/

Griffin, P. (2024, January 25). *Contested Logistics: Adapting Cartel Submarines to Support Taiwan*. U.S. Naval Institute. https://www.usni.org/magazines/proceedings/2024/january/contested-logistics-adapting-cartel-submarines-support-taiwan

Hansen, L. F. (2023). *Starlink PNT for SOF: How proliferated low Earth orbit satellite constellations can increase operational resilience in GPS degraded environments* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/72534

Hazdun, N. (2023, March 27). Council post: Cloud versus on premises: Advantages and disadvantages of both models. *Forbes*. https://www.forbes.com/sites/forbestechcouncil/2023/03/27/cloud-versus-on-premises-advantages-and-disadvantages-of-both-models/

Helfrich, E. (2022, September 2). *Iran briefly seized two U.S. Navy unmanned sailboats in the Red Sea (updated)*. The War Zone. https://www.twz.com/iran-briefly-seized-two-u-s-navy-unmanned-sailboats-in-the-red-sea

Herman, A. (2012, May 8). *Freedom's forge: How American business produced victory in World War II*. Random House Trade Paperbacks.

International Maritime Organization. (n.d.). *AIS transponders*. Retrieved September 3, 2024, from https://www.imo.org/en/OurWork/Safety/Pages/AIS.aspx

International Maritime Organization. (n.d.). Introduction to IMO. International Maritime Organization. https://www.imo.org/en/About/Pages/Default.aspx

Janes. (n.d.). https://customer.janes.com/

JaySea Archaeology. (2020, October 2). *The archaeology of "narco subs*." https://jayseaarchaeology.wordpress.com/2020/10/02/the-archaeology-of-narco-subs/

Jodalen, V., Solberg, B., Eggen, A., Leere, A. B., & Gronnerud, K. (2003). IP over HF as a bearer service for NATO formal messages. *2003 Ninth International Conference on HF Radio Systems and Techniques*, 19–24. https://doi.org/10.1049/cp:20030422

Joint Chiefs of Staff. (2015, September 25). *Joint concept for logistics* (Version 2.0). https://www.jcs.mil/Portals/36/Documents/Doctrine/concepts/joint_concept_logistics.pdf?ver=2017-12-28-162028-713

Jones, S. (2022, February 4). In too deep: The epic, doomed journey of Europe's first narco-submarine. *The Guardian*. https://www.theguardian.com/society/2022/feb/04/europe-first-narco-submarine-agustin-alvarez

Joshi, S. (2019, April 10). DEMYSTIFYING THE ANTI-ACCESS/AREA DENIAL (A2/AD) THREAT. *Medium*. https://sameerjoshi73.medium.com/demystifying-the-anti-access-area-denial-a2-ad-threat-d0ed26ae8b9e

Ka-27/28 and Ka-29 Helix. (n.d.). Naval Technology. Retrieved August 13, 2024, from https://www.naval-technology.com/projects/ka272829-helix/

Kanjir, U., Greidanus, H., & Oštir, K. (2018). Vessel detection and classification from spaceborne optical images: A literature survey. *Remote Sensing of Environment*, 207, 1–26. https://doi.org/10.1016/j.rse.2017.12.033

Katz, J. (2023, January 30). Inside the Marine Corps' project to automate the journey through key "last mile." *Breaking Defense*. https://breakingdefense.com/2023/01/inside-the-marine-corps-project-to-automate-the-journey-through-key-last-mile/

Katz, J. (2024, February 20). Navy's Combat Logistics Force on "narrow margins," U.S. Pacific Fleet chief warns. *Breaking Defense*. https://breakingdefense.sites.breakingmedia.com/2024/02/navys-combat-logistics-force-on-narrow-margins-us-pacific-fleet-chief-warns/

Katzman, M. D. (2022). *Sustaining Stand-in Forces*. https://www.mca-marines.org/wp-content/uploads/Sustaining-Stand-in-Forces.pdf

Kim, K. S., Hwang, S. Y., & Lee, J. H. (2014). Naval ship's susceptibility assessment by the probabilistic density function. *Journal of Computational Design and Engineering*, 1(4), 266–271. https://doi.org/10.7315/JCDE.2014.026

King, P. (2024, June 13). *CLB-12 Marines operate covert logistics*. DVIDS. https://www.dvidshub.net/image/8509186/clb-12-marines-operate-covert-logistics

Kossiakoff, A., Biemer, S. M., Seymour, S. J., & Flanigan, D. A. (2020). *Systems engineering: Principles and practice* (3rd ed.). Wiley.

Lague, D., & Murray, M. (2021, November 5). T-Day: The Battle for Taiwan. *Reuters*. https://www.reuters.com/investigates/special-report/taiwan-china-wargames/

Lane, F. C. (1951). Ships for victory; a history of shipbuilding under the United States maritime commission in World War II. Johns Hopkins Press.

Larter, D. (2018, October 11). 'You're on your own': U.S. sealift can't count on Navy escorts in the next big war. *Defense News*. https://www.defensenews.com/naval/2018/10/10/youre-on-your-own-us-sealift-cant-count-on-us-navy-escorts-in-the-next-big-war-forcing-changes/

Mahmood, Z., & Hill, R. (Eds.). (2011). Cloud computing for enterprise architectures. Springer. https://doi.org/10.1007/978-1-4471-2236-4

Marine Traffic. (n.d.). *Global Ship Tracking Intelligence | AIS*. Retrieved September 3, 2024, from https://www.marinetraffic.com/en/ais/home/centerx:144.2/centery:3.8/zoom:6

Martin, B., & Pernin, C. G. (2022). The problem of intra-theater lift: moving things around in the pacific area of responsibility. *RAND Commentary.* https://www.rand.org/pubs/commentary/2022/09/the-problem-of-intra-theater-lift-moving-things-around.html

Martin, B., & Pernin, C. G. (2023, June 23). So many questions, so little time for Pacific logistics. *RAND Commentary.* https://www.rand.org/blog/2023/06/so-many-questions-so-little-time-for-pacific-logistics.html

Mills, W. D., & Limpaecher, E. (2020). *Sustainment will be Contested*. U.S. Naval Institute. https://www.usni.org/magazines/proceedings/2020/november/sustainment-will-be-contested

Mills, W., Phillips-Levine, D., & Fox, C. (2020, July 22). *"Cocaine Logistics" for the Marine Corps*. War on the Rocks. https://warontherocks.com/2020/07/cocaine-logistics-for-the-marine-corps/

Muñoz, J. A. (2011, September 27). Dos “narcosubmarinos” confiscados en Colombia. *CNN*. https://cnnespanol.cnn.com/2011/09/27/dos-narcosubmarinos-confiscados-en-colombia

Naval Air Systems Command. (n.d.). *CH-53E Super Stallion*. https://www.navair.navy.mil/product/CH-53E-Super-Stallion

Naval Air Warfare Center. (1999). Electronic Warfare and Radar Systems Engineering Handbook: Radar Horizon/Line of Sight. 2nd Rev. Point Magu, CA: Naval Air Warfare Center, Weapons Division. https://www.rfcafe.com/references/ electrical/ ew-radar-handbook/radar-horizon-line-of-sight.htm

Naval Signature Measurement | FMV Test and Evaluation. (n.d.). Retrieved September 4, 2024, from https://testandevaluation.fmv.se/naval/system-platforms/signature-measurement/

Naval Technology. (n.d.). Luyang-III Class / Type 052D Destroyers. Retrieved August 13, 2024, from https://www.naval-technology.com/projects/luyang-052d-destroyers/

Navy Lookout. (2023, September 18). *BAE Systems Herne XLUAV concept* [Video]. YouTube. https://www.youtube.com/watch?v=STw6g06Ahz0

O’Connor, C. (2024, August 1). *Source an unmanned fleet from 50 states*. U.S. Naval Institute. https://www.usni.org/magazines/proceedings/2024/august/source-unmanned-fleet-50-states

OpenAI. (2024). *DALL-E 3.* [Large language model]. https://copilot.microsoft.com/

Oruç, A. (2022). Potential cyber threats, vulnerabilities, and protections of unmanned vehicles. *Drone Systems and Applications*, *10*(1), 51–58. https://doi.org/10.1139/ juvs-2021-0022

Packer, M. (2021). Without Rival: Mimetic Theory in a First-Year Seminar. *Christian Scholar’s Review*, 50(2), 219–230. https://www.proquest.com/docview/2492334821/abstract/724B58A483EA45B4PQ/1

Peláez, J. G., & Sevilla, I. A. N. (2013). Estela térmica en narco-semi-sumergibles y otros efectos vórtice [Thermal wake in narco-semi-submersibles and other vortex effects]. *Revista científica General José María Córdova* [Scientific Journal of General José María Córdova], *11*(11), Article 11. https://doi.org/10.21830/ 19006586.208

Plumer, B. (2017, March 22). *This is an incredible visualization of the world’s shipping routes*. Vox. https://www.vox.com/2016/4/25/11503152/shipping-routes-map

Porche, I. R. I., Wilson, B., Johnson, E.-E., Tierney, S., & Saltzman, E. (2014). *Data flood: Helping the Navy address the rising tide of sensor information* (Report No. RR315). RAND. https://www.rand.org/pubs/research_reports/RR315.html

Ramirez, B., & Bunker, R. J. (2015). Narco-submarines: Specially fabricated vessels used for drug smuggling purposes. [Faculty Publications and Research, Claremont Graduate University]. CGU Archive: Scholarship @ Claremont. https://scholarship.claremont.edu/cgu_fac_pub/931/

Real-Time Innovations, Inc. (2022). *Top 10 data requirements for JADC2*. https://www.rti.com/hubfs/_Collateral/Datasheets/rti-datasheet-jadc2.pdf

Reynolds, G. (2015, January 2). DVIDS. *Crane operations.* https://www.dvidshub.net/image/1715244/crane-operations

Rogin, J. (2024, June 10). Opinion | If China attacks Taiwan, the U.S. military is planning a “Hellscape”. *The Washington Post*. https://www.washingtonpost.com/opinions/2024/06/10/taiwan-china-hellscape-military-plan/

Sadiku, M., Musa, S., & Nelatury, S. (2016). Free Space Optical Communications: An Overview. *European Scientific Journal*, 12, 1857–7881. https://doi.org/10.19044/esj.2016.v12n9p55

Scharre, P. (2018). *Army of none: Autonomous weapons and the future of war* (1st ed.). W. W. Norton & Company.

Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois Press.

Shelbourne, M. (2022, September 2). Iran temporarily captures two U.S. Saildrones in Red Sea. *USNI News*. https://news.usni.org/2022/09/02/iran-temporarily-captures-two-u-s-saildrones-in-red-sea

Shrader, M. (2023). *DoDIIS takeaways: Future DoD and IC initiatives for AI, ML and the cloud*. Carahsoft. https://www.carahsoft.com/community/carahsoft-dodiis-ai-ml-multicloud-blog-2023

Sierra, S. (2024). *Unmanned low profile vessels (ULPVs): “Narco subs” for contested logistics* (Report No. SYM-AM-24-064). Naval Postgraduate School. https://dair.nps.edu/handle/123456789/5127

Song, L., Sun, H., Xu, K., Huang, L., & Chen, H. (2022). Interference intention classification of moving obstacles used for USV collision avoidance. *International Journal of Naval Architecture and Ocean Engineering*, *14*, 100459. https://doi.org/10.1016/j.ijnaoe.2022.100459

Spencer, R. V., Wilson, H., & Esper, M. T. (2019, January 7). Memorandum for Service Acquisition Executives and Program Executive Officers. Washington, DC, Washington, DC; Pentagon.

Staff, N. N. (2024, August 6). Kraken partners with Capewell for Air Deployment of USV. *Naval News*. https://www.navalnews.com/naval-news/2024/08/kraken-partners-with-capewell-for-air-deployment-of-usv/

Staff, U. S. N. I. (2024, February 29). Report to Congress on Navy Distributed Maritime Operations Concept. *USNI News*. https://news.usni.org/2024/02/29/report-to-congress-on-navy-distributed-maritime-operations-concept

Starlink. (n.d.a). *Specifications*. Retrieved May 6, 2024, from https://www.starlink.com/specifications

Starlink. (n.d.b). *Starlink satellite tracker*. Retrieved August 12, 2024, from https://satellitemap.space

Stock, W., Hofmann, C. A., & Knopp, A. (2023). *LEO-PNT with Starlink: Development of a burst detection algorithm based on signal measurements*. ArXiv. https://www.proquest.com/docview/2803673774?pq-origsite=primo&sourcetype=Working%20Papers

Stoyanov, Y. J. (1987). Radar cross-section reduction of naval ships. *American Society for Engineering Education.* https://apps.dtic.mil/sti/citations/ADA186107

Strahan, J. E. (1994). Andrew Jackson Higgins and the boats that won World War II. Louisiana State University Press.

Suciu, P. (2020, June 9). *The Really Boring Way China Would Try to Win a War Against America*. The National Interest; The Center for the National Interest. https://nationalinterest.org/blog/buzz/really-boring-way-china-would-try-win-war-against-america-162036

Sung, L. P., Laun, A., Leavy, A. J., Ostrowski, M., & Postma, M. (2022). Preliminary Hull-Form Design for a Semi-Submersible Vessel Using a Physics-Based Digital Model. *Naval Engineers Journal*, 134(4), 65–71. https://www-ingentaconnect-com.nps.idm.oclc.org/content/asne/nej/2022/00000134/00000004/art00016

Sung, L. P., Matveev, K. I., & Morabito, M. G. (2023). Exploratory Study of Design Parameters and Resistance Predictions for Semi-Submersible Vessels. *Naval Engineers Journa*l, 135(1), 185–203. https://www-ingentaconnect-com.nps.idm.oclc.org/content/asne/nej/2023/00000135/00000001/art00027

Sutton, H I. (2017, February 13). *SEALION and Alligator stealth boats*. Covert Shores. http://www.hisutton.com/SEALION%20and%20Alligator%20stealth%20boats.html

Sutton, H I. (2020, March 29). *Narco Subs 101*. Covert Shores. http://www.hisutton.com/Narco%20Subs%20101.html

Sutton, H I. (2021a, March 12). *Narco-submarine-found-in-Spain*. Covert Shores. http://www.hisutton.com/Narco-Submarine-Found-In-Spain.html

Sutton, H I. (2021b, September 1). *Colombian Navy Interdicts Super Low-Profile Narco Submarine*. Covert Shores. http://www.hisutton.com/New-Type-Of-Narco-Submarine-2021-09-01.html

Taylor, C. (2024, February 23). *Preparing to Win the First Fight of the Next War*. Modern War Institute. https://mwi.westpoint.edu/preparing-to-win-the-first-fight-of-the-next-war/

The Mob Reporter. (2021, March 14). *Narco-sub built in tiny town reveals Spain as gangland gateway* [Video]. YouTube. https://www.youtube.com/watch?v=bm3sZ0zZqN4

ThermoWorks. (n.d.). *Infrared emissivity table*. Retrieved May 19, 2024, from https://www.thermoworks.com/emissivity-table/

Thuloweit, K. (2010, April 23). *Aircrew breaks C-17 record with heaviest airdrop*. Air Force. https://www.af.mil/News/Article-Display/Article/116889/aircrew-breaks-c-17-record-with-heaviest-airdrop/

Toledano, J. S., (2023, October 12). *Narco-Submarines Guide: The Underwater World of Drug Trafficking*. Grey Dynamics. https://greydynamics.com/narco-submarines-guide-the-underwater-world-of-drug-trafficking/

Torrey Pines Logic. (n.d.). *LightSpeed™ technology*. Retrieved August 19, 2024, from https://tplogic.com/lightspeed/

Tryhorn, D., Dill, R., Hodson, D. D., Grimaila, M. R., & Myers, C. W. (2023). Modeling fog of war effects in AFSIM. *The Journal of Defense Modeling and Simulation*, 20(2), 131–146. https://doi.org/10.1177/15485129211041963

United States Air Force. (2019). *Air mobility operations: Air refueling operations* (AFDP 3–36). https://www.doctrine.af.mil/Portals/61/documents/AFDP_3-36/3-36-D25-Mobility-Refuel-Ops.pdf

United States Air Force. (n.d.). *C-130 Hercules*. Retrieved August 8, 2024, from https://www.af.mil/About-Us/Fact-Sheets/Display/Article/1555054/c-130-hercules/

United States Marine Corps. (2018). *MCDP 3: Expeditionary operations*. https://www.marines.mil/Portals/1/Publications/MCDP%203.pdf?ver=2019-07-18-093631-287

United States Marine Corps. (2021). *A concept for stand-in forces*. https://www.hqmc.marines.mil/Portals/142/Users/183/35/4535/211201_A%20Concept%20for%20Stand-In%20Forces.pdf

United States Marine Corps. (2023a). *Logistics* (MCDP 4). https://www.marines.mil/portals/1/publications/mcdp%204.pdf?ver=2019-07-18-093629-880

United States Marine Corps. (2023b). *Marine Corps logistics* (MCWP 3-40). https://www.marines.mil/portals/1/Publications/MCWP%203-40.pdf?ver=2017-03-15-124213-007

United States Marine Corps. (2023c). *Installations and logistics 2030*. https://www.marines.mil/Portals/1/Docs/Installations%20and%20Logistics%202030.pdf

United States Marine Corps. (2023d). *Tentative manual for expeditionary advanced base operations 2nd edition*. https://www.marines.mil/Portals/1/Docs/230509-Tentative-Manual-For-Expeditionary-Advanced-Base-Operations-2nd-Edition.pdf?ver=05KvG8wWlhI7uE0amD5uYg%3d%3d

United States Naval Institute. (2020, January 1). *China's Luyang III/Type 052D Destroyer Is a Potent Adversary*. https://www.usni.org/magazines/proceedings/2020/january/chinas-luyang-iiitype-052d-destroyer-potent-adversary

United States Navy. (2024, May 9). *Expeditionary Sea Base (ESB)*. https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2169994/expeditionary-sea-base-esb/

Vavasseur, X. (2019, April 29). New details on China's KQ-200 maritime patrol aircraft. *Naval News*. https://www.navalnews.com/naval-news/2019/04/new-details-on-chinas-kq-200-maritime-patrol-aircraft/

VICE. (2011, October 26). *Mother board | Colombian narcosubs* [Video]. YouTube. https://www.youtube.com/watch?v=2Rp-C1ph_g8&t=94s&ab_channel=VICE

Voropayev, S.I., Filippov, I.A., Afanasyev, Y.D., Barenblatt, G.I., Fernando, H.J.S., Smirnov, S.N., McEachern, B., Morrison, R., & Nath, C. (2011, September, 7–9). Jets, wakes and momentum eddies in stratified fluids and their surface signatures: Laboratory experiments, theoretical modeling and possible applications. Conference on UKTC 2011, Imperial College, London. 2011.

Williams, P. D. L., H. D. Cramp, and K. Curtis. 1978. "Experimental Study of the Radar Cross-Section of Maritime Targets." *IEE Journal on Electronic Circuits and Systems*, *2*(4), 121–136. https://digital-library.theiet.org/content/journals/10.1049/ij-ecs.1978.0026

Wright, R. G. (2020). Unmanned and autonomous ships: an overview of MASS. Routledge. https://doi.org/10.1201/9780429450655

Zhao, L., Liu, H., Hao, Y., Sun, H., & Wei, Z. (2019). Effects of Atmospheric Turbulence on OAM-POL-FDM Hybrid Multiplexing Communication System. *Applied Sciences*, 9(23), 5063. https://doi.org/10.3390/app9235063

Acquisition Research Program
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net