Hybrid Air Vehicles for Military Logistics Heavy Lift

In Support of Canadian Forces Northern Operations

A. Ghanmi
CJOC Operational Support Operational Research & Analysis

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Principal Author

Original signed by Ahmed Ghanmi

Ahmed Ghanmi

CJOC Operational Support Operational Research & Analysis

Approved by

Original signed by Isabelle Julien

Isabelle Julien

Section Head, Land, Commands & Readiness

Approved for release by

Original signed by Paul Comeau

Paul Comeau

Chief Scientist, DRDC CORA

Abstract

Hybrid Air Vehicles (HAVs) are airships that combine characteristics of heavier-than-air technology, fixed-wing aircraft, and lighter-than-air aerostat technology. HAVs are being considered by the Canadian Forces (CF) as potential platforms to address deficiencies in military logistics heavy lift, particularly for northern operations. HAVs could provide a cost-effective point-to-point delivery capability and could mitigate several limitations associated with other forms of transport. This paper presents an assessment of the HAV lift performance in support of CF northern operations. A Monte Carlo simulation framework was developed to simulate various lift scenarios in the North using HAVs and conventional aircraft, which indicated that HAVs could potentially improve the CF's logistics lift capability for northern operations. Potential lift cost, response time and greenhouse emission reduction could be achieved using HAVs versus conventional aircraft. From an energy perspective, the use of HAVs for logistics heavy lift would potentially reduce the military operational energy demand due to their payload capacities and fuel consumption efficiency.

Résumé

Les véhicules aériens hybrides (HAV) sont des dirigeables qui combinent les caractéristiques de la technologie propre aux aérodynes, aux aéronefs à voilure fixe et aux aérostats. Les Forces canadiennes (FC) voient les HAV comme des plates-formes potentielles susceptibles de combler les lacunes dans le domaine du transport logistique militaire lourd, notamment pendant les opérations nordiques. Les HAV pourraient offrir un moyen économique de livraison point à point et repousser plusieurs limites inhérentes aux autres formes de transport. Le présent document renferme une évaluation de la capacité d'emport des HAV en appui aux opérations nordiques des FC. Un cadre Monte Carlo a été préparé afin de simuler divers scénarios de transport dans le Nord faisant appel à des HAV et à des aéronefs conventionnels, ce qui a permis de constater que les HAV pourraient éventuellement améliorer la capacité de transport logistique des FC pendant les opérations nordiques. L'utilisation de HAV à la place d'aéronefs conventionnels pourrait se traduire par une possible réduction des coûts de transport, du délai d'intervention et des émissions de gaz à effet de serre. Du point de vue énergétique, le recours à des HAV pour assurer le transport logistique lourd pourrait entraîner une réduction de la demande énergétique opérationnelle militaire, compte tenu de la capacité d'emport et de la meilleure consommation de carburant de ces véhicules.

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Executive summary

Hybrid Air Vehicles for Military Logistics Heavy Lift

In Support of Canadian Forces Northern Operations

Ahmed Ghanmi; DRDC CORA TM 2013-061; Defence R&D Canada – CORA; April 2013.

Introduction

Airships are being considered by the Canadian Forces (CF) as potential charter platforms to address deficiencies in military logistics heavy lift, particularly for northern operations. Airships could provide a cost-effective point-to-point delivery capability and could mitigate several limitations associated with other forms of transport. There are two types of airships, namely conventional airships and Hybrid Air Vehicles (HAVs). Conventional airships are aerostatic vehicles with vertical takeoff and landing capability. Unlike aerodynamic aircraft which produce lift by moving a wing through the air, conventional airships derive their lift from the buoyancy of helium gas contained within their envelope. Although conventional airships have the potential of lifting very large loads and carrying them economically at modest speeds, such operations require relatively large airships, with the attendant problems of structural design and low-speed control. In addition, airships are vulnerable to wind on the ground and have issues with the buoyancy compensation, making them less attractive for northern activities.

Addressing the buoyancy compensation problem of conventional airships is one of the main reasons driving the consideration of HAVs. A HAV is an air vehicle that combines buoyant, aerodynamic and propulsive lift to extend its endurance and payload capacity. The vehicle intended to fill the middle ground between the low operating costs and low speeds of conventional sealift and the higher speed but more expensive heavier-than-air aircraft. By combining dynamic and buoyant lift, HAVs may be able to provide otherwise unattainable air-cargo payload capacity and/or a hovering capability. In addition, use of powered lift during takeoff and landing would minimize ballasting and allow transfer of heavy logistics, landing on unprepared surfaces, and enhanced stability on the ground.

The Canadian Joint Operations Command (CJOC) is considering the possibility of using HAVs for Operations Nanook. The Nanook series of operations are joint, inter-agency sovereignty operations conducted annually by the CF in the North. These exercises are designed to develop and refine the inter-agency relationships that underpin the whole-of-government approach to Arctic sovereignty and enhance CF capability to operate in the challenging Arctic environment.

Objective

The objective of the study is to examine HAVs' capability for military logistics heavy lift in support of CF northern operations for CJOC.

Methodology

Performance measures were developed to assess the cost effectiveness, time responsiveness, and greenhouse emission effectiveness of the HAVs' logistics lift. A Monte Carlo simulation framework was also developed to simulate various lift options in the North using HAVs and conventional aircraft. A case study using a generic deployment scenario in the North and the CF operational hub concept was used to assess the HAV lift effectiveness.

Results

The study indicates that HAVs could potentially improve the CF logistics lift capability for northern operations. Potential lift cost, response time and greenhouse emission reduction could be achieved using HAVs versus conventional aircraft. In particular, up to 70% of the lift cost could potentially be avoided using HAVs for northern operations, depending on the deployment location. The HAV response time would vary from 0.5 to 3 times the aircraft response time. A potential green house emission (up to 50%) could also be reduced using HAVs. However, as the analysis used generic data and theoretical performance characteristics, the results of the HAV performance should be interpreted as indicative estimates. From an energy perspective, the use of HAVs for military logistics heavy lift would reduce the operational energy demand of the CF domestic operations due to their potential payload capacities and fuel consumption efficiency.

Recommendations

Following this study, it is recommended that:

- CJOC consider HAVs for supporting northern operations and exercises once the capability has been demonstrated and certified by Transport Canada. In particular, HAVs could be used to deliver fuel and supplies to CF Station Alert during Operation Boxtop.

- CJOC look for contracting HAVs for the deployment and sustainment lift during Operations Nanook. This would be a great opportunity to test the HAV's lift capability in a northern operational environment and capture performance data and lessons learned.

- CJOC examine HAV's logistics and ground support requirements in the development of future northern operational hubs.

- Further studies be conducted to explore HAVs' capability for other military applications such as high altitude unmanned surveillance, communications relay, intelligence gathering, jamming, and air defence.

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Hybrid Air Vehicles for Military Logistics Heavy Lift

In Support of Canadian Forces Northern Operations

Ahmed Ghanmi; DRDC CORA TM 2013-061; R & D pour la défense Canada – CARO; avril 2013.

Introduction

Les Forces canadiennes (FC) voient les dirigeables comme d'éventuelles plates-formes affrétées qui pourraient servir à combler les lacunes dans le domaine du transport logistique militaire lourd, notamment pendant les opérations nordiques. Les dirigeables pourraient offrir un moyen économique de livraison point à point et repousser plusieurs limites inhérentes aux autres formes de transport. Il existe deux types de dirigeables, à savoir les dirigeables conventionnels et les véhicules aériens hybrides (HAV). Les dirigeables conventionnels sont des véhicules aérostatiques à décollage et atterrissage vertical. Contrairement aux véhicules aérodynamiques qui génèrent leur portance à partir d'une aile qui se déplace dans l'air, les dirigeables conventionnels tirent leur portance de la flottabilité de l'hélium contenu dans leur enveloppe. Bien que les dirigeables conventionnels soient capables de transporter de façon économique des charges imposantes à des vitesses relativement modestes, de telles opérations nécessitent l'utilisation de dirigeables relativement grands, avec tout ce que cela implique au niveau de la conception de leur structure et de leur pilotabilité à basse vitesse. De plus, les dirigeables sont sensibles au vent au sol et souffrent de problèmes de compensation de la flottabilité, ce qui les rend moins intéressants pour des activités nordiques.

La recherche d'une solution au problème de la compensation de la flottabilité des dirigeables conventionnels constitue l'une des principales raisons ayant conduit à s'intéresser aux HAV. Un HAV est un véhicule aérien qui tire sa portance d'une combinaison de moyens aérodynamiques et propulsifs ainsi que de sa flottabilité, ce qui lui permet d'avoir une plus grande autonomie et une meilleure capacité d'emport. Ce véhicule devrait pouvoir constituer un intermédiaire entre les moyens maritimes conventionnels à bas coûts d'exploitation et à basses vitesses, et les moyens aériens classiques plus rapides mais plus coûteux. En tirant leur portance à la fois de moyens dynamiques et de leur flottabilité, les HAV devraient être en mesure d'offrir des capacités d'emport impossibles à atteindre avec d'autres moyens de transport aérien et/ou pouvoir voler en stationnaire. De plus, la portance générée par des dispositifs de propulsion au décollage et à l'atterrissage devrait minimiser les problèmes de lest et ainsi permettre le transfert de lourdes charges logistiques, autoriser les atterrissages sur des surfaces non préparées et améliorer la stabilité au sol.

Le Commandement des opérations interarmées du Canada (COIC) étudie la possibilité d'utiliser des HAV pendant les opérations Nanook, lesquelles sont une série d'opérations de souveraineté interarmées et inter-organisationnelles menées chaque année par les FC dans le Nord. Ces exercices servent à consolider et à peaufiner les relations inter-organisationnelles qui constituent

la base de l'approche pangouvernementale quant à la souveraineté du pays sur l'Arctique et qui permettent aux FC d'apprendre à mieux évoluer dans l'environnement arctique difficile.

Objectif

La présente étude vise à examiner les moyens que pourraient offrir les HAV pour aider au transport logistique militaire lourd pendant les opérations nordiques des FC menées pour le compte du COIC.

Méthodologie

Des moyens de mesure des performances ont été élaborés afin d'évaluer la rentabilité, les gains de temps et la réduction des émissions de gaz à effet de serre qui pourraient résulter de l'emploi de HAV dans des missions de transport logistique. Un cadre Monte Carlo a également été préparé afin de simuler divers scénarios de transport dans le Nord faisant appel à des HAV et à des aéronefs conventionnels. Une étude de cas reposant sur un scénario de déploiement générique dans le Nord et sur le concept de la plaque tournante opérationnelle des FC a servi à évaluer l'efficacité du transport par HAV.

Résultats

L'étude montre que les HAV pourraient améliorer la capacité de transport logistique des FC pendant les opérations nordiques. Une réduction des coûts de transport, des délais d'intervention et des émissions de gaz à effet de serre est envisageable grâce à l'utilisation de HAV à la place d'aéronefs conventionnels. Jusqu'à 70 % des coûts de transport pourraient notamment être évités en utilisant des HAV pendant les opérations nordiques, les économies étant fonction du lieu du déploiement. Les délais d'intervention devraient varier entre 0,5 et 3 fois le délai d'intervention obtenu avec des aéronefs. Il est également permis d'envisager une réduction des émissions de gaz à effet de serre (pouvant aller jusqu'à 50 %) grâce à l'utilisation de HAV. Toutefois, comme l'analyse a fait appel à des données génériques et à des caractéristiques théoriques au niveau des performances, il ne faut voir dans les résultats sur les performances des HAV que des estimations purement indicatives. Du point de vue énergétique, le recours à des HAV pour assurer le transport logistique militaire lourd pourrait entraîner une réduction de la demande énergétique opérationnelle pendant les opérations intérieures des FC, compte tenu de la capacité d'emport potentielle et de la meilleure consommation de carburant de ces véhicules.

Recommandations

À la suite de la présente étude, nous recommandons que :

- Le COIC étudie la possibilité d'utiliser des HAV en soutien aux opérations et aux exercices nordiques, une fois que ce moyen de transport aura été éprouvé et certifié par Transports Canada. Les HAV pourraient notamment servir à ravitailler en carburant et en fournitures la Station des Forces canadiennes Alert pendant l'opération Boxtop.

- Le COIC cherche à louer des HAV pour le déploiement et le maintien de moyens de transport pendant les opérations Nanook. Il s'agirait là d'une belle occasion de tester la capacité d'emport des HAV dans un environnement opérationnel nordique, de recueillir des données sur les performances de ces véhicules et d'en tirer des enseignements.

- Le COIC examine les exigences en matière de logistique et de matériel de servitude au sol nécessaires aux HAV en prévision du développement de futures plaques tournantes opérationnelles.

- D'autres études soient menées afin d'explorer les capacités des HAV dans d'autres applications militaires, comme la surveillance à haute altitude par des véhicules non habités, les relais de communication, la collecte de renseignement, le brouillage et la défense aérienne.

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1 Introduction

1.1 Background

As the economic activity in northern Canada continues to grow, a number of safety, security, and sovereignty issues are expected to emerge. These may influence the nature, frequency, and scale of activities conducted by Canadian authorities in the region. To maintain its sovereignty over the northern region, Canada will need to develop enforcement and surveillance capabilities for the Arctic. From a military perspective, establishing and maintaining an increased federal presence in the North would require future deployments of the Canadian Forces (CF) to address specific scenarios. However, northern operations present unique logistical challenges for the CF due to the remoteness, harsh climate, fragile environment, and sparse population of the region.

To address these challenges, the CF have been developing mitigation strategies for improving the deployability and sustainability of assets in response to potential events in the North. One of the strategies being examined would be the establishment of northern operational hubs. Northern operational hubs are airfields that would be used by the CF to conduct operations and to maintain certain operational support capabilities, such as the ability to pre-position equipment and resources required by contingency plans. These hubs would be primarily used as staging bases for the reception, refuelling, distribution, and onward movement of troops and materiel.

From a transportation perspective, the CF would require an effective logistics heavy lift capability to support the deployment and sustainment of northern operations. While the CF have procured a fleet of four CC-177 Globemaster aircraft for strategic lift, these assets can land in only a few northern airfields due to their runway requirements. In addition, the North lacks a road infrastructure network that can effectively connect the north to the south. Airships are being considered by the CF as potential charter platforms to address deficiencies in military logistics heavy lift, particularly for northern operations. Airships could provide a cost-effective point-to-point delivery capability and could mitigate several limitations associated with other forms of transport. There are two types of airships: conventional airships and Hybrid Air Vehicles (HAVs).

1.1.1 Conventional Airships

Conventional airships are aerostatic vehicles with vertical takeoff and landing capability. Unlike aerodynamic aircraft which produce lift by moving a wing through the air, conventional airships derive their lift from the buoyancy of helium gas (or hydrogen) contained within their external structure, or envelope. Although conventional airships have the potential of lifting very large loads and carrying them economically at modest speeds, such operations require relatively large airships, with the attendant problems of structural design and low-speed control. In addition, airships are vulnerable to wind on the ground and have issues with the buoyancy compensation. Indeed, when an airship takes off with neutral buoyancy the aerostatic lift produced by the helium is equal to the total weight of the vehicle—the combined weight of the structure, payload, and fuel. As fuel is burned en route, however, the total weight of the airship decreases but the aerostatic lift remains the same. If nothing is done, over time the airship will gain significant positive buoyancy. As this is undesirable from both a control and structural viewpoint, the airship must have a mechanism for buoyancy compensation.

For hydrogen-filled airship, the buoyancy compensation is simply achieved by venting excess hydrogen into the atmosphere. This is an acceptable solution as hydrogen is inexpensive and can easily be generated locally. For helium-filled airships, the buoyancy compensation is achieved by condensing and recovering the water from the engine exhaust. While a seemingly appropriate solution to the en route buoyancy compensation problem, the water recovery system is heavy, sometimes unreliable, and the condensers mounted on the skin of the airship add drag. Another aspect of the buoyancy compensation problem occurs when cargo is offloaded at destination. If an airship arrives at a destination with neutral buoyancy and offloads its cargo load, it immediately has excess lift. For an airship in commercial operations, this is addressed by onloading equivalent ballast, either outbound cargo, water, or both, as the inbound cargo is removed. It can be problematic for a military airship however, as there is often no outbound cargo during a build-up at a forward operating base.

1.1.2 Hybrid Air Vehicles

Addressing the buoyancy compensation problem of conventional airships is one of the main reasons driving the consideration of HAVs. The vehicle combines buoyant, aerodynamic and propulsive lift to extend its endurance and payload capacity. The vehicle intended to fill the middle ground between the low operating costs and low speeds of conventional sealift and the higher speed but more expensive heavier-than-air aircraft. By combining dynamic and buoyant lift, HAVs may be able to provide otherwise unattainable air-cargo payload capacity and/or a hovering capability. In addition, use of powered lift during takeoff and landing would minimize ballasting and allow transfer of heavy logistics, landing on unprepared surfaces, and enhanced stability on the ground. With this added flexibility come several penalties. First, because HAVs always operate heavier-than-air (but partially, not like a fixed-wing aircraft), they cannot takeoff or land vertically or hover with heavy payload. Second, because of the induced drag generated by the aerodynamic component of lift, HAVs are less efficient than pure conventional airships. However, they can still be considerably more efficient than airplanes.

The Canadian Joint Operations Command (CJOC) is considering the possibility of using HAVs for Operations Nanook. The Nanook series of operations are joint, inter-agency sovereignty operations conducted annually by the CF in the North. These exercises are designed to develop and refine the inter-agency relationships that underpin the whole-of-government approach to Arctic sovereignty and enhance CF capability to operate in the challenging Arctic environment.

1.2 Objective

The objective of the study is to examine HAVs' capability for military logistics heavy lift in support of CF northern operations for CJOC.

1.3 Literature Review

In the literature, several studies have been conducted to assess the airship lift effectiveness for commercial and military applications. Gazder and Rajkumar [1] conducted a comparative cost analysis of conventional airships and helicopters as alternative modes of passenger transportation in Uttaranchal, India. They developed a methodology for estimation of direct operating costs of airships and helicopters and used two five-seater non-rigid airships and two five-seater helicopters for the analysis. The study indicated that helicopters would have better payload capability at all operating altitudes and lower overall annual operating cost than airships. Indeed, even though airships are much more fuel-efficient than helicopters, their annual operating costs are still significantly higher than helicopters due to the initial investment for ground support infrastructure.

Prentice et al [2] examined the commercial market for airships and discussed the inherent advantages and disadvantages of the airship mode of transportation. They developed an economic model to evaluate the cost effectiveness of heavy lift airships and analyzed two potential airship lift applications: a long-haul airship service for the transport of pineapple and papaya between Hawaii and North America and a short-haul airship service for the transport of goods and passengers to remote northern communities in Canada. The study indicated that airships would be a potential cost-effective mode of transport particularly for logistics heavy lift to remote areas such as northern Canada. Prentice and Thomson [3] conducted an economic evaluation of use of a new generation of cargo carrying airships to support northern mining operations. They developed an economic model to analyze fuel transportation costs for a cluster of mines located in the Canadian Northwest Territories. They considered a generic airship that could carry 84 tonnes of fuel or general freight and conducted a lift cost analysis. The study indicated that logistics lift for northern resources development would be a potential application for which a heavy lift airship could be economically viable, based on reasonable performance assumptions.

For military applications, Newbegin [4] conducted a quantitative analysis of the use of airships for deploying United States (US) Army forces in a theatre of operations. He considered three typical deployment scenarios for the analysis (strategic airlift of an interim brigade combat team to Southeast Asia, strategic airlift of an armoured cavalry regiment to the Middle East, intra-theatre airlift of a Helicopter battalion) and compared the airship lift cost and time with various strategic lift aircraft. The study indicated that while airships have a slight edge in total deployment time, they have an advantage in deployment cost as they burn much less fuel to accomplish the mission. Gordon and Holland [5] conducted a qualitative assessment of the operational requirements and effectiveness of airship strategic lift for deployed operations for the US Air Force. They indicated that airships could potentially be used for strategic and tactical deployment lift of expeditionary operations.

In the Defence Research and Development Canada, Ghanmi and Sokri [6] conducted an operational assessment of the conventional airship lift effectiveness for the CF and examined the operational requirements and the limitations of using airships for military logistics heavy lift in northern Canada. Ghanmi [7, 8] conducted studies to examine the hub concept effectiveness for northern operations and provided insights into the optimal hub locations. Caron et al [9] further extended the work by Ghanmi to include additional scenarios and decision factors in the analysis and selection of effective northern hub locations.

1.4 Methodology

This study is a further examination of the logistics lift requirements for CF northern operations combining the HAV lift capability and the operational hub concept. Performance measures were developed to assess the cost effectiveness, time responsiveness, and greenhouse emission effectiveness of the HAVs' logistics lift. A Monte Carlo simulation framework was also developed to simulate various lift options in the North using HAVs and conventional aircraft.

1.5 Report Organization

The paper is organized as follows: Section 2 discusses technical characteristics of several promising HAV prototypes and examines the operational performance of the HAV lift capability. Section 3 develops performance measures for analyzing the HAV lift effectiveness and Section 4 presents a quantitative assessment of the HAV lift for northern operations. Concluding remarks and recommendations for future work are found in Section 5.

2 Hybrid Air Vehicles

In this section, different HAV prototypes are presented for illustration purposes. Key operational characteristics of the HAV lift are also examined.

2.1 HAV Prototypes

Promising HAV prototypes presented in the Cargo Airships for Northern Operations Workshop[1] are examined, including: *Aeroscraft, DynaLifter, HAV-366, ARH-50,* and *ATLANT-100.* Details about these prototypes are extracted from promotional material.

2.1.1 Aeroscraft

The Aeroscraft prototype (Figure 1) is a variable buoyancy air vehicle being developed by Aeros, a California-based Corporation. The vehicle uses a combination of aerodynamic and aerostatic principles to remain airborne. Approximately two-thirds of the craft's lift is provided by helium gas. The remaining lift is provided by the forward thrust of the craft's propellers, in combination with its aerodynamic shape and its canards (forward fins) and empennage (rear fins). The Aeroscraft has also six downward-pointing turbofan jet engines for vertical take-off and landing.

The vehicle operates off a dynamic buoyancy management system which controls and adjusts the buoyancy of the vehicle, making it light or heavy for any stages of ground and flight operation. Automatic flight control systems give it equilibrium in all flight modes and allow it to adjust helium pressurized envelopes depending on the buoyancy requirements. It has an internal ballast control system, which allows it to offload cargo, without using ballast. Built with a rigid structure, the Aeroscraft can control lift at all stages with its Vertical Takeoff and Landing capabilities and carry maximum payload (about 60 tonnes) while in hover.

Figure 1 Aerscraft prototype

[1] http://event.arc.nasa.gov/airships/index

2.1.2 DynaLifter

The DynaLifter prototype (Figure 2) is a semi-buoyant cargo hybrid air vehicle developed by the Ohio Airship Inc. It uses helium to achieve 50% of its lift; the remaining lift will be provided by four wings and propellers. Inside the prototype is an aluminum spine running its length and two patented tower-like structures that support the spine, wings, gas-powered engines, cockpit, and landing gear, and lend stability to the design. Helium stored in bags use up one third of the vehicle's interior. The DynaLifter has a payload capacity of 160 tonnes and can travel at up to 160 km/h. Key technical features of the DynaLifter are:

- Heavier than air
- Takeoff and land like an aircraft (i.e., wheels on a runway)
- Hull is integrated with wing for dynamic lift generating
- Patented structure allows aircraft and airship integration
- Large cargo bay/ large useful gross weight capability
- Patented structure allows concentrated loading of cargo
- Short takeoff and landing capability
- All weather ruggedness
- Long range/ persistent loitering

The DynaLifter will require a runway to land and takeoff, making it less flexible for employment in the North and other austere environments.

Figure 2 DynaLifter prototype

2.1.3 HAV-366

The HAV-366 prototype (Figure 3) is a 50-ton hybrid air vehicle developed by the United Kingdom (UK) Hybrid Air Vehicles Corporation. The vehicle is planned to enter to service in 2014 and intended for the local mining and natural resources markets in northern Canada. The CF is planning to use HAVs for Operation Nanook 2015 and this prototype would be a potential capability for this exercise.

The vehicle design includes a number of aerodynamic technologies involving:

- Construction hull technology with a superheat buoyancy control system
- Vectored thrusts
- Composite structures
- Fly-by-light flight control systems
- Turbine propulsion system
- Lifting body hulls
- Hover cushion landing system

The envelope is made of laminated fabric construction hull with an internal catenary system supporting the payload module. The hull's aerodynamic shape, an elliptical cross-section allied to a cambered longitudinal shape, provides up to 40% of the vehicle's lift. The internal diaphragms required to support this shape allow for a limited amount of compartmentalization further enhancing the fail-safe nature of the vehicle. Multiple ballonets located fore and aft in each of the hulls provide pressure control. Hover skirts on the underside of the two outer hulls of the vehicle provide an enhanced ground handling capability. Hover skirts are 'sucked-in' for a clean-in-flight profile and enhanced all-round visibility.

Figure 3 HAV-366 prototype

2.1.4 ARH-50

The ARH-50 prototype (Figure 4) is a 50-ton cargo hybrid air vehicle developed by the UK VariaLift Airships Corporation. The vehicle has a variable lift with controlled buoyancy air transport system. Key technical features of the ARH-50 include:

- Aluminum rigid hull
- Vertical takeoff and landing
- Operates in strong front & cross wind conditions
- Does not require airport infrastructure and ground crew
- Operates on any flat space
- Uses 80% - 90% less fuel than equivalent aircraft
- Flies at 250 – 350 km/h
- Costs 80% less than of an equivalent load aircraft to purchase and operate
- Lowers air transport greenhouse emissions by 80-90%
- Has 40 years work life
- Further configurations with larger payloads are being investigated

The ARH-50 prototype testing was completed in November 2011, when the test flight was successfully conducted with the unit lifting off the ground under full control using its variable buoyancy units.

Figure 4 ARH-50 prototype

2.1.5 ATLANT-100

The ATLANT-100 prototype (Figure 5) is a cargo hybrid air vehicle concept developed by Augur RosAerosSystems – a Russian aerospace corporation. The vehicle has a maximum payload of 60 tonnes and is planned to enter in service in 2017. Key technical features of this concept include:

- Rigid shell structure allowing hangarless operations at strong side winds
- Non-ballast loading and discharge
- 60% – 100 % of lift by means of buoyancy
- Ability to land on ice, water, and unprepared sites without ground operations
- Ability to withstand strong winds while moored
- Up to 200 km/h speed
- Vectored thrusts
- Active ballasting system in flight using Phlegmatized hydrogen (i.e., additives in hydrogen that can suppress explosions in a closed volume). This system improves the fuel economy and range and the vehicle.

Like many of the airship companies, the RosAerosSystems corporation has identified the northern regions as well as other austere environments as key market areas. In addition to the HAV-366, the ALTANT-100 would be a potential capability for consideration in Operation Nanook as they are more advanced in their development than the other prototypes.

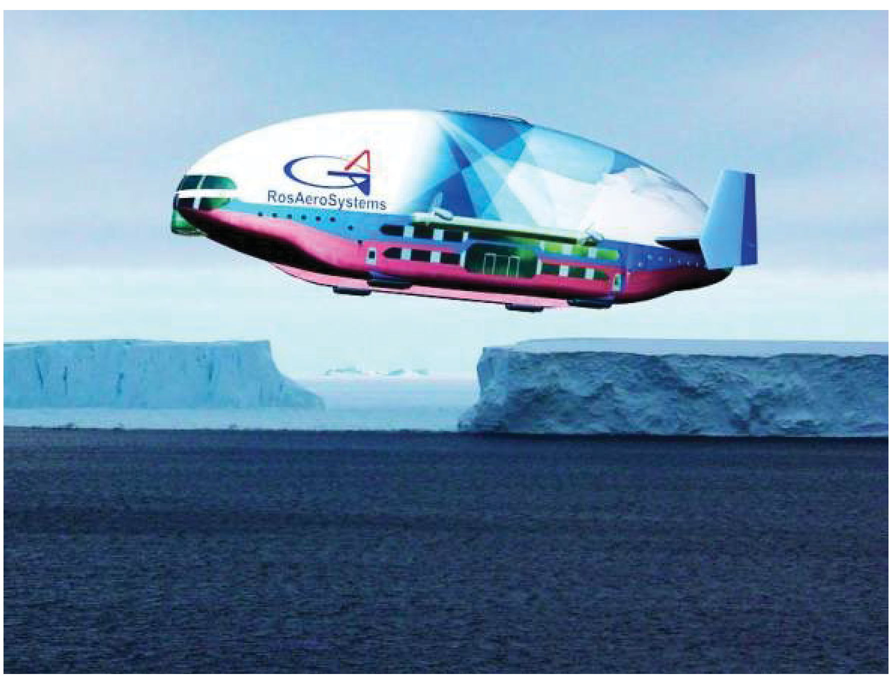

Figure 5 ATLANT-100 prototype

2.2 Operational Characteristics

Several operational characteristics of the HAV lift in northern environments are discussed, including operational economics, environmental impact, operational vulnerability, and operational requirements.

2.3.1 Operational Economics

Despite the lack of reliable HAV lift performance data (prototype models are currently under development and their operational parameters are estimated using computer simulations), various studies [1-5] tend to indicate that they could have significant economies of scale due to their potential payload capacities and their fuel consumption efficiency. Indeed, HAVs could contribute almost 30 – 40% of their gas dead-lift to cargo (lighter structures require less lift) [5]. To compare the operational economics of different transport assets, one could use the lift cost ratio ($/km×tonne). The lift cost ratio is defined as the ratio of the lift cost rate ($/hour) to the speed (km/h) times the payload (tonne) of the asset. Table 1 presents the lift cost ratios of selected transport aircraft (CC-177 Globemaster, Antonov 124 (AN-124), Ilyusin 76 (IL-76), CC-130 Hercules) and HAV-366 prototype (as example). The payloads used for the aircraft are operational figures, which are usually smaller than the theoretical payloads due to various operational conditions. The lift cost rates of the AN-124 and IL-76 aircraft are based on historical charter rates whereas the lift cost rates of the CC-177 and CC-130 are based on the CF cost factors manual. The lift costs of the HAVs are indicative estimates. Depending on the vehicle configuration, the lift cost ratio of HAVs would be between the lift cost ratios of the CC-177 and the AN-124 aircraft.

Table 1 Lift cost ratios of selected transport assets.

Transport Asset	**Payload (tonne)**	**Speed (km/h)**	**Lift Cost Rate ($/h)**	**Lift Cost Ratio ($/tonne × km)**
CC-177	60	700	30000	**0.48**
CC-130	16	550	12000	**1.36**
AN-124	80	700	50000	**0.89**
IL-76	30	600	20000	**1.11**
HAV-366	50	180	7000	**0.78**

2.3.2 Environmental Impact

HAVs are anticipated to be fuel-efficient and to produce less greenhouse gas emissions than conventional aircraft as an important fraction of their static lift is provided by the buoyancy of the helium gas. In addition, due to the large surface area of the HAV envelope, the potential to utilize photovoltaic solar energy systems to augment the vehicle power can further reduce emission and lower operating costs. The environmental impact of HAVs could be assessed using the greenhouse effect index – a quantitative parameter for analyzing the relative environmental pollution associated with various greenhouse gases [10]. Taylor [11] indicates that HAVs could potentially have a greenhouse effect index three to five times less than conventional aircraft. Figure 6 shows the existing technology level and expected future improvements in fuel consumption, greenhouse gas emissions, and productivity for both hybrid and fixed-wing aircraft [11]. Hybrid aircraft have lower greenhouse gas emissions because they consume less fuel and operate at a lower altitude.

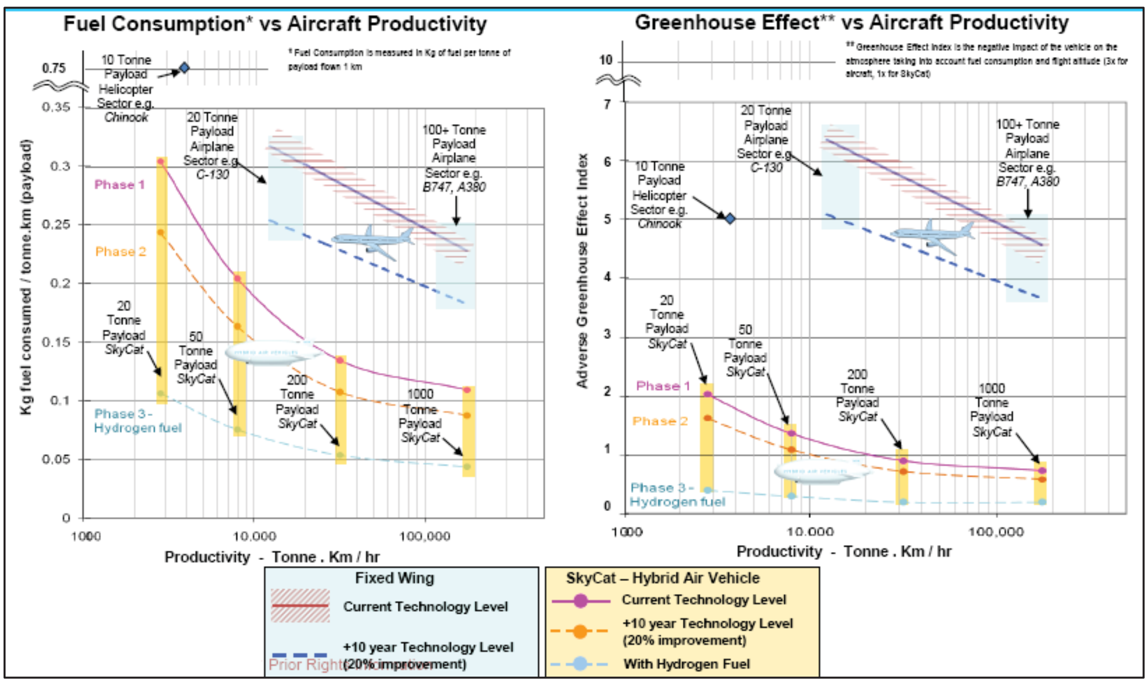

Figure 6 Fuel consumption and greenhouse effect for selected transport assets [11].

2.3.3 Operational Vulnerability

The vulnerability of a HAV to a hit would be higher than an aircraft as it would normally fly at a relatively low speed and at an altitude that is within reach of many surface-to-air weapons, except for small arms. However, because of its size and its lower speed, the HAV might be able to land under some control after a hit. Indeed, because of the low pressure of the lifting gas, the rate of exchange between the helium and the ambient air would not prevent the vehicle from completing its mission. For a domestic context, the use of HAVs in northern operations would have unlikely risk of military threats.

For northern operations, the greater concern is the impact of weather on HAV utilization. Strong headwinds and routings to avoid severe weather will require more fuel and reduce the vehicle effectiveness. Like all forms of transport, severe weather will also limit the operating window for HAVs and affect ground handling. Using historical environmental data (e.g., temperature, snow, wind speed, storms, etc.) at various northern locations, Sklar [12] indicated that "HAVs could generally operate under Arctic weather conditions for almost 10 months (excluding January and February)". The operational performance of HAVs could also be affected by the increase in ambient temperature. Dexter [13] indicated that "temperatures above standard temperature (e.g., -16°C at 4.8 km altitude) would have an adverse effect on buoyancy, since at higher temperatures, the expansion of the surrounding air is more pronounced than for helium". Typically, buoyancy is lowered by 1% for every 2.7°C rise above standard temperature due to expansion of air and helium [13]. However as HAVs combine both static and dynamic lift, their operational performance would unlikely be affected by the increase of ambient temperature. On the other hand, while colder temperatures generally impose greater stresses on all transportation equipment, HAVs do benefit from greater lift as the density of air increases.

2.3.4 Operational Requirements

Unlike an airplane, a HAV does not require a runway to takeoff and land and does not have crosswind limits. Relative to other modes of transport, a HAV would have a comparative advantage when operating across rougher terrains with less developed surface transport infrastructure, and where intermodal transfers occur (i.e., HAVs can land anywhere and would require less intermodal transfers) [2]. However, higher mountain ranges would impose some limitations on HAV routes as they fly at low altitudes compared to an aircraft flight ceiling. In contrast with a traditional airship which requires a large landing zone (500 - 1500 m radius depending on the vehicle load), a HAV requires comparatively a smaller landing zone (as it has a smaller footprint than a traditional airship). In addition, a HAV does not require ground handling systems to address the buoyancy compensation problem.

Similar to conventional aircraft, in-flight icing of HAVs would be addressed by a number of anti-icing and de-icing measures. Ice accumulation while the HAV is parked on the ground could be challenging as the vast area of the envelope means even a thin coating of ice would have significant weight. Conventional de-icing by truck would not be feasible because of the vehicle size. A mechanism could be included in the vehicle design to disperse anti-icing solution over the envelope. This would also include de-icing systems guard against icing and snow through electrically heated pilot tubes, fluid de-iced propulsor, and hull envelope [14].

3 Performance Measures

In this section, performance measures were developed to assess the effectiveness and the responsiveness of the HAV lift for northern operations. The main measures of effectiveness for a logistics transportation system are the cost effectiveness and the time responsiveness. The cost effectiveness refers to the optimal use of transportation assets, whereas the time responsiveness is related to the speed of logistics distribution. The cost avoidance is defined as the lift cost that could potentially be avoided using HAVs instead of the conventional aircraft. On the other hand, the HAV lift responsiveness is assessed using the response time measure. Response time is defined as the total time required for the logistics lift from the origin to the destination. As HAVs are inherently fuel efficient and would have low greenhouse gas emissions, a carbon emission avoidance measure is used to assess the HAV environmental effects. The carbon emission avoidance is defined as the quantity of greenhouse gas emissions that could potentially be avoided using HAVs instead of the conventional aircraft. These performance measures are developed for a deployment scenario using the northern operational hub concept.

3.1 Northern Deployment Scheme

To improve its deployability in the Arctic, the CF has been developing an operational hub concept for northern scenarios. Northern operational hubs are airfields that would be used by the CF to conduct operations and to maintain certain operational support capabilities, such as the ability to pre-position equipment and resources required by contingency plans. These hubs would be primarily used as staging bases for the reception, refuelling, distribution, and onward movement of troops and materiel.

Using the current transport approach, the logistics lift for the CF northern operations would be conducted using a strategic lift aircraft (e.g., CC-177) from an airport of embarkation (APOE) to an airport of disembarkation (APOD), followed by a tactical lift to the final destination using a utility transport aircraft (e.g., CC-138 Twin Otter). It is assumed that the utility aircraft will be deployed from their main base to the APOD in order to conduct the tactical logistics lift and will return to the main base at the end of the lift. The northern operational hubs would be used as APODs for transshipment between strategic and tactical lift.

With HAVs, the logistics lift could be conducted directly from an APOE to the final destination in theatre. Great circle distances were used to estimate the transport time for both the HAV and the aircraft, neglecting issues such as weather conditions, etc. Depending on the travel distance and the asset range, at most one refuelling stop may be required to service some areas of the North. As the cost and time for a single refuelling stop are small compared to the overall cost and time of the logistics lift, refuelling costs and times are not considered in this study.

Figure 7 depicts an example of deployment scheme in the North for illustration purposes. The dots represent the APODs that could also be potential refuel locations. In this example, the CC-138 aircraft deploy from Yellowknife to Resolute Bay to conduct tactical airlift. The CC-177 aircraft conduct strategic lift from Trenton to Resolute Bay whereas HAVs deploy directly from Trenton to the theatre of operations.

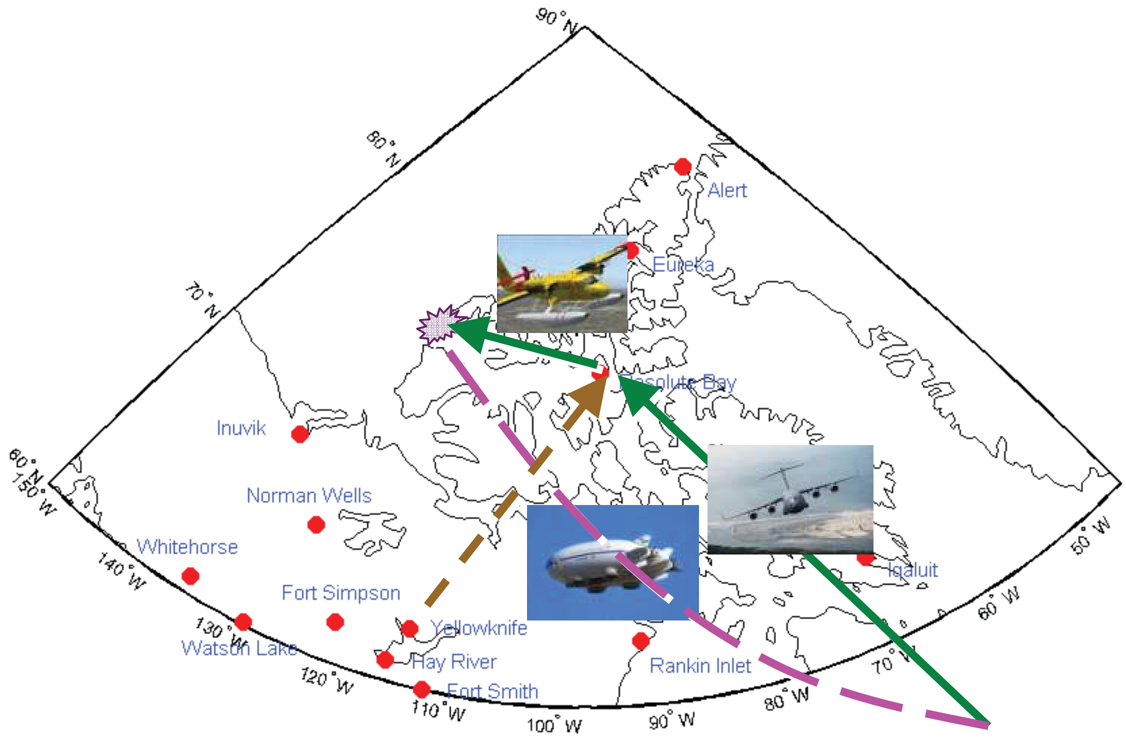

Figure 7 Example of deployment scheme in the North.

3.2 Cost Avoidance

The cost avoidance metric is formulated as follows. Given a list of APOEs and a list of APODs, consider the movement of a quantity of supplies to a given destination in northern Canada using a lift asset x ($x = s$ for strategic lift aircraft, $x = t$ for tactical utility aircraft, and $x = a$ for HAV). Let n_x be the number of sorties of asset x, v_x its cruise speed (km/h) and r_x its flying rate ($/h). Let d_{ij} be the great circle distance between APOE i and destination j, d'_{ik} the great circle distance between APOE i and APOD k, and d''_{kj} the great circle distance between APOD k and destination j.

Using the current transportation approach, the total lift cost (R_{ijk}) for the movement of a quantity of supplies from APOE i to destination j through APOD k is the sum of the strategic lift cost from APOE i to APOD k, the tactical lift cost from APOD k to destination j and the lift cost for the tactical utility aircraft to reach APOD k from its main base (round trip):

$$R_{ijk} = 2 n_s r_s \frac{d'_{ik}}{v_s} + 2 n_t r_t \frac{d''_{kj}}{v_t} + 2 r_t \frac{d_k}{v_t}, \tag{1}$$

where d_k is the distance between the utility aircraft main base and APOD k. Note that the additional distance required to reach refuelling stops (particularly for the CC-138 aircraft) is not included in equation 1. The minimum lift cost to destination j (R_j^*) is given by:

$$R_j^* \quad = \quad \min_i \left(\min_k \left(R_{ijk} \right) \right). \tag{2}$$

For the HAV lift, the total lift cost from APOE i to destination j (A_{ij}) can be formulated as follows:

$$A_{ij} \quad = \quad 2 n_a r_a \frac{d_{ij}}{v_a}\,, \tag{3}$$

and the minimum airship lift cost to destination j (A_j^*) is given by:

$$A_j^* \quad = \quad \min_i (A_{ij})\,. \tag{4}$$

The relative cost avoidance for the airlift to destination j (Z_j) is given by:

$$Z_j\,(\%) \quad = \quad \frac{R_j^* \; - \; A_j^*}{R_j^*} \times 100\,. \tag{5}$$

3.3 Response Time

To calculate the response time for the current transportation approach, it is assumed that the tactical utility aircraft is already available at the APOD before the strategic lift aircraft arrives to the APOD in the first sortie (i.e., an early deployment notice would be given to the tactical aircraft for positioning at the APOD). The response time is the sum of the total tactical lift time and the strategic lift time for the first sortie. Let ℓ_x be the loading time (hours) of asset x and u_x its unloading time (hours). The response time (T_{ijk}) from APOE i to destination j through APOD k using the current transportation approach can be formulated as follows (assuming that the next CC-177 flight will arrive to the APOD before the CC-138 has transferred all the cargo):

$$T_{ijk} \;=\; \ell_s + u_s + \frac{d'_{ik}}{v_s} + n_t \left(\ell_t + u_t + 2\frac{d''_{kj}}{v_t} \right) - \frac{d''_{kj}}{v_t}\,, \tag{6}$$

and the minimum response time (T_j^*) to destination j is given by:

$$T_j^* \quad = \quad \min_i \left(\min_k \left(T_{ijk} \right) \right). \tag{7}$$

For HAVs, the response time (t_{ij}) from APOE i to destination j is given by:

$$t_{ij} = n_a\left(\ell_a + u_a + 2\frac{d_{ij}}{v_a}\right) - \frac{d_{ij}}{v_a}, \tag{8}$$

and the minimum response time (t_j^*) to destination j using an airship is given by:

$$t_j^* = \min_i \left(t_{ij}\right). \tag{9}$$

As with the relative cost avoidance, the relative response time was also used to compare the airship lift capability with the current transportation approach. The relative response time is the ratio of the aircraft lift response time to the HAV lift response time.

3.4 Carbon Emission Avoidance

Let f_x be the fuel consumption rate (kg/hour) and e_x be the carbon emission rate (kg/hour) of a lift asset x. The carbon emission rate is the average weight of greenhouse gas emitted by the asset per flying hour and is related to the fuel consumption rate as follows[2] (assuming that the same type of fuel is consumed by all assets involved):

$$e_x = 3.15 \times f_x. \tag{10}$$

The carbon emission avoidance metric is the difference between the weight of greenhouse gas emitted by the current transportation approach and the weight of greenhouse gas emitted by an airship. It can be formulated similarity to the cost avoidance formulation but using the carbon emission rate (e_x) instead of the airlift rate (r_x) in the cost avoidance equations. A relative carbon emission avoidance factor is also calculated in the same manner as the relative cost avoidance.

[2] www.carbonindependent.org

4 HAV Lift Performance Analysis

This section presents the data and the scenario used to analyze the HAV performance for military logistics heavy lift in support of Northern operations and discusses the analysis results.

4.1 Deployment Scenario

To analyse the HAV lift performance, a generic deployment scenario to a given northern location was considered. The scenario operational demand (i.e., quantity of supplies required per sustainment period) was estimated using the historical Operation Boxtop [6] sustainment flights. Operation Boxtop is the resupply operation for the CF Station Alert. A nominal operational demand of 100 tonnes (approximately 35 pallets) was assumed for the scenario. For the purpose of the study, the northern Canada region was divided into a large number of grid cells, with the centre of the grid cell being the deployment location.

Two potential APOEs (the main aircraft bases of Trenton and Edmonton) were assumed for the analysis. A generic 50-tonne HAV was used to simulate the HAV lift and a combination of one CC-177 aircraft and one CC-138 aircraft (currently based in Yellowknife) to simulate the current transportation approach. For the purpose of this analysis, the HAV-366 was selected to demonstrate the methodology. Table 2 depicts the performance characteristics and the lift cost rates of the selected lift assets. For the aircraft, planning factors (obtained from the cost factors manual[3]) were used to estimate the lift cost and the fuel consumption rates. The aircraft technical and operational parameters (payload capacity, speed, loading and unloading times) were determined from the aircraft technical specifications. The performance characteristics of the HAV-366 were obtained from the vehicle manual. They are based upon computer simulations and do not represent historical experience under real world conditions. A Monte Carlo simulation model was developed to represent the stochastic variations of the scenario parameters. A 10% variation was considered for all model variables.

Table 2 Performance characteristics and lift cost rates of selected transport assets.

Asset	Payload (tonne)	Loading time (h)	Unloading time (h)	Cruise Speed (km/h)	Lift Cost Rate ($/h)	Fuel Consumption Rate (kg/h)
CC-177	60	2	2	700	30,000	8000
CC-138	3	0.5	0.5	265	1,200	260
HAV-366	50	1.5	1.5	180	7,000	4000

[3] http://admfincs.mil.ca/subjects/fin_docs/cfm_09/cfm09_e.asp

4.2 Northern Operational Hubs

Canada's North covers a huge area roughly equivalent to the size of Europe. Although sparsely populated, it includes many airfields that could be used as forward operational bases. However, many of these airfields cannot receive some of the bigger and heavier military aircraft, and those that can accommodate these assets may only be able to do so on a seasonal basis due to runway thaw and weather conditions. The lack of infrastructure at many airfields also prevents prolonged operations from them. Since the cost of developing new infrastructure in the Arctic can be prohibitive, any airfield potentially designated as a hub must already exist and meet minimum requirements for a set of CF platforms.

For the purpose of the analysis, 13 illustrative airfields were selected as potential operational hubs in the North as shown in Figure 8; they do not necessarily reflect the likelihood of their future use by the CF. The choice of airfield was determined largely by the requirement that the runway be sufficiently long and strong to accommodate the CC-177 aircraft. It should be noted that the airfields at Resolute, Eureka and Alert will require development and remediation before the CC-177 can be accommodated.

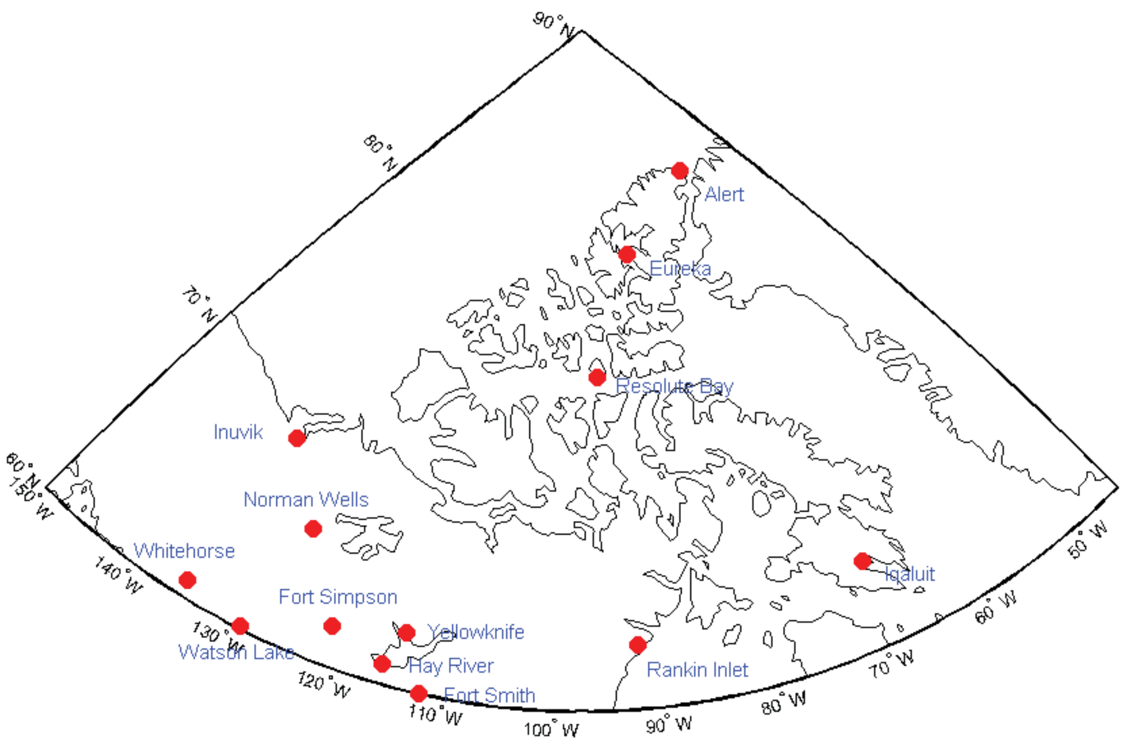

Figure 8 Potential northern operational hubs

4.3 Cost Avoidance Analysis

Logistics lift was simulated for the baseline case and performance measures were collected for a large number of simulation runs (e.g., 100000). Figure 9 presents the expected relative cost avoidance distribution and indicates that potential savings (up to 60%) on the lift cost could be realized using HAVs. The minimum cost avoidance (less than 20%) is observed at locations around the operational hubs. The relative cost avoidance increases as the distance from the hubs increases due to the tactical airlift costs. Indeed, due to the large number of sorties of CC-138, the tactical airlift cost would be the most expensive portion of the lift, particularly for locations distant from the hubs. Examination of Figure 9 indicates three potential regions of relative cost avoidance as follows:

- Regions with low relative cost avoidances (0% - 20%). They generally represent locations that require tactical airlift for relatively short distances from the hubs (e.g., < 300 km). The HAV lift cost for these regions is comparable to the aircraft lift.

- Regions with medium relative cost avoidances (20% - 40%). These regions generally represent locations within a medium range from the hubs (e.g., 300 – 1000 km). The HAV lift for these regions is more cost-effective but the total amount of savings is not significant.

- Regions with high relative cost avoidances (greater than 40%). These regions generally represent locations that require tactical airlift for relatively long distances from the hubs (e.g., > 1000 km). The HAV lift for these regions is more cost-effective than the aircraft lift.

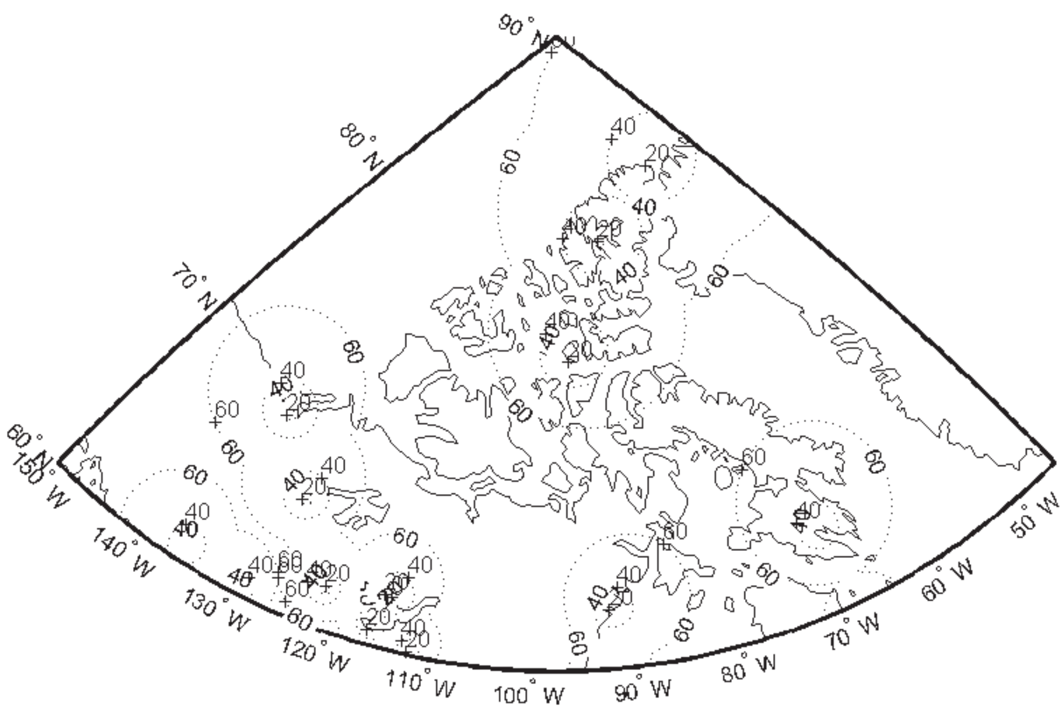

Figure 9 Relative cost avoidance distribution

4.4 Response Time Analysis

Figure 10 depicts the iso-relative response time distribution of the HAV lift. It indicates that the aircraft response time varies from 0.5 to 3 times the HAV response time, depending on the location. The response time calculation does not include refuelling service times and the time required for the HAV to reach a refuelling stop. As the range of the HAV is about 3000 km at full load, at most one refuelling stop would be required for some deployment locations (return flights would not require refuelling as the HAV could carry additional fuel to extend their range). The time for a single refuelling stop would be small compared to the overall lift time.

The minimum relative response time (less than 1.0) is observed at the hub locations. In this case, the tactical airlift time is null and the HAV response time would be greater than the aircraft response time. As the distance from the hubs increases, the relative response time increases because of the increased tactical airlift time and the HAV lift becomes more time-effective than the aircraft lift. In particular, for some remote locations the HAV response time would be three times less than the aircraft response time. However, if two tactical lift assets were used instead of one, this ratio would be much lower.

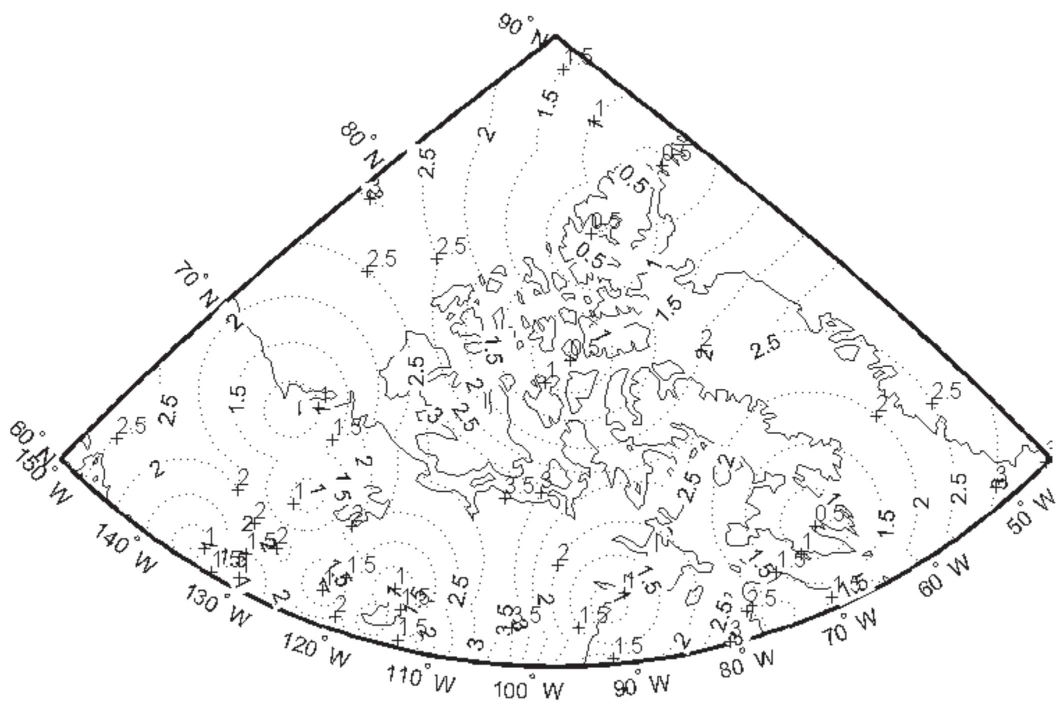

Figure 10 Relative response time distribution

4.5 Carbon Emission Avoidance Analysis

The carbon emission avoidance determines the quantity of greenhouse gas emissions that could potentially be avoided when using HAV for military logistics heavy transport. To simulate the quantity of greenhouse gas emitted by the different transport assets, the carbon emission rate was used in the simulation framework instead of the airlift cost rate. Figure 11 presents the expected relative carbon emission avoidance distribution and indicates that significant quantity of greenhouse gas emissions (up to 50%) could potentially be avoided by using the HAV lift instead of the current transportation approach for northern operations. As both the airlift cost rate and the carbon emission rate are proportional to the fuel consumption rate, the carbon emission avoidance and the relative cost avoidance distributions show similar patterns. A close examination of Figure 11 indicates three potential regions of carbon emission avoidance:

- Regions with low relative carbon emission avoidances (0% - 20%). They generally represent locations that require tactical airlift for relatively short distances from the hubs (e.g., < 300 km). The HAV carbon emission for these regions is comparable to the aircraft carbon emission.

- Regions with medium relative carbon emission avoidances (20% - 40%). These regions generally represent locations within a medium range from the hubs (e.g., 300 – 1000 km). As the carbon emission rate of the CC-138 is much smaller than the carbon emission rates of the HAV and the CC-177 aircraft, the carbon emission of HAV lift for these locations is not significantly different from the aircraft carbon emission.

- Regions with high relative carbon emission avoidances (greater than 40%). These regions generally represent locations that require tactical lift for relatively long distances from the hubs (e.g., > 1000 km). In this case, the aircraft carbon emission would be much greater than the HAV carbon emission due the distance travelled by the tactical lift.

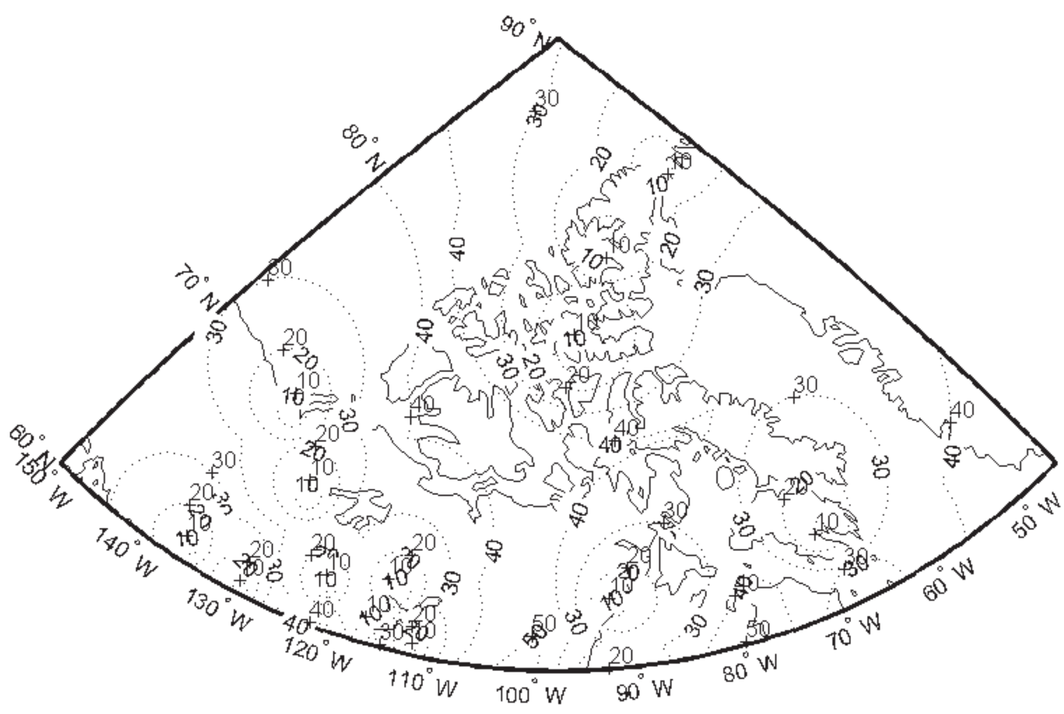

Figure 11 Relative carbon emission avoidance distribution

4.6 Discussions

The analysis was conducted using a generic scenario with nominal operational data and theoretical HAV performance characteristics. Therefore, the results of the HAV performance should be interpreted as indicative estimates. Further analysis with real operational performance data should be conducted in the future to confirm and validate these results. CJOC is considering the possibility of using HAVs for sustainment lift during Operation Nanook (an annual military exercise in the North) in 2015 once the capability has been demonstrated and certified by Transport Canada. This would be a great opportunity to test the HAV lift capability and collect performance data.

In the study, a nominal operational demand of 100 tonnes was used to analyze the HAV effectiveness and responsiveness. While this demand was selected randomly to demonstrate the methodology, a sensitivity analysis should be conducted to further examine the effectiveness of HAVs with different scenario demands. In addition, a payload of 60 tonnes was considered for the CC-177 aircraft. It is important to note that the operational payload of the CC-177 aircraft would vary from 40-60 tonnes, depending on the operation environment. For example, historical CC-177 loads for Operation ATHENA in Afghanistan were about 50 tonnes (on average), which are comparable to the HAV-366 payload. Therefore, using a nominal demand of 100 tonnes in the analysis would not necessarily favour the HAV-366 (with a payload of 50 tonnes). Furthermore, the big advantage of the HAV-366 over the CC-177 is not in the strategic lift but in the tactical lift. Indeed, the HAV-366 provides point-to-point delivery services to any location in the North whereas with the CC-177 aircraft tactical lift is required for most locations (an expensive operation). Even with an extreme case scenario (e.g., 180 tonnes) requiring three CC-177 aircraft sorties (or four HAV-366 sorties), the HAV-366 lift would be more cost-effective for most locations far from the APOD.

The author has already conducted a preliminary analysis on the airship lift performance for Northern operations [6]. The study recommended that the CF should consider airship technologies to address deficiencies in logistics transportation to support Northern operations and should examine the different options for contracting airship services, including long term lease and time charter options, which requires a better understanding and analysis of future logistics lift requirements. Compared with the airship analysis, the HAV performance analysis shows different distributions of lift cost avoidance, response time and greenhouse emission. Indeed, the HAV analysis used a different set of northern operational hubs (revised number and locations of potential northern hubs) than the airship analysis. However, both assets would in general provide significant reduction in lift cost, response time and greenhouse emission with respect to the current transportation approach.

In the model, the response time calculation did not include the additional time required to reach refuelling stops. However, there might be some cases where a significant detour would be required for HAVs to reach a refuel point. To take into consideration potential detours, the model could be modified to include a distance multiplying factor in equation 6 to adjust the total distance travelled by HAVs. In addition, while variation in loading and unloading times would not have significant impact on the HAV and the CC-177 lift times (small number of sorties), the tactical lift time would be sensitive to the loading and unloading times (large number of sorties), depending of the deployment location. One option for reducing the tactical lift time would be using two or more CC-138s to shuttle between the APOD and destination. While this option would have significant impact on the total response time it would reduce the operational availability of the CC-138 fleet and would not improve the cost effectiveness. Other options to consider could include changing the basing of the CC-177 (e.g., Yellowknife) or the CC-138 (e.g., more than one base). However, the benefits of these changes would not be enough to make a difference.

The examination of the fuel consumption rates of the CC-177 aircraft and the HAV-366 (shown in Table 2) indicates that the CC-177 would be more efficient than the HAV-366. However, the HAV-366 can still perform better by going straight to the destination and avoiding the requirement for CC-138s. In addition, the lift cost rate of the aircraft and the HAVs includes not only the cost of fuel but also other important costs (maintenance, operations and support, etc.), which would be much cheaper for HAVs. In summary, HAVs would particularly be more effective than aircraft for destinations that require both strategic and tactical lift operations.

In the analysis, while the response time for transferring the entire cargo by the HAV-366 is often shorter than the response time with a combination of CC-177 and CC-138, the time of arrival of the first 3-tonne portion of the load is usually much shorter using the aircraft than the HAV. In many scenarios, the first load could allow things to get started at destination, with the rest of the cargo perhaps not necessary until later. The flow of cargo over time would be another important measure of effectiveness for consideration in future work.

5 Conclusions and Recommendations

This paper examines HAVs' capability for military logistics heavy lift in support of CF northern operations. HAVs provide faster point to point lift capability, consume significantly less fuel than conventional aircraft, and do not require robust ground support infrastructure. In this study, an analysis was conducted to assess the cost effectiveness, time responsiveness, and greenhouse emission effectiveness of the HAVs' logistics lift. A Monte Carlo simulation framework was also developed to simulate various lift options in the North using HAVs and conventional aircraft. A case study using a generic deployment scenario in the North and the CF operational hub concept was used to assess the HAV lift effectiveness.

The study indicates that HAVs could potentially improve the CF logistics lift capability for northern operations. Potential lift cost, response time and greenhouse emission reduction could be achieved using HAVs versus conventional aircraft. In particular, up to 70% of the lift cost could potentially be avoided using HAVs for northern operations, depending on the deployment location. The HAV response time would vary from 0.5 to 3 times the aircraft response time. A potential green house emission (up to 50%) could also be reduced using HAVs. However, as the analysis used generic data and theoretical performance characteristics, the results of the HAV performance should be interpreted as indicative estimates. From an energy perspective, the use of HAVs for military logistics heavy lift would reduce the operational energy demand of the CF domestic operations due to their potential payload capacities and fuel consumption efficiency.

Following this study, it is recommended that:

- CJOC consider HAVs for supporting northern operations and exercises once the capability has been demonstrated and certified by Transport Canada. In particular, HAVs could be used to deliver fuel and supplies to CF Station Alert during Operation Boxtop. Although the CC-177 seems to be more cost-effective than HAVs for destinations close to APODs, use of HAVs for Operation Boxtop would increase the CC-177's availability.

- CJOC look for contracting HAVs for the deployment and sustainment lift during Operations Nanook. This would be a great opportunity to test the HAV's lift capability in a northern operational environment and capture performance data and lessons learned.

- CJOC examine HAV's logistics and ground support requirements in the development of future northern operational hubs.

- Further studies be conducted to explore HAVs' capability for other military applications such as high altitude unmanned surveillance, communications relay, intelligence gathering, jamming, and air defence.

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List of abbreviations/acronyms

AN-124	Antonov 124
APOD	Airport of Disembarkation
CF	Canadian Forces
CJOC	Canadian Joint Operations Command
HAV	Hybrid Air Vehicle
IL-76	Ilyusin 76
OSH	Operational Support Hub
SPOD	Seaport of Disembarkation
UK	United Kingdom
US	United States

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Ghanmi, A.

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A Hybrid Air Vehicle (HAV) is an airship that combines characteristics of heavier-than-air technology, fixed-wing aircraft, and lighter-than-air aerostat technology. HAVs are being considered by the Canadian Forces (CF) as potential platforms to address deficiencies in military logistics heavy lift, particularly for northern operations. HAVs could provide a cost-effective point-to-point delivery capability and could mitigate several limitations associated with other forms of transport. This paper presents an assessment of the HAV lift performance in support of CF northern operations. A Monte Carlo simulation framework was developed to simulate various lift scenarios in the North using HAVs and conventional aircraft, which indicated that HAVs could potentially improve the CF's logistics lift capability for northern operations. Potential lift cost, response time and greenhouse emission reduction could be achieved using HAVs versus conventional aircraft. From an energy perspective, the use of HAVs for logistics heavy lift would potentially reduce the military operational energy demand due to their payload capacities and fuel consumption efficiency.

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