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AIRSHIP SUSTAINMENT IN THE ARCTIC

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JCSP 47

Service Paper

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PCEMI 47

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CANADIAN FORCES COLLEGE - COLLÈGE DES FORCES CANADIENNES

JCSP 47 - PCEMI 47
2020 – 2021

SERVICE PAPER – ÉTUDE MILITAIRE

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By Lieutenant-Commander Norm A. Normand

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Word Count: 2,601

Nombre de mots : 2.601

AIRSHIP SUSTAINMENT IN THE ARCTIC

AIM

1. This paper will evaluate the feasibility of using semi-autonomous and/or remotely piloted lighter-than-air craft to supply and sustain the Arctic and recommend how CJOC should proceed with trialling this feasibility.

INTRODUCTION

2. When examining airships, it is impossible to avoid discussing the Hindenburg disaster. The image of a German airship bearing a swastika burning as it crashes to the ground is powerful. Propagandistic value to the allies in WWII aside, this disaster "led to the end of commercial lighter-than-air flight and the stalling of hydrogen as a reliable fuel."[1] The US Congress enacted a ban on the use of hydrogen as a lifting gas which, "when the US became the dominant aviation power, its regulations were "rubber-stamped" into aviation regulations around the world, including Canada."[2] Fellow for the American Institute of Chemical Engineers, William Van Vrost found "that the material used to coat the "skin" of the airship, not hydrogen, was the cause of the disaster."[3] Transport Canada's Airworthiness Manual Chapter 541 - Airships states, "Hydrogen is not an acceptable lifting gas for use in airships".[4] This anti-hydrogen view of airship lifting gas is problematic but using airships for sustainment in the Arctic is still feasible.

DISCUSSION

4. This paper will discuss the feasibility of using ridged airships, referred to as dirigibles, in the arctic rather than non-rigid airships (also known as blimps). This is because non-rigid airships are pressurized, thus subjecting them to climatic vulnerability. Amontons' Law demonstrates that the pressure of a gas is directly proportional to its temperature. As temperature decreases, so does pressure.[5] This means that the "envelope" (the inflatable lifting gas tank on an airship) will become deformed with non-rigid airships, impacting aerodynamic performance. Annex A shows pictures of envelope deformation as a function of temperature and humidity. The concept of employing lighter-than-air craft in the arctic for sustainment must take into account temperature and humidity variations that could occur throughout a flight. Additionally, the dirigibles provide a form of lighting protection because their frames act as Faraday cages.[6] This would be a very important consideration if they are to be used to transport cargo that could be

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[1] Martin Kelly, "The Hindenburg Disaster," accessed 6 February 2021, https://www.thoughtco.com/the-hindenburg-disaster-104703.
[2] Buoyant Aircraft Systems International "Possibilities as a lifting gas." Accessed 6 February 2021, https://www.buoyantaircraft.ca/hydrogen.php.
[3] "Hindenburg Disaster Explained." *Chemical Engineering Progress* (Aug, 1998): 7.
[4] Transport Canada, Part V – *Airworthiness Manual Chapter 541 – Airships* (Ottawa: Canadian Aviation Regulations, 2009), 541.7.
[5] Purdue University, "Gas Laws," accessed 6 February 2021, http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch4/gaslaws3.html#amonton.
[6] "Navy's Super-Airship Nears Completion." *Scientific American* 144, no. 5 (1931): 297-300. Accessed January 21, 2021. http://www.jstor.org/stable/24975669.

negatively impacted by lightning strikes such as ammunition and explosives; blimps do not have this feature.

5. In 1914, mapmaker, John Bartholomew produced an isochronic map detailing the length of time it would take to travel from London to destinations around the world.[7] Tthe high arctic in Canada would have taken over 40 days to access from London. In 2016, the multimodal transport search engine "Rome2Rio" produced an updated map pictured in Figure 1.

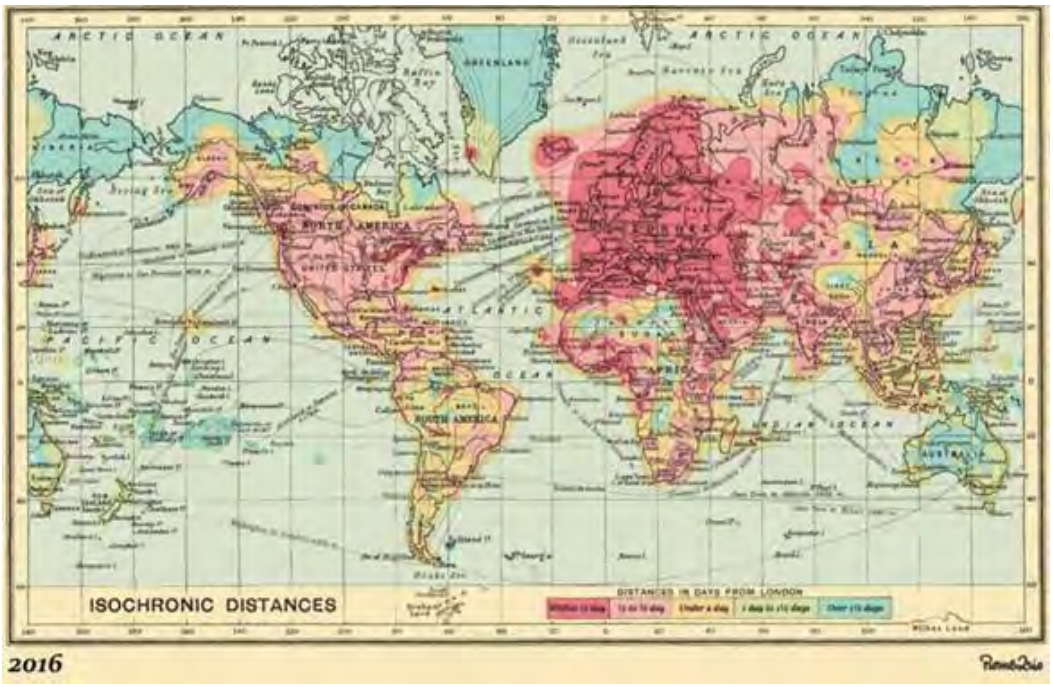

Figure 1 – Isochronic Map from 2016
Source: Rome2Rio. *Time flies? According to these maps it does*[8]

7. One can see that despite the passage of 102 years, the high arctic remains one of the world's least accessible locations. This paper will demonstrate that dirigibles could be used to improve the accessibility of this region significantly.

8. Interest in using dirigibles in Canada has been primarily on linking mining operations in the North to the existing lines of communication (LOCs) and transportation nodes such as road/rail networks and air/seaports. This is because the Arctic region represents a massive and unexploited source of minerals.[9] Furthermore, "[r]educed sea ice in the Arctic over the last decade, improved ship access and new infrastructure have contributed to heightened mineral

[7] "Time Flies? According to these maps it does." Accessed 6 February 2021, https://www.rome2rio.com/blog/2016/01/08/time-flies-according-to-these-maps-it-does/.

[8] Ibid.
[9] P. A. J. Lusty and A. G. Gunn. "Challenges to global mineral resource security and options for future supply." In *Geological Society, London, Special Publications* 393 (2015): 272, https://sp.lyellcollection.org/content/specpubgsl/393/1/265.full.pdf.

exploration interest in the region."[10] There are also ongoing territorial sovereignty issues both between Canada and other Arctic States[11] as well as Indigenous land issues rights in the region.[12] There are also "major concerns about the major vulnerability of the environment and social impacts."[13]All of this is pointing toward a solution space that is flexible, environmentally friendly, sustainable, and has a small infrastructure footprint/bill.

9. Much like the mining industry, the CAF will also need to find a solution to arctic sustainment that considers similar constraints associated with operating in an extreme environment by using assets that take up minimal infrastructure footprint while maximizing the use of existing LOCs. The established LOCs in Canada are pictured in figures 2 and 3.

Figure 2 – Rail and Port Infrastructure
Source: *Statistics Canada*[14]

[10] Ibid, 272.
[11] Zachary Fillingham. "Arctic Ownership Claims." *Geopolitical Monitor* (8 April 2009): accessed 6 February 2021, http://www.geopoliticalmonitor.com/arctic-ownership-claims/.
[12] Robin Campbell. "An Introduction to Inuit Rights and Arctic Sovereignty" *LawNow* (7 May 2015): accessed 6 February 2021, https://www.lawnow.org/introduction-inuit-rights-arctic-sovereignty/.
[13] P. A. J. Lusty and A. G. Gunn. "Challenges to global mineral resource security and options for future supply." In *Geological Society, London, Special Publications* 393 (2015): 272, https://sp.lyellcollection.org/content/specpubgsl/393/1/265.full.pdf.
[14] Statistics Canada, The Canadian Transportation System (Ottawa: Transportation Data and Information Hub, 2018).

10. Ground Christening (Tuktoyaktuk, Hay River, the Mackenzie River, Churchill, and Moosonee):

a. The blue oval in between Tuktoyaktuk and Hay River represents the Mackenzie River LOC. This LOC connects settlements on Great Slave Lake (such as Yellowknife and Hay River) to Tuktoyaktuk and other communities on the Arctic Ocean. Barges are "coupled into 'trains' for the river journey. […] From Tuktoyaktuk, the barges are towed by sea-going tugboat to the Inuit communities along the coasts of Canada's Arctic islands."[15] There is also a large shipyard at Hay River that "maintains the fleet of tugs and during winter months. There is a floating dry dock in Tuktoyaktuk for emergency repairs during the short, hectic navigation season."[16] This LOC is not open for an extended period. For example, in 2020, the Mackenzie LOC's shipping season lasted from 10 July to 19 September.[17]

b. Although Churchill, Manitoba currently does not have road access, it does have a seaport, regional airport with access to Winnipeg, rail access. With the completion of (and lessons learned from) the Inuvik to Tuktoyaktuk highway, there has been recent pressure to connect Churchill, to the Canada's transportation network via road.[18] This would establish redundancy along the existing rail ground LOC.

c. Moosonee is not connected to Canada's transportation network by road, however, there is a rail LOC to Moosonee and a regional airport. Its relative proximity to southern Ontario and Quebec situate it as a viable candidate for a node in Eastern Canada.

[15] Canadian Council for Geographic Education. "Mackenzie River: Barging ahead" (2011): accessed 6 February 2021, https://web.archive.org/web/20111028020808/http://www.ccge.org/resources/rivers_of_canada/mackenzie_river/barging_ahead.asp.
[16] Ibid.
[17] Government of Northwest Territories. *GNWT completes marine resupply for northern communities.* (2020).
[18] Cameron MacLean. "'It's about time to build a road to Churchill': Engineer says it's possible Social Sharing" *CBC News* (24 June 2017): accessed 6 February 2021, https://www.cbc.ca/news/canada/manitoba/churchill-build-road-engineer-1.4174034.

Figure 3 – Highway and Air Infrastructure
Source: *Statistics Canada*[19]

11. Ground Christening (Goose Bay, Labrador City, and Nanisivik):

    a. CFB Goose Bay is capable of handling a variety aircraft and is connected to a road network with intermodal road/rail connections to the Quebec North Shore & Labrador Railway (QNSL) connecting Sept Îles, Quebec to Labrador City, Newfoundland.[20]

    b. The Nanisivik Fuel Facility is another key location in the arctic region. The fuel facility there will act as "the Arctic logistics and refuelling hub for the Navy's Arctic Offshore Patrol Ships."[21] The concept is to have it sparsely crewed[22] but there will inevitably be consumable items used for maintenance and repair that will periodically need to be shipped to Nanisivik.

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[19] Statistics Canada, The Canadian Transportation System (Ottawa: Transportation Data and Information Hub, 2018).
[20] Glyn Williams, "Railways in Labrador and Quebec North Shore," accessed 6 February 2021, https://www.sinfin.net/railways/world/canada/lab-qns.html.
[21] Defence Construction Canada. One-of-a-kind ship fuelling system coming online in Canada's North. (Ottawa: DCC at Work, October 2019) accessed 6 February 2021, https://www.dcc-cdc.gc.ca/english/dcc_at_work/2019/october/1910_article2/.
[22] Ibid.

12. Similar to the Operational Support Hub (OS Hub) "hub and spoke" concept from which a military force may be "launched into a theatre of operations, are established along the Strategic lines of communications, and "spokes" are activated to support a specific operation",[23] the author proposes using existing LOCs and transportation nodes to establish a circuit that could be traversed by dirigibles as indicated by the red line on figure 4. This would allow for all-season semi-regular cargo delivery windows for the entire region.

Figure 4 – Proposed Dirigible Sustainment Circuit
Source: *Statistics Canada*[24]

13. Nodes with existing access to ground LOCs are indicated with a green star. These nodes could be used as the "hub". The impetus for maximizing ground LOCs results from the fact that Air is "by far, the most expensive way to ship [25]" than the other modes of transportation (road, rail, pipeline, and sea). Also, the "level of emissions produced by air transport are also the highest of any mode."[26] Establishing nodes at locations where intermodal transportation can take place enables cargo to be pushed forward into the Arctic region conventionally via

[23] Department of National Defence. B-GL-005-400/FP001. *Canadian Forces Joint Publication 4-0 Support*. (Ottawa : DND Canada, 2016), 2-14.
[24] Statistics Canada, The Canadian Transportation System (Ottawa: Transportation Data and Information Hub, 2018).
[25] "The 6 Modes of Transportation", *Mihlfeld & Associates* 19 October 2018, https://blog.mihlfeld.com/the-6-modes-of-transportation.
[26] Ibid.

road/rail/sea/air and transferred to a dirigible that will be transiting a circuit on a regular or *ad hoc* "freight run".

14. Nodes that are accessible only by sea/air are indicated with a blue star. Nanisivik has already been discussed, but Iqaluit is another key location. It has an international airport (linkages to Greenland), it can accommodate the C-17 Globemaster III [27] and will soon be home to a deep sea port[28]

15. A concept of employment for dirigibles to be used in a sustainment capacity for mining operations and remote community access in Canada was proposed at the 2020 Annual Canadian Transportation Research Forum.[29] The proposed concept is for an airship to operate from one fixed base to another. These proposed fixed bases are called Buoyant Aircraft Rotating Terminals (BARTs). Figure 5 illustrates the proposed model.

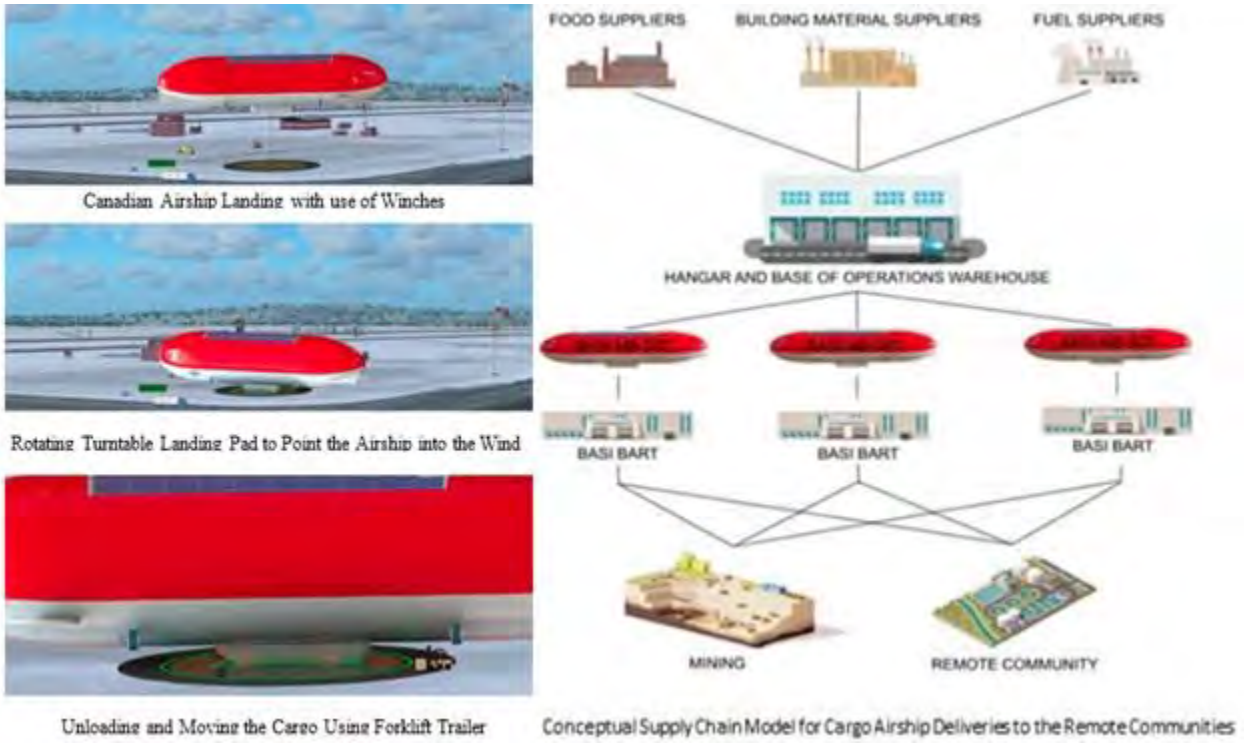

Figure 5 – Proposed Cargo Dirigible Transportation System
Source: Prentice and Wilms, *Cargo Airship Fuel Transport: Canadian Shield Case Study,* 433[30]

[27] "Jet blast from cargo plane smashes windows out of Iqaluit van." *CBC News* (23 Jul 2015): accessed 6 February 2021, https://www.cbc.ca/news/canada/north/jet-blast-from-cargo-plane-smashes-windows-out-of-iqaluit-van-1.3164605.
[28] Dustin Patar, "Iqaluit deepsea port project remains on schedule for 2021 completion." *CBC News* (13 October 2020): accessed 6 February 2021, https://nunatsiaq.com/stories/article/iqaluit-deepsea-port-project-remains-on-schedule-for-2021-completion/.
[29] Barry E. Prentice and John Wilms, "Cargo Airship Fuel Transport: Canadian Shield Case Study." Canadian Transportation Research Forum. Proceedings Issue: 55th Annual Meeting (2020): 433.
[30] Ibid.

16. The payload capacity for the proposed cargo airship is 30 metric tons and there would be a need for water to be available at each base to act as ballast.[31] The ballast factor is a key consideration because dirigibles have constant lift. If a return load weighs less than the dirigible's lift capacity, ballast (potentially in the form of water) would be required to ensure the amount of lift is appropriate for flight.

17. This model proposes that cargo is pushed to a warehouse with the airship pushing out further into the remote region to facilitate the cargo delivery. Delivery is affected with the use of winches similar to the "bear trap" on RCN vessels. A rotating landing pad is used which can be fixed while the forklift transits from the ground onto the airship and then released so that the airship can remain pointed into the wind. This reduces stress on the airframe associated with maintaining an orientation other than into the wind. The cruising speed for the proposed airship was 150km/h.[32] The proposal was for three airships and 22 BARTs. The cost estimate that was presented has been reproduced in figure 6.

1. Turnaround time at each stop – 1.5 hour	
2. Average cruise speed – 150 kmph	
3. Days of Operation/yr - 300	
4. Fuel use - 500 liters/hr. at $1.00 per liter or C$500 per flying hour	
5. Crew cost on airship - C$200 per operating hour	
6. Cost to build one ship of a multiple series –	$50,000,000
7. Fixed costs based on initial years of service	
a. Aircraft (3) amortized over 20 years at 5%	$12,000,000/yr
b. Hangar ($50 million - amortized over 25 years)	$ 3,600,000/yr
c. BARTs (22 locations - amortized over 25 years)	$ 3.600,000/yr
d. Insurance (airships, hangar and BARTs)	$ 3,600,000/yr
e. Administration and ground support	$ 1,000,000/yr
Total Annual Fixed Costs	$23,800,000/yr
8. Depreciation Aircraft (3) per year at 5%	$ 7,500,000/yr

Figure 6 – Specifications and Cost Assumptions for three 30-ton Cargo Airships
Source: Prentice and Wilms, *Cargo Airship Fuel Transport: Canadian Shield Case Study,* 432[33]

18. The costs outlined in figure 6 would be similar to those incurred by DND were this solution to be implemented. That said, the move toward autonomous or semi-autonomous dirigibles could reduce some of the crew costs and fuel use. While an autonomous cargo dirigible does not yet exist today, a request for proposal to industry could help bridge this technical gap.

19. At a cruising speed of 150km/h, over a 12hr period, the airship could intentionally deviate from its regular circuit by up to 1,800km to provide support in a location in the arctic that is not along the regular flight path. In this case personnel at the target site would need to be trained in dirigible recovery and potentially deploy with equipment to affect a recovery in a remote region. The aforementioned BART is portable and can be deployed alongside a military

[31] Ibid.
[32] Ibid, 432.
[33] Ibid.

force into the arctic. It is also possible to transport a disassembled BART via dirigible though this would degrade the payload capacity of that dirigible.

20. A circle with radius of 1,800 km has been superimposed over the Hay River "freight run" node to demonstrate how over a 12-hr period, one airship could cover a substantial portion of the arctic to support an arctic operation and after a 24-hr period, any point in the entire Canadian Arctic region is accessible. This range is shown in Figure 7.

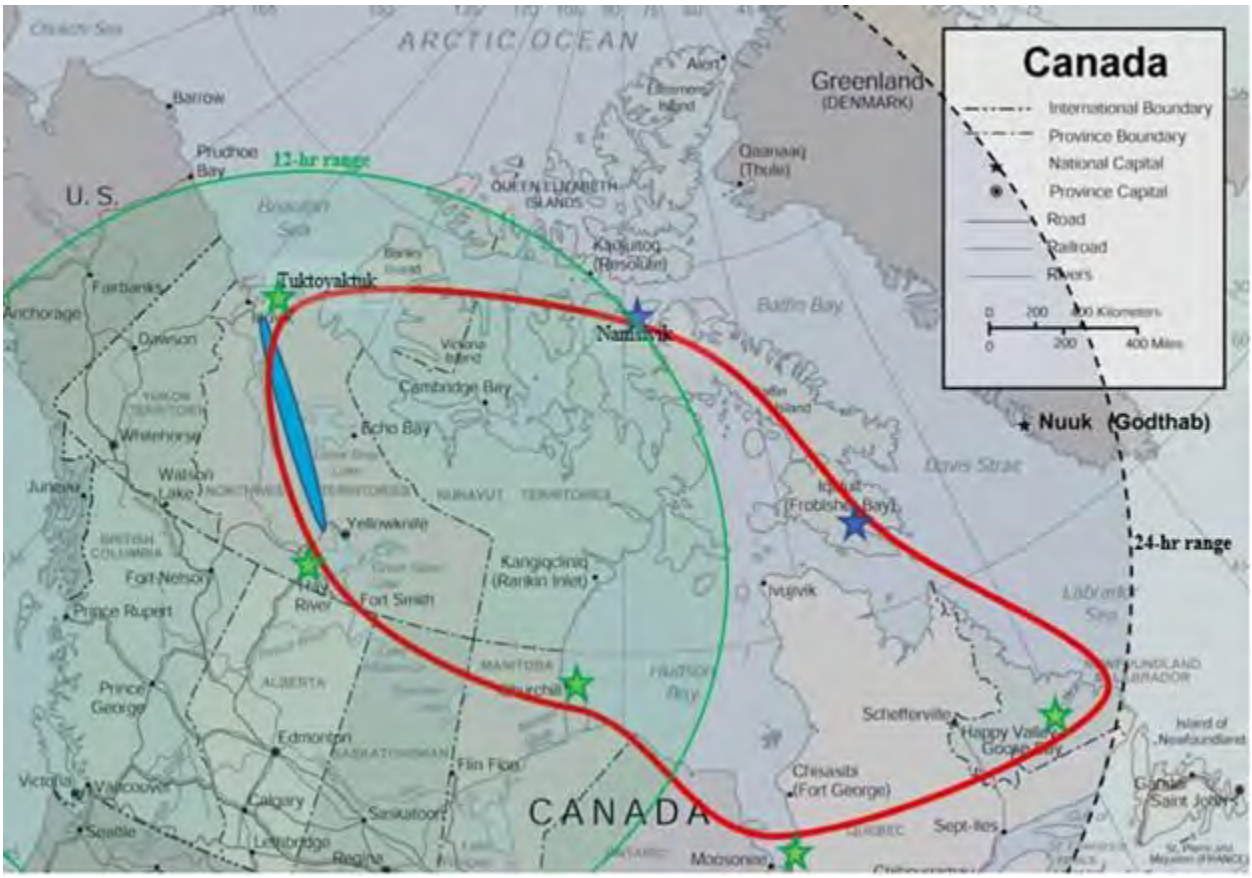

Figure 7 – Potential Airship Reach Within 12/24hrs from Hay River
Source: *Statistics Canada*[34]

21. The green circle represents the distance a dirigible can travel in a 12hr period in any direction away from a potential node in Hay River. The existence of one dirigible delivering cargo as described would effectively redraw the 2016 Isochronic Map, making all the Canadian Arctic accessible for cargo movement within one day. Increasing the number of airships to two or three will increase the coverage and response area as detailed in Figure 8.

[34] Statistics Canada, The Canadian Transportation System (Ottawa: Transportation Data and Information Hub, 2018).

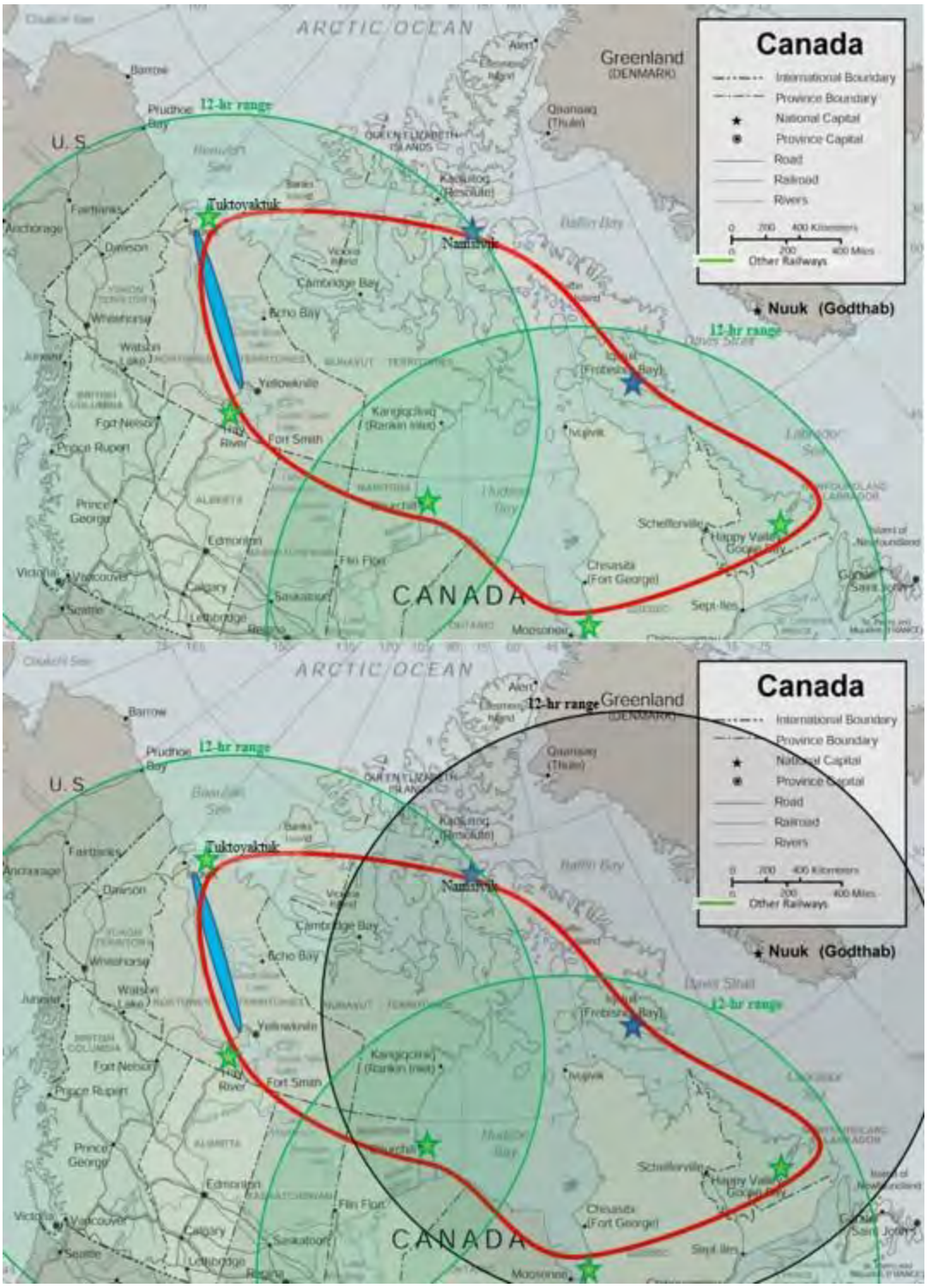

Figure 8 – Potential Airship Reach Within 12hrs with two/three Dirigibles
Source: *Statistics Canada*[35]

[35] Statistics Canada, The Canadian Transportation System (Ottawa: Transportation Data and Information Hub, 2018).

The second airship in this scenario is stationed in Moosonee and the third airship is in Iqaluit. The range of the Iqaluit airship is in black to differentiate it from the airships that have access to ground LOCs.

22. With cargo continuously being pushed to warehouses in the nodes along the circuit, even one airship transiting a "freight run" circuit would be able to deliver cargo to anywhere within the arctic region within 24hrs. With two and three dirigibles in the circuit, the region becomes much more accessible, enabling sustainment within 12 hrs of a node. One of the limitations of airpower is a lack of persistence. This is because conventional aircraft must spend a much greater percentage of time on the ground than in the air. With Airships this is not the same. While they will still need to be maintained and refuel, the time they can spend in the air is much greater than with conventional aircraft.[36]

23. Multiple airships also help with redundancy when maintenance activities need to be performed on the airships. Cargo airships have been estimated to function for 300 days per year[37]. However, maintenance periods will require them to be taken out of the sky and repaired. The establishment of a dirigible maintenance facility would also be required but this could potentially be handled with an in-service support contract.

24. As the airship technology advances, components such as "vectoring engines, tail thrusters and modern aircraft avionics that give pilots sufficient control to land and take off independently […] eliminates the need and expense of large ground crews."[38] This means at each of the nodes, personnel can be sourced locally and trained to handle the ground support piece when the airship needs to embark/disembark cargo at one of the nodes.

25. Hydrogen fuel cells are currently being researched and developed for use in dirigibles.[39] Hydrogen fuel would be ideal for dirigible usage in the arctic. It is a zero-emission fuel and "has begun to be used in commercial fuel cell vehicles […] and has been used in fuel cell buses for many years."[40] Water can be electrolyzed to produce Hydrogen and renewable energy sources can be used to produce hydrogen.[41] If hydrogen fuel could be produced in some or all of the nodes proposed in this paper using a combination of renewables such as wind and solar, there would be no need to ship dirigible fuel to the nodes, decreasing strain on the LOCs that feed the nodes and eliminating the emissions associated with fossil fuel combustion. Furthermore, the exhaust produced by burning hydrogen is water. As noted in para 16, water would be required in some cases to act as ballast. It is possible that the exhaust from a hydrogen fuel cell could be used to help perform this function.

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[36] Defence R&D Canada, *Airships for military logistics heavy lift.* (Ottawa: Centre for Operational Research and Analysis: 2010) accessed 6 February 2021 https://cradpdf.drdc-rddc.gc.ca/PDFS/unc92/p532881.pdf.
[37] Barry E. Prentice and John Wilms, "Cargo Airship Fuel Transport: Canadian Shield Case Study." Canadian Transportation Research Forum. Proceedings Issue: 55th Annual Meeting (2020): 433.
[38] Barry E. Prentice and Robert Knotts, "Cargo Airships: International Competition," *Journal of Transportation Technologies* 4, (2014): 195.
[39] Buoyant Aircraft Systems International "Possibilities as a lifting gas." Accessed 6 February 2021, https://www.buoyantaircraft.ca/hydrogen.php.
[40] Ibid.
[41] International Renewable Energy Agency, "Hydrogen from Renewable Power," accessed 6 February 2021, https://www.irena.org/energytransition/Power-Sector-Transformation/Hydrogen-from-Renewable-Power#.

26. As mentioned in the introduction, the use of hydrogen as a lifting gas (as opposed to using it as a fuel) in Canada is prohibited by Transport Canada's Airworthiness Manual.[42] Currently this leaves helium as the only contender for a lighter than air lifting gas. That said, production of hydrogen fuel at the node sites could be upscaled to produce lifting gas one day should this regulation be revised.

CONCLUSION

27. Sustainment in the arctic even using a single dirigible is feasible. With the hydrogen fuel cell being sought as a propulsion solution for dirigibles used in remote regions for cargo transport, the opportunity exists to conduct sustainment in an environmentally responsible way as well. DND already has an exemption from the transportation of dangerous goods act[43] , meaning it could be possible to trial hydrogen for use as a lifting gas. This would have to be done in concert with an awareness/education campaign designed to dispel the myths about hydrogen's danger as a lifting gas.

RECOMMENDATION

28. The author recommends CJOC work with PSPC to develop a Request for Proposal (RFP) from industry to provide an airship solution to arctic sustainment that includes a renewable fuel source and the establishment of an airship maintenance site in the vicinity of a node. There will need to be a ground crew training component but this does not necessarily need to be performed by a DND member. If the RFP indicates that industry can provide an dirigible solution to DND's arctic sustainment requirements, CJOC will also need to source warehousing space at the nodes it wishes to utilize. Because of the LOC-connectedness of Hay River, this site should be carefully reviewed for suitability as a node. Additionally, because of Moosonee's proximity to Ontario/Quebec, it would also make an ideal site for a node. A dirigible "freight run" between Hay River and Moosonee could be established. Operation NANOOK could act as a testing ground for this capability.

Annex: A. Temperature & Humidity vs. Envelope Deformation

[42] Transport Canada, Part V – *Airworthiness Manual Chapter 541 – Airships* (Ottawa: Canadian Aviation Regulations, 2009), 541.7.
[43] Department of Justice, *Transportation of Dangerous Goods Regulations (SOR/2001-286): National Defence* (Ottawa, 2001), section 1.20

ANNEX A

Temperature & Humidity vs. Envelope Deformation

Adapted from: Buoyant Aircraft Systems International "Cold Weather Testing." Accessed 6 February 2021, https://www.buoyantaircraft.ca/cold-weather-testing.php.

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