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OPERATIONALIZING UAS ABOARD NAVY AND USCG SHIPS

by

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14. ABSTRACT

Uncrewed aerial system (UAS) technologies can serve as a force multiplier for United States Navy and United States Coast Guard (USCG) ships without organic aviation capabilities and may present cost savings by supplementing or replacing crewed aviation assets for limited mission sets. However, several challenges exist in understanding when and how to employ UAS on Navy and USCG vessels, especially for vessels without preexisting aviation capabilities. To meet the Chief of Naval Operation's (CNO's) 2045 hybrid fleet goal, the Navy and USCG must adapt a more flexible and scalable system for the integration and employment of UAS into fleet elements. This research investigates possible Concepts of Operation (CONOPS), returns on investment, employment strategies, and roles which UAS can perform. This research will attempt to answer the following questions: What CONOPS are possible when incorporating UAS on small and large Navy and USCG surface platforms? What is the return on investment using UAS versus crewed aircraft to execute Navy and USCG missions? What UAS employment strategies are appropriate for various vessel types based on launch and recovery capabilities? What roles can UAS realistically assume from crewed aircraft? The research plan is as follows: 1) Survey related literature on current UAS operations technologies and strategies aboard Navy and USCG ships, 2) Survey existing CONOPS and similar information for current UAS missions aboard Navy and USCG ships, 3) Identify potential future CONOPS for UAS missions aboard Navy and USCG ships, 4) Examine different missions UAS may perform from different Navy and USCG ships, 5) Conduct cross-analysis of existing capabilities and future requirements to determine gaps, and 6) Match potential UAS missions and platforms with different vessel types based on launch and recovery capabilities (both current and envisioned future capabilities). The following are the research deliverables: 1) Final report and presentation, 2) Quarterly in-progress reviews—a set of briefings for Topic Sponsor (PowerPoint slide sets), and 3) Research poster for annual Naval Research Working Group meeting at Naval Postgraduate School.

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ABSTRACT

Uncrewed aerial system (UAS) technologies can serve as a force multiplier for United States Navy and United States Coast Guard (USCG) ships without organic aviation capabilities and may present cost savings by supplementing or replacing crewed aviation assets for limited mission sets. However, several challenges exist in understanding when and how to employ UAS on Navy and USCG vessels, especially for vessels without preexisting aviation capabilities. To meet the Chief of Naval Operation's (CNO's) 2045 hybrid fleet goal, the Navy and USCG must adapt a more flexible and scalable system for the integration and employment of UAS into fleet elements. This research investigates possible Concepts of Operation (CONOPS), returns on investment, employment strategies, and roles which UAS can perform. This research will attempt to answer the following questions: What CONOPS are possible when incorporating UAS on small and large Navy and USCG surface platforms? What is the return on investment using UAS versus crewed aircraft to execute Navy and USCG missions? What UAS employment strategies are appropriate for various vessel types based on launch and recovery capabilities? What roles can UAS realistically assume from crewed aircraft? The research plan is as follows: 1) Survey related literature on current UAS operations technologies and strategies aboard Navy and USCG ships, 2) Survey existing CONOPS and similar information for current UAS missions aboard Navy and USCG ships, 3) Identify potential future CONOPS for UAS missions aboard Navy and USCG ships, 4) Examine different missions UAS may perform from different Navy and USCG ships, 5) Conduct cross-analysis of existing capabilities and future requirements to determine gaps, and 6) Match potential UAS missions and platforms with different vessel types based on launch and recovery capabilities (both current and envisioned future capabilities). The following are the research deliverables: 1) Final report and presentation, 2) Quarterly in-progress reviews—a set of briefings for Topic Sponsor (PowerPoint slide sets), and 3) Research poster for annual Naval Research Working Group meeting at Naval Postgraduate School.

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I. INTRODUCTION

This is the technical report summarizing work done for the Naval Research Program (NRP) project NPS-23-N008-A, titled “Operationalizing UAS Aboard Navy and USCG Ships.” The project as a whole has been fully successful in completing the research objectives stated by the NRP proposal. A student capstone team under the direct supervision of the faculty research team assisted in completing many of the main research objectives. CONOPS (Concepts of Operation) were explored and developed, returns on investment for UAS compared with crewed platforms were explored, employment strategies were developed, and UAS roles which might be taken over from crewed platforms were investigated. This report is partially a summary and review of the student capstone report [1] and provides additional context and further work performed beyond the student capstone report.

II. BACKGROUND

With the continuing rapid growth of uncrewed aerial system (UAS) technologies, there are new capabilities and options for satisfying Navy and USCG mission requirements that have not been fully explored. In particular, the increase in capabilities of small- and medium-sized UAS presents potential for ship launch and recovery operations of UAS. Implementing UAS technologies that can provide new capabilities to Navy and USCG vessels without organic aviation assets has the potential to greatly increase the utility of some surface fleet elements. However, several challenges exist in understanding when and how to employ UAS on Navy and USCG vessels. Much of the current understanding of UAS roles was developed before small, uncrewed assets became as highly capable as they are currently. To meet the Chief of Naval Operation's (CNO's) 2045 hybrid fleet goal, the Navy and Coast Guard must adopt a more flexible and scalable system for the integration and control of UAS into fleet elements.

This report summarizes the work done in the process of satisfying the research study analysis objectives as stated by the project proposal:

1. What CONOPS are possible when incorporating UAS on small and large Navy and USCG surface platforms and how do policy constraints affect those CONOPS?
2. What is the return on investment using UAS versus crewed aircraft to execute Navy and USCG missions?
3. What UAS employment strategies are appropriate for various vessel types based on launch and recovery capabilities?
4. What roles can UAS realistically assume from crewed aircraft?

In addition to answering the above questions, several research tasks were outlined as necessary to complete the study:

Task 1: Perform Literature Review

Task 2: Request/Obtain Data from Topic Sponsor

Task 3: Identify and Develop Potential Future CONOPS

Task 4: Examine Missions UAS May Perform from Different Navy and USCG Ships

Task 5: Conduct cross-Analysis of Existing Capabilities and Future Requirements

Task 6: Determine What Ship Platforms Specific Classes of UAS Can Be Launched From

Task 7: Identify UAS Roles in the Next 2, 5, and 10 Years

Task 8: Conduct Trade-off Study

Task 9: Present Initial Findings

All the above tasks were completed, and this report summarizes efforts as they relate to the above tasks where applicable, although some tasks, such as Task 9: Present Initial Findings, will not be covered as they do not relate to the technical research deliverable content of this report.

III. APPROACH

While Naval Postgraduate School (NPS) faculty expects and maintains the ability to execute NRP research projects directly, there is also sometimes a possibility to work with a capstone or thesis student group to greatly increase effort available to the project. This project was one such project, and as such the student capstone team under close supervision of the NPS faculty and with extensive NPS faculty support completed all primary research objectives and some additional stretch goals. The breadth and depth of analysis presented in this document is only possible via the force-multiplier of the students. The student capstone report contains all relevant information and has been turned over to project sponsors as part of the promised deliverables.

This technical report serves to summarize major findings of the student capstone report [1], as well as condense those findings to fit in a 25-page document. Further, this technical report maps how specific findings from the capstone relate to the research questions and objectives. Please note that it is not the authors' intent to present the work done by the capstone team as original to this report. As the capstone report is over 100 pages in length, this technical report attempts to summarize key takeaways from the capstone as they function to answer research questions from the project proposal, with an additional section summarizing content which does not easily fit in the context of the research questions. As such, Chapter IV, "Summary of Capstone Report," is broken into the following sections:

A. **CONOPS**: Findings relating to what CONOPS are possible when incorporating UAS on small and large Navy and USCG surface platforms and how policy constraints affect those CONOPS.

B. **Return on Investment**: Findings relating to what the return on investment is for using UAS versus crewed aircraft to execute Navy and USCG missions.

C. **UAS Employment Strategies**: Findings relating to what UAS employment strategies are appropriate for various vessel types based on launch and recovery capabilities.

D. **UAS Roles**: Findings relating to what roles UAS can realistically assume from crewed aircraft.

E. **Software Tools**: Review of software tools developed and their use.

IV. SUMMARY OF CAPSTONE REPORT

This section serves to review work done as part of the student capstone report, which is expected to be published in late 2023 [1]. It should be assumed that content in the following section is referencing the same report, although in-text citations may not be present as they would be redundant. Note that while this section may state that the capstone team performed a specific action or task, the action or task was performed with the support and supervision of the NPS faculty team. Thus, this chapter reports on the broader team effort of both faculty and students working together to fulfill project requirements.

A. CONOPS

During the process of CONOPS development, the capstone team conducted a literature review, collected data from the topic sponsor, and identified and developed present and future CONOPS for UAS employment. The majority of CONOPS exploration, development, and literature review is contained in Chapters 1 and 2 of the capstone report. Below is a summary of key findings from this process. The capstone's literature review is summarized on page 5 of the capstone report, and the capstone identifies a literature gap in the area of UAS CONOPS:

> "There is little work that explores establishing a CONOPS (Concept of Operations), system architecture or framework that could fulfill multiple roles and missions of interest to the USN and USCG. This lack of research is especially true when transposed to the maritime domain. The vast body of work exploring the use of UAS for search and rescue is almost exclusively devoted to SAR operations conducted over land."

The capstone report goes on to identify an existing focus in UAS logistics CONOPS, and a subsequent lack of coverage for maritime logistics CONOPS:

> "[existing literature and research] is typically focused on delivering packages in an urban environment while using the logistics infrastructure of a multinational firm."

While there is little literature available on the use of UAS for maritime missions, particularly Search And Rescue (SAR); Intelligence, Surveillance, and Reconnaissance (ISR); and logistics missions, the capstone report does review relevant law and policy on the use of UAS in different types of airspace. Specifically, due regard is identified as a limiting range factor for many UAS use cases:

> "It becomes apparent that operating [UAS] in accordance with the prescribed duties and responsibilities introduces operational limitations outside those which are typically thought of for aircraft. Generally, the range an aircraft can fly is determined by its fuel efficiency and fuel load. However, in the case of [UAS], the range a UAS can fly is determined by how far the controlling platform can adequately surveil the UAS and its airspace, or how capable the UAS onboard detect-and-avoid capabilities are. There are numerous tactical and operational constraints that are introduced to UAS operations as a result of these requirements per international law. The analysis of these constraints, the optimization of operating UAS under the regulations, and the risk associated with deviating from accepted procedures are outside the scope of this [research]. However, UAS will be able to fully realize their operational potential until the 'Due Regard' question is answered. As such, the tactical and operational implications and how to minimize their impacts, is ground for future work."

It should be noted that during the course of the project, the sponsors vectored the project team (both the NPS faculty and students) away from the question of "due regard" and instead asked the project team to focus more on the other aspects of the work.

The capstone effort in CONOPS development was channeled into two main CONOPS areas: SAR/ISR, which are very similar, and logistics missions. These CONOPS areas were specifically chosen in consultation with the sponsors because they are representative of missions Groups 1-3 UAS can be expected to initially perform, and because they are CONOPS that can be publicly releasable, which was a goal for the sponsors. CONOPS developed by the capstone team were focused on small UAS (Groups 1-3) for vessels that would not otherwise have organic aircraft capabilities, with a particular focus on ISR/SAR and logistics:

> "[W]hile vessels with and without organic aircraft capability may benefit from UAS integration, the primary benefactor of UAS integration are those ships that do not possess organic aircraft capability. This means that while they may possess one or two of the critical components

> necessary for airborne operations at sea, they do not possess all of them. As a result, the majority of vessels in this CONOPS are missing one or all [of] the following aspects: flight deck, aircraft handling equipment, hangar, and SWAP-C for aircraft maintenance and crew habitability. These vessels include DDG Flight Is and IIs for the USN, and USCG OPCs and WPCs."

The ISR/SAR CONOPS can be summarized as follows: A UAS is launched, possibly from a vessel without a flight deck, and positive control from an operator onboard the vessel is confirmed. In the next phase, the UAS is used to patrol an area of ocean around the vessel for ISR or SAR operations. UAS may be used to patrol areas not adequately covered by surface-search radar or may be used to add resolution to an area covered by radar, allowing vessels to maintain standoff distance with targets of interest. The UAS may be controlled from the ship to investigate Target(s) Of Interest (TOI) with additional sensing power, relaying relevant information back to the ship to provide surveillance capabilities normally reserved for ships with organic aviation capability. For SAR missions, UAS would operate very similarly to ISR missions, with the UAS being tasked to search a given area of ocean, but also able to be vectored to investigate radar contacts.

The Logistics CONOPS is similar is some aspects to the ISR/SAR mission, but the capstone report identifies some important differences:

> "There are two main differences between the maritime logistics scenario and the ISR/SAR scenarios. The first difference is the payload being carried by the UAS: rather than a robust sensor suite being carried by the UAS, the payload is a parcel for delivery either to or from a unit at sea. The second difference is the flight path of the UAS. The SAR/ISR missions could potentially cover an unknown range, in which case the mission length is a function of the fuel source of the UAS. The time that the UAS has to search is directly related to the battery life or fuel onboard. Generally speaking, before the UAS takes off from the ship for a logistics mission, the operators will know the start point, the endpoint, and the range that the UAS will need to cover to complete the mission. Therefore, successful mission completion criteria are determined by the payload lifting capabilities of the UAS, as well as the operational energy life of the UAS - be it fuel or battery power. It is possible to know whether a given type of UAS is capable of completing a particular mission before launching the UAS. This has implications for mission planning as well as for UAS selection [….]

> There exist multiple variations of the logistics mission for UAS attached to a ship at sea, but they can be generalized to the following scenario: a UAS is launched either from 'own-ship' or a supply ship and proceed to travel to a supported or supporting ship for parts pickup or delivery. The same principals and standard operating procedures that apply to supply ships at sea may be applied to shore-based facilities for the purposes of modeling potential benefits derived from integrating UAS into the logistics mission."

The ISR, SAR and logistics CONOPS developed can be explored more thoroughly in Chapter 1, Section D of the capstone report, and in Chapter 4's analysis sections, which present simulation results of models, exploring a number of factors such as cost benefit, added capabilities, and comparison against organic aviation platforms.

B. RETURN ON INVESTMENT

Cost-saving analysis of UAS implementation is investigated primarily in Chapter 4, Section F of the capstone report, although costs are also touched on in Section C of the same chapter. The capstone used publicly available data to develop a Total Ownership Cost Per Hour (TOC PH) for notional UAS. This TOC PH number also accounted for ancillary equipment, such as support equipment and additional spares, which is not commonly listed with the price of certain commercial-off-the-shelf (COTS) systems. The capstone used publicly available data to investigate procurement cost compared to cost per hour, as well as TOC per hour:

> "To develop TOC PH for a notional UAS, several assumptions must be made. First, it is assumed that the unit procurement costs identified for UAS do not capture ancillary equipment that may be required to operate the UAS. For a typical DoD acquisition program this would include support equipment, initial spares, technical data, and various other content. Using procurement data from the MQ-8 and MH-60S programs, this additional cost as a factor of recurring flyaway cost [of] 39.5% and 17.7%, respectively, is calculated. That is, for every $100 spent on procuring MQ-8 units, an additional $39.5 (of procurement dollars) was spent procuring ancillary materiel to enable operations of the MQ-8. To be conservative, the MQ-8 factor will be utilized for the TOC CPH analysis.
>
> Second, as there is limited cost data for operating COTS UAS, we must generate assumed O&S cost PH values. To do this, the ratio of procurement unit cost to cost per hour is calculated where possible. These values are shown in Table 57. For the larger systems with much higher unit

procurement costs, this ratio is much lower. For the only small drone with O&S costs available, the ratio is much higher. To maintain conservatism, the higher RQ-21 ratio is utilized.

Third, as a stand-in for the notional UAS, the Martin UAS procurement costs are used. The Martin UAS values included a low and high number for different configurations. They represent a mid-point between the much smaller and less capable UAS systems and the RQ-21.

Table 57. Procurement Cost to Cost Per Hour Ratio

System	**Unit Procurement Cost**	**Unit O&S Cost Per Operating Hour**	**Ancillary Procurement Factor**	**Unit Procurement Cost/Unit O&S Cost Per Hour**
Unit of Measure	Constant Year 2023 dollars, in thousands	Constant Year 2023 dollars, in thousands	Percentage	Percentage
Wingtra One	26.9	unavailable	unavailable	unavailable
Spirit Blue UAV	61.0	unavailable	unavailable	unavailable
Skydio X2D	10.4	unavailable	unavailable	unavailable
Aviator UAV 200	45.5	unavailable	unavailable	unavailable
Martin UAS	**156.7/418.0**	unavailable	unavailable	unavailable
RQ-21 Blackjack	837.5	4.6	unavailable	**0.00551**
MQ-8B/C	35,215.2	6.8/8.6	**0.395**	0.00022
MQ-9	28,863.9	0.8	unavailable	0.00003
MH-139A	36,603.3	4.7	unavailable	0.00013
TH-73	Unavailable	2.3	unavailable	unavailable
MH-60S	36,099.0	7.8	0.177	0.00021

Based on the assumptions and the normalized values in Table 57, notional high and low TOC PH values are calculated assuming the UAS is flown for 100, 500, and 1000 hours. These calculations are shown [in] Table 58.

Table 58. TOC PH Values

	COTS UAS Low ($K)	**COTS UAS High ($K)**
Unit Cost	$156.7	$418.0
Ancillary Factor	0.395	0.395
Total Procurement Unit Cost	$218.6	$583.1
O&S Cost Per Hour Factor	0.00551	0.00551
O&S Cost Per Hour	$1.2	$3.2
TOC Per Hour (100 Hours)	**$3.4**	**$9.0**
TOC Per Hour (500 Hours)	**$1.6**	**$4.4**

TOC Per Hour (1000 Hours)	**$1.4**	**$3.8**

Prices are in thousands of dollars in constant price 2023—e.g., $3.4 = $3,400

> Note that TOC PH is sensitive to the total number of hours that are flown. If it is assumed that the drone is only flown for 100 hours, TOC PH is significantly higher than O&S cost PH. As the assumed number of hours increases, the TOC PH reduces, eventually approaching the O&S cost PH numbers. Comparing the COTS UAS TOC PHs to the normalized O&S unit cost per hour for helicopter systems, the COTS UAS TOC PH numbers at the 500 Hour assumption are lower than the O&S Cost PH for the MH-139A and the MH-60S, while the COTS UAS Low value is lower than all three helicopters in the data set. This suggests that if small UAS are used in lieu of queuing other manned assets to aid in surface ship missions, the cost per hour of that support is likely to be reduced, even when factoring in procurement costs. However, this is based on several key assumptions, including procurement cost for the UAS, number of hours flown, and UAS O&S cost per hour. If those assumptions are updated with real-world information, this methodology can be used to assess expected savings."

The approach utilized by the capstone could easily be applied to specific user cases, where more detailed manufacturer cost information is available. The capstone also investigated the break-even point for notional high- and low-cost UAS, when compared to an MH-60S, where it is assumed a UAS is used to effectively replace the crewed asset hour for hour. The capstone also considered a case where the UAS is less effective, and only 50% of UAS hours reduce MH-60 hours. Depending on UAS price and effectiveness compared to a MH-60S, the break-even point occurred between the 34th and 834th flight hour:

> "Another calculation that can be considered using the data in Tables 56 and 57 is the point at which the procurement investment in a UAS is paid back or reaches the break-even point via reductions in O&S cost. This number can be calculated by starting with the COTS UAS procurement costs and reducing those costs each hour flown by the delta between the O&S cost of the system being substituted and the O&S cost of the UAS. Figure 29 shows the results of those calculations for the high and low COTS UAS assuming the MH-60S is the system being substituted.

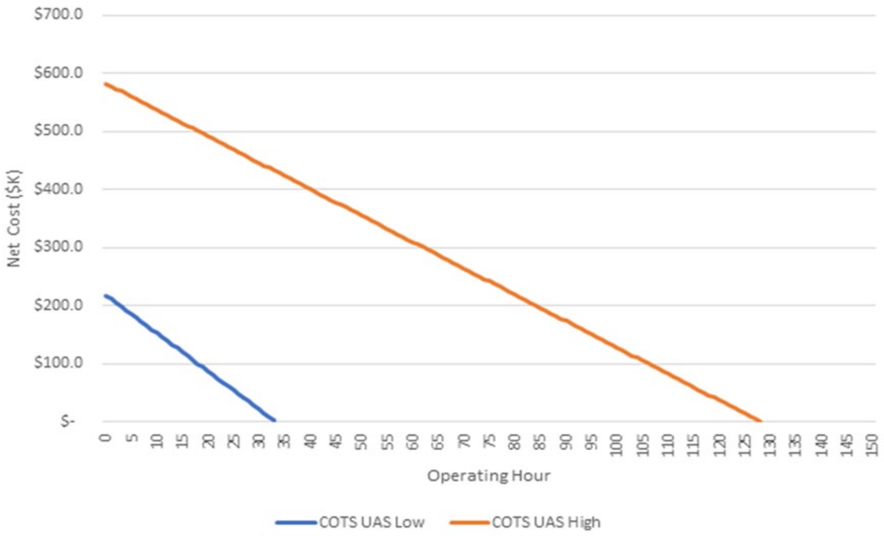


Figure 29. Break-Even Calculation

For the COTS UAS Low case, the break-even point is achieved in the 34th operating hour. For the COTS UAS High case, which includes a higher procurement cost and a higher UAS O&S cost per hour, the break-even point is achieved in the 129th hour. This analysis assumes that each UAS hour is effectively replacing an MH-60S hour. Again, this assumption should be validated with real world data. Figure 30 shows how these values change if this assumption is updated to assume that only 50% of the UAV Hours are reducing MH-60S hours.

At higher UAS costs, substitution rate assumed dramatically affects the break-even point. UAS High (50% Substitute) line continues to 834th operating hour.

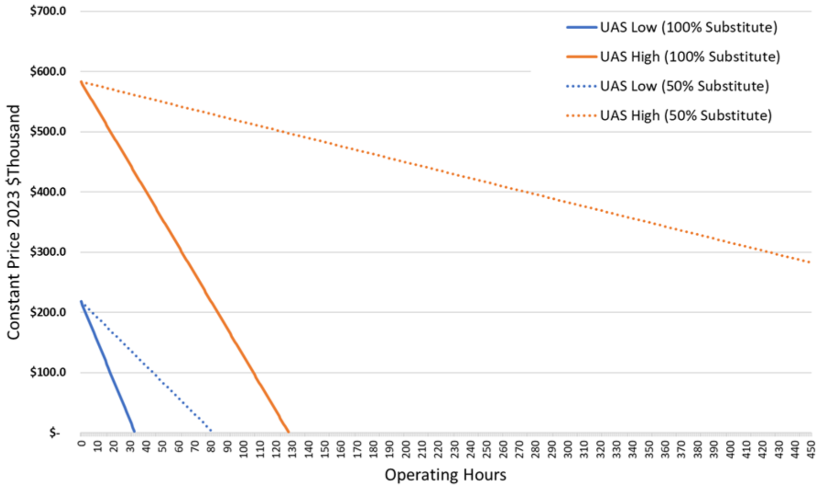


Figure 30. Break-Even Calculation at 50% Substitution Rate

In this case, the break-even point for the COTS UAS Low option is extended to the 82nd hour, which is still early in the system's life. However, for the more expensive drone option, the break-even point is not reached until the 834th hour. This is 683% longer than under the 100% substitution case."

In summary, the capstone determined that UAS would quickly provide a return on investment and pass the break-even point for cases in which they are able to replace a crewed asset. This is especially true of UAS with a low total cost of ownership per hour. It should be noted that this break-even point is contingent on the UAS, effectively replacing a crewed asset on an hour-by-hour basis, and some UAS will be more capable than others in this regard.

C. UAS EMPLOYMENT STRATEGIES

The capstone report details how UAS might be integrated onto USN and USCG vessels, looking at UAS capabilities, requirements for UAS being integrated onto vessels, and the ships and ship-based constraints that drive some of the UAS requirements.

For employment on ships, there are many factors that can disqualify a UAS from integration as an organic aviation capability. Beyond size at takeoff, storage size, takeoff space and equipment required, and control equipment may cause incompatibility depending on the vessel-UAS combination. Launch and recovery specifications are a particularly difficult requirement, as the vessels in consideration for this study, USCG cutters and USN destroyers, may not have a large flight deck. The capstone report took all of these factors into consideration and developed a Drone Selector Tool, also called the Mix-and-Match Tool, which serves to pair potential UAS solutions with vessels. One factor that was revealed as key by the capstone was the ability to properly store the UAS underdeck when not in use:

> "A key component of ship compatibility with specific UAS airframes is the ship's ability to appropriately store the UAS, GCS, and additional supporting equipment. A key metric for determining ship-UAS compatibility is the interior storage space capacity and layout. This data, while difficult to acquire remotely, should be trivial to acquire and implement if the tool is used for fleet-use."

The capstone report includes a baseline of UAS capabilities, created by taking the lowest performance in each requirement category from various COTS UAS. This baseline can then be used to compare other UAS, and highlight what unique capabilities beyond the baseline a given UAS might have:

Table 1. UAS Baseline Capabilities. Adapted from [1].

Metric	Lowest Expected Value
Max Speed	22.3 mph
Weight	56 lbs
Max Altitude	10,000 ft.
Loiter Time (mission endurance)	27 minutes
Controller Range	2.15 nautical miles
Video Resolution	1080p
Photo Resolution	8 MP
Infrared	Not Equipped

This baseline represents the bare minimum UAS capabilities, and many COTS UAS provide significantly enhanced capabilities beyond the baseline. In addition to the baseline provided above, the capstone report investigated UAS requirements for operations on ships, and provided a set of generic requirements for COTS UAS to be integrated onboard existing USN and USCG vessels:

- Must be capable of organic (inherent to the system) ISR, SAR, or logistics
- Must be easily launched
- Must be easily recovered post-mission
- Must be capable of extended range of operation
- Must be a Group 1, 2, or 3 UAS
- Must have a suitably small footprint
- Must be commercial-off-the-shelf (COTS)

These requirements remain at a high level and are somewhat ambiguous due to variance in the exact mission requirements and vessel/organizational constraints which must be stratified for any given mission. A more detailed breakdown is available in Chapter 2, Section D of the capstone report.

For ships and ship-based constraints, this study focused on existing USN and USCG vessels that do not have organic aviation capabilities. The capstone report includes a number of ships in the Excel-based Drone Selector Tool, also called the Mix-and-Match Tool, which is reviewed in Section E, “Software Tools,” of this chapter. Beyond the context of the software tool, the capstone report identifies USN DDGs and USCG cutters as the primary focus of much of the research discussion. Analysis for other ship types can be performed through the Drone Selector Tool. The capstone report identifies a number of ship capabilities and characteristics as influential to the integration of potential UAS:

Length and Width: Length and width are an expected limiting factor, as the size of the ship is correlated to the internal storage space available and smaller ships will be limited in the size and number of UAS they can carry.

Flight Operations Equipment: Flight Operations Equipment, such as a flight deck, hanger, and maintenance equipment, is a key enabling factor for supporting UAS operations. With that in mind, it is possible for a ship to support certain small UAS types without any of the above support equipment. Larger, more capable UAS will generally require more support equipment.

Speed and Endurance: Beyond their effects on possible mission type for a given vessel, speed and endurance play a role in UAS effectiveness as well, as vessels with high speed and endurance may be expected to operate in many different and extreme environments, placing additional requirements on the UAS they might host to operate in those same environments. Speed and endurance also factor into how effective a given UAS is in adding capabilities for a given mission type, as slow, short-range UAS may become less effective compared to simply moving the vessel directly if the home vessel is sufficiently fast by comparison.

Sensor Types: While the sensor types available to a ship may vary, they often include surface search radar, and in some cases Electro-Optical/Infra-Red equipment, although ship sensors are limited by line of sight. UAS may be particularly effective in missions where they operate beyond the range of onboard ship sensors. The capstone report identifies sensor capabilities as a major factor in determining the mission type a ship may perform and how UAS may be employed:

> "Surface Search and Air Search Radars allow a vessel to be cued to the presence of some type of contact in the air or on the ocean surface, but the type of information they can provide is limited. Using other sensors in concert, for example, an EO/IR sensor onboard the ship can allow the ship to determine vessel type, and perhaps identification. This too is limited by the curvature of the earth and the height-of-eye, much like surface search radars. The more sensors a ship has, both quantity and diversity, will not only determine its likely mission sets but also, its propensity

> for intelligence gathering as well as search and rescue capabilities. These capabilities will be greatly aided by an organic air asset and will help determine which ship is ideal for mission employment."

UAS Capable Crew Type: Operating UAS effectively requires personnel with the requisite skills and experience. The capstone report identifies crew training as an important but potentially costly factor:

> "Ships that do not have personnel that are a part of the aviation community either directly or indirectly may still be able to employ an organic UAS asset but will probably require training to do so. Any potential operator or maintainer of the UAS will require some requisite amount of training, but the cost of said training, both in time and money, will vary with the personnel's experience. It is expected that this could be a driving factor when determining both the cost of establishing an UAS-on-Ships program of record and the ease with which these assets may be integrated into existing surface ships and their crews."

The section above reviewed many of the important factors that may play a role in UAS employment strategies. The capstone report shows that even with COTS UAS, procurement cost alone is only one of many factors that must be considered to effectively integrate UAS on USN and USCG vessels. UAS capabilities, UAS requirements, and ship capabilities all play important roles in the effective employment of small UAS.

D. UAS ROLES

The capstone report analyzed the feasibility of UAS being employed in a variety of roles to conduct missions that would traditionally require crewed assets. To accomplish this, the capstone report analyzed several mission sets in depth, using systems engineering approaches and modeling to explore the benefits and costs of using UAS for the missions in question. This work is covered primarily in Chapter 4 of the capstone report and is summarized in this section. The capstone report introduces a series of operational cases to represent ships conducting ISR/SAR and logistics missions, and then uses models to compare performance with and without UAS. Modeling for these missions was conducted in ExtendSim and Microsoft Excel.

1. ISR/SAR Scenarios

The ISR and SAR scenarios are similar enough that they can be approached together for modeling purposes. For the ISR scenario, the searching surface vessels clears a box of ocean via a regular search pattern, using radar to detect possible objects of interest before leveraging the UAS capabilities to confirm whether the objects detected are the objective of the search. For cases without a UAS, this confirmation is achieved by moving the ship into visual range of the object. As illustrated by the capstone, there are slight differences in the models with/without UAS and between ISR/SAR. For the ISR without UAS case:

> “Figure 3 illustrates the generic operational context for the project’s ISR and SAR scenarios. Figure 3 contains the various elements that make up the ExtendSim modelling portion: a search sector of 160 NM by 160 NM, tracks within the search sector that represent the path the surface vessel takes to conduct their search of the box, TOIs to be detected by the searching platform, and shaded green and blue circles which represent the visual search range and radar range, respectively of the searching platform. This generic context is consistent across the various base case and UAS case scenarios. The variables that change are the radar and search range and how the ship reacts to targets that have been detected.

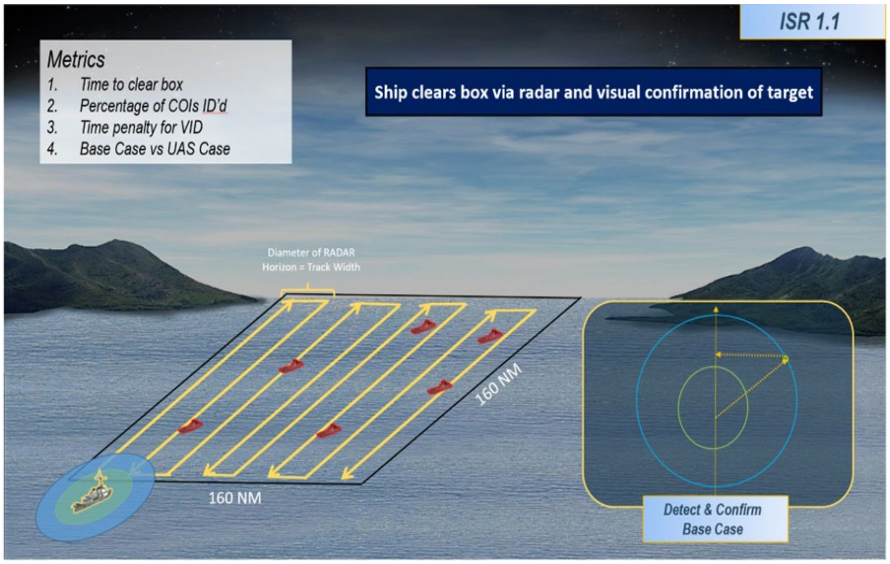
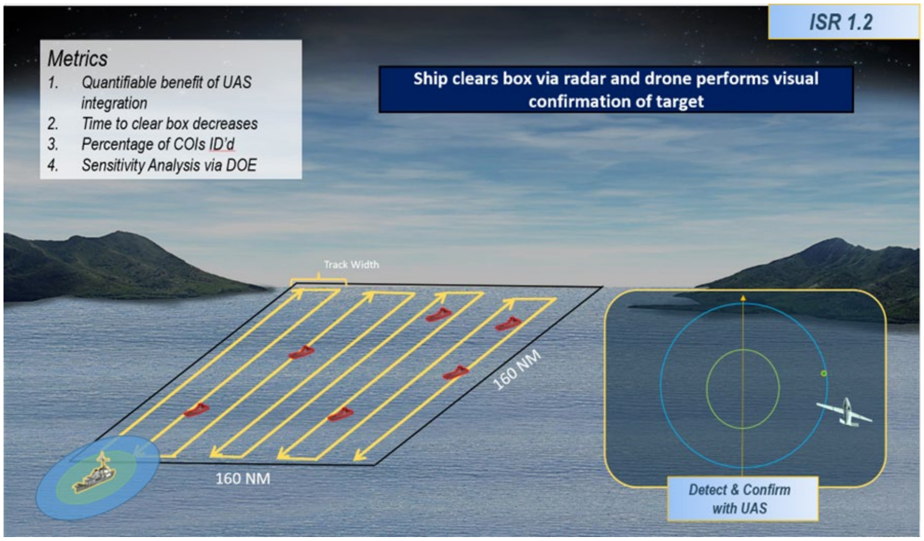


Figure 3. ISR Scenario 1.1”

For the ISR with UAS case:

> “This scenario is displayed in Figure 4. It is identical to the one discussed in the previous section with one important exception: rather than the search platform having to divert from its

> base case for TOI identification, the vessel has a UAS onboard to aid in TOI ID. The UAS in this case is used to conduct a cued search based on a radar contact from the ship. The search platform had to divert from its base course when the radar came in contact with a TOI, but in this case, rather than diverting, the ship launches a UAS, fly the UAS to the TOI radar contact, and identify the target of interest with the UAS' onboard sensors. As a result, the search platform is able to continue on its base course to search its sector vice having to divert for TOI ID. Once the UAS IDs the TOI, the UAS returns to the search platform, waiting to be cued to the next radar contact.



Metrics

1. *Quantifiable benefit of UAS integration*
2. *Time to clear box decreases*
3. *Percentage of COIs ID'd*
4. *Sensitivity Analysis via DOE*

Ship clears box via radar and drone performs visual confirmation of target

Figure 4. ISR Scenario 1.2”

The SAR cases are similar to the ISR cases, with the adjustment of a reduced track width due to the increased detection requirements. It is assumed detections must be made visually. For the SAR without UAS case:

> “The SAR 1.1 scenario is one in which the TW is the search platform's visual range for human detection. This scenario is displayed in Figure 5. Due to the smaller TW, relative to the ISR scenarios, the search platform must drive to an increased number of tracks within the search sector to complete the search of the area. Radar or sensor range is not a factor in the SAR 1.1 scenario as all detections are made visually. SAR 1.1 serves as the base case upon which the rest of the SAR scenarios are built. As such, the metrics for ‘search time’ and ‘TOIs detected’ are used to ascertain the potential benefit of incorporating UAS into the SAR mission.

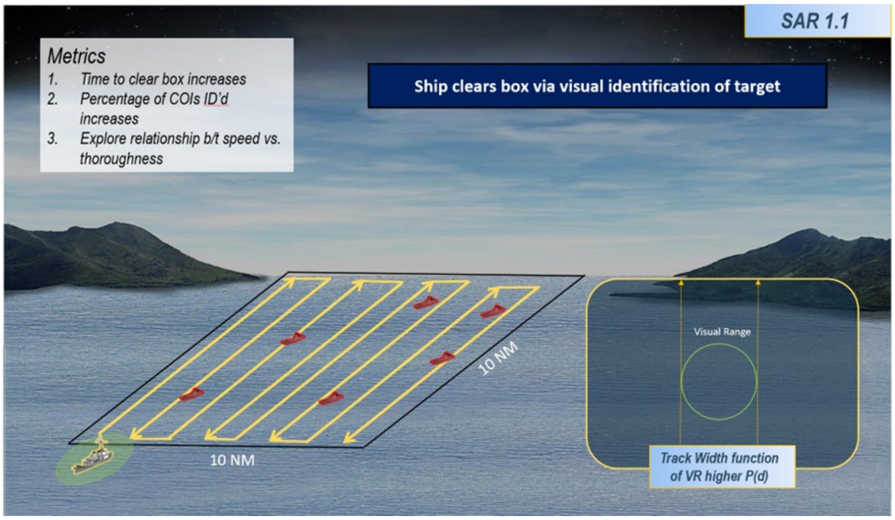
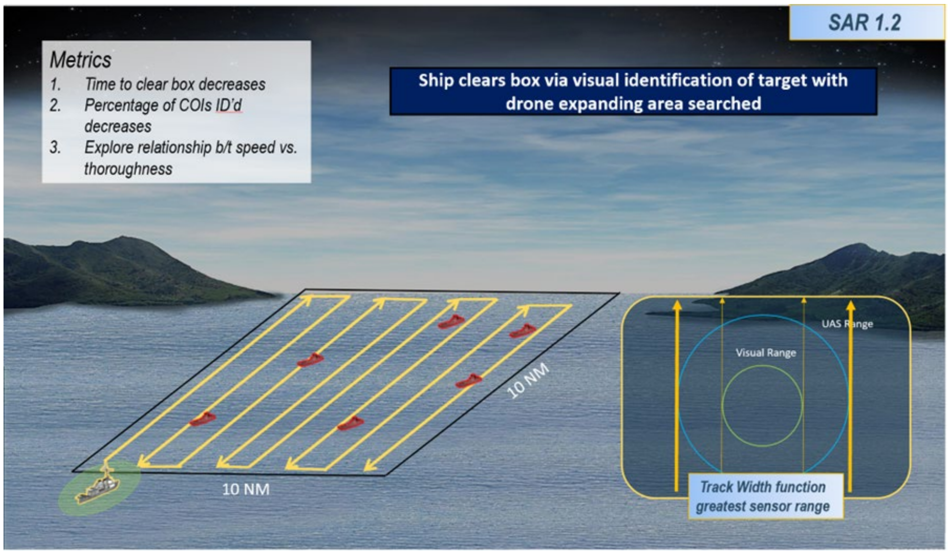


Figure 5. SAR Scenario 1.1”

For the SAR with UAS case:

“The critical difference between SAR 1.1 and SAR 1.2 is the track width of the search platform. SAR 1.2 is the first SAR scenario that utilized a UAS, and it is represented by Figure 6. The UAS in this scenario is centered on the search platform, at an increased altitude. This has the effect of increasing the range at which the search platform is able to detect TOIs. This has the effect of decreasing the time it takes a vessel to clear its search sector due to having to run fewer tracks within the sector as a result of its increased track width. However, due to the difficulty of detecting human-sized objects in the vastness of the ocean, increasing the range at which a sensor can detect them, may have a corresponding decrease in the number of TOIs detected. Therefore, while the time it takes to search the sector may decrease, the accuracy with which the sector is searched may have a corresponding decrease as well. This has the effect of not detecting objects when they are present. SAR 1.2 may be thought of as a scenario where the speed at which a search may be conducted may outweigh the focus on the accuracy of the search. This may be representative of a scenario where the time to complete a search is the more important factor during real-world scenarios; for instance, the scenario where a person is in the water in extremely cold water. This scenario is one where the person in the water has a small amount of time before they succumb to the elements and, as such, covering a large amount of water quickly is vitally important.



SAR 1.2

Metrics

1. Time to clear box decreases
2. Percentage of COIs ID'd decreases
3. Explore relationship b/t speed vs. thoroughness

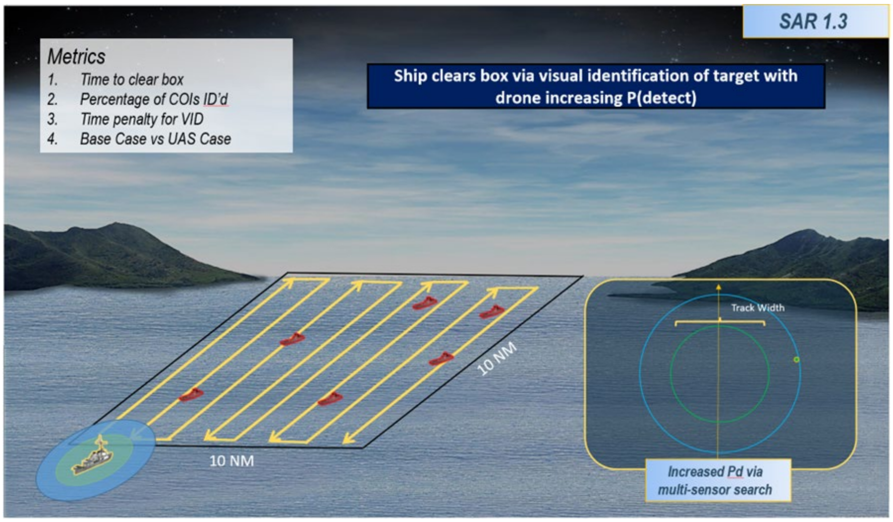
Ship clears box via visual identification of target with drone expanding area searched

Track Width function greatest sensor range

Figure 6. SAR Scenario 1.2”

The capstone also modeled a third SAR scenario in which the UAS was used to supplement ship sensors over the same area, increasing probability of detection:

“SAR 1.3 is another scenario where the UAS is integrated into the scenario. The UAS is once again centered on the ship at an increased altitude. However, unlike in SAR 1.2, the track width is not increased to the UAS sensor range. Rather, the TW remains the visual detection range from the ship, as is the case in SAR 1.1. In this usage pattern, the UAS is being used to increase probability of detection as opposed to expanding the search range. SAR 1.3 is displayed in Figure 7. This scenario is designed to test the assumption that using the UAS centered on the ship and keeping a small TW leads to an increased probability of detection of human-sized objects at sea. Unlike SAR 1.2, the time it takes the search platform to clear its search sector is similar to SAR 1.1 but it does so with increased accuracy, and with a higher probability of detecting the object in the water.



SAR 1.3

Metrics
1. Time to clear box
2. Percentage of COIs ID'd
3. Time penalty for VID
4. Base Case vs UAS Case

Ship clears box via visual identification of target with drone increasing P(detect)

Figure 7. SAR Scenario 1.3”

The above scenarios provided the basis for ExtendSim modeling, with the primary factors of interest being the time required to search a given area, and the number of targets identified.

The modeling showed that in most cases, the addition of a UAS for SAR/ISR missions was of some benefit, either by reducing search time or increasing the area searched, as the capstone results below show:

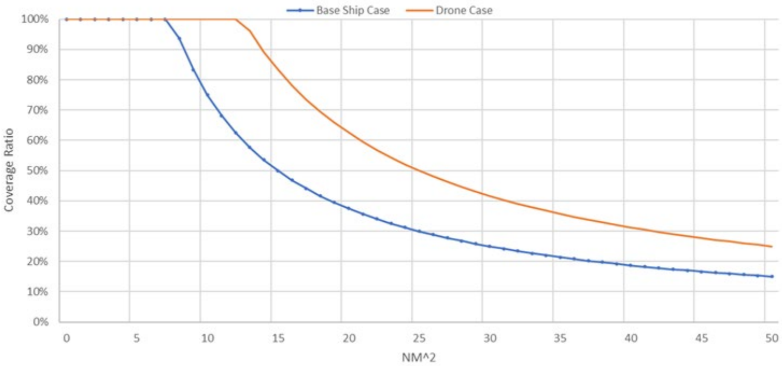


Figure 1. SAR Coverage Ratio with Two-Hour Search Time. Adapted from [1].

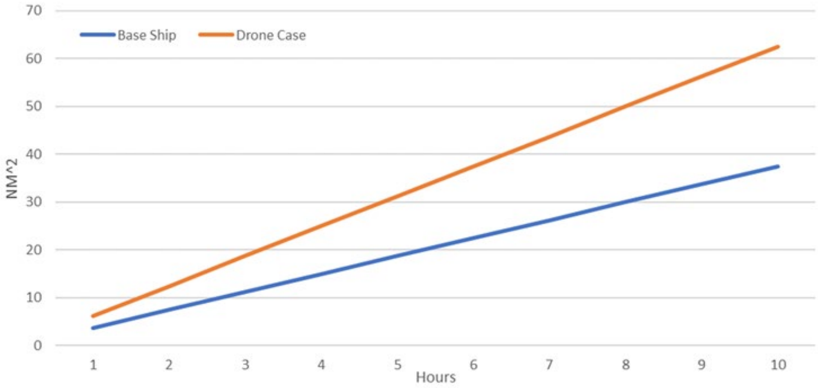


Figure 2. SAR Area Covered Per Unit Time. Adapted from [1].

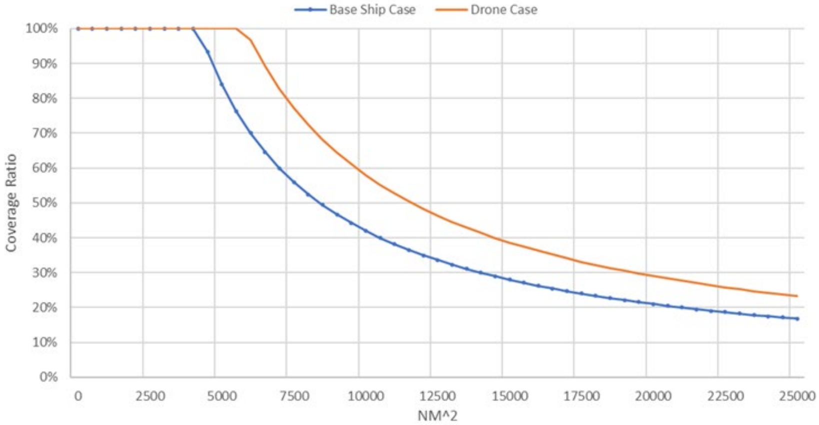


Figure 3. ISR Coverage Ratio with Four-Hour Search Time. Adapted from [1].

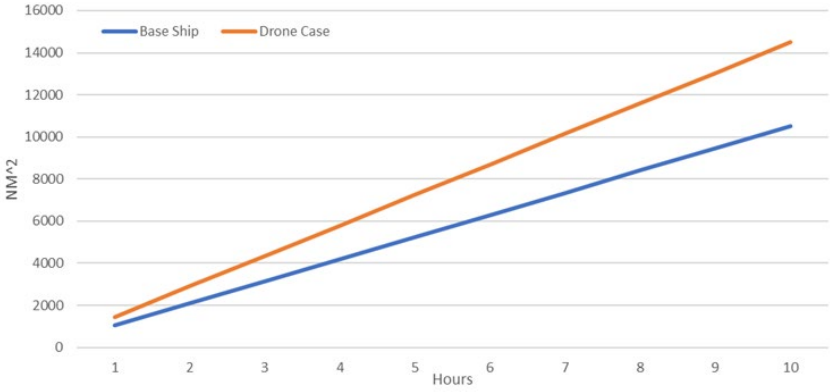


Figure 4. ISR Area Covered Per Unit Time. Adapted from [1].

The above plots are only preliminary calculations, however. The capstone report used ExtendSim modeling to go more in depth, varying many input factors across multiple simulation runs. The results of this modeling effort are too extensive to fully represent in this report but are available in the full capstone report. High-level takeaways are summarized here. The ExtendSim modeling showed that UAS may or may not reduce search time, depending on UAS capabilities and vessel capabilities. To better understand which factors played the largest roles, the capstone report completed a design of experiment (DOE) and calculated results for both ISR and SAR. The DOE results for ISR are summarized in the following two figures from the capstone report:

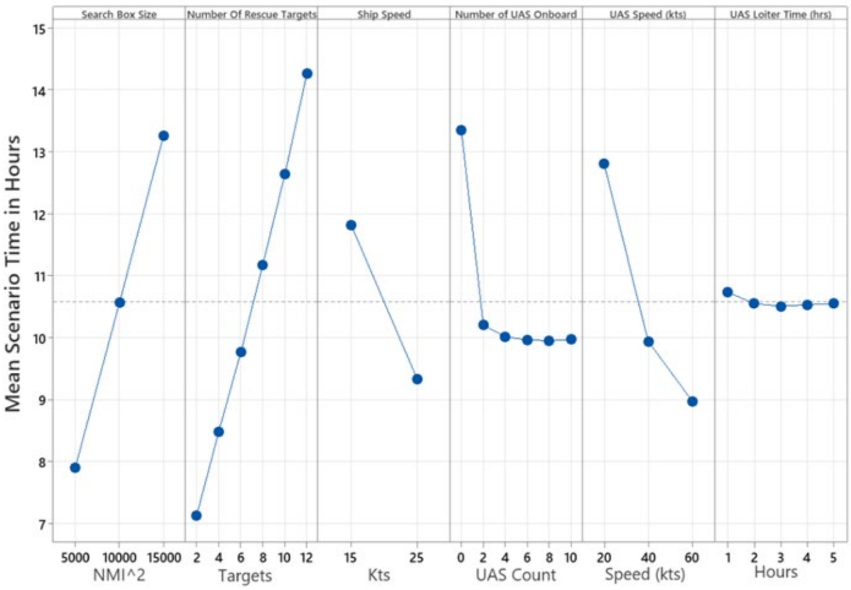


Figure 5. ISR Detect and Confirm Main Effects Plot for Time. Adapted from [1].

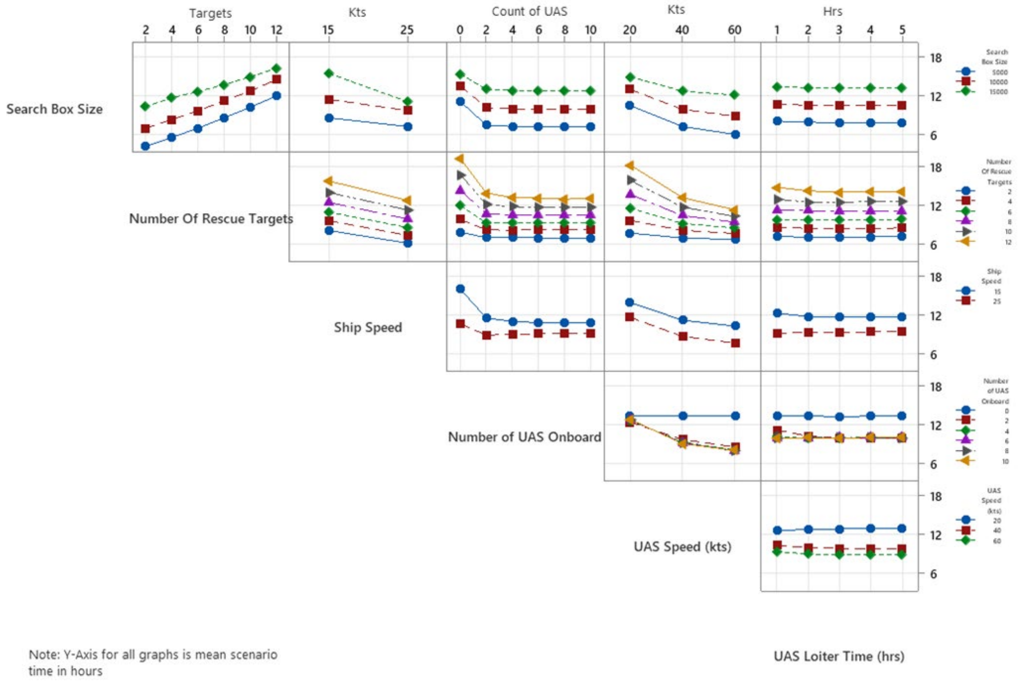


Figure 6. ISR Detect and Confirm Interaction Plot for Time. Adapted from [1].

These figures show that among UAS factors, UAS speed and number of UAS employed are the most drastic impacting factors on search time, while loiter time does not have as dramatic of an effect. It should also be noted that the benefits from additional UAS give diminishing returns, depending on the search scenario. For most of the scenarios investigated, employing more than 2-4 UAS did not show any notable decrease in search time.

For SAR, it was found that the employment of UAS dramatically reduced search time, with additional results showing the number of UAS, loiter time, and UAS visual range (sensor range) having significant impacts on search time:

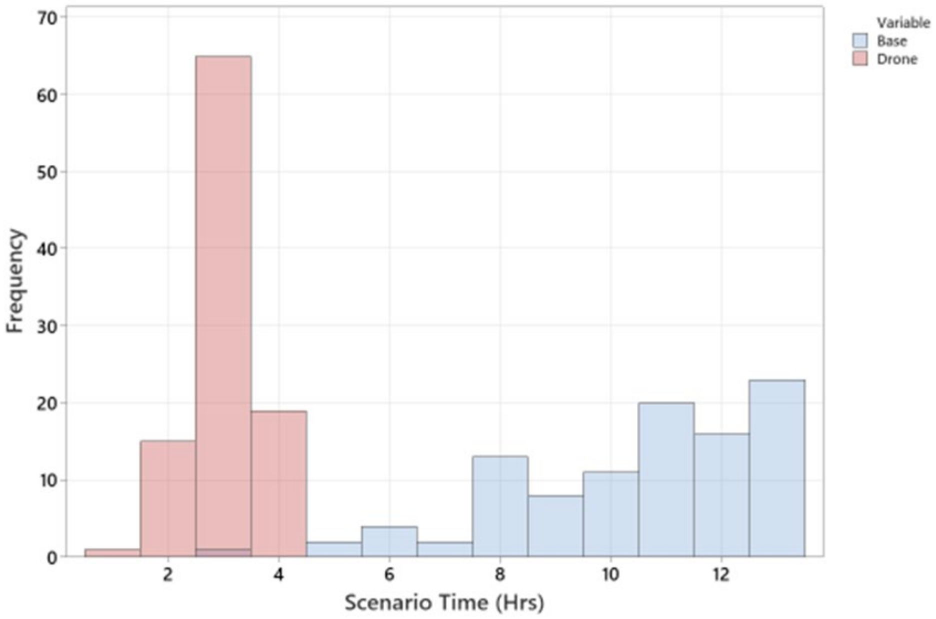


Figure 7. SAR Decrease Search Time Scenario Time Data Histogram. Adapted from [1].

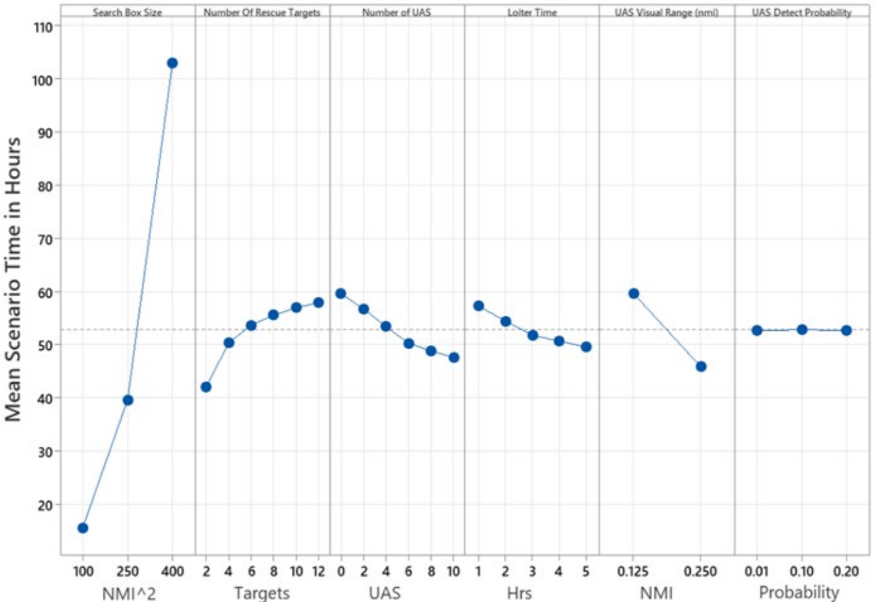


Figure 8. SAR Decrease Search Time Main Effects Plot for Time. Adapted from [1].

Additional results are available in Chapter 4, Section E of the capstone report.

2. Logistics Scenarios

The logistics scenarios modeled by the capstone report served to investigate the potential benefits of using a UAS for at-sea logistics. Specifically, this study was interested in the use of small UAS to carry high-priority items to a vessel at sea, in place of a return to port by the vessel. The capstone report calculated four main variables for two cases, where the difference between cases was UAS speed and range:

Table 2. Logistics Case 1. Adapted from [1].

Parameter	Units	Value
Distance From Shore	NM	150
Ship Speed	NM/hr	20
Two-Way Range of UAS	NM	30
UAS Speed	NM/hr	40
Distance to Rendezvous Location	NM	120
In-Port Transit Time	Hr	1
Part Onload Time	Hr	.25
Part Offload Time	Hr	.25

Table 3. Logistics Case 2. Adapted from [1].

Parameter	Units	Value
Distance From Shore	NM	150
Ship Speed	NM/hr	20
Two-Way Range of UAS	NM	15
UAS Speed	NM/hr	30
Distance to Rendezvous Location	NM	135
In-Port Transit Time	Hr	1
Part Onload Time	Hr	.25

Part Offload Time	Hr	.25

For both cases, the capstone report was interested in finding the cost in time for logistics deliveries:

- Time to Shore (ship without UAS)
- Time to Rendezvous Location (ship with UAS)
- Total Time (ship without UAS)
- Total Time (ship with UAS)

The results of these valuations are contained in the tables below:

Table 4. Logistics Case 1 Results. Adapted from [1].

Parameter	**Value**
Time to Shore – Ship without UAS	7.5 Hrs.
Total Time – Ship without UAS	17.5 Hrs.
Time to Rendezvous – Ship with UAS	6 Hrs.
Total Time – Ship with UAS	14 Hrs.
Time Saved	3.5 Hrs.

Table 5. Logistics Case 2 Results. Adapted from [1].

Parameter	**Value**
Time to Shore – Ship without UAS	7.5 Hrs.
Total Time – Ship without UAS	17.5 Hrs.
Time to Rendezvous – Ship with UAS	6.75 Hrs.
Total Time – Ship with UAS	15 Hrs.
Time Saved	2.5 Hrs.

The capstone report shows that employment of UAS in a logistics role might provide significant time savings, and by extension cost savings as well:

> "As evidenced by these results, even with a sharp decrease in UAS capability (range and speed), the time saved to conduct these deliveries is not inconsequential. The impacts to be derived from their use are especially stark when considering the cost per hour incurred by maneuvering these vessels including fuel and manpower requirements. These cost benefits are calculated and further discussed in a following subsection."

E. SOFTWARE TOOLS

During the process of investigating questions and completing tasks from the research proposal, the capstone team developed several software tools to aid both in internal modeling and as deliverables to the sponsor with the purpose of informing decision makers on the possible compatibility of COTS UAS with USN and USCG vessels. This section will briefly describe the Drone Selector Tool, also called the Mix-and-Match Tool, which is the Excel-based tool created as a deliverable to the sponsor. For a more comprehensive description of the tool, refer to Chapter 3 of the capstone report.

The Drone Selector Tool (see Figure 9) uses data collected from USN, USCG and UAS manufacturers to aid in determining which UAS are most compatible for a given mission type. The user inputs mission type, ship selection, environment type (contested/uncontested), minimum UAS speed, loiter time, and altitude, then the Drone Selector Tool uses pre-collected data to down-select UAS options, providing the user with a ranked list of which UAS would be best suited for the mission in question.

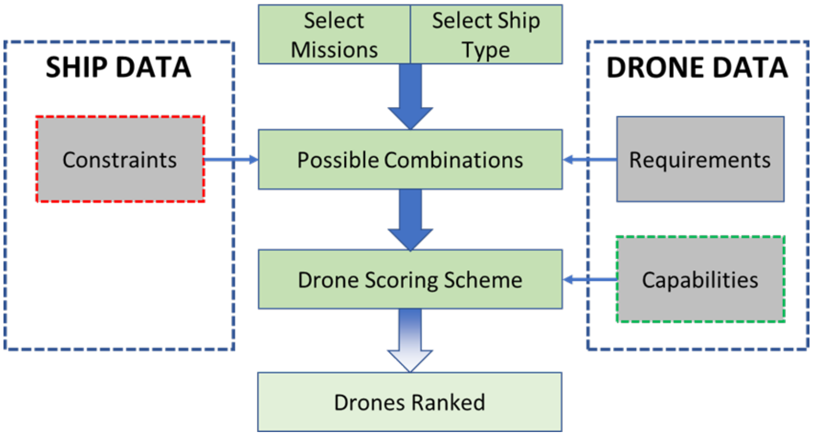


Figure 9. The Drone Selector Tool. Adapted from [1].

The effective use of this tool comes with several caveats. First, the tool is only as good as the input data it is built on and was completed with open-source data only. However, this limitation was expected; the tool was designed with a modular nature which allows end users to add their own data, both on ship capabilities and drone specifications, to increase the tool's accuracy and effectiveness. Second, the tool represents a methodology for drone selection, and provides recommendations with limited scope. It does not factor in actions beyond the scope of the tool, such as modification of an otherwise non-compatible ship to host a specific UAS system. To be effective, it should be used as an informative tool to aid in the decision-making process, keeping in mind the limits of the software.

V. CONCLUSIONS:

This research effort studied the possibilities for UAS use on USN and USCG ships. Through the employment and close oversight of a student capstone team, all research objectives were completed. This report served to summarize outcomes, primarily from the student capstone report. Within the capstone report, current and future CONOPS were reviewed and developed, return on investment for UAS replacing crewed assets was explored, and employment strategies and roles for UAS based on various vessel types were developed through analysis and software modeling in ExtendSim. As a general trend, it was found that UAS, when employed correctly, can present a real capability increase and/or costs savings in SAR, ISR, and logistics scenarios.

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LIST OF REFERENCES

[1] C. R. Eilertsen, A. J. Greene, L. J. Loukas, and J. A. VanWhy, “Research on Potential Unmanned Aerial Systems CONOPS for USN and USCG Ships,” capstone report, Naval Postgraduate School, Monterey, CA, 2023. Available: https://calhoun.nps.edu/handle/10945/72161

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