

## Article

# Transport Airships for Scheduled Supply and Emergency Response in the Arctic

Barry E. Prentice <sup>1</sup>, Yui-Yip Lau <sup>2,\*</sup> and Adolf K. Y. Ng <sup>3,4</sup>

<sup>1</sup> Department of Supply Chain Management, I.H. Asper School of Business, University of Manitoba, Winnipeg, MB R3T 5V4, Canada; Barry.Prentice@umanitoba.ca

<sup>2</sup> Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Hong Kong, China

<sup>3</sup> Division of Business and Management, Beijing Normal University—Hong Kong Baptist University United International College, Zhuhai 519085, China; adolf.ng@umanitoba.ca

<sup>4</sup> St. John's College, University of Manitoba, Winnipeg, MB R3T 5V4, Canada

\* Correspondence: yuiyip.lau@cpce-polyu.edu.hk

**Abstract:** As climate change progresses, the Arctic Ocean creates opportunities for new resource development and navigation routes. Such economic opportunities are attractive, but carry with them an increased risk of accidents and oil spills. Existing methods of emergency response face enormous challenges in the Arctic because of its lack of transportation infrastructure and support services. Cargo airships offer a practical solution. Many airship designs are proposed that can carry over 30 tons, travel long distances at 150 km per hour, and land close to the emergency site. However, it is difficult to justify the economics of having enough capacity waiting and available to be marshaled in response to infrequent events. One solution is to develop a synergy with a new civilian cargo airship industry that can serve the regular transport needs of remote communities and mining operations. Through contingency contracts with these civilian operations, the Government of Canada could stretch its budgets and have access to the latest airship models and trained crews at locations across the Arctic. This paper gives valuable insight into the development of cargo airships. Advances in technology that make cargo airships a practical option in the 21st century are reviewed, and five competing airship designs are discussed. A case study of an existing rare earth mine proposal is used to illustrate the cost comparison of roads versus airships that could provide contingency services.



**Citation:** Prentice, B.E.; Lau, Y.-Y.; Ng, A.K.Y. Transport Airships for Scheduled Supply and Emergency Response in the Arctic. *Sustainability* **2021**, *13*, 5301. <https://doi.org/10.3390/su13095301>

Academic Editor: José Manuel Vassallo

Received: 16 April 2021

Accepted: 6 May 2021

Published: 10 May 2021

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**Keywords:** climate change; Arctic Ocean; oil spills; emergency response; cargo airships; hydrogen; mining

## 1. Introduction

Climate change has moved from theory to fact, and we are in the early stages of experiencing the effects of that change. In the past few decades, we have experienced changing climate change patterns and tremendous weather incidents such as droughts, sea level rise, heat waves, landslide, flooding and storms, to name but a few [1]. According to research [2], almost 70% of carbon dioxide released since the 1750s can be traced to the 90 largest cement and fossil fuel producers. Surprisingly, most of them remain operational. As expected, human activities (e.g., deforestation, intensive agriculture and industrialization) speed up the adversely impact of climate change. Even with global best efforts (e.g., The Paris Agreement, UN Sustainable Development Goals) to reduce carbon emissions, temperatures are expected to rise for at least the next 25 years [3], with greenhouse gases boosting global warming by an average of about 4.5 °C before 2100 [4].

The impact of global warming is greater in higher latitudes, where the Arctic Ocean is undergoing an unprecedented reduction of sea ice. The minimum sea ice extent of the Arctic has decreased on average 1.2% per year from 1979 to 2015, based on analysis of

the US National Snow and Ice Data Center (NSIDC). Due to climate change, the Arctic is progressively becoming ice-free in some areas of the ocean for longer times of year [5].

From a geographical perspective, the top of the Northern Hemisphere can be called the polar area, the High North, and the Arctic [6]. The Arctic covers around 11% of the earth's surface. The Arctic is described as a cold context, a severe and uninhabited landscape which [7,8] describes geographically as:

“All of Alaska, Canada jurisdiction north of 60° N together with northern Quebec (Nunavik) and Labrador (Nunatsiavut), all of Greenland, the Faroe Islands, and Iceland and the northern most counties of Norway (Nordland, Troms, Finnmark and Svalbard), Sweden (Västerbotten and Norrbotten), Finland (Lapland), Russia (Murmansk Oblast, the Nenets, Yamalo-Nenets, Taimyr, and Chukotka Autonomous Okrugs), Vorkuta City in the Komi Republic, Norilsk and Igarka in Krasnoyarsky Krai, and those parts of the Sakha Republic whose boundaries lie closest to the Arctic Circle”.

Opening up new navigation routes in the Arctic may be desirable for providing alternative routes to the Suez and Panama canals, but creates risks for ships and crews under specific hazards such as heavy snowfall, thick fog, polar lows, floating ice, and violent storms, as well as the environment (e.g., marine pollutants) [9,10]. These harsh circumstances together with crews' lack practical training in polar waters induces a high possibility of marine accidents. Such topics have been discussed widely among researchers, international organizations, industrial practitioners, and policymakers [5].

Increased shipping traffic does not make accidents inevitable, but it certainly increases their likelihood. The rapid deployment of staff and resources to deal with accidents in the Arctic is extremely challenging. It is in this vein that interest is turning to the use of airships for emergency response. This article considers the case for transport airships that could carry cargoes of 30 tons or more, and land close to the location of most accidents. The focus is economic, rather than engineering. Airships were crossing oceans prior to the “jet age”, and many new designs are competing for attention [11]. The question in 2021 is not whether cargo airships will work, but their competitiveness relative to other modes of transport.

Following this introduction, a review of the literature on emergency response in remote areas is provided. This is followed by the specific problem presented by emergency response in the Canadian Arctic. The rationale for considering airships and the economics of using stand-by contracts is proposed. Following a description of advances in airship technology, a brief survey of leading cargo airship designs is provided. Subsequently, a case study example of a mining operation that could employ cargo airships is presented along with an economic analysis of their viability. The paper ends with a brief conclusion and limitations of the research.

## 2. Literature Review

### 2.1. Emergency Response to Remote Area

Ref. ([6], p. 3) defines “an emergency as an exceptional event that exceeds the capacity of normal resources and organization to cope with it”. Emergency response is similar to emergency preparedness, which states that “preparedness within the field of emergency management can best be defined as a state of readiness to respond to a disaster, crisis, or any other type of emergency situation” (Haddow et al., 2014, [12], p. 392). The emergency response process needs the capacities and knowledge developed by government in response to existing hazard conditions or incidents [6]. The main objectives of the emergency response are the reconstruction of disrupted services (e.g., transport, water, electricity), the mitigation of suffering, and the preservation of human life [13].

In the past few decades, the notion of emergency response has been widely adopted by researchers, governments, non-governmental organizations, communities, industry practitioners, and policymakers. Ref. [14] identified various studies in emergency response via using Common Operating Practice (COP). In the COP, it includes a typical understanding of threats, accessible forces and resources, chances of action and evaluations of work

in progress. As such, COP produce typical direction and encourage units to collaborate and connect their efforts to the entire mission. In addition, [15,16] proposed that robust emergency management may apply in remote or rural areas where we need to solve the insufficient basic facilities and infrastructure and re-establish social networks between city and remote or rural areas. Furthermore, [17] identified that emergency response supports urban sustainability, notably after the natural disasters.

In general, past research studies have focused on emergency response models by using stimulation models or numerous data [13,18,19]. Such research studies mainly addressed natural disaster (e.g., earthquake, typhoon, tsunami, rainstorm), weather forecasting, warning system, epidemic, medical crises or medical emergency (e.g., COVID-19, the Ebola epidemic in 2014) [20], critical infrastructure [21], social mobility [22,23], and the relationship between the economic cost and re-establishment of air transport networks [24,25]. However, such models have shortcomings that are either conceptual, theoretical or econometric modeling [18].

The demand for emergency response typically occurs in remote locations in which transportation is difficult. Any area lacking transportation infrastructure can be considered remote, but physical geographical barriers make some locations more inaccessible. Mountainous regions, deserts, jungles and polar areas are much more difficult to reach with personnel and equipment. Transport of emergency response in these seriously remote areas, notably the Arctic region, is not addressed in the literature. We summarize the relevant literature in emergency response to remote area in Table 1.

**Table 1.** Summary of Literature in Emergency Response to Remote Area.

The Studied Remote Area	The Main Aim of the Study	Methods Used to Conduct the Study	The Year of the Study	Results and Conclusions of the Study	References
USA and Canada	Air transport service improve the economic benefits for remote regions	Literature reviews and experiences with air services	2012	The subsidies, the level of air fares, and the process of competitive tendering are the key factors to improve the regional air transport system	[25]
Japan	Investigate the role of regional air transport after a catastrophe	Interviews	2012	Providing public subsidies for unprofitable regional air transports encourages giving access to and improving economic development of remote regions	[26]
Australia	Address key issues surrounding remote and rural airports	A network governance framework	2012	Improving air transport network could strengthen remote services to communities	[22]
Scotland	Investigate the economic impacts of improved accessibility in remote regions	Econometric modeling	2012	Ferry operators require to keep the operating day in remote island communities	[23]
Gulf of Mexico	Explore the associations between an environmental disaster and the judicial system	Case study	2012	The industry and government fail to identify risk management in providing emergency responses of oil spill	[27]

Table 1. Cont.

The Studied Remote Area	The Main Aim of the Study	Methods Used to Conduct the Study	The Year of the Study	Results and Conclusions of the Study	References
Northern Canada	Examines the possible of a transport airship to decrease the costs of food transportation to isolated communities	Econometric modeling	2017	The airship design creates an economic advantage in providing the cargo transportation needs of isolated regions in northern Canada	[24]
England and India	Explore the effectiveness of Unmanned Aircraft Systems (UAS) in response and prepare for flood emergencies	Interviews and literature review	2020	The information and data created by UAS can be applied to enhance flood risk management activities	[13]
China	Explore the development of China's emergency logistics system and identify the critical success factors for emergency logistics system	Interviews	2020	Demand forecasting and planning, inventory management, distribution network, and systematic information management are the key success factors for providing emergency response during a chaotic time	[28]
Arctic	Identify the challenges of operating in Arctic waters and the needs of preparedness to encounter with the challenges	Document studies	2021	The knowledge, structures, and the preparedness equipment could encounter with the challenges	[6]
China	Investigate the possibility of creating and storing cleaner water	Detection methods	2021	Improve emergency response capability for drinking water self-sustainment on isolated waters	[19]

Panahi et al. [5] pointed out in 2021 that Arctic research studies are required to bring attention to global-scale issues, especially given the trend of melting ice in the Arctic region. Nevertheless, scant research studies address emergency response in the Arctic region. To the best of our knowledge, the Arctic region has four key challenges. First, the Arctic region is remote such that it takes an extremely long time for critical assistance, rescue operation, and scheduled supply to arrive. Second, poor infrastructure induces limited transportation modes (e.g., snow mobiles, helicopters, boats) operate or accessible to the Arctic region. However, such transport means are low capacity and inflexible [6]. Third, the Arctic region is characterized by “extreme and rapidly changing weather” that poses remarkable challenges to human life ([7], p. 1277). In the Arctic region, there is quickly shifting weather pattern with changing visibility and heavy storms. The physical geography and harsh weather conditions put a constraint on emergency operations. For example, maritime operations will be adversely affected when its operation is near sea ice and glaciers. To this end, airships can overcome the existing weaknesses of transport operations and can be considered as an alternative method to provide emergency response and recovery in a challenging and dynamic context.

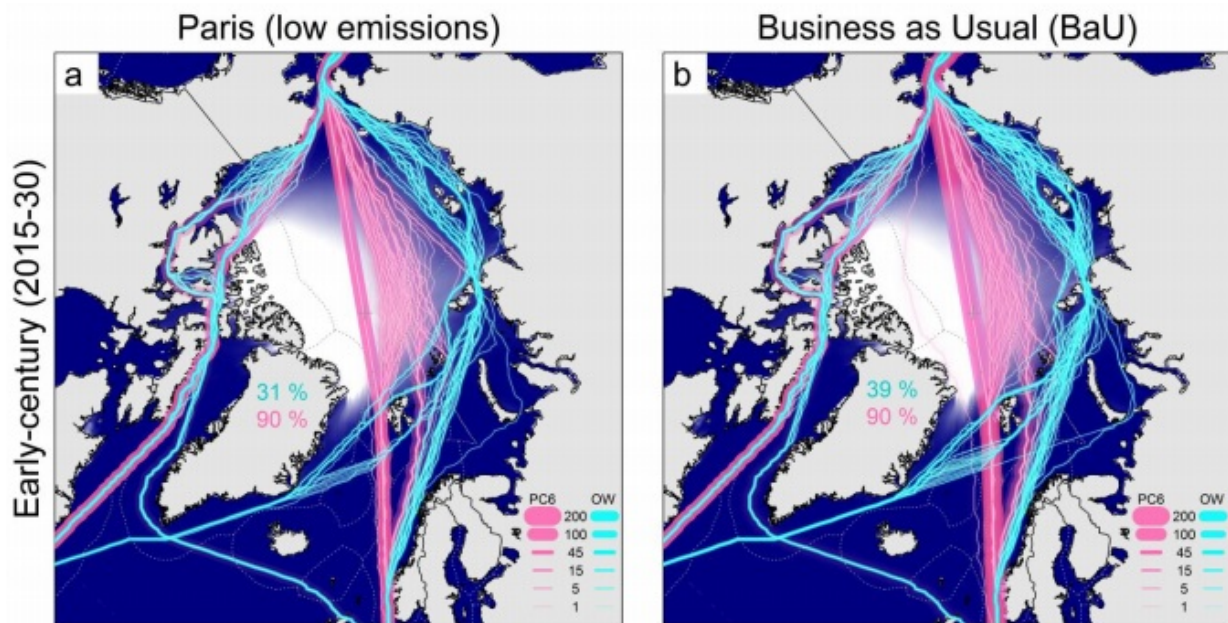
## 2.2. The Challenge of Emergency Response

The Intergovernmental Panel on Climate Change (2013) [29] indicates that ice extent in the seas of the Northern Hemisphere may retreat to  $1.5 \times 10^6$  km<sup>2</sup> before 2025. The warming trend is expected to accelerate in coming years and extend the navigation of the North West Passage (NWP). Ocean shipping and tourist cruises through the NWP could rise significantly in the next 20 years [30–38]. More inter-ocean traffic and the development of natural resources increase the risk of marine accidents that require emergency

response. Van and Richard (2009) [39] describes the environmental risk and the state of the regulatory system:

“Petroleum activities in Arctic waters, while potentially economically attractive, pose significant risks to the environment. These risks are exacerbated by the unconventional locations, climatic conditions, lack of infrastructure, and the unique features of the Arctic ecosystems.” ([39], p. 24)

Figure 1 illustrates the opening up ocean transport routes through the Arctic that is expected by 2030. Ref. [9] estimate that ships will be able to pass through the NWP and the North East Passage during September, 30 to 40 percent of the years, while ice-strengthened ships will sail through the weakened ice cap. By mid-century, they anticipate that ordinary sea vessels will be passing through the passages 82 percent of the Septembers.



**Figure 1.** Anticipated September Sea Routes through the Arctic (2015–30) based on scenarios of low emissions and a continuation of current trends; (a) the low emissions scenario under the Paris Accord; (b) does nothing, the Arctic ice cap is still going to melt sufficiently for marine traffic to increase. Source: [9].

Thinning and receding Arctic sea ice generates increased access to natural resources, while new logistics routes create opportunities for global trade and economic development. As shipping traffic and resource development expands oil spills are a major concern for Arctic marine ecosystems. The extent of the damage depends on many factors, but the faster the pollution can be contained, the less harm inflicted on shorelines and wildlife.

Resupply missions to coastal communities and a few mining sites in the Arctic have been conducted safely for many years. Ship captains are familiar with these sea routes, the volumes are relatively small, and they only travel during the summer months. Diesel fuel is the largest single commodity moved to coastal communities and mining sites. With the exception of the facilities at Churchill, MB, the Canadian Arctic has no public sea port infrastructure. Many coastal communities now receive oil products in bulk via floating hoses from anchored ships.

The challenge of handling potential oil spills in the Arctic from a shipping accident or an oil well blowout is of a different magnitude. Moving large amounts of personnel and materiel to remote areas with virtually no existing infrastructure would be difficult under any conditions in the Arctic, but speed is important. Once the oil spill becomes too large, booms are impractical. Furthermore, high winds, rough seas and large tides can limit the use of booms. The time required for the Coast Guard to reach an oil spill could easily take a week or longer.

Skimmers can be used to suck up the oil floating on the surface inside the booms, providing there is not too much debris. The water and oil are stored in collapsible bladders to be reprocessed. These bladders could remain in the Arctic until barges are be towed to the site. Of course, the formation of ice, and ice flows in the area make it impractical to leave the bladders in the water for long.

The booms (designed to encircle the spill and contain it during the recovery process) are 50' structures in 8' to 10' sections. Approximately 10,000 feet of boom is required to contain a 2500-ton oil spill. While significant, this scale of spillage is dwarfed by the 37,000 ton Exxon Valdez spill of 1989 or the Erika's 20,000 tons off France in 1999. The 10,000' boom length has a shipping weight of about 30 to 35 tons. Sorbents can be spread on the surface to mop up small amounts of oil, or if the oil spill exceeds the booms. Common sorbent materials are straw, peat moss and vermiculite. Transporting the volume of sorbent material required and distributing it can be problematic, also it must be retrieved before it gathers weight and sinks to the bottom.

Two other approaches to oil spill clean-up are burning in situ and using dispersants. Burning works and may be a preferred approach in the Arctic, but only if the oil slick is thick enough. Dispersants can be effective but leave tar-balls that can foul beaches and toxic chemicals that impact on marine ecosystems.

Manual labor is necessary to operate booms and other equipment, as well as using shovels, rakes and other hand tools to remove oily debris from the shoreline. In isolated areas, personnel accommodation and dining areas are usually provided by portable housing. Specialized trailers that are about the size of marine containers are used in mining camps throughout the North. Again, the problem is to move such temporary housing to the clean-up site. Lack of accommodation at remote sites sets the upper limit of personnel at 20 to 30 individuals.

The easiest and most cost-effective means of dealing with oil spills is to "let nature take its course." In time, the impact of sunlight, waves and natural microbes can breakdown oil spills. However, the Arctic's sensitive environment and cold temperatures, this is unlikely to be acceptable. A rapid response must be staged to carry a variety of cargoes over long distances, and place them in close proximity to the problem. Cargo airships may be the only means of transport that can meet such demands.

### 3. Economic Proposition

Modern cargo airships could improve the security of the Arctic, but the costs and potential efficiencies must be considered. Typically, when emergencies arise, a lot of lift capability is required all at once. It is difficult to justify the economics of having sufficient capacity on stand-by in case of random events. We propose the use of contingency contracts with commercial airship operators to provide sufficient lift to meet emergency applications in the North.

Emergency response and the commercial use of cargo airships are complementary. The use of airships on scheduled services to mines and remote villages could be interrupted briefly to carry emergence supplies from prepositioned locations to the site of a shipwreck or oil spill. In such arrangements, governments normally pay an annual stand-by to the aircraft operators that is much less than the cost of owning and operating equipment. At the same time, financial support for stand-by operations could reduce the costs of commercial operations of airships in the North.

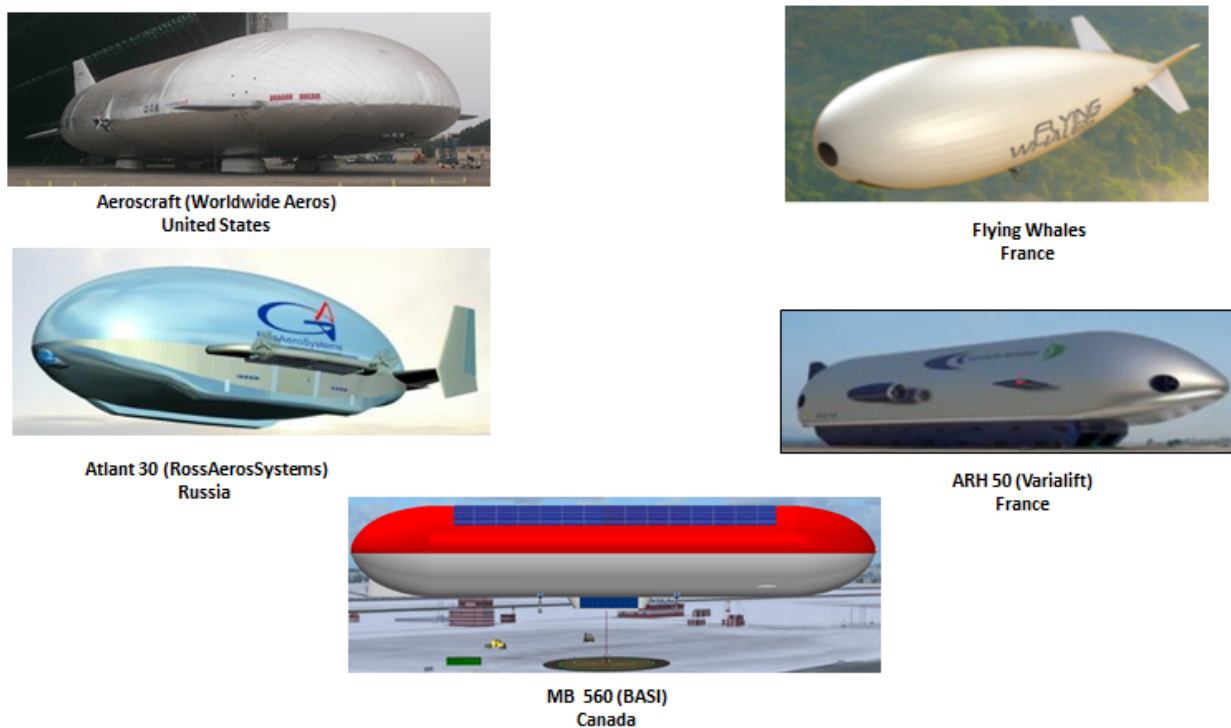
### 4. Developments in Airship Design

Dramatic accidents figure prominently in the history of giant rigid airships, such as the Macon, Akron, R101 and the Hindenburg. Most accidents occurred when the large airships were caught in violent storms, in maneuvering or in docking. These failures are a direct result of the trial-and-error construction methods that were used to build early airships. All the giant rigid airships were built before the invention of the strain gauge (i.e., The strain gauge was invented independently by Professors Authur Ruge of MIT and

E.E. Simmons of Caltech, and patented in 1939). Models were tested in wind tunnels, but could not estimate the stresses and torques that vehicles of this size encounter. The early airship engineers had no means of measuring where the stresses were accumulating, and structural failures were the result.

Computer simulations and digital twins can now, after 80 years, reduce the costs of aircraft design and certification. The ability to predict and adjust for extreme stress factors will make the next generation of airships safer. Advances in materials and methods will also make airships lighter and stronger. Airships of the future can use hydrogen fuel-cells powered electric motors and leave no carbon footprint. Eventually, most cargo airships are likely to operate as remotely piloted drones.

An international competition is emerging to lead the airships return [11]. Figure 2 presents five of the rigid transport airships that are under development. They vary in terms of their shape and other details, but all are designed to carry 30 tons or more. Where they are alike is in their structure. A rigid airship has a metal frame, similar to the fuselage of a fixed-wing aircraft. This structure supports the motors, control surfaces, cargo hold and bears all the stresses of flight. The lift is provided by a series of gas cells that are non-pressurized. The gas cells have cabling arrangements that transfer the loads from the gas cells to the superstructure of the airship.



**Figure 2.** Rigid-structure Transport Airships Under Development. Source: Courtesy of the various airship companies as provided to Barry E. Prentice.

Changing elevation can be done by altering the airship's buoyancy or with propulsion. Several methods are possible to change buoyancy: venting, compressing or heating the gas, or by releasing ballast. Elevation can also be changed by using propulsion system. If the nose of the airship is pointed up, aerodynamic forces will lift it higher. Conversely, pointing the nose down will take the airship lower. The American Aeroscraft and the French Varialift are designed to change elevation by compressing their lifting gas. The Russian Altant has some gas compression, but relies on a mix of measures including propulsion to adjust its elevation. The BASI airship plans a combination of venting gas and adjusting ballast. This is possible because of the use of hydrogen. Airships that use helium cannot afford to vent this expensive gas. BASI also intends to use hydrogen fuel-cells for propulsion which will

make ballasting easier. For every kilogram of hydrogen consumed by the fuel-cell, the system generates eight kilograms of pure water that can be held as ballast, or released.

Rigid airships have some distinct operational and economic advantages. They are less expensive and more fuel-efficient to operate than fixed-wing or rotary-wing aircraft. Airships can accommodate oversized and low-density freight. They have minimal impact on the terrain, and do not require expensive infrastructure for ground-handling. Airships have long range capabilities and can remain on station longer than other aircraft.

Airships are the most energy-efficient form of air transport per ton of cargo moved because the lift is free. Either helium or hydrogen can be used to operate the airship (i.e., in most jurisdictions, hydrogen remains banned because of a US Congress decision in 1923 that has never been challenged. See [40] for details of how helium lobbyists got hydrogen banned). Compressed hydrogen gas is practical for propulsion of an airships because a large hydrogen fuel tank can easily be stored inside their hull without impinging on cargo space. The large surface areas of airships offer the potential for some solar power but mainly for back-up emergency power, or to remove snow and ice from the top of the airship.

Rigid airships are constructed to distribute the cargo weight evenly over their structure. The Zeppelins of the 1930s could carry up to 70 tons, but with modern materials and methods, rigid airships should be possible that 250 tons or more. This would be the equivalent to 10 tractor-trailer loads. Indivisible cargo or freight with awkward length and dimensions can be suspended outside the airship.

Airships must adjust for their change of weight when the cargo is removed. Taking on water as ballast to replace the cargo is generally the most convenient approach. Although none of the airships described in this paper are illustrated with floats, landing on lakes or bays is entirely feasible. These landing sites also provide a ready source of ballast water if there is no return load.

Airships are slower than airplanes, but have much longer endurance. The Graf Zeppelin was the first aircraft to circumnavigate the world, and made the first non-stop flight across the Pacific Ocean. The ability to remain aloft for weeks at a time is very desirable for surveillance missions in the Arctic, and ideal for drone operations. At a cruising speed of 150 km per hour (kmph) an airship should be able to reach any part of the Arctic within 24 h.

Computerized avionics and vectoring propellers have reduced the labor intensity of rigid airships. As pictured in Figure 3, modern airships, such as the Zeppelin NT, require only two pilots on board and use GPS and engine thrust to land and take off unassisted.

The lift of an airship equals the weight of the air they displace. Consequently, gross lift decreases with elevation as the atmosphere becomes thinner. The operating ceiling for large cargo airships is approximately 3000 m, but flying at lower altitudes is desirable because they can carry heavier loads. Most of the Canadian Arctic is under 1000 m and there are only a few mountainous areas. The cold environment presents challenges for the year-round operation of airships, but also has benefits. The ride is smoother (no thermal updrafts) and the airships can carry more weight in the winter because the cold air is denser.





**Figure 3.** Zeppelin NT landing at Frederikshavn, Germany 2004. Source: Photo taken by Barry E. Prentice.

### 5. Northern Resource Development and Resupply

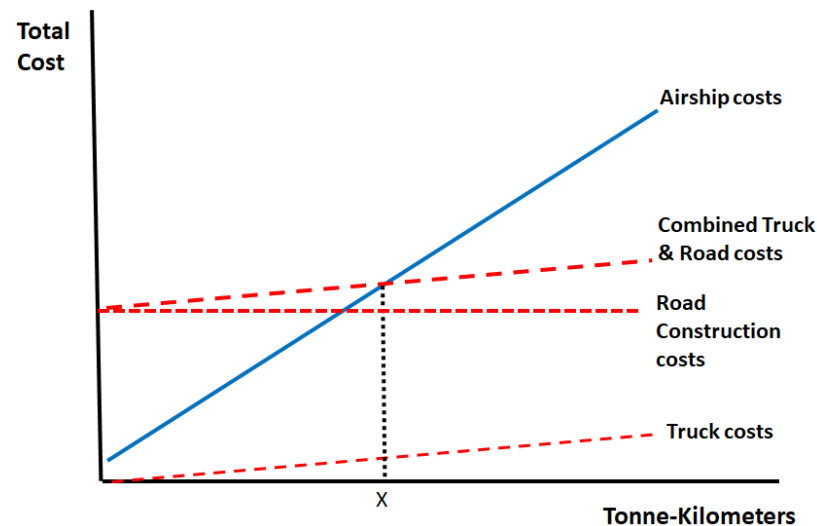
Over the past two decades, mineral exploration has declined and known reserves have diminished. Mining companies are forced to go deeper or seek new deposits in more remote areas. The Arctic regions are considered to hold large, untapped, mineral deposits, but the challenges facing land-based mining development are monumental. “Although this largely under-explored [Polar] region has the potential for the discovery of new world-class mineral deposits, the challenges and risks for explorers and miners are significant. In addition to the practical issues of operating in this remote and extreme environment, there are ongoing territorial disputes, and major concerns about the vulnerability of the environment and social impacts” [41].

Arctic logistics are expensive because the distances are great, transportation infrastructure is limited, and economic uncertainties are significant. Access is limited to a short window of opportunity when the winter roads are open (generally three to six weeks depending on latitude). All materials needed for the year’s operation of the mine must be moved within the winter road season. The pressures on logistics, heightens the financial risks associated with investing in frontier developments. Winter roads can be used to mineral diamonds and gold because their output can be flown out weekly in a small airplane. The economics of winter roads do not work for copper, nickel, zinc or rare earth elements. They have greater volumes of output and need year-round transport.

Canada has many known deposits of base metals and rare earths that are located far from established infrastructure. They remain untapped because the construction of gravel roads is too expensive. The average cost of building gravel roads is approximately \$3 million per kilometer in the Canadian Shield and Arctic regions. The only other possible means of developing mines in these inaccessible areas is a cargo airship.

An economic model that compares the trade-off of using cargo airships versus building gravel roads and using trucks is presented in Figure 4. Trucks are much less expensive than airships, but not if the costs also include building a road to the mine. Clearly, it depends on the length of the road, the volume of material to move and the expected economic life of the mine. Most roads can last 40 years with proper maintenance, but if the mine lasts only

15 years, the road becomes a stranded asset, and in some jurisdictions mining companies have to remove the road and rehabilitate the area when the mine ends. If the volume of tonne-kilometers (t-km) is less than X, it is more profitable to use transport airships.



**Figure 4.** Conceptual Model of Combined Truck and Road Costs Versus Cargo airships serving Remote Mining Operations. Source: [41].

The Strange Lake rare earths deposit is an example of a mine location that is uneconomic to reach by ground transport [42,43]. Figure 5 illustrates the site of Strange Lake in Northern Quebec that lies 240 km (km) north of the closest railway line, through rough terrain, river crossings, muskeg and permafrost soils. The mine developer, Torngat Metals, cannot raise \$720 million (\$3 million/km) to build a gravel road access to move 200,000 tons of rare earth ore concentrate annually for delivery to the rail head at Schefferville. From Schefferville the concentrate is to be moved by rail to Sept-Iles where it will be trans-shipped to barges for transport to Becancour for further refining. Finally, the output will be transported to Norway for final production.



**Figure 5.** Strange Lake Mine Development in Northern Quebec. Reprinted with permission from ref. [44]. Copyright 2016 ISOPolar Airships.

This is an example of many northern mineral deposits that could be served by cargo airships. The mine announced plans to use the 20-ton lift, Lockheed-Martin airship to fly the rare earth concentrate from Strange Lake to Schefferville. This plan was side-lined when a major investor withdrew, but the project is still active and open to any airship that can offer an economic service.

## 6. Cargo Airships versus Trucks Over Road—Cost Comparison

The economics of serving this mine by airship is modeled, as an illustration of the possibilities for having cargo airships available for emergency response. Data for the Lockheed-Martin airship are unavailable, so this analysis uses the BASI MB560 airship that is designed to carry 30 tons. Specification data for the BASI airship are presented in Table 2. This data are used to calculate the cost of serving the mine based on certainty of production as provided by the mine developer.

**Table 2.** General Operating Specifications of the BASI MB-30 T. Reprinted with permission from ref. [45]. Copyright 2021 Buoyant Aircraft Systems International.

Length	560 feet
Max. Diameter	80 feet
Max. Height	90 feet
Max. Width	100 feet
Volume	2.2 Million Cubic Feet
Ballast	Water
Fineness Ratio	6.2
Tail Surfaces	One Rear Stabilizer and Rudder
Elevators	Forward Canards, 45 degree
Vectoring Control	Full 180 degree, up and down
Max. Gross Lift	60 Tons
Max. Takeoff Weight	62 Tons
Useful Load	30 Tons
Power	Twin, Pratt & Whitney PT-6 APUs
Propulsion	Four, 390 kw Siemens Electric
Propellers	Hoffman 12'-6", 20 degree
Fuel Capacity	1000 US Gallons
Fuel Reserve	200 US Gallons
Fuel Consumption	880 lbs/hour
Fuel Type	Jet A Diesel (colored)
Cruise Speed	80 Knots
Max. Speed	100 Knots (full rich settings)

**Table 2.** *Cont.*

Stall Speed	0 Knots
Max. Takeoff Angle	10 degrees
Max. Cross Wind	25 Knots at 90 Degrees
Max. Wind Limit	50 Knots
Max Endurance	10 Hours
Max. Range Nautical Miles	1200 Miles (lean settings)
Typical Range Nautical Miles	800 Miles
Service Ceiling	5000 feet
Cargo Bays Twin door	with aircraft roll-out floors
Max. Cargo Length	160 feet
Pilots Single	with Co-Pilot or Unmanned
Min. Ground Crew	2
Ground Control Terminal Support System	Buoyant Aircraft Rotating Terminal, (BART)

The requirements for the mine are to move 200,000 tons of concentrate per year. Given a 30-ton lift, three flights per day, and 325 days of annual operation, this could be achieved with approximately seven BASI airships. The cost comparison for the airship versus a gravel road is calculated based on this operation. The BASI transport system has a landing pad for transshipment and mooring called a BART (Buoyant Aircraft Rotating Terminal). These are large turntable structures that allow the airship to “weathervane” with changes in the wind, but provide a safe surface where the cargo can be handled. BASI estimates the cost of each BART is \$2 million installed. A conceptual model of the logistics to serve the mine is presented in Figure 6.

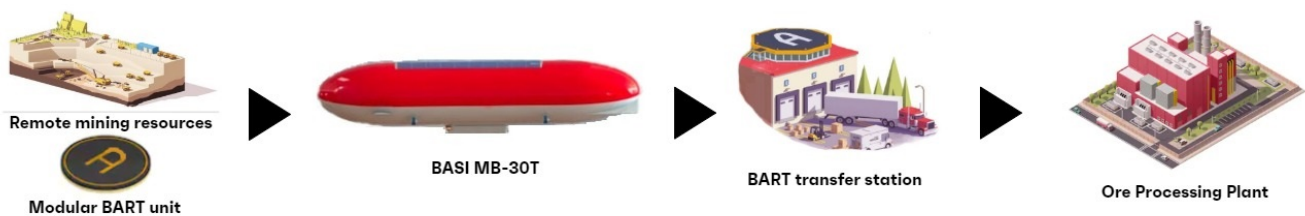
**Figure 6.** Conceptual model of airship transport from mining BART to transshipment BART.

Figure 7 presents the key assumptions for the airship. The 480 km round-trip from the transshipment points to the mine would take approximately 3.5 h allowing for some headwinds, and 1.5 h at each end for loading/unloading. Each airship could easily complete three round trips per day. This is a conservative estimate that allows a 4.5 h margin for unexpected delays. Assuming only inbound freight, and empty returns, seven airships could deliver 200,000 tons per year allowing 40 days for each airship to receive maintenance, inspections or be grounded by inclement weather. All monetary values are expressed in Canadian dollars.

1. Turnaround time at each stop—1.5 hour
2. Average cruise speed—150 kmph
3. Operating window—325 days/year
4. Fuel use—500 liters/hr. at \$1.00 per liter or \$500 per flying hour
5. Crew cost on airship—\$200 per operating hour
6. Cost to build one ship of a multiple series—\$50,000,000

**Figure 7.** Specifications and Cost Assumptions for BASI Airship.

The fixed costs for a fleet of seven airships, two BARTs and one hangar are presented in Figure 8. The hangar needs to be available in order to undertake major repairs and to conduct inspections. It might be located at the transshipment site (Schefferville) or closer to Becancour (Montreal) where the airships would be originally assembled. The estimated cost of the airship hangar is \$50 million. The airships are amortized over 20 years while the fixed facilities are expensed over 25 years. The total annual cost to operate the fleet is \$40,480,000 and the depreciation on the aircraft is \$24,500,000.

1. Aircraft (7) amortized over 20 years at 5%	\$27,000,000/yr
2. Hangar (\$50 million - amortized over 25 years)	\$ 3,600,000/yr
3. BARTs (2 @ \$2 million - amortized over 25 years)	\$ 280,000/yr
4. Insurance (airships @ 2% of hull value, hangar and BARTs)	\$ 7,600,000/yr
5. Administration, maintenance and ground support	\$ 2,000,000/yr
<b>Total Annual Fixed Costs of Fleet</b>	<b>\$40,480,000/yr</b>
 Depreciation Aircraft (7) per year at 5%	 \$24,500,000/yr

**Figure 8.** Fixed Cost Assumptions for a fleet of seven BASI Airships.

The operating cost assumptions are based on crew costs for 20 h per day (two flight crew and one ground-handler). This is \$9.1 million (\$200/h @20 h/day, seven airships, 325 days) and \$2.6 million for fuel (\$500/flying hour for seven airships), plus \$1 million for maintenance and contingencies. This amounts to variable costs of \$12.7 million per year for the fleet based on 325-day operations. The total costs per year are \$12.7 million variable costs plus total fixed costs of \$40,480,000 (ignoring depreciation) for a grand total of \$53,180,000 to transport 200,000 tons of mineral concentrates. The cargo airship is assumed to need a 0.8 operating ratio to provide a return on investment that is typical in aviation. This is calculated by dividing the operating expense (minus depreciation) by its gross operating income. This implies revenues of \$66,475,000 to produce the necessary profit margin of \$13,295,000.

The cost comparison of using airships versus building a \$720 million road and trucks requires some estimate of trucking costs and road maintenance. Current trucking rates are approximately \$3 per kilometer or about \$1500 for a round-trip. On an annual basis, this

is \$15 million to move 200,000 tones. In addition, road maintenance and snow-clearing average about \$16,000 per kilometer for an annual cost of \$0.5 million.

A comparison of cargo airships versus moving trucks over gravel roads is presented in Table 3. This table provides the base case, as set out in the text for a 20-year horizon and a five percent discount rate to arrive at the Net Present Value (NPV) of the two alternatives. The NPV is commonly used in capital budgeting and investment planning to compare two alternatives that have different timeframes. The method involves using inverse of compounding interest formula to calculate the present values of future costs. Revenues are not included in this comparison, although this would be to the advantage of the airship because it would start operations sooner. In order to make the comparison fair, the three-year time frame to build the road is also used to provide the airship hangar, BARTs and the airships that would be delivered in the third year. The cost of the road is spread out over the three-year period. The base case of moving 200,000 tons of concentrate per year, over a 20-year period favors the airship method by approximately \$200 million.

**Table 3.** Cost Comparison for Cargo Airships and Trucks over Gravel Road: Total, Net Present Value (@5% discount rate) and Sensitivity Analysis for higher Airship Operating costs and Increase Volume.

Year	Base Case		50% Increase in Airship Cost			50% Increase in Mine Output		
	Cargo	Truck	Year	Airship	Over Road	Year	Airship	Over Road
1	50	240	1	50	240	1	50	240
2	4	240	2	4	240	2	4	240
3	350	240	3	350	240	3	500	240
4	26	15.5	4	39	15.5	4	39	23
5	26	15.5	5	39	15.5	5	39	23
6	26	15.5	6	39	15.5	6	39	23
7	26	15.5	7	39	15.5	7	39	23
8	26	15.5	8	39	15.5	8	39	23
9	26	15.5	9	39	15.5	9	39	23
10	26	15.5	10	39	15.5	10	39	23
11	26	15.5	11	39	15.5	11	39	23
12	26	15.5	12	39	15.5	12	39	23
13	26	15.5	13	39	15.5	13	39	23
14	26	15.5	14	39	15.5	14	39	23
15	26	15.5	15	39	15.5	15	39	23
16	26	15.5	16	39	15.5	16	39	23
17	26	15.5	17	39	15.5	17	39	23
18	26	15.5	18	39	15.5	18	39	23
19	26	15.5	19	39	15.5	19	39	23
20	26	15.5	20	39	15.5	20	39	23
Total	846	983.5	Total	1067	983.5	Total	1217	1111
NPV	\$606.80	\$804.53	NPV	\$733.41	\$804.53	NPV	862.99	\$877.58

Two scenarios are advanced to test the sensitivity of the results. In the first case, the operating costs of the airship are doubled. This could represent fewer trips completed per year or some cost factors that turned out to be greater. Regardless, the NPV for the cargo airship is still better by about \$70 million. The second scenario considers a ramping up of the mine output by 50 percent. In this case, the cargo airship and the trucking alternatives are about equal.

Generally speaking, the economics of an investment in road infrastructure should improve the longer the lifetime of the mining operation. The analysis could be extended, but it is not clear that the results would be much different. After 20 years of operations, roads and bridges need substantial re-investment. Moreover, these 30-ton lift airships would likely be replaced by larger aircraft that could carry 100 tons or more. Consequently, the economic comparison is unlikely to change greatly.

The full economic analysis in this case is far from complete. The inevitable delays in obtaining permits and agreements with the local people to build a road would result in lost market opportunity costs while waiting for the mine to open. Cargo airships could also improve relations with the local people in the North. Some small deviations in the routing of the airships on their way to the mine could enable the delivery of goods to the local communities that depend on ice roads or annual sealifts. Finally, the cost of the airships could be offset somewhat by entering into contingency contracts with the agencies responsible for emergencies in the North.

Contingency contracts would introduce some uncertainty in mining operations that are designed to have a constant flow in their supply chain. At only three trips per day, enough slack in the system exists to catch up with any shortfall in logistics over a short period of time. Moreover, the concentrate is non-perishable and can easily be stockpiled in the event that one or more of the airships are required to assist in an emergency response.

## 7. Conclusions

The impact of climate change in the Arctic is accelerating. Sea routes that were considered impossible to navigate 50 years ago are now in use, and direct sailing across the Arctic Ocean is being anticipated within a few decades. In the meantime, expansion of traffic through the North West Passage and plans to development natural resources are taking place. From an economic perspective this may be welcome, but greater access poses environmental risks that circumpolar countries are ill-equipped to address. In particular, oil spills that could result of shipping accidents or resource extraction would be extremely difficult to contain and clean up. The ability to transport sufficient people and equipment to such remote areas in a timely manner simply does not exist.

Cargo airships may be the only conceivable means of transport that can carry large bulky loads over long distances and operate in areas devoid of established infrastructure. A worldwide race is on to develop this new generation of large rigid airships. This once abandoned technology is making a return because of advances in materials and engineering, which are reducing costs and improving safety, while interest is increasing in airships as a “green technology”. The most energy-efficient means of air transport, electric airships, can already operate over long distances and carry heavy loads with zero carbon emissions.

The economic problem for emergency response is to have the necessary lift available when it is needed. Governments cannot afford to have large fleets of airships on stand-by in case of accidents, but they could engage in contingency contracts with airship operators in civilian markets to make equipment and crews available during emergencies. This paper uses a case analysis of a rare earth-mining proposal to illustrate the economics of using cargo airships in place of building access roads. The operation of the Strange Lake mine shows that a fleet of seven 30-ton lift cargo airships would serve their needs at a lower cost than constructing a road and operating trucks. This mine alone could provide the necessary lift for emergency response in the Arctic, but of course many more mining and other uses for cargo airships will emerge as the technology is re-introduced.

This study has a number of limitations. The social benefits of the proposal for the remote communities are not addressed. The reason is level of detail required to do justice to this topic. The problems of food insecurity and overcrowded housing that the airships could address is worthy of a separate paper. The analysis also provides no measure of the impact that an uncontrolled oil spill could have in the Arctic. This is a very delicate environment that takes much longer to recover than in the South.

The estimates of the airship’s costs are based on engineering designs not actual vehicles. Similarly, the operating costs can only be approximated by the costs for general aviation in the same market. This can be offset to some degree by using a sensitivity analysis, as was done here, to test the robustness of the results. Over time, better data will emerge to refine the analysis, and the technical details are included for that purpose.

A useful policy exercise would be to undertake an emergency response simulation. For various sizes of oil spills, how much equipment and accommodations for the crews would

have to be moved? Where would the caches of critical components be located? Lastly, all the other logistical questions that would determine how many airships are required, as well as their response times to the incident.

Finally, governments should bring together the stakeholders and vested interests to obtain the collective views on the development of a new airship transportation to benefit and protect the North.

**Author Contributions:** B.E.P., Y.-Y.L. and A.K.Y.N. contributed equally to all sections of this paper. All the authors contributed to the research design, prepared the first draft, revised and approved the final manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable for studies not involving human.

**Informed Consent Statement:** Not applicable for studies.

**Data Availability Statement:** The study did not report any data.

**Conflicts of Interest:** The authors declare no conflict of interest.

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