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Analysis of Alternatives: Cost Effectiveness of the Airlander 10 in the Arctic

March 2023

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Thesis Advisors: Dr. Nicholas Dew, Professor
Christian R. Fitzpatrick, Faculty Associate

Department of Defense Management

Naval Postgraduate School

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ABSTRACT

Melting ice in the Arctic Circle is opening international shipping lanes and exposing new resources. The 2022 National Strategy for the Arctic Region, Department of the Navy Strategic Blueprint for the Arctic, and U.S. Navy Arctic Roadmap 2014–2030 call for an increase in maritime presence. The region has the same operational requirements as any maritime environment, but the difficult climate makes systems less effective or incapable. A reliable system with exceptional endurance is required to patrol the vast region and conduct multiple missions. The Airlander 10, a hybrid aircraft manufactured by Hybrid Air Vehicles in the United Kingdom, is a promising platform that could meet the regional demand. This thesis utilizes Office of Management and Budget guidelines to conduct an analysis of alternatives by developing a trade space analysis and Evaluation of Alternatives for the Airlander 10. The analysis investigates multiple Department of Defense systems that are currently in use and compares them to the Airlander 10. The results confirm the utility of the Airlander 10 in the Arctic and conclude there is a cost-to-benefit ratio surpassing its alternatives. The outcome is a baseline for Title 10 milestone decision authority requirements for Milestone A acquisition of the Airlander 10.

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ACKNOWLEDGMENTS

Thank you, Neil Gee, Robert Venner, Mike Durham, and everyone at Hybrid Air Vehicles. I could not have done this without the countless meetings, vast amounts of information, and your unlimited patience. I cannot thank you enough for working with me.

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LIST OF ACRONYMS AND ABBREVIATIONS

AoA	analysis of alternatives
AUV	autonomous underwater vehicles
CNO	Chief of Naval Operations
CRADA	Cooperative Research and Development Agreement
DOD	Department of Defense
DoDi	Department of Defense instruction
EEZ	exclusive economic zone
FMS	foreign military sales
FY	Fiscal Year
HAV	Hybrid Air Vehicles LLC
ISR	intelligence, surveillance, and reconnaissance
LEO	low earth orbit
LTA	lighter-than-air
MANPADS	man-portable air-defense system
MILCON	military construction
OMB	Office of Management and Budget
RDT&E	research, development, test and evaluation
SAR	selected acquisition report
UAS	unmanned aircraft system

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EXECUTIVE SUMMARY

The United States Navy Arctic Roadmap for 2014 to 2030 states, "The Arctic Ocean will be increasingly accessible and more broadly used by Arctic and non-Arctic nations seeking the Region's abundant resources and trade routes" (Chief of Naval Operations [CNO], 2014, p. 3). The CNO (2014) states that this region is no different from any other maritime region, but the environment makes the execution of the Navy's responsibilities much more difficult.

Hybrid aircraft, a new but tested technology, may provide a solution to some specific challenges the Navy faces in the Arctic. Hybrid aircraft use principles of conventional lift generation, but the entire fuselage becomes a lift-generating surface in place of a wing. The lift generated by the streamlined fuselage is enough to compensate for heavier-than-air characteristics, which increases stability while retaining the ability to land and take off without a runway.

This study investigates the potential utility of a hybrid airship for mission in the Arctic. It is the third study under a Cooperative Research and Development Agreement between NPS and Hybrid Air Vehicles (HAV), a United Kingdom company. The study determines that the Airlander 10, a 10-ton hybrid aircraft variant, may potentially be well suited to the needs of the Department of Defense in the Arctic. In a one-on-one interview with HAV engineers, the Airlander 10 was described as a

> hybrid aircraft which uses a combination of aerodynamic lift, vectored thrust, and helium gas buoyancy to create a stable, low-dynamic stress platform capable of sustaining long-endurance airborne missions across vast areas operating from remote, austere sites without the need for roads, runways, or other infrastructure. The resulting flight characteristic is minimal noise and vibration, making for a stable platform for sensors and communications equipment.

This study assesses the costs and benefits of systems used in the Arctic by using Office of Management and Budget Circular A94 guidelines for a Cost-Effectiveness Analysis of Alternatives. The outcome of this study is aimed at starting the cost estimation process that meets the United States Code Title 10 requirements for Milestone A in the procurement of the Airlander 10. The benefits of the Airlander 10 need to outweigh the cost of development, procurement, operation, and disposal of other systems.

The second chapter of this study is a Trade Space Analysis that provides a qualitative look at the policies and political atmosphere driving requirements in the Arctic Circle. The chapter concludes by linking the regional requirements to Airlander 10's capabilities. Personal correspondence and one-on-one interviews with HAV engineers assisted in detailing a simulation of the Airlander 10 in an operation from Eielson Air Force Base in Alaska. The mission time totaled just over four days, covered 2,684 nautical miles, and used only a fraction of the fuel that a C-130J would consume.

The third chapter of this study evaluates alternatives, focusing on a quantitative assessment of the Airlander 10 and its alternatives. Uncertainty regarding the weather effect on the Airlander 10 is addressed in a risk analysis that determined the Airlander 10 would not be affected by the wind to the degree that would prohibit operations on any given month. During the winter months, operations may need to be tailored by reducing the payload, shortening the mission distance, establishing a mid-mission refuel, or altering flight altitudes along the route.

The final section of this study is a cost-benefit-analysis that compares alternative platforms to the Airlander 10. In summary, the Airlander 10 outperforms other platforms by having a lower life-cycle cost, being multi-mission capable, staying on station longer than its conventional aircraft alternatives, deploying remote sensors such as unmanned aerial vehicles and autonomous underwater vehicles, consuming less fuel (which translates to fewer emissions), and having greater mobility than any surface-bound alternative.

Due to the limited number of icebreakers and the limited ice-breaking capability of destroyers, the Airlander 10 stands to benefit the Navy's surface fleet the most. The Airlander 10 can effectively employ sensors of all kinds due to its ability to land on almost any surface. By taking over the responsibility for some missions, the surface fleet would be freed to concentrate on missions that require its unique capabilities.

The study concludes that the intelligence, surveillance, and reconnaissance (ISR) systems detailed in this study should work together to verify information and get the maximum amount of coverage possible in the Arctic. Due to operating under 10,000 ft and at a slower speed than other aerial platforms, the Airlander 10 does not replicate any other capability while uniquely being able to conduct all missions. If other systems continue to operate in the region, the Airlander 10 will improve the overall capability the DOD is able to deploy in the region.

References

Chief of Naval Operations. (2014, February). *The United States Navy arctic roadmap for 2014 to 2030*. Department of the Navy. https://publicintelligence.net/us-navy-arctic-roadmap/

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I. INTRODUCTION

The United States Navy Arctic Roadmap for 2014 to 2030 states, “The Arctic Ocean will be increasingly accessible and more broadly used by Arctic and non-Arctic nations seeking the Region’s abundant resources and trade routes” (Chief of Naval Operations [CNO], 2014, p. 3). The roadmap notes the development of oil and gas, fishing, tourism, and mineral extraction as a reason for the regional strategic importance. The acting Undersecretary of the Navy, Meredith Berger, stated that the region is a concern for the Navy due to melting sea ice, enabling more commerce in the region (Aranake, 2022). The current issue the Navy is having is that the Arctic is a challenging environment not akin to anywhere else on the planet. Commander of the U.S. Naval Meteorology and Oceanography says that communications and sensing issues, such as weak GPS signals and ionosphere interferences, make it difficult to transmit communications and monitor remote sensors (Aranake, 2022).

The CNO states that this region is no different from any other maritime region, but the environment makes the execution of the Navy’s responsibilities much more difficult (CNO, 2014). Existing systems such as satellites and aircraft that currently perform sensing missions have a high cost and are needed elsewhere in the world. For example, the C-130 is the only Department of Defense (DOD) aircraft equipped with skis to land on snow. The KC-130J cost per flying hour without fuel is roughly $9,900 in Fiscal Year (FY) 2021 dollars (Cohen & Schmaltz, 2022). That might seem expensive, but it is a bargain compared to a satellite constellation, which costs more than $2 billion for procurement and launch and provides up to seven years of coverage (DeBois, 2017).

Per Department of Defense Instruction (DoDI) 5000.73 (2020, March 13) Cost Analysis Guidance and Procedures, cost estimation is critical to effectively allocating budgets. It must be applied to all acquisitions made by service components. This mixed-method analysis aims to determine the feasibility of procuring new or modifying existing systems to meet the 2022 National Strategy for the Arctic goals. This study will quantify the costs and benefits of alternatives by using Office of Management and Budget (OMB) Circular A94 guidelines for a Cost-Effectiveness Analysis of Alternatives. The outcome of this study is not thorough enough to meet the United States Code Title 10 requirements for Milestone A, but it should serve as a starting point for policymakers to investigate further.

This study uses sections, figures, and tables from a co-authored study related to this research by Nick Dew, Imre Balogh, Christian Fitzpatrick, Kristen Fletcher, Marina Lesse, and Captain Timothy Socha, titled *Interactive Synthetic Environment to Evaluate Zero Carbon UAS Launch Platforms in the Arctic* (Dew et al., 2022).

A. LITERATURE REVIEW

Most people think of the zeppelins of World War 2, the *Graf Hindenburg*, or the Goodyear Blimp when conversing about lighter-than-air (LTA), but the descriptor can be applied to most balloons as well. Indeed, anything that weighs less than the air and floats is an LTA aircraft. The mode of flight goes back centuries and has had a substantial amount of research to back up its capabilities. Reconnaissance for military operations and the exploration of the arctic is at the core of the LTA concept.

The first LTA aircraft used for military operations, a simple balloon with a basket attached, allowed a human occupant to observe distant targets for artillery in the French Revolution in 1794 (Haydon, 1941). More widespread use came in the American Civil War for reconnaissance and spotting. However, these concepts were limited to static positions due to being tethered to the ground and unpowered in flight.

In 1926, General Umberto Nobile of the Italian Air Force flew the semi-rigid dirigible *Norge* over the North Pole, which marked the first recorded accomplishment of this feat in an airship (Bendrick et al., 2016). This flight was purely experimental, and General Nobile still needed to prove the concept. In 1928, he launched a second expedition from Milan, Italy, aboard a new dirigible named *Italia*, seen in Figure 1. This expedition would include a landing on the ice to allow a scientific party to conduct research.

Figure 1. The Airship *Italia*. Source: Holland (2017).

The trip would ultimately result in tragedy, despite a successful landing, and would be a stark reminder of how inhospitable the Arctic could be. The airship Italia encountered problems with ice buildup on the control cables and elements, and a strong headwind forced the ship onto the ice. However, the blame for the crash was placed solely on General Nobile for his incompetence as an airship pilot (Bendrick et al., 2016). Widely debated, the cause of the crash is uncertain. However, there is an essential lesson learned from these attempts, the arctic is navigable by LTA aircraft, and it can land on the ice successfully.

Meanwhile, the United States Navy was initiating its research and development of LTA dirigibles with the procurement of the German airship LZ-126 in 1924 (Syon, 2005). This original design explored the formula of long-distant travel with exceptionally high carry capacity. The Navy procured two other concept airships, the *USS Macon* and the *USS Akron*, in the 1930s for utilization as a mothership for scout biplanes. As seen in Figure 2, both airships had a 25-ton payload capacity and could operate five parasite aircraft for up to 3 days (SAIC, 2016). The capability to launch additional aircraft leveraged the strengths of the LTA aircraft, lift capacity, and efficiency without any drawbacks, such as attack power or independent scouting. A modernized parasite concept will be explored in this study in a later chapter.

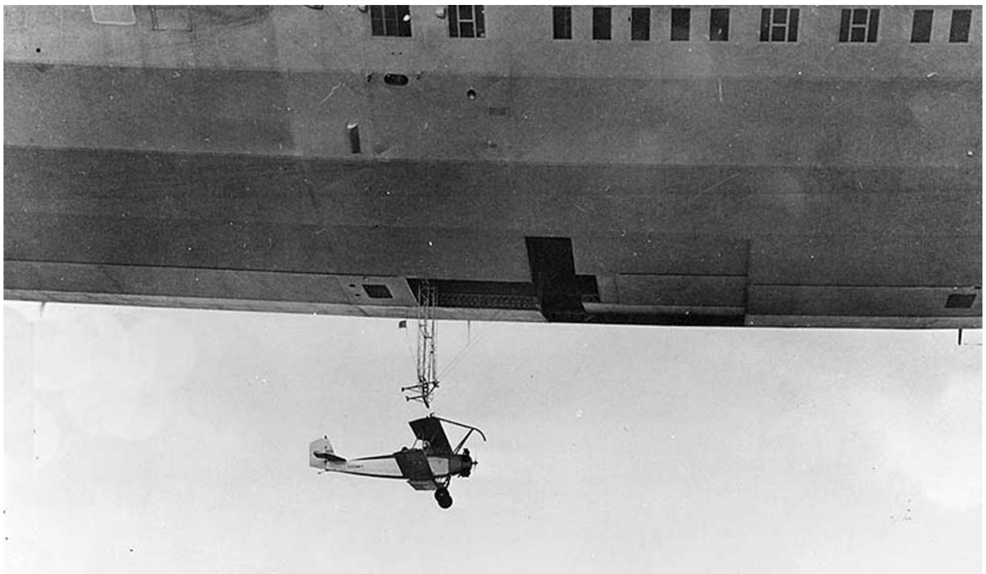

Figure 2. N2Y-1 Training Plane Beneath T-Shaped Opening to Akron's Hanger Deck. Source: Airships.net at https://www.airships.net/us-navy-rigid-airships/uss-akron-macon/ (2023).

While initially proving successful, the airship concept did not continue due to a series of highly publicized crashes that evaporated public confidence in the platform. The Navy continued to use dirigibles for submarine spotting and convoy escort in the 1960s, but the concept saw little development (Syon, 2005).

Fast forward more than 50 years, LTA aircraft are seeing a renaissance of interest due to climate change and emerging technologies. Growing interest focuses primarily on heavy payload airlifts and low carbon emissions, but the aircraft design is also inherently beneficial to military applications. As explored later in this study, the survivability of LTA aircraft exceeds conventional aircraft designs, and an airship's constant presence on the battlefield would have a phycological effect that could be profound (SAIC, 2016).

New technologies have enabled the fusing of the LTA concept with conventional aircraft. The new concept is known as a hybrid aircraft, which uses the principles of conventional lift generation. However, in place of a wing, the entire aircraft fuselage becomes a lift-generating surface. The concept can be seen in Figure 3. The lift generated by the streamlined fuselage is enough to compensate for heavier-than-air characteristics, which increases stability while retaining the ability to land and take off without a runway.

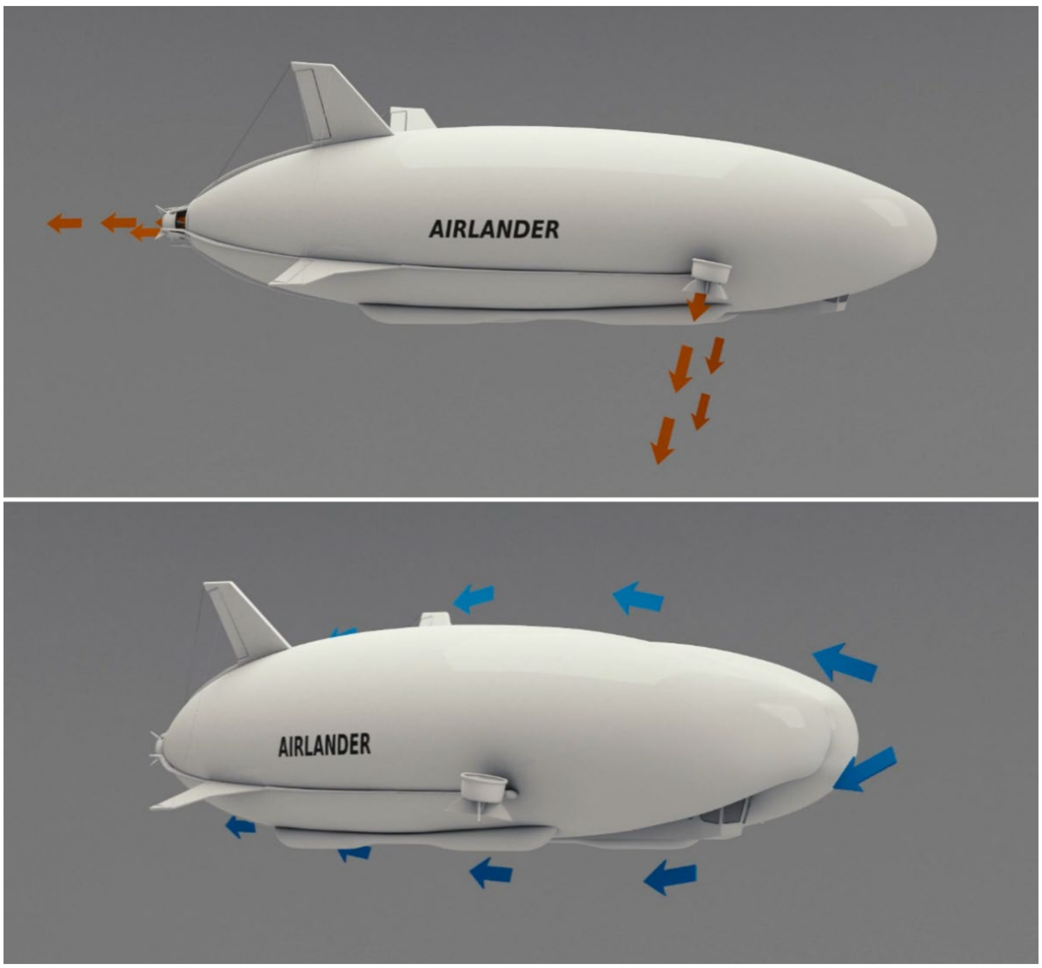

Figure 3. Airlander Lift Sources. Source: HybridAirVehicles.com at https://www.hybridairvehicles.com/our-aircraft/our-technology/ (2023).

A United Kingdom company, Hybrid Air Vehicles (HAV), received funding in 2010 from the U.S. Army to design and build a hybrid aircraft for an unmanned 21-day intelligence, surveillance, and reconnaissance (ISR) operation (Dew et al., 2022). A full-scale prototype aircraft flew from Lakehurst Airforce base, New Jersey under the U.S. Army Long Range Multi-Intelligence Vehicle program in 2012. The project was ultimately discontinued, and the full-scale prototype was sold back to the company, but the HAV continued to receive outside funding due to growing interest. The aircraft was subsequently returned to flight during 2016 and 2017 as part of continuing prototype development. HAV is currently developing the production (TRL8) variant with plans for the aircraft to enter service circa 2026. Thanks to a Cooperative Research and Development Agreement (CRADA) with HAV, the Naval Postgraduate School was able to assist in tying the hybrid aircraft's capabilities to use cases and evaluate the performance characteristics in various missions.

In 2021, Naval Postgraduate School students Captain Benjamin Cohen, and Captain John Schmaltz, initiated a study with HAV to investigate the cost of operating the hybrid aircraft for logistics around the Indo-Pacific region, for household goods movement from San Diego to Hawaii, and for fighting wildfires (Cohen & Schmaltz, 2022). Their study, *An atlas for navigating the innovation ecosystem: Hybrid airships as a use case to engage the commercial sector*, highlighted the capabilities of the hybrid aircraft, which could be applied to other missions and regions.

Similar to the Cohen and Schmaltz thesis, this study uses the CRADA partnership by leveraging one-on-one discussions with HAV engineers to determine hybrid aircraft utility. It was quickly determined that the Airlander 10, a 10-ton hybrid aircraft variant, would suit the needs of the DOD in the Arctic. In personal correspondence with HAV, they describe the Airlander 10 as a "hybrid aircraft which uses a combination of aerodynamic lift, vectored thrust, and helium gas buoyancy to create a stable, low-dynamic stress platform capable of sustaining long-endurance airborne missions across vast areas operating from remote, austere sites without the need for roads, runways, or other infrastructure. The resulting flight characteristic is minimal noise and vibration, making for a stable platform for sensors and communications equipment."

While the advantages of the hybrid airship seem to be worth investment at face value, the decision is ultimately up to decision makers who may not be subject matter experts. Gregory Mislick and Daniel Nussbaum state in their book, *Cost Estimation:*

Methods and Tools, that choosing among alternatives is one of the three central decisions made in congress that require cost estimation. Decision makers rely on products such as economic analysis, cost and operational effectiveness analysis, or analysis of alternatives. While slightly different in content, these products can be simply called a cost-benefit analysis. Mislick and Nussbaum define a cost-benefit analysis as, "A systematic approach to the problem of choosing the best method of allocating scare resources to a given objective" (Mislick & Nussbaum, 2015, p. 271). They go on to state on page 272 that the following eight steps describe a typical cost-benefit analysis process:

1. Define the problem / opportunity. Include the background and circumstances
2. Define the scope and formulate facts and assumptions
3. Define and document alternatives (including the status quo, if relevant)
4. Develop cost estimates for each alternative (include status quo, if relevant)
5. Identify quantifiable and nonquantifiable benefits
6. Define alternative selection criteria
7. Compare alternatives
8. Report results and recommendations

B. RESEARCH QUESTION

If the Airlander 10 is capable of operations in the Arctic, are the life-cycle costs affordable compared to its alternatives? The benefits of the Airlander 10 need to outweigh the cost of development, procurement, operation, and disposal of other systems. Is the Airlander 10 a cost-effective alternative to current systems used in the Arctic? If it is, to what extent do the benefits outweigh the cost?

This study found that the Airlander 10's characteristics leveraged specific capabilities that outperformed its alternatives in the Arctic region. Some systems, such as submarines, were identified as deficient in several characteristics and could exacerbate a race to militarize the Arctic. While the benefit of the Airlander 10 strongly outweighed those alternatives, it is determined that all systems covered in this study were in stark contrast when benefits and costs were cumulated. In particular, the Airlander 10 exceeds all alternatives in the ISR role.

C. METHODOLOGY

(1) Analysis of Alternatives (AoA): Cost-Effectiveness Analysis

DoDI 5000.84 (2020, August 4) states that a service component will conduct an AoA pursuant to Section 832 of the National Defense Authorization Act for Fiscal Year 2020 and Section 2366a of Title 10, United States Code (Cost Assessment and Program Evaluation [CAPE], 2020). These two documents state that an AoA must be conducted pursuant to a material development decision prior to Milestone A approval for a major defense acquisition program (US Code Title 10, 2002). Due to the development and type certification of the Airlander 10 still needing to be completed, this study serves as a cursory finding for further investigation.

Within an AoA, OMB Circular A94 states, "Cost-effectiveness analysis is a less comprehensive technique, but it can be appropriate when the benefits from competing alternatives are the same" (Office of Management and Budget [OMB], 1972, p. 4). The Circular goes on to state that a "Cost-effectiveness analysis is appropriate whenever it is unnecessary or impractical to consider the dollar value of the benefits provided by the alternatives under consideration" (OMB, 1972, p. 5). A cost-effectiveness analysis consists of the following elements that fall within the perspective of this study:

(2) Trade Space Analysis

DoDI 5000.84 (2020, August 4) *Analysis of Alternatives*, states that a Trade-Space Analysis must balance each option's capabilities against mission accomplishment. In the cases where monetary value cannot be assigned to a benefit or cost, OMB Circular A94 states that a qualitative analysis may still be helpful. The Trade Space Analysis chapter provides a qualitative look at the policies and political atmosphere driven by change in the Arctic Circle. The chapter concludes by linking requirements to Airlander 10 capabilities.

(3) Evaluation of Alternatives

The Evaluation of Alternatives chapter of this study is a quantitative study of the Airlander 10 and its alternatives. This consists of two parts: Assumptions and Cost Analysis. OMB Circular A94 states, “The analysis should include a statement of the assumptions, the rationale behind them, and a review of their strengths and weaknesses” (OMB, 1972, p. 5). Due to high degrees of uncertainty regarding weather effects on the Airlander 10, a Risk Analysis is conducted to determine mission success rates.

The second section of the Evaluation of Alternatives chapter is the Cost Analysis, which focuses on the life-cycle costs of the Airlander 10. Where possible, a present value will be assigned to the Airlander 10 based on comparable costs to its alternatives. This section measures benefits minus costs for the status quo and the direct purchase of systems used in the Arctic.

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II. TRADE SPACE ANALYSIS

A. ARCTIC REGION DESCRIPTION AND CHALLENGES

Parts of this chapter were previously published by Naval Postgraduate School (Dew et al., 2022).

The boundary of the Arctic Circle (66.5° North) is the latitude where the sun remains above or below the horizon for 24 hours for at least one day per year. The Curator of the Arctic exhibit at the British Museum, Amber Lincoln, claims the winter months in the Arctic are dark and cold, commonly reaching -40° C, and summer months only reach up to 30–35°C. Due to the climate extremes, the 7.7 million square miles are only inhabited by around 4 million people (Lincoln, 2020). The Arctic Ocean, depicted in Figure 4, is the predominant geographic feature within the Arctic Circle which is typically covered with year-round sea ice. The biggest challenge to human settlements in the region is the movement of consumables such as water, food, and fuel, which need to be shipped in to sustain human life.

Figure 4. Arctic Circle Boundaries. Source: Lincoln (2020).

The Ted Stevens Center for Arctic Securities Studies highlighted tundra greening, increased river discharge, and a record decrease in sea ice volume as the leading climate impact in the Arctic (Arctic Region Security Orientation Course Executive Seminar PowerPoint, May 2022). The receding ice exposes more earth and water to solar rays, exponentially increasing the region’s temperature.

1. New Trade Routes

Figure 5 shows the three established trans-arctic routes through the Arctic Circle. As discussed later in this study, the increasing temperature has resulted in the Northern Sea Route and the Northwest Passage opening to traffic for a few months every year. The Central Arctic Route has even been accessible for a few weeks in the summer. These routes cut several days off sea shipping that would typically go through the Suez Canal.

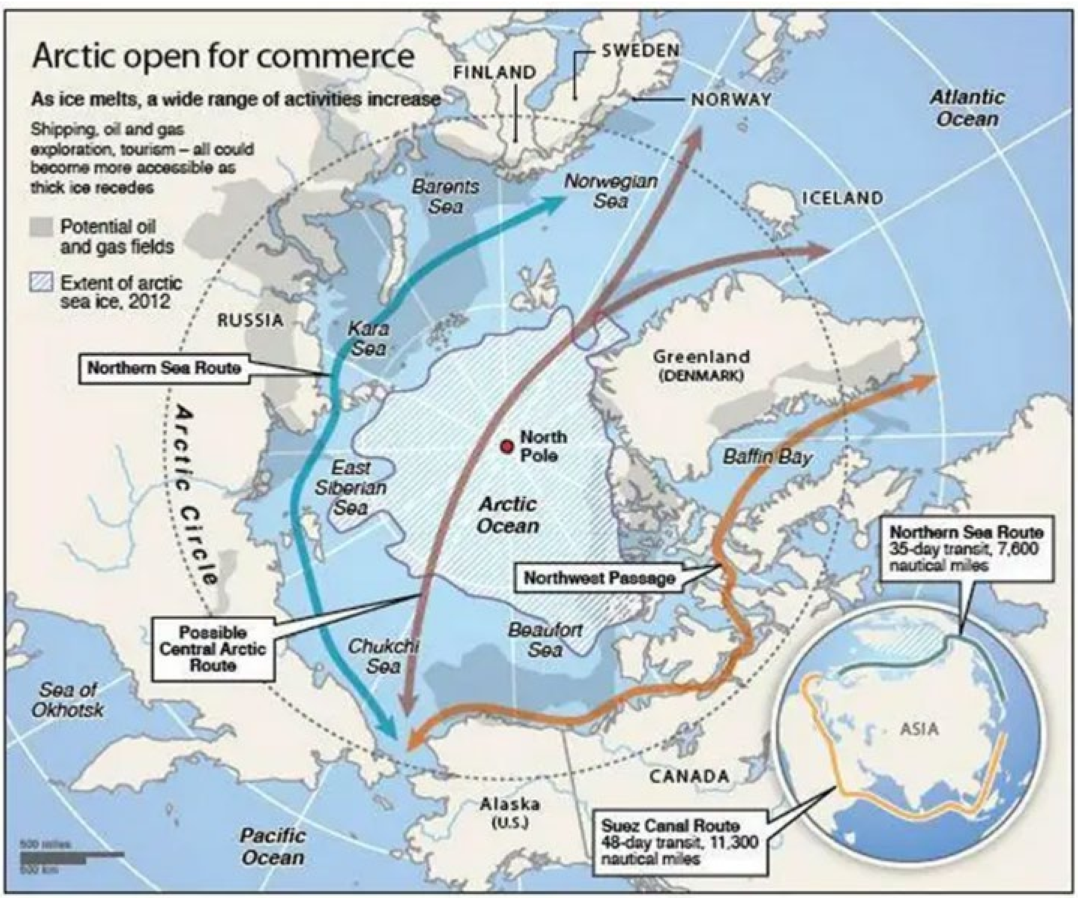


Figure 5. Arctic Trade Routes. Source: Bender and Kelley (2014).

Russia has very few warm-water ports which severely hamper its international trade potential, but that might not be the case for very long. The Arctic Circle accounts for 10% of the Russian gross domestic product, and the warming winters will free up more land for resource collection and shipping (King, 2022). Russia is looking to the Arctic as its key to returning to a dominant world power. To secure its place in the Arctic Circle, Russia has begun reinforcing its bases in the area, and it plans to expand its fleet of icebreakers to more than 50 vessels by 2030 (Grady, 2021).

For China, the melting ice will open a more direct route to ports on the Atlantic Ocean. The shorter shipping time would decrease the transportation cost of products, making them more favorable in the market. While China is not a member state of the Arctic, its influence in the region has taken the form of Russian backing. China also boasts a fleet of six icebreakers, four more than the United States (King, 2022).

A 2016 Scientific Reports article *A quantitative assessment of Arctic Shipping in 2010–2014* by Victor Eguiluz et al., stated that a total of 11,066 ships were detected in the Arctic in 2014. Only a tiny fraction (around 100) of the total traffic transited completely through the Arctic Ocean. The study noted that shipping activity in the Norwegian and Barents Seas highly skewed distribution, but the result provides a good baseline for measuring an increase in traffic.

Automatic Identification System data shows that hundreds of ships passed through the Northwest Passage in Canada, and thousands of ships passed through the Kara Sea in Russia in 2021 alone (Marine Traffic, 2021). The Central Arctic route currently remains impassable due to thick ice. The rise in traffic is likely due to new routes for LNG carriers and cargo movement from Russia and Europe to China and Asia. Bulk carriers are projected to increase in numbers as the arctic ice recedes and routes become more predictable (Dew et al., 2022).

2. Boundaries and Borders

Figure 6 captures the extent of the Arctic Circle, including each nation's Exclusive Economic Zone (EEZ), a 200-nautical-mile boundary that is governed by the individual sovereign coastal arctic nation (United Nations [UN], 1982). While the EEZ delineates sovereign waters, it does not prohibit air or sea travel by other States. As written in the United Nations Convention on the Law of the Sea, Article 73, the state may "take such measures, including boarding, inspection, arrest, and judicial proceedings, as may be necessary to ensure compliance with the laws and regulations adopted by it in conformity with this Convention" (UN, 1982, p. 52; Dew et al., 2022).

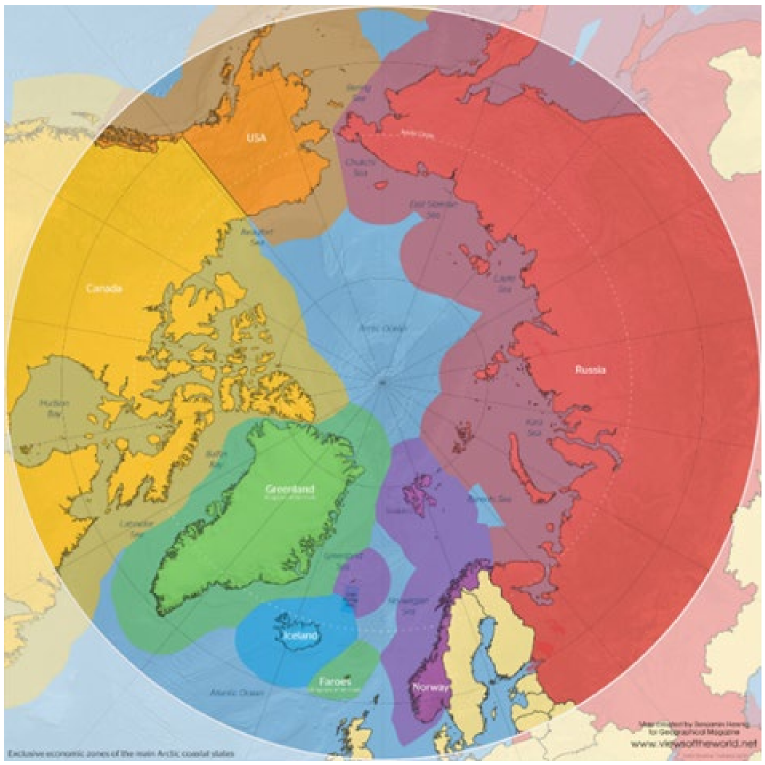


Figure 6. National Arctic Borders. Source: Hennig (2021).

The boundary that has the most significant implication for sea travel is the Territorial Sea border, which is 12 nautical miles from land. Within this border, a country has the authority to restrict the movement and passage of an outside State. To increase the size of this boundary, a country might build artificial islands within its EEZ, which might expand a Territorial Sea claim. The People's Republic of China has used this tactic in the South China Sea and could potentially implement this tactic in the Arctic (Doshi et al., 2021; Dew et al., 2022).

3. Geo-Political and Naval Implications

Wang Hong, Chief of State Oceanic Administration with China's Ministry of Natural Resources, stated that The People's Republic of China is a "near-Arctic state" at the 2019 Arctic Circle China Forum in Shanghai (Nilsen, 2019). While this claim is not founded on legality and is widely rejected, China's interest in the region is unsurprising.

Icebreakers XUE LONG and XUE LONG II have been operating in the Arctic since 1993 (De Pomereu, 2008). These two vessels have paved the way for China to expand its economic interests in a similar fashion to other Belt and Road initiatives. For example, Novatek, a Russian gas company, has agreements with a Chinese company for the trans-arctic shipment of LNG on tankers from a Russian arctic port to Rudong, China (Nilsen, 2019; Dew et al., 2022).

The People's Republic of China has sought to influence the region by shaping local governance by doubling regional investments (White House, 2022). As a direct result, Russian Defense Minister Sergei Shoigu said in March 2019 that the Russian Federation has built or reinforced 475 military facilities that directly impacted arctic operations over the past six years (Woody, 2019). Russia plans to restrict navigational freedom with excessive maritime claims while expanding new economic infrastructure to exploit hydrocarbon and minerals deposits and untapped fisheries (Gricius, 2021).

4. The Solution: Airlander 10

The U.S. needs to deploy a system to monitor expansion from growing international interest in the region, while keeping below the threshold that fuels competition (Office of the Undersecretary of Defense for Policy [OUSDP], 2019). The 2019 DOD Arctic Strategy states, "A stable and conflict-free Arctic benefits the United States by providing favorable conditions for resources development and economic activity" (OUSDP, 2019, p.7). The system needs to be robust enough to work in the harsh climate, capable enough to cover vast distances without support, benign enough to reduce the risk of competitive escalation, and clean enough to show the world that the U.S. is serious about preserving the Arctic. Today, the DOD does not have a system capable of meeting those requirements, so it is calling for selective acquisition of new capabilities (OUSDP, 2019).

A potential acquisition the DOD should consider is the Airlander 10. As depicted in Figure 7, the HAV manufactured Airlander 10 would be well suited to the Artic and can perform the missions needed to support U.S. policy and strategy.

Figure 7. Artistic Impression of the Airlander 10 in the Arctic. Source: Hybrid Air Vehicles (2023a).

To best illustrate the Airlander 10's capabilities, a team within HAV helped generate the following scenario that satisfies the DOD's regional requirements. Details of this scenario were generated via one-on-one conversations and correspondence, which is not available to the public.

The Airlander 10 departs Eielson Air Force Base for the Bering Strait and Chukchi Sea with four pilots and four operators. After 11 hours, the aircraft arrives in the operational area and starts using a suite of onboard systems and deployable sensors to locate air, surface, and subsurface traffic. Figure 8 shows the suite of sensors and associated ranges deployed aboard the aircraft. The Airlander 10 also acts as a mothership for six short-range ScanEagle UAVs, which extend the overall visual surveillance range to 150km in all directions. With help from ScanEagle deployments, over 866,000 square kilometers were visually surveilled, and over 900,000 square kilometers were scanned using signals intelligence systems and imaging sensors. The detection mission continues for 48 hours straight, as the hybrid airship can operate 24 hours a day. HAV claims that conventional aircraft are not conducive to crew rest, but the hybrid aircraft enables proper rest cycles while in transit and on station. In the Airlander 10, vibration and noise from the engines and wind turbulence are undetectable to the crew. This characteristic also aids the precision of sensitive detection equipment. Upon return to Eielson Air Force Base, mission time totaled just over four days, covered 2,684 nautical miles, and used only a fraction of the fuel that a C-130J would consume.

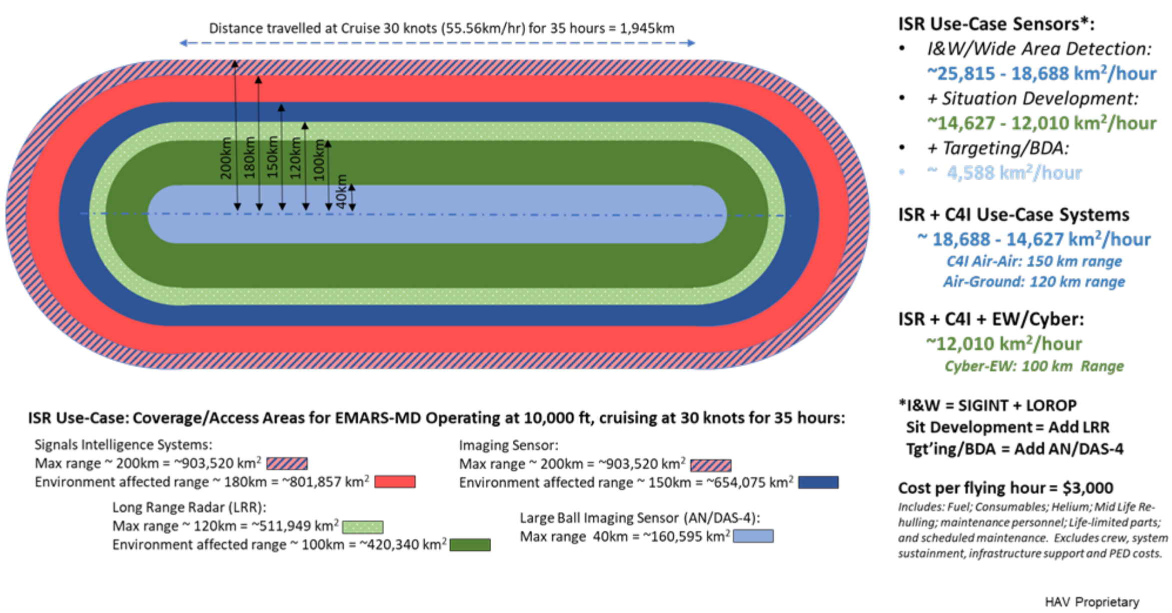


Figure 8. Airlander 10 Sensor Suite and Ranges. Source: Personal Correspondence with HAV.

Due to the Airlander 10's short takeoff and landing, HAV claims the above scenario could be conducted from any location with a 2,000ft by 2,000ft empty lot or body of water up to sea state three/four. In addition to surveillance, the Airlander 10 can easily change out payload modules to take on a logistics role. This modularity makes a fleet of Airlander 10 self-supporting, which means they can transport their own maintenance crew and rescue their own downed aircraft. An instance where an Airlander 10 is downed might be rare, though, as the aircraft only requires two of its four engines to fly any mission safely.

HAV stated that the Airlander 10 can be configured to conduct rescue operations, deploy ground forces and vehicles, launch weapons or drop bombs, deploy sub-systems such as unmanned aircraft system (UAS), and act as a command-and-control center. The 2019 DOD Arctic Strategy lists command, control, communications, computers, and ISR as essential for operations in the Arctic and more communication and data networks are needed (OUSDP, 2019). The Airlander 10 is ideally suited for this role as it can be used as a communications relay and a position, navigation, and timing coordination point which is free from solar and magnetic degradation.

III. EVALUATION OF ALTERNATIVES

A. ASSUMPTIONS

(1) Classified Alternatives

To keep this study available to the broadest audience possible, all information is from sources that are available to the public. There are, undoubtedly, exact dollar values and performance parameters for all the alternatives in this study, but that is beyond the scope of this study.

(2) Affordability Analysis

Per DOD instruction 5000.84, an AoA should contain "Consideration of affordability, to include any Milestone Decision Authority established affordability goals" (Cost Assessment and Program Evaluation [CAPE], 2020, p. 5). Due to the incomplete nature of the Airlander 10's development and the limited scope of this study, no assessment of affordability will be made.

(3) Uncertainty

Due to the inherent imprecision and bias in data and modeling, uncertainty should be assumed for all estimates (OMB, 1972). OMB Circular A94 dictates that probability distributions should be used to compensate for uncertainty whenever possible. The variance will be noted for some measurements within this study, but distribution curves have not been applied for any costs or benefits. All values are expected values, which are unbiased estimates of a sum across all potential outcomes (OMB, 1972).

b. Risk Assessment for Weather

To a casual observer, a large aircraft like the Airlander 10 would be highly susceptible to wind conditions, but that should not be the case. HAV has years of aerospace development, knowledge, experience, wind tunnel testing, and computational fluid dynamics testing to ground their hybrid aircraft designs on. HAV claimed in personal correspondence that the Airlander 10 can complete a 2,000 nautical-mile trip without wind but was initially uncertain how the weather would affect that capability. With certainty, they said the Airlander 10 would be able to choose its operating altitude with a greater degree of flexibility to suit wind conditions than a conventional aircraft which is bound to altitudes based on efficiencies.

HAV provided aircraft characteristics for flight at 10,000ft and the wind data for that in the Alaska area. They claimed the wind data was generated from National Aeronautics and Space Administration Global Gridded Upper Air Statistics (version 1.1), dated 1980 to 1995. The weather data for the first simulation can be found in Appendix A. Each month of the year was given a frequency and average wind speed associated with a direction of wind travel. The wind frequency variable dictated the wind speed used for the given month. The mean wind speed was applied to a Weibull distribution to simulate realistic wind variation. Oracle Crystal Ball is used to develop a schedule simulation for integrating the Weibull distribution to each mission to find risk probability.

It would stand to reason that wind information would vary widely between the Alaskan interior and the Arctic Ocean. Due to a lack of local weather information, the data in Appendix A was applied to the entire mission area. HAV's in-depth assessment took weather data from along the planned route rather than from a single point, significantly increasing the simulation's accuracy. It should be noted again that the Airlander could easily vary its altitude to take advantage of favorable wind conditions.

The simulation requires an additional step for a schedule risk assessment on Oracle Crystal Ball. Wind speed needs to be converted into ground speed and ground speed into duration. The ground speed is calculated using an online calculator found at omnicalculator.com (Abdurrazaque, 2022). The calculation requires wind heading, wind speed, aircraft heading, and aircraft speed. The mission's duration can be calculated with the ground speed, which is the speed at which the aircraft moves after the wind has taken effect. Finally, an estimated burn rate is applied to the duration.

For this model, 122 kilograms per hour for a burn rate is used, which is an estimate based on an average of 40 knots of cruising speed using the rear two engines only. Overall mission success is measured by time against the available fuel capacity of the Airlander

10, which is 6,000 kilograms in this simulation. The engineers at HAV stated that the fuel carried can be increased to 7,000kg or 8,000kg with a modest re-ballasting “dip” during the flight. This configuration dramatically improves the success rates of the mission. The scope of this study requires a baseline, so the 6000kg fuel capacity without re-ballasting is used to reduce flight profile variations.

The key areas of interest for this simulation are the Bering Strait and Wrangler Island, as these are natural choke points for shipping and suitable locations for military bases. The start location for the simulation is Eielson Air Force Base due to its existing infrastructure. The route is detailed in Figure 9.

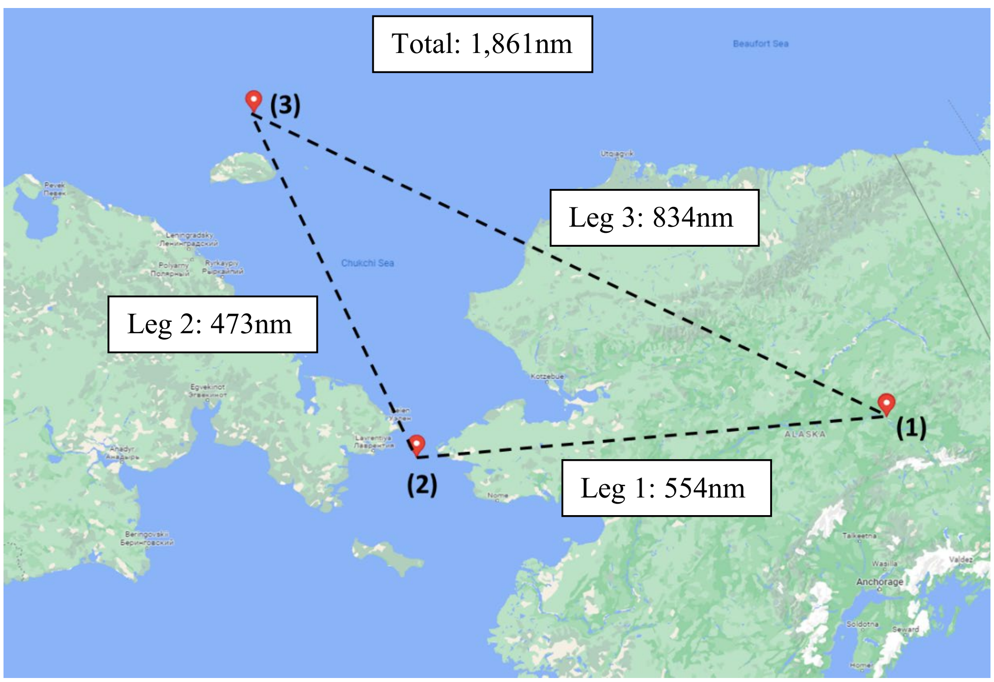


Figure 9. Simulated Surveillance Mission

The mission can be completed with 100% certainty in less than 50 hours without wind. At the 50-hour point, the aircraft’s usable fuel is depleted, and a 20% reserve tank takes over. The 50-hour threshold will be the mission success or failure point because the reserve tank is specified for emergency use only. The resulting probability along the Weibull distribution determines the probability of success. Figure 10 shows the result for the third leg in January in a clockwise patrol. A similar distribution was created for each leg in each month. Note that the model determines the success rate at 50 hours, not the median point on the distribution. For example, the mission success for an April counterclockwise patrol is 70%, which falls much further down the curve at 50 hours.

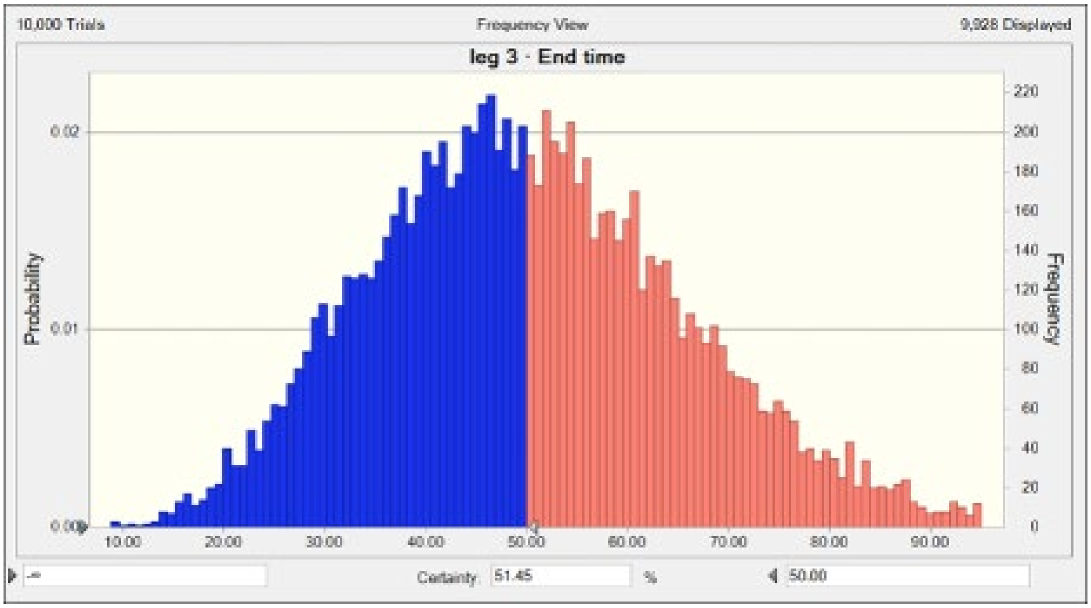
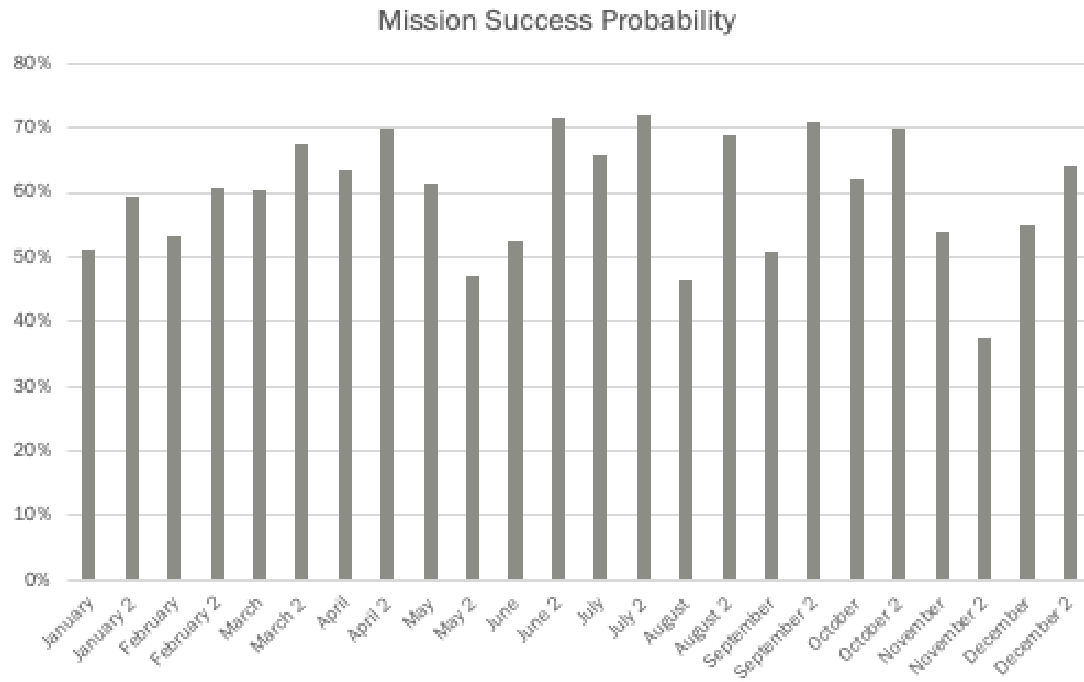


Figure 10. Weibull Distribution Example

After running simulations for each month in a clockwise direction (leg 1, leg 2, and then leg 3), it was determined that a counterclockwise direction (leg 3, leg 2, and then leg 1) should be run to find any differences. The order in which the legs were completed and the direction of travel impacted the mission's success and can be seen in Figure 11. The greatest chance of mission success occurs in June and July using the counterclockwise route configuration. More importantly, the probability of success was almost always more significant when the counterclockwise route configuration was used. This is likely due to the direction of travel in relation to wind direction on Leg 3, which has the greatest distance. It is concluded that headwind significantly impacts leg duration, and route planners should minimize the amount of time the aircraft is heading into the wind. To further complicate a conclusion, HAV noted that it is more effecient to fly headwind legs first, which increases aircraft performance when heavily laden with fuel.



Counterclockwise missions are marked with a “2.”

Figure 11. Mission Success Probability Results

It should be noted that none of the missions have zero risk or 100% success chance. To help explain this finding, HAV ran a similar simulation with a proprietary aircraft performance calculator. Aircraft drag, weight, variances in speed, altitude, and fuel burn were more closely controlled in their simulation. Table 1 shows the results for their simulation, which show a wider variation in results and a better outcome for the Airlander 10 in June.

Table 1. HAV Risk Analysis Data for Alaska Mission. Source: Personal Correspondence with HAV.

	35 knots	40 knots	42 knots	45 knots
Jan	22.3%	24.9%	24.5%	14.3%
Feb	20.7%	36.7%	36.5%	17.2%
Mar	46.4%	56.4%	53.3%	46.7%
Apr	55.0%	66.9%	67.8%	53.7%
May	72.9%	74.8%	75.8%	72.8%
Jun	70.2%	75.3%	76.1%	74.0%
Jul	70.4%	75.7%	76.0%	73.7%
Aug	59.9%	68.6%	72.6%	62.9%
Sep	61.5%	67.5%	65.8%	62.1%
Oct	53.3%	68.7%	65.3%	52.0%
Nov	47.3%	52.2%	52.1%	49.5%
Dec	26.4%	49.5%	44.9%	21.3%

The highlighted figure shows the optimal mission success chance for the Airlander 10 on this particular mission. The aircraft has the best chance of success in the month of June, traveling at an average of 42 knots.

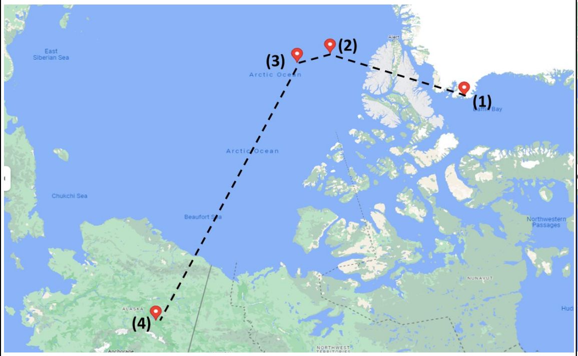
While the best results only produce a 76.1% chance of success, this is not a vote of no confidence. The Airlander 10 is not accounting for a 20% reserve fuel that could be used. Conventional aircraft need reserve fuel for diverting during emergencies or runway closers. The Airlander 10 will not have the same problems, as it can land virtually anywhere there is a clearing. Due to constantly evolving technologies and sensor requirements, the estimated payload for the Airlander 10 is also highly subjective. With less payload, the Airlander 10 could take on more fuel, increasing endurance. The Airlander 10 could complete nearly any mission with zero risk if a mid-mission refuel on the water or land was factored in.

It should be noted that the mission could be shortened if an unfavorable headwind reduced the total distance covered. A mid-mission evaluation would determine how much time on station is possible given the wind direction and speed for a return trip.

HAV further evaluated three missions for the Airlander 10 in the Arctic using the same model with updated weather information. Figure 12 shows the routes and associated mission success probability. The first two missions are intended to reach the North Pole and serve as a ferry route between Thule and Eielson. These routes would frequently be used for maintenance or cargo transportation, which would be more direct and result in a much higher success rate. Missions to surveil the Northwestern Passage would also be more direct. The third mission is a patrol route that would surveil the Russian Nagurskoye Military Airport and choke points into the Barents Sea.

The conclusion from this Risk Assessment is that the Airlander 10 is affected by the wind conditions in the Arctic Circle, but not to the degree that would prohibit operations on any given month. Some operations need to be tailored by reducing the payload, shortening the mission distance, establishing a mid-mission refuel, or altering flight altitudes along the route. Surface shipping may be stopped entirely during the winter months due to ice, but the Airlander 10 will still be able to operate in a limited capacity.

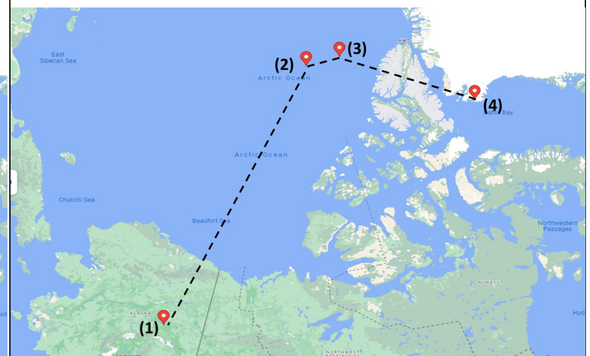
Thule to Eielson



	35 knots	40 knots	42 knots	45 knots	50 knots
Jan	43.2%	46.8%	47.4%	43.6%	0.0%
Feb	44.7%	44.5%	44.0%	41.5%	0.0%
Mar	42.1%	43.2%	44.3%	43.9%	0.0%
Apr	44.1%	52.7%	48.8%	42.9%	0.0%
May	51.3%	50.9%	51.5%	49.1%	21.3%
Jun	42.3%	51.1%	43.5%	42.3%	18.2%
Jul	45.4%	49.5%	45.7%	45.5%	18.2%
Aug	43.4%	48.7%	44.8%	41.0%	21.8%
Sep	34.4%	41.7%	39.1%	33.5%	16.1%
Oct	31.8%	40.5%	40.5%	31.5%	0.6%
Nov	48.7%	50.3%	45.0%	41.9%	0.0%
Dec	44.0%	43.0%	45.2%	43.0%	0.0%

1949 n.miles, 10000ft, 6000kg heavy, 7008kg of payload, 6000kg useable fuel, 20% fuel margin, 10kw of mission power.

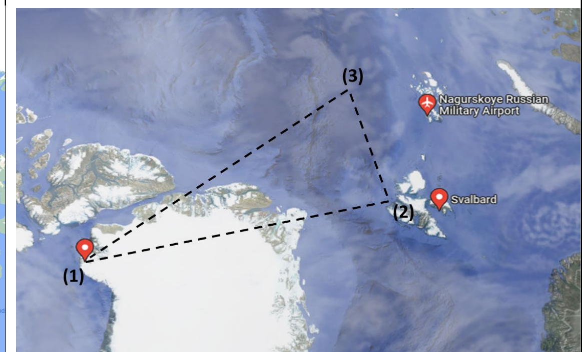
Eielson to Thule



	35 knots	40 knots	42 knots	45 knots	50 knots
Jan	34.0%	35.4%	36.8%	33.8%	6.0%
Feb	35.1%	35.9%	36.8%	35.9%	8.8%
Mar	40.9%	39.6%	41.3%	40.6%	10.0%
Apr	41.6%	44.0%	44.6%	40.0%	12.0%
May	56.0%	56.4%	55.9%	44.2%	23.0%
Jun	62.4%	62.1%	62.1%	56.9%	38.3%
Jul	46.5%	62.7%	58.0%	47.9%	34.1%
Aug	51.6%	64.0%	61.5%	52.7%	38.3%
Sep	48.5%	52.9%	49.0%	48.5%	26.3%
Oct	53.2%	52.6%	52.7%	53.7%	25.3%
Nov	44.5%	42.3%	42.9%	39.3%	10.6%
Dec	35.5%	37.8%	37.4%	38.1%	8.6%

1949 n.miles, 10000ft altitude, 6000kg heavy, 7008kg of payload, 6000kg useable fuel, 20% fuel margin, 10kw of mission power.

Thule Patrol Pattern



	35 knots	40 knots	42 knots	45 knots	50 knots
Jan	43.7%	42.9%	42.7%	41.3%	4.6%
Feb	43.0%	42.4%	40.1%	37.5%	4.5%
Mar	39.8%	42.8%	37.8%	36.7%	7.3%
Apr	40.3%	38.7%	38.2%	37.1%	4.4%
May	37.7%	36.2%	36.2%	35.7%	4.6%
Jun	38.8%	37.5%	37.5%	36.8%	6.3%
Jul	38.1%	42.3%	38.9%	38.1%	13.9%
Aug	41.0%	39.0%	39.0%	39.0%	7.1%
Sep	38.5%	39.3%	40.3%	36.5%	6.3%
Oct	39.9%	34.5%	35.0%	32.3%	4.4%
Nov	48.6%	46.7%	46.8%	47.2%	5.3%
Dec	40.2%	42.2%	40.9%	39.2%	4.1%

2381 n.miles, 10000ft altitude, 6000kg heavy, 7008kg of payload, 6000kg useable fuel, 20% fuel margin, 10kw of mission power.

Figure 12. HAV Risk Analysis for Alternative Airlander 10 Missions. Source: Personal Correspondence with HAV (2022).

B. COST ANALYSIS

Parts of this section were previously published by Naval Postgraduate School (Dew et al., 2022).

1. Status Quo

a. Current State of Arctic Operations

Doctor Philip McGillivary, the United States Coast Guard PACAREA Icebreaker Science Liaison, stated in personal correspondence that specially designed vessels are increasingly capable of traversing the region under select conditions. Liquified Natural Gas (LNG) carriers have been making trans-polar crossings without icebreaker escorts, and the frequency of these transits will increase the demand for rescue and emergency services, which the United States is not prepared to execute (Dew et al., 2022). The United States Coast Guard Pacific Area is responsible for operations within the Arctic Circle, except the United States Coast Guard Cutter *Polar Star* and *Healy* are the only icebreakers in the United States inventory that can deploy in thick ice.

The United States DOD regional operation gap is predominantly surveillance and detection. The National Strategy for the Arctic Region states, "The United States will maintain and, driven by requirements, refine and advance military presence in the Arctic in support of our homeland defense, global military and power projection and deterrence goals" (White House, 2022, p. 9) In other words, the need for intelligence collections assets is imperative for the DOD's scaling of force. In the near term, the Arctic Strategy calls for an expansion of maritime security, law enforcement, search and rescue, and emergency responses with an expanded U.S. Coast Guard icebreaker fleet.

b. U.S. Maritime Fleet Employment

While ice breakers are a logical choice for maritime patrols in the Arctic, the ship class is far too rare in the U.S. inventory for routine surveillance, which is a problem the U.S. Coast Guard is trying to fix. It was announced in 2019 that a first-of-its-kind heavy icebreaker cutter for polar security started construction (Larter, 2022). Until a fleet of these new ships can be deployed, the U.S. Navy has picked up the mission with destroyers which are more than capable of the task during summer months (Dew et al., 2022).

In a 2020 Defense News article titled *The U.S. Navy Returns to an Increasingly Militarized Arctic*, David Larter states that the Navy has started making regular patrols into the Arctic circle via the Barents Sea for the first time in 30 years. That year, three U.S. Arleigh Burke-class guided-missile destroyers under the U.S. Navy's 6th Fleet and a British Royal Navy frigate conducted submarine detection missions (Larter, 2020). Similar operations are projected to grow to six destroyers or more due to increasing requirements outlined in the 2022 National Strategy for the Arctic Region (The White House, 2022; Dew et al., 2022).

With modifications, the Arleigh Burke-class destroyer can be "ice-hardened" to cut through just under a foot of ice, which may be adequate for the summer months in the Arctic (Werner, 2019). Figure 13 shows the number of ships passing through arctic shipping channels and their current and projected ice levels. Open water is lasting longer in every channel, which makes the operation of an ice-hardened destroyer viable. The Navy surface fleet may be able to operate in the Bering Strait for a significant amount of the year, effectively monitoring all traffic into and out of the Arctic Circle from the Pacific Ocean.

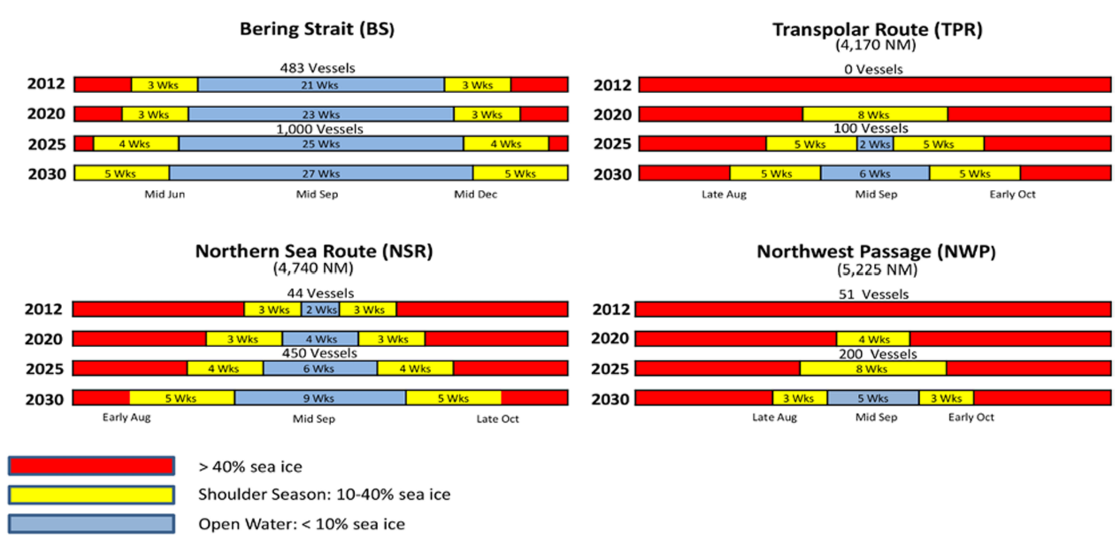


Figure 13. Arctic Sea Route Navigability. Source: CNO (2014).

The Navy may argue against operating its surface fleet in the arctic due to unpredictable ice flow and incomplete nautical charts (CNO, 2014). The region needs to be thoroughly mapped and marked for safe navigation. The risk of losing a ship to inexperience does not outweigh the benefit provided to the region, but that will likely change. The U.S. Navy Arctic Roadmap states that the far-term plan calls for increased search and rescue, Disaster Response/Defense Support of Civil Authorities, maritime security, and freedom of navigation operations, which can only be conducted by a surface fleet (CNO, 2014). Unless new technology and systems are adopted, the fleet may be exposed to the hazardous environment.

The Navy's subsurface fleet has been operating below the Arctic Ocean ice for decades and contains the majority of the experience in the region (CNO, 2014). While these assets are a valuable tool to monitor traffic, the cost may not warrant their constant presence. The U.S. Navy Arctic Roadmap states, "It remains unlikely that any of the five Arctic littoral states will risk a large-scale, intrastate military conflict" (CNO, 2014, p. 14). Due to the high cost of operating and building new submarines, they could be more effective where conflict is most likely. A submarine's limited utility in rescue, logistics, and interception degrades its overall benefit.

c. Naval Aviation

The Boeing P-8A Poseidon is currently the most common platform for surveillance in the Arctic Circle. Based on the Boeing 737–800ERX, the P-8A has a commercial airliner's lift capacity, operating altitude, and speed but with modifications for extended operations. The Northrop Grumman MQ-4C UAV is designed to operate with the P-8A, as depicted in Figure 14. The MQ-4C supplements the P-8A by creating a 30-hour presence to cover more area that the P-8A can investigate as needed (Vavasseur, 2020). The complete system provides detection of sub-surface and surface traffic with a multitude of sensors along with weapons to deal with any threat. While highly capable, the P-8A and MQ-4C rely on U.S. Navy and Coast Guard surface vessels to intervene in any police action (Dew et al., 2022).

Figure 14. Artist Impression of MQ-4C and P-8 Poseidon. Source: Kanavaskis (2016).

The C-130 has performed cold weather logistics missions within the Arctic Circle and Antarctica with reliability, which gives it special consideration for this study. If outfitted with skis, as seen in Figure 15, the C-130 is uniquely capable of missions that the P-8A and MQ-4C cannot execute. While not a typical ISR platform, the C-130 could perform the same roles as the P-8, but the sensitive equipment would be subjected to the C-130's inherent vibration and noise from its four turboprop engines. For example, the KC-130J used by the Marine Corps is outfitted to be ISR capable (Office of the Under Secretary of Defense [OUSD], 2022).

Figure 15. LC-130 "Skibird" at Raven Camp. Source: Gizara (2017).

d. Low Earth Orbit Satellites

The 2022 National Arctic Strategy highlights the lack of communication and satellite coverage in the Arctic that commercial, maritime, and air safety sectors need (The White House, 2022). The expansion of satellite capabilities has the potential to fill a critical gap in surveillance for the DOD. Currently, four Defense Meteorological Satellite Program systems are in polar orbit and monitored by the U.S. Space Force. However, these platforms are 17 years beyond their life expectancy and severely hampered by aging technology (Erwin & Berger, 2021). U.S. Space Force Vice Commander, General David Thompson, testified to Congress in 2019 about the importance of updating these satellites. A May 2021 Space News article by Sandra Erwin and Brian Berger stated that the Space Force has two satellite systems projected to launch in 2023 with passive microwave sensing and visible and infrared imaging (Erwin & Berger, 2021; Dew et al., 2022).

Satellites operating in low earth polar orbit fly over both poles between 150 and 1000 kilometers above the earth and can pass a point 16 times each day (European Space

Agency, 2020). While satellites are an option for arctic surveillance, these systems are costly and highly subject to weather, transmission lag, and resolution. Due to these limitations, it is essential to maintain a diverse surveillance suite for greater accuracy (Dew et al., 2022).

While the Arctic Circle's vast, inhospitable terrain might seem like a perfect place to employ satellites for surveillance, the cost may not be realistic. A RAND study indicated that a low earth orbit satellite (LEO) would cost more than $9 billion to employ, while a geosynchronous satellite would cost over $200 million. A LEO satellite has the benefit of better resolution and detection. However, its station coverage is limited to around 500 km, whereas a geosynchronous satellite has unlimited visibility in relation to its orbit (Jamison, 2005).

In a 2022 RUSI podcast, *Space Economics 101*, Professor Akhil Rao, Ph.D., of Middlebury College, stated that satellite surveillance would expand to become a publicly available market. Most companies only launch satellites to sell imaging to governments because the cost remains too high compared to the relatively inexpensive cost of terrestrial surveillance, but that might change (Suess, 2022). Dr. Rao concluded that the cost of satellite launches would not likely exceed terrestrial systems due to orbital use fees and the risk of space collisions, but the cost should come down.

2. Alternative: Airlander 10

a. Air Base Operations

Thule Airbase in Greenland is the DOD's northernmost installation and home to the 821st Space Base Group (U.S. Air Force, 2022). The base has a runway and airfield support squadron to keep the flight line operational year-round (Dew et al., 2022). Due to existing facilities, Thule Air Base could facilitate Airlander 10 operations with minimal improvement and serve as a hub for operations on the Atlantic side of the Arctic Circle. On the Pacific side of the Arctic Ocean, Eielson Air Force Base currently hosts multiple flying squadrons that conduct cold weather operations around Alaska and the Arctic Circle. Thule and Eielson could provide a quick and inexpensive basing location for the Airlander

10, but the platform could effectively operate out of any unimproved location, including a seaport.

An example of an unimproved basing location that would serve Airlander 10 but not large military aircraft is Utqiagvik, Alaska. 2022 Federal Aviation Administration Airport Master Record states that the asphalt runway at Utqiagvik is 7,100 ft long and does not allow aircraft with more than a 30-passenger capacity to land without written approval (United States Department of Transportation, 2022). As seen in Figure 16, Airlander 10 could utilize the open terrain next to the runway for operations without extensive improvement. Due to this airfield's location at the northernmost point of Alaska, this base would significantly enhance the patrol radius of the Airlander 10, enabling surveillance of the Northern Sea Route along Russia's border.

Figure 16. Wiley Post–Will Rogers Memorial Airport, Utqiagvik Alaska.
Source: Google (2022).

Nome, Alaska, would also be an ideal basing location for the Airlander 10. Within 100 nautical miles of the Bearing Strait, Nome is close to a critical choke point into the Arctic Sea. The proximity would allow the Airlander 10 to spend most of its flight time conducting operations. As seen in Figure 17, Nome has two potential runways and an extensive sheltered port. Consolidated Appropriations Act of 2021 provided funding to the

Port of Nome to complete the 505 million-dollar extension of the western causeway and construct a deep-water basin (Alaska Public Media, 2021).

Figure 17. Nome Alaska. Source: Google (n.d.a).

HAV explained in an interview that the Airlander 10 can land on water and ice with minimal environmental impact. They claimed that while under max weight, the Airlander 10 only exerts 0.179 lbs/in2 of pressure on the surface, while an equally loaded C-130E on skis exerts 2.8 lbs/in2, or 133 lbs/in2 with conventional landing gear. With a landing and takeoff area of 2,000ft by 2,000ft, the Airlander 10 also reduces the airfield footprint requirement compared to conventional aircraft. As a comparison, Raven Camp Skiway in Greenland is the primary C-130 training site for landing and takeoffs on snow.

Ravan Camp utilizes an 8,000ft by 230ft snowpack runway (Battelle, 2023). This runway is substantially longer than what an Airlander 10 would need, and it requires basic maintenance to keep operational.

b. *Susceptibility and Vulnerability*

The Airlander 10's fabric hull can absorb an impact from multiple weapon systems. A RAND 2005 study by Jamison et al., *High-Altitude Airships for the Future Force Army*, stated vulnerability testing was conducted against a small nonrigid airship at 15,000ft elevation. The results of that study are outlined in Table 2, indicating a survival rate that is better than a conventional aircraft (Jamison et al., 2005).

Table 2. Airship Vulnerability Test Results. Information Sourced from Jamison et al. (2005).

Threat	Number of Holes	Decent rate (hours)
Small Arms	200	0.42 to 2.25
50-Caliber	50	3
20mm Cannon	100	0.7
Stinger Missile	1 impact	1.4

To complement Table 2, Major Charles E. Newbegin prescribed that the SkyCat, a 1,100-ton LTA airship, could withstand significantly more damage. With a pressure differential between 0.25 and 0.55psi, which is much higher than the Airlander 10, the SkyCat would continue flying with battle damage for a significant amount of time.

Figure 18 shows the vent rates for the SkyCat with 300 holes from 23mm projectiles, 10,000 holes from 7.62mm projectiles, and a Man-Portable Air-Defense Systems (MANPADS) detonation 1.5 feet from the airship surface, creating 9 square feet of damage (Newbegin, 2003). Major Newbegin concluded that a hit from a MANPADS would inflict the most damage, resulting in a four-hour descent. Without the raw data from this study, it is difficult to figure out how the alternate systems would compare. However, HAV stated in personal correspondence that the Airlander 10's 0.15psi differential would likely produce even slower leak rates.

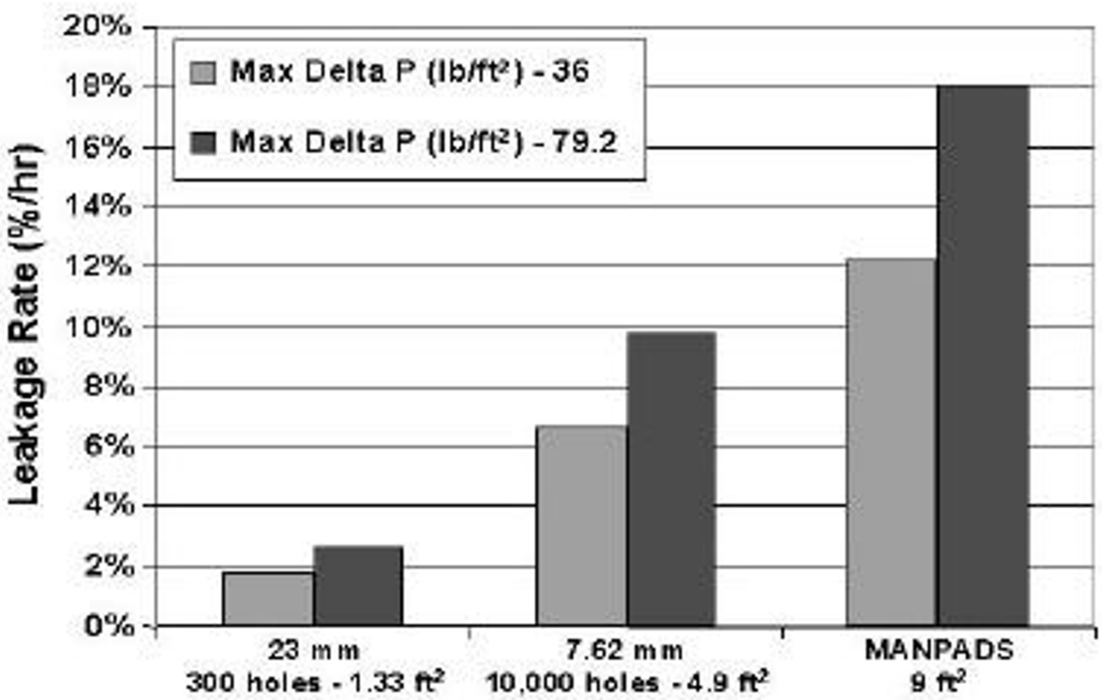


Figure 18. SkyCat Airship Vent Rates. Source: Newbegin E. (2003).

Due to the limited release of information regarding the study that Jamison et al. cited, it is not easy to make direct comparisons to the Airlander 10. Likewise, the SkyCat airship is significantly bigger than the Airlander 10, and both studies involved used LTA aircraft. It would be unfair to draw any direct conclusions, but it is fair to assume that Airlander 10 would perform somewhere between.

The hull is by far the largest part of the Airlander 10 and, therefore, most likely to be struck, but it should be noted that the critical components would fare comparably well. HAV engineers claimed in a one-on-one interview that the Airlander 10's four widely dispersed engines and independent auxiliary power units reduce infrared signature while creating redundancy, as the aircraft only needs two engines for mission-capable flight. Critical systems are also dispersed across a large area, reducing the chance that a single impact will result in catastrophic failure. Information from a proprietary presentation with HAV claimed that if the threat level required, Airlander 10's payload and flight characteristics allow for the fitment of self-protection systems, countermeasures, and self-defense systems. HAV claims that air-to-air missiles such as AIM-9/120/260, and air-to-ground missiles such as AGM-88E/G could be fitted for self-defense.

The infrastructure required for conventional aircraft is susceptible to enemy attack, which can jeopardize an entire system. Airlander 10's capability to stay aloft for an extended period, land and take off with little space, and utilize unimproved surfaces make it free from most danger. It is outside this study's scope to estimate this benefit's value. However, it could be significant if runways become a priority target for enemy attack.

c. Surveillance Capabilities

The rough sea state, unpredictable ice flow, and the rugged nature of ice fields around the Arctic Sea make maritime and land travel difficult and time-consuming. Due to the various hazards, air travel is the safest mode of transportation in the region, and even slow aircraft can cover a greater distance than a surface-bound vehicle. Under favorable weather conditions in the Arctic Circle, the Airlander 10 can reliably navigate within a 1,000nm radius from its basing location. Figure 19 shows the extent of an "out-and-back" patrol radius of the Airlander 10 around Eielson Air Base and Thule Air Force Base. When factoring the Russian EEZ and Territorial Sea boundaries, the Airlander 10 can provide surveillance for nearly all of the Arctic Ocean.

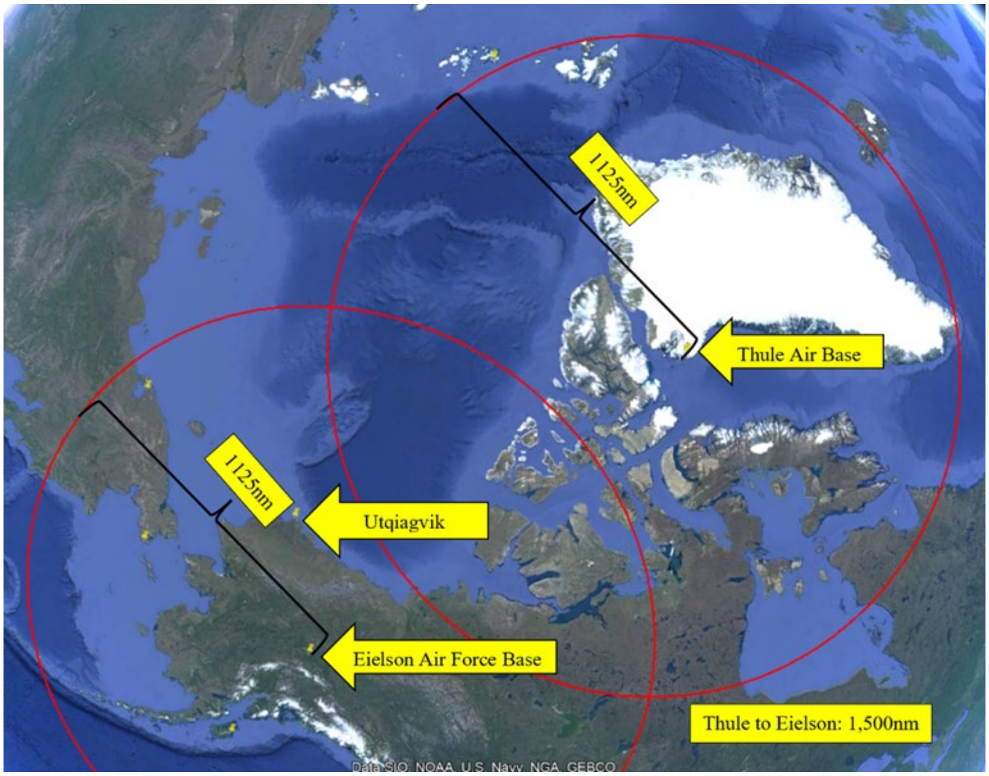


Figure 19. Airlander 10 Patrol Radius. Source: Google (n.d.b).

To enhance the Airlander 10's surveillance and sensing capabilities, additional sensors can be deployed directly from the aircraft to create a web of detection. Autonomous and Unmanned Arial Vehicles (UAV), Autonomous Underwater Vehicles (AUV), and a multitude of surface sensors could be carried and deployed on a single mission.

The United States Coast Guard and the Naval Postgraduate School have successfully tested and utilized the Boeing ScanEagle Unmanned Aerial Surveillance vehicle in the Arctic. According to personal correspondence with Professor Aurelio Monarrez at the Naval Postgraduate School and Coast Guard representatives, the ScanEagle can remain in flight for about 12 hours, fly at 52 knots, and fly as far away as 150 kilometers. As depicted in Figure 20, the Airlander 10 can be retrofitted with a retrieval and deployment ramp, which enables the aircraft to act as a mothership for many ScanEagles. This configuration would extend the surveillance range by over 80 nautical miles, and deployment operations could be conducted without deviating from the Airlander 10's flight path or profile (Dew et al., 2022).

The catch line and retrieval hoist are seen on the left. Refueling stations and maintenance are performed on the center platform. The launch guide rail is painted yellow and is located at the front of the platform for launch into the wind.

Figure 20. Airlander 10 ScanEagle Launch and Catch Module in a Simulated Environment.

The Coast Guard and Navy have also utilized Autonomous Underwater Vehicles to detect shipping in the region with promising results. Some of these systems have been shown to stay active for months. A payload beam attached to the Airlander 10 would enable retrieval or deployment of these systems. However, the outfit of equipment to monitor, deploy, and maintain AUVs might dominate most of the aircraft's mission (Dew et al., 2022).

The Airlander 10's slow and low flight profile increases the visual surveillance capability of optics and human observation. Interviews with HAV engineers determined that from 10,000ft, the Airlander 10 can monitor 20nm in any direction using Electro-Optical/Infra-Red cameras. In contrast, the same sensor at a higher altitude will experience less clarity and a smaller field of vision. When deploying ScanEagles, the total surveillance coverage extends to 80 nautical miles in any direction, which creates a broader search pattern than any other aerial platform. Utilizing signals intelligence gathering systems, the sensor range of the Airlander 10 will exceed 100 nautical miles (Dew et al., 2022).

Considering the ScanEagle has a sensor radius of approximately 100km (or 54 nm), this data point was used as a critical planning factor in determining routes and the number of airships needed for persistent ISR. Each route selected assumed the Airlander would proceed on the most direct route to the Arctic Ocean or the Bering Strait to ensure maximum loiter time. In addition, upon reaching the maximum range, which was ~1100-1200 nm, simulation behaviors were created to have the Airlander fly a parallel route. This was to provide surveillance over different areas of the ocean during the flight back to Thule or Eielson. Along each route, two ScanEagles would provide 200 km sensor coverage, as shown in Figure 21 (Dew et al., 2022).

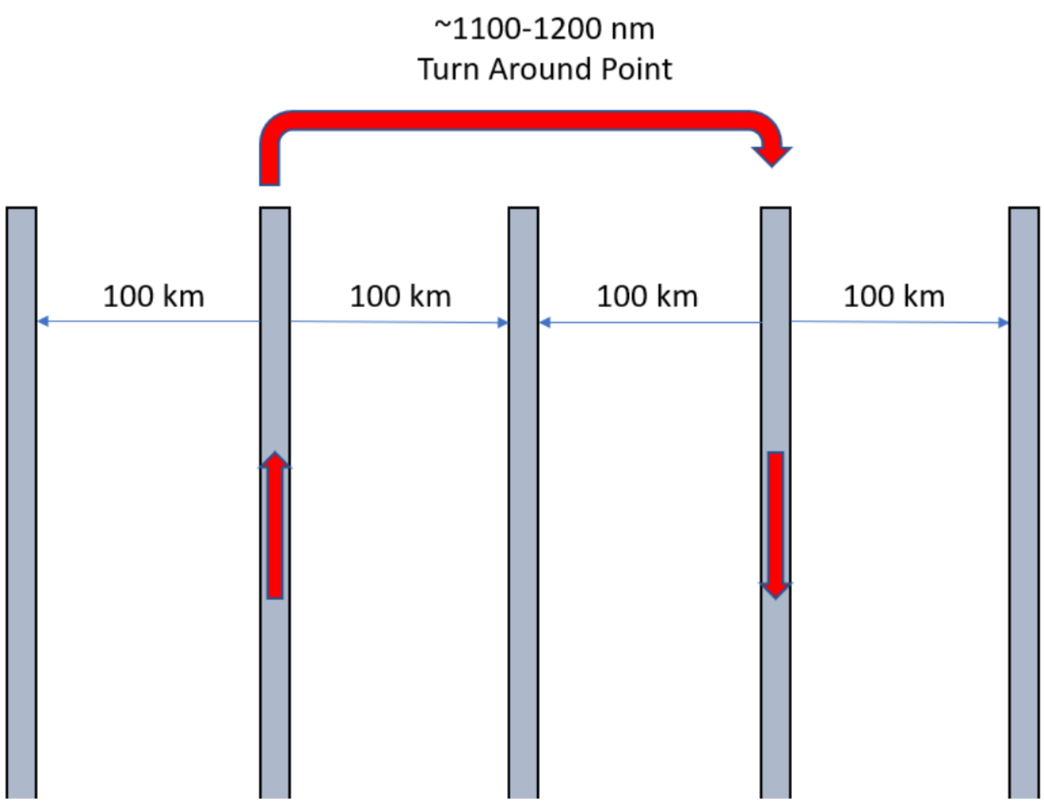


Figure 21. Airlander 10 Route Coverage to Ensure Maximum Surveillance Coverage. Source: Dew et al. (2022).

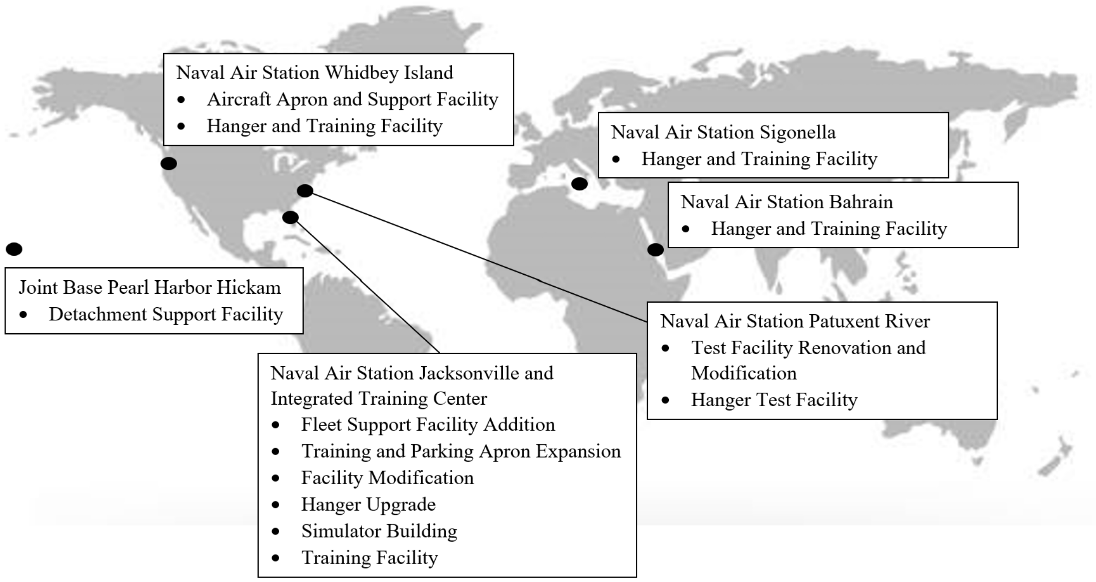
Considering operations from Thule Air Base based on the maximum range of the Airlander 10, ISR coverage of approximately 4,482,143 square kilometers of the Arctic Ocean was obtained. This is 51.5% of the Arctic Ocean. Thule Air Base is in a strategically ideal location to support Airlander operations. With 43 planned routes, a fleet of 10

Airlander aircraft (assuming none are down for maintenance) could provide coverage of the 4.4 million square kilometers every five days. This accounts for the sensor range of the ScanEagle (Dew et al., 2022).

The same planning factors for Thule were applied to Eielson Air Force Base, where coverage of 1,769,770 square kilometers of the Arctic Ocean was estimated. This would provide another 20.4% coverage of the Arctic Ocean. Eielson is also in an ideal location for this mission as it is very close to the Bering Strait, allowing for reactive ISR mission tasking. With 21 routes planned for Eielson, a fleet of five Airlander aircraft could provide coverage of 1.7 million square kilometers every five days (Dew et al., 2022).

d. Life Cycle Cost

Fiscal Year 2016 Selected Acquisition Report (SAR) for the P-8A Poseidon is an excellent example of Military Construction (MILCON) dollars used for major aircraft acquisition. At the time of the report, the fleet of 114 projected aircraft required $317.9 million (BY10$) to finish all MILCON projects (Department of Defense [DOD], 2016). Figure 22 shows the MILCON projects outlined for the P-8A program under the FY 2016 SAR.



Map image from Sridara (n.d.); text sourced from DOD (2016).

Figure 22. Proposed P-8A MILCON Projects Under Fiscal Year 2016 SAR. Adapted from Sridara (n.d.) and DOD (2016).

It can be surmised that operations at Sigonella, Bahrain, and Hickam are for forward deployment sites or international training centers. Facilities like these would need to be created for Airlander 10 operations at Thule and Eielson, but the overall construction requirement will be lower. A training facility like Naval Air Station Jacksonville would likely need to be constructed for pilot and crew training. The remaining facilities that the P-8A requires are beyond the scope of what is required for Airlander 10 initial operations in the Arctic.

Regarding maintenance, depot-level repairs could take place at Thule Airbase, limiting the MILCON budget for a separate location. Facilities at Thule would benefit from short logistic lines to Airlander 10's manufacturing facilities in the United Kingdom. Organizational-level repair facilities and forward deployment support facilities would not be required due to Airlander 10's minimal facility requirements. As seen in Figure 23, Forward sites are inherently small and take very little construction beyond clearing the area of obstacles. Hardened structures are minimal compared to the robust facilities required by a conventional aircraft such as the P-8A. A Garrison setup would be established at Thule

Airbase, a Central Operating Base at Eielson Air Force Base, and Forward Operating Bases or Forward Area Rearm Refuel Points at Utqiagvik and Nome.

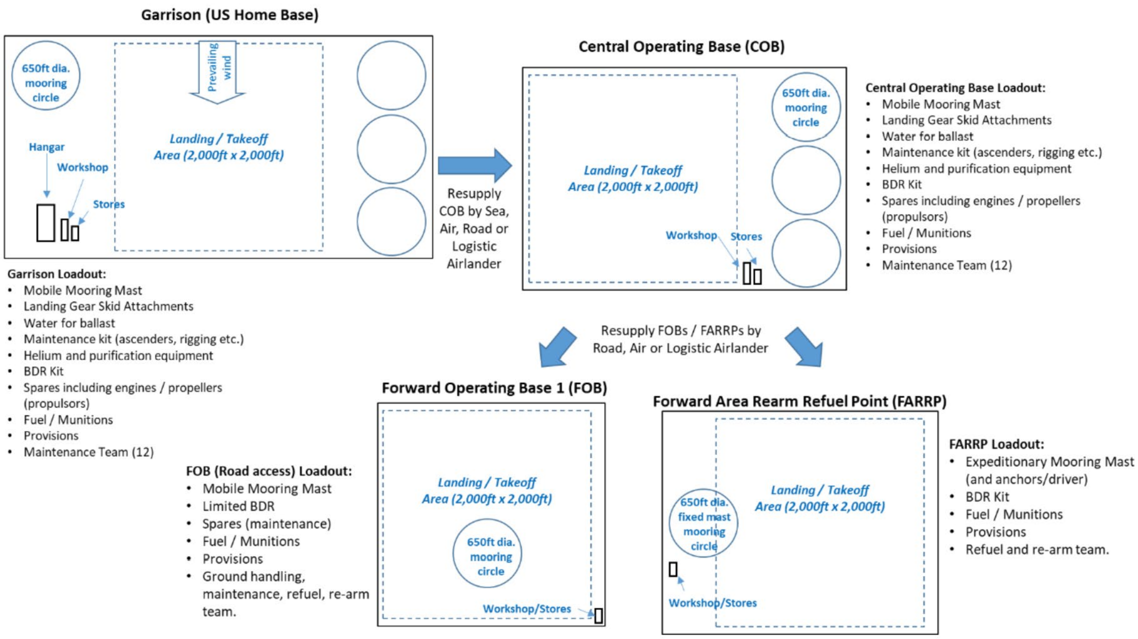


Figure 23. Facilities Operating Concept. Source: Personal correspondence with Hybrid Air Vehicles (2022).

In personal correspondence, HAV stated, "While the shape [of the Airlander 10] is different, many of the systems and hardware elements are exactly the same as found on conventional airplanes. This ensures that technician training and maintenance costs can be kept low." Therefore, finding an aviation system within the DOD that performs similar roles, has similar characteristics, and has a similar procurement pipeline will suffice for cost estimation. According to the Fiscal Year 2023 DOD Budget Request, the P-8A Poseidon program requires $241.2 million, the MQ-4C (family of systems) requires $1,046.7 million, and the C-130J Hercules requires $1,141 million (OUSD, 2022). The P-8A should be analyzed due to its similar role and procurement method, the MQ-4C for similarities in roles, and the C-130J for its similar capabilities. Due to each program's varying stages and scale of procurement, each program needs to be broken down into similar production runs.

The C-130J has had a long production run that benefits from a mature learning curve. According to the FY23 DOD Budget Request, the last three fiscal years called for 51 new aircraft valued at roughly $108.157 million per unit. Within those 51 units, 16 are KC-130J, and 6 are MC-130J. MC-130J is used for special operations, and the Marine Corps use the KC-130J for air-to-air refueling; tactical transportation; radio relay; ISR; and close air support (OUSD, 2022). These two unique mission variants have a relatively similar cost of procurement. Research, Development, Test, and Evaluation (RDT&E) spending averaged $50.567 million per year (OUSD, 2022), of which most of the funding went towards search and rescue and special operations variants.

The C-130J aircraft is similar to the Airlander 10 because it has four engines and carries similar weights. The KC-130J is even more similar in that it performs ISR and acts as an airborne radio relay. Table 3 outlines some of the similarities between these aircraft in a logistics role. While the C-130J is predominantly outfitted as a cargo aircraft, the Airlander 10 can easily change its payload modules for virtually any mission. The Airlander 10’s versatility means fewer systems are needed for a single region, and alternate systems can concentrate on performing missions that leverage their unique strengths.

Table 3. C-130 and Airlander 10 Comparison Chart. Source: Personal Correspondence with Hybrid Air Vehicles (2022).

	Airlander 10	C-130J-30
Payload (lbs)	27,550	34,500
Fuel (lbs)	13,200	42,000[1]
Range at Payload (nm)	2,000	1,835
Ferry Range (nm)	4,600	2,850
Clear Space for Take-Off & Landing (ft)	2,000	8,000

[1] Increased with external fuel tanks.

The MQ-4C Triton UAS will restart production in FY23 with a low-rate initial production run of three aircraft, totaling six in the last three years. The average aircraft per unit cost is $263.78 million, while RDT&E averaged $155 million per year (OUSD, 2022). The MQ-4C varies wildly from the Airlander 10 in characteristics, but it performs some of the same roles as the Airlander 10. The overlap indicates potential cost similarities, but the airframe costs do not.

The P-8A Poseidon may be the most similar aircraft to the Airlander 10 in mission requirements and procurement method. While new aircraft are constructed to fill the Navy's requirement, the P-8 is built on a commercial airframe which takes advantage of a mature learning curve and robust production run size. FY23 DOD Budget Request states that nine P-8A aircraft were procured in FY21 at $175 million per unit. An average of $197.23 million was requested for RDT&E (OUSD, 2022).

All three aircraft are different from one another and the Airlander 10, so an average should not be a definitive cost estimate. A side-by-side comparison of these costs can be seen in Table 4. A detailed Work Breakdown Structure for the Airlander 10 would need to be used against similar individual components to find a more precise cost estimate.

Table 4. FY23 DOD Budget Request Cost Data

($M)	Average procurement cost per unit	Average RDT&E
C-130J	108.16	50.57
MQ-4C	263.78	155.00
P-8A	175	197.23

HAV engineers provided a rough order of magnitude cost of $55–60 million per aircraft in FY22 dollars. Their figure was provided to the DOD after a request for information and is for the baseline type certified aircraft before missionization. While the mission package for the Airlander 10 will increase the total price, it can be concluded that the total procurement cost will be under or more similar to the C-130J.

We can assume the C-130J, a cargo aircraft that has largely been the same design for decades, will have a lower RDT&E cost than the Airlander 10, but we cannot assume the P-8A is the ceiling. The P-8A is based on a Boeing 737–800ERX, which indicates the platform was well-developed prior to military investment (Tallant et al., 2008). The sensor package on the P-8A is very sophisticated, which has likely driven the RDT&E costs. This cost will not be any different for the Airlander 10.

The Airlander 10 has significant cost savings regarding indirect and direct operating costs. The P-8A fleet of 108 aircraft was projected to expend $20.882 billion (BY04$) for operating expenses throughout its life (Tallant et al., 2008). These costs are driven mainly by complicated jet engines and control surfaces requiring delicate maintenance and tight tolerances. At a minimum, the Airlander 10 should not exceed the operating expenses of the P-8A. Hybrid Air Vehicles stated in personal correspondence that the modular construction of the Airlander will allow for cheaper and quicker upgrades and modifications. They also mentioned there is no hydraulics, wheels, brakes, tires, or wings, it has smaller and more efficient engines, and the module is unpressurized. These factors would result in a total reduction in cost per flying hour. As stated in Figure 8, "Cost per flying hours equal $3000, which includes fuel, consumables, helium, mid-life rehulling, maintenance personnel, life-limited parts, and scheduled maintenance." The cost per flying hour estimate excludes crew costs, sustainment for the mission systems, and infrastructure.

Transportation of fuel to Arctic bases such as Thule Airbase and Eielson Air Force Base requires a significant logistics train, presenting an operational vulnerability. The Airlander 10 current configuration uses jet fuel like the P-8A but in a significantly reduced quantity. When comparing distance covered to fuel consumption, the Airlander 10 consumes a quarter of the fuel that the P-8A consumes over the same distance (HAV, 2023). These fuel savings translate to a massive reduction in fuel needed in the Arctic, significantly mitigating logistics risk and vulnerability. While this is already a substantial cost benefit over alternatives, the Airlander 10 is being further developed to take advantage of electric and hydrogen engines as they become available. In the long run, this may eliminate fuel transportation costs to Thule and Eielson almost entirely.

Conventional aircraft that patrol the vast expanse of the Arctic Ocean typically require mid-air refueling, which substantially increases the cost of fuel. The Airlander 10's capability to land on unimproved surfaces or water means it can be refueled on the ground, mitigating the need for mid-air refueling aircraft. Ground refueling is also safer, increasing the aircraft's cost-benefit.

In their 2022 study, Captain Cohen and Captain Schmaltz compared the cost per ton-kilometer traveled for the Navy and Marine Corps fleet of C-130s against a generic hybrid airship design. The fuel per ton-kilometer traveled for their hybrid aircraft was $0.43, compared to the C-130J's $1.65 (Cohen & Schmaltz, 2022). The study estimated that the hybrid aircraft would burn about 30% less fuel than the C-130J and concluded that these fuel savings would directly translate to a reduction in emissions. Considering the social impact of this reduction, the emission decreased the cost of a fleet of 40 hybrid airships by between $93.52 and $199.58 million (Cohen & Schmaltz, 2022). HAV said in an interview that the Cohen and Schmaltz study focused on the larger Airlander 50 hybrid aircraft design configured for a freight role. They claim the Airlander 10 in an ISR role could produce an order of 90% less emissions then the Airlander 50.

The U.S. Government has vowed to reduce emissions from the Arctic and work to conserve the Arctic ecosystem (White House, 2022). Adopting the Airlander 10, a platform expected to transition to full electric in the future, the DOD is moving towards the White House's second pillar in their Arctic Strategy. In its current configuration with kerosene engines, the Airlander 10's fuel efficiency will produce only a fraction of the pollutants of the P-8A. The CO_2 the aircraft emits is also released at lower altitudes, which has less damage to the atmosphere. The Airlander 10's engines also produce far less noise than jet engines, which will significantly impact wildlife and human settlements.

In early 2022, Hybrid Air Vehicles established a partnership with Air Nostrum Group with the purchase of ten aircraft, which will start operations in 2026 (Hybrid Air Vehicles [HAV], 2023b). The commercial market is investing in the hybrid aircraft concept for passenger travel. Due to its modularity, it should be expected that there will be residual value on the civilian market for the Airlander 10. Some of the systems in this study, such as the MQ-4C, may be available for foreign military sales (FMS), but they cannot be easily repurposed and sold to the commercial sector.

IV. CONCLUSION

A. ASSESSMENT

The DOD wants surveillance in the Arctic, so it should use the most cost-effective sensor platforms available. The platform should be able to conduct operations year-round, without ice and weather restrictions, and use high-fidelity equipment to detect sub-surface, surface, and aerial traffic. An indexed value was applied to multiple categories of interest to assist in deciding the most cost-effective platform for arctic operations. Table 5 is a compilation of values assigned to the data collected for this study. The definition of each value and the data used to generate those definitions is captured under Appendix B. In short, all characteristics were given a score of one, two, or three. A higher number translates to a more significant benefit-to-cost ratio. When totaling all category values together, the total value of the platform can be compared to its alternatives. Some indexed values are generalized to encompass qualitative findings. This model should not be used outside this study and only serves as a benchmark for comparisons between platforms in the setting outlined in this study.

Table 5. Indexed Values.

	Navy Submarine Fleet	Satellite	MQ-4C Triton	P-8A Poseidon	C-130J Hercules	Arleigh Bruke-class guided-missile destroyer	Icebreaker	Airlander 10
Ground Speed and Mobility Index	2	3	3	3	3	1	1	3
Sensor Capability Index	1	1	2	3	2	3	3	3
Role Diversity Index	2	1	1	1	3	3	3	3
Endurance Capability Index	3	3	2	1	1	3	3	3
Sub-system Capability Index	1	1	1	2	2	3	3	3
End of life resale Index	1	1	2	3	2	2	3	3
Fuel Consumption and Emissions Index	2	3	1	1	1	2	2	2
MILCON Index	1	1	3	3	2	1	2	2
Procurement Index	1	1	1	2	2	1	1	3
RDT&E Index	2	1	2	1	3	2	1	2
Operating Cost Index	1	3	1	1	1	1	1	2

Figure 24 is a visual depiction of the values found in Table 5. While this study does not encompass strong enough evidence to quantify the disparity between platforms, there are still interesting outcomes to analyze.

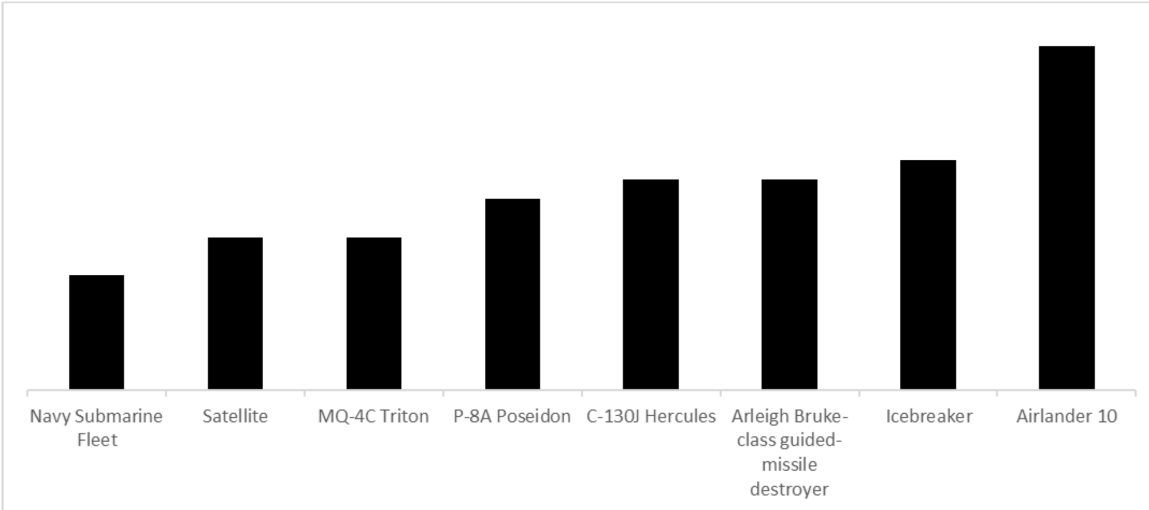


Figure 24. Platform Capability Totals Based on Indexed Values.

After reading this study, it should not be surprising that the Airlander 10 is well suited to the arctic environment. Characteristics that put it above other platforms include life-cycle costs, multi-role mission capability, endurance, sub-system deployment capability (such as UAV and AUV), fuel consumption, and mobility. On the other side of the spectrum, submarines accumulate fewer index values due to their specialized nature. While submarines excel at detecting surface and subsurface vessels, they fall short of the other missions that will be increasingly important in the Arctic Circle. Simply put, the platforms on the far left of Figure 24 should be considered complementary assets to the platforms on the right.

The Airlander 10 is estimated to be a cheaper alternative than any of the systems outlined in this summary. With a unit cost of under $100 million, an operating cost that is less than half of its alternatives, and a small infrastructure requirement, the Airlander 10 would be a cost-effective addition to the current network of platforms. Airlander 10 allows the DOD to move assets away from the Arctic for operations elsewhere or allow other systems to perform missions that are better aligned with their unique strengths. Destroyers and Icebreakers can be freed up for rescue operations, submarines for deterrence missions, and MQ-4Cs for hazardous situations.

B. RECOMMENDATIONS

The systems detailed in this study should work together to verify the information and get the maximum coverage possible. Due to operating under 10,000ft and at a slower speed than other ariel platforms, the Airlander 10 does not replicate any other capability while uniquely being able to conduct all missions. If other systems continue to operate in the region, the Airlander 10 will only improve the overall capability of the DOD's combined systems.

Due to the limited number of icebreakers and the limited ice-breaking capability of destroyers, the Airlander 10 stands to benefit the surface fleet the most in terms of providing additional operational capability. By taking over deploying and maintaining all sensors in the Arctic, the surface fleet would be freed up to concentrate on interdiction. The Airlander 10 can effectively employ sensors of all kinds due to its ability to land on almost any surface. Taking on this mission will dramatically reduce the fleet's workload, reducing the overall requirement for ships in the region, potentially offering significant cost savings.

C. FUTURE RESEARCH OPPORTUNITIES

This study provides an analysis of the Airlander 10 based on open-source resources, emphasizing identifying requirements and alternatives. A thorough and detailed analysis of alternatives that utilizes work breakdown structures is required to get a more precise cost estimation for the Airlander 10 in an ISR configuration. This will likely involve building the base aircraft in the UK with the mission packages added in the U.S.

Next, a wargame should be conducted with accurate cost and performance information to determine the appropriate Airlander 10 fleet size and total fleet cost. Realistic wargaming will identify where the current inventory of DOD platforms fall short and help identify precisely where the Airlander 10 could make the most significant impact and therefor provide the most value possible to the DOD.

Lastly, an assumption built into this study is that the crew can sleep and rest aboard the Airlander 10 while it is in flight. A hallmark of this aircraft is its ability to loiter in an area of interest for days. Without this ability, the Airlander 10 loses a critical advantage over its alternatives. A study is required that analyzes the appropriate crewing model for the Airlander based on up-to-date understands of crew performance, and sleep rest while the aircraft is in operation.

APPENDIX A. WEATHER DATA FOR ALASKA SIMULATION

Month	000°		045°		090°		135°		180°		225°		270°		315°		Calm (%)
	Mean speed (m/s)	Occurrence frequency (%)	Mean speed (m/s)	Occurrence frequency (%)	Mean speed (m/s)	Occurrence frequency (%)	Mean speed (m/s)	Occurrence frequency (%)	Mean speed (m/s)	Occurrence frequency (%)	Mean speed (m/s)	Occurrence frequency	Mean speed (m/s)	Occurrence frequency (%)	Mean speed (m/s)	Occurrence frequency (%)	
Jan	10.5	9.2	10.3	10.2	11.1	12.5	10.7	13.7	11.2	14.2	11.8	16.3	11.3	13.6	11.0	10.1	0.2
Feb	11.3	10.2	10.7	10.6	10.7	9.2	9.6	11.9	11.5	15.6	11.5	17.1	11.3	13.9	10.1	11.4	0.1
Mar	8.9	8.2	9.5	11.0	8.3	9.4	8.1	10.8	8.5	13.7	9.9	20.9	10.1	15.9	9.5	10.0	0.3
Apr	7.8	7.6	8.3	7.8	7.9	13.8	8.1	14.3	8.7	14.6	9.2	18.5	9.7	13.8	9.4	9.4	0.5
May	5.2	6.0	5.8	6.7	7.1	16.8	7.8	19.2	8.1	16.4	8.2	15.2	8.8	12.9	7.0	6.3	0.6
Jun	6.8	7.3	6.3	8.4	6.7	11.3	7.3	15.1	7.5	15.4	8.3	16.4	9.2	16.9	7.4	8.7	0.4
Jul	6.5	6.4	5.6	7.3	6.7	9.5	7.4	12.7	7.1	14.3	8.3	19.9	9.0	19.6	7.2	9.8	0.5
Aug	6.2	7.4	6.0	6.2	7.0	8.2	7.9	8.6	7.8	12.5	9.8	20.6	10.2	23.6	8.1	12.5	0.3
Sep	6.8	8.3	7.1	7.9	7.4	10.4	7.6	8.4	8.6	10.4	9.0	19.6	9.5	20.4	8.5	14.4	0.3
Oct	7.9	9.0	7.0	9.2	7.7	8.9	8.1	9.3	8.3	12.5	9.3	20.5	9.0	17.6	8.5	12.5	0.4
Nov	9.1	9.8	9.9	13.1	9.4	16.0	9.2	13.5	9.3	12.8	9.2	14.6	9.4	10.5	9.1	9.4	0.3
Dec	9.0	8.9	9.0	8.7	10.6	14.0	9.9	13.4	10.7	14.2	11.0	17.2	10.9	14.3	9.5	9.4	0.0
Year	8.0	8.2	8.0	8.9	8.4	11.7	8.5	12.6	8.9	13.9	9.6	18.1	9.9	16.1	8.8	10.3	0.3

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APPENDIX B. CUMULATED DATA TABLE

	Cost	Benefit
Ice Breaker	New fleet required May not reach ice-locked areas New fleet will require new port facilities	Capable near year round Ice breaking services for commercial vessels Long endurance Sub-system deployment and management End of life resale to commercial sector
Arleigh Bruke-class guided-missile destroyer	Need to be ice-hardened for near year-round service Limited numbers available for world-wide service Will not reach ice-locked areas Navigation hazards and incomplete charts increase risk of accidents	Highly capable of any mission in open waters Long endurance Sub-system deployment and management End of life resale to foreign military financing
Navy Submarine Fleet	Limited numbers available for world-wide service Limited air detection capabilities Limited rescue and logistics utility End of life cycle disposal cost	Capable year round Long endurance
P-8A Poseidon	Surveillance only MILCON cost: $317.9m (BY10$) High fuel consumption / high emissions Fast ground speed No rescue and logistics utility Total FY23 program cost: $241.2 mil Procurement per unit: $175 mil RDT&E per year: $197.23 mil Total lifecycle cost of 108 aircraft: $20.882 bil (BY04$) Cost per flying hour: >$9,900	Capable year round End of life resale to commercial sector
MQ-4C Triton	Surveillance only. Limited payload for sensors. Infrastructure intensive High fuel consumption / high emissions Fast ground speed No rescue and logistics utility Total FY23 program cost: $1,046.7 mil Procurement per unit: $263.78 mil RDT&E per year: $155 mil	Capable year round Long flight duration End of life resale to foreign military financing
C-130J Hercules	Multi-role capable Requires a maintained runway (snow or improved surface) Rescue and logistics utility limited by runway High fuel consumption / high emissions Total FY23 program cost: $1,141 mil Procurement per unit: $108.157 mil RDT&E per year: $50.567mil Fuel cost per ton-kilometer: $1.65 Cost per flying hour: >$9,900	Capable year round Limited endurance End of life resale to foreign military financing
Satellite	New fleet required Surveillance only. Limited to orbital revolutions. Subjective to weather, transmission lag, and resolution Procurement and launch: $200 mil to $9 bil Orbital use fee for deorbiting at end of life cycle	Capable year round No operating cost
Airlander 10	MILCON cost: <$317.9m (BY10$) Multi-role capable Procurement per unit: >$55 to $60 mil RDT&E per year: $50.567mil to $197.23 mil Total lifecycle cost of 108 aircraft: <$20.882 bil (BY04$) Cost per flying hour: <$3,000 Fuel cost per ton-kilometer: <$0.43	Limited environmental impact Resilient and survivable Capable year round Long flight duration Fuel economy reduces fuel supply threat Sub-system deployment and management Savings in emissions cost per ton-kilometer: >$93.52 to $199.58 End of life resale to commercial sector

Sensor Capability Index	3: No Restrictions 2: Some Restrictions 1: Many Restrictions
Role Diversity Index	3: Many Roles 2: Few Roles 1: One Role
RDT&E Index	3: <$60mil per year 2: $156mil to $60mil per year 1: >$156mil per year
Endurance Capability Index	3: >100hr time-on-station 2: 10hr to 100hr time-on-station 1: <10hr time-on-station
Sub-system Capability Index	3: All sub-systems deployable 2: 1 type of sub-system capable 1: Not sub-system capable
End of life resale Index	3: Commercial Resale 2: FMF 1: Disposal Cost
Fuel Consumption and Emissions Index	3: No Emissions 2: Low Fuel Consumption 1: High Fuel Consumption
MILCON Index	3: Not Required 2: <$300mil 1: >$300mil
Ground Speed and Mobility Index	3: >100knots and unrestricted movement 2: <100knots but unrestricted movement 1: <100knots and restricted movement
Procurement Index	3: <$100mil per unit 2: $100mil to $200mil per unit 1: >$200mil per unit
Operating Cost Index	3: None 2: <$3,000 per hour but not zero 1: >$3,000 per hour

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