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UP IN THE AIR: AN AIRSHIP SOLUTION FOR STRATEGIC LIFT?

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Abstract

Despite the acquisition of four CC-177 *Globemaster* strategic lift aircraft in 2007 and 2008, the Canadian Forces remains challenged in providing high-volume, heavy-weight strategic lift to and from theatre. An emerging niche capability that may fill this strategic lift gap is modern hybrid airships. While the word 'airship' may evoke images of the cigar-shaped, hydrogen-filled *Hindenburg* Zeppelin that crashed spectacularly in 1937, modern airships are undergoing a renaissance that promises to deliver new capabilities relevant to the 21st century. In order to establish this premise, this study examines the CF need for strategic lift, the CF Strategic Capability Roadmap, the strategic environment, and the operational environment. Following this review, this study provides an overview of airship basics, airship history, modern airships, and a notional airship to be used for analysis. Current Canadian Forces Aerospace, Joint Movement, and Air Movement Support doctrine are then used to analyze the notional airship's inherent aerospace capabilities and air movement planning factors. Finally, this paper provides a comparison of the airship's advantages and disadvantages in relation to conventional sealift and airlift.

This analysis suggests that modern hybrid airships show promise in providing routine, high-volume, heavy-weight strategic lift. In particular, they may be ideally suited for point-to-point delivery of over-size cargo to austere destinations. Such a capacity would complement, but not replace, conventional sealift and airlift. However, this capability is not yet viable for the CF as it remains under development.

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List of Acronyms and Abbreviations

AMS	Air Movement Squadron
AN-124	Antonov 124
AO	Area of Operations
AOR	Auxiliary Oil Replenishment
APOD	Air Port of Disembarkation
APOE	Air Port of Embarkation
ATG	Advanced Technology Group
CANOSCOM	Canadian Operational Support Command
CC-130	CC-130 Hercules
CC-177	CC-177 Globemaster
CF	Canadian Forces
CFAWC	Canadian Forces Aerospace Warfare Centre
CFDS	Canada First Defence Strategy
CFS	Canadian Forces Station
DARPA	Defence Advanced Research Project Agency
DELAG	*Deutsche Luftschiffahrts-Aktien-Gesellschaft*
GPS	Global Positioning System
HAV	Hybrid Air Vehicles
HAV 606	Hybrid Air Vehicle 606
HULA	Hybrid Ultra-Large Aircraft
ICAO	International Civil Aviation Organization
INS	Inertial Navigation System

ISO	International Standards Organization
JHL	Jess Heavy Lifter
JSS	Joint Support Ship
JTF	Joint Task Force
LAV III	Light Armoured Vehicle Mark III
LEMV	Long-Endurance Multi-Intelligence Vehicle
LMSR	Large, Medium-Speed Roll-On/Roll-Off Ship
LTA	Lighter-Than-Air
LZ	Luftschiff
MANPADS	Man Portable Air Defence System
MOB	Main Operating Base
MV	Maritime Vessel
NATO	North Atlantic Treaty Organization
POD	Port of Disembarkation
RORO	Roll-on/Roll-off capacity ship
SAM	Surface-to-Air Missile
SCR	Strategic Capability Roadmap
SPOD	Sea Port of Disembarkation
SPOE	Sea Port of Embarkation
US	United States
VIP	Very Important Person

Chapter 1 – Introduction

The year 2010 quickly proved interesting for Canada's Air Force. In the midst of providing continued support to deployed forces in Afghanistan, and engaged in final preparations for the Canadian Forces (CF) support to the Vancouver Olympic Games, nearly every air wing in Canada was engaged in operations.[1] This high operational tempo increased on 12 January, when a shattering earthquake measuring 7.3 on the Richter scale struck near Port-au-Prince, Haiti. This large tremor destroyed most of that capital city's infrastructure and some three million people were affected by the loss of basic services such as water and electricity. Canada's response was swift and decisive. The military component of the whole-of-government humanitarian response was dubbed Operation HESTIA; at the peak, more than 2000 military personnel were engaged in the mission.[2] By the time Operation HESTIA was complete, the Air Force had airlifted nearly 5000 passengers and delivered nearly two and a half million kilograms of supplies to Haiti. It did so via an air bridge established by CC-177 *Globemaster* aircraft from Canada to an upgraded airfield at Jacmel. This air bridge also consisted of chartered civilian aircraft, which flew their cargo to Jamaica for transfer and furtherance to Jacmel by CC-130 *Hercules*.[3] While ultimately successful, this circuitous flow of supplies to Haiti exposed a capability gap in CF strategic lift. Indeed, despite the acquisition of four

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[1] Lieutenant-General André Deschamps. "Into the 21st Century – An Overview of Canada's Air Force in 2010," *Canadian Military Journal* Vol. 4 no. 4 (Autumn 2010): 59.

[2] Department of National Defence. "Operation HESTIA"; http://www.comfec-cefcom.forces.gc.ca/pa-ap/ops/hestia/index-eng.asp"; Internet; accessed 23 March 2011.

[3] Deschamps, "Into the 21st Century…", 59.

CC-177 *Globemaster* strategic lift aircraft in 2007 and 2008, the CF remains challenged in providing high-volume, heavy-weight strategic lift to and from theatre.[4]

As articulated in the *Canada First Defence Strategy*, this movement support is critical in sustaining forces deployed to meet Canada's defence commitments at home and abroad.[5] Standard methods involved either airlift or sealift; the former exploits the speed and range of transport aircraft, while the latter has larger carrying capacity and endurance. However, as these methods rely on airport and seaport facilities, their effectiveness and efficiency are reduced in areas with austere infrastructure.[6] Such areas include Canada's Arctic, where vast distances and extreme weather conditions further compound these challenges.

An emerging niche capability that may fill this strategic lift gap is modern hybrid airships. The word 'airship' may evoke images of the cigar-shaped, hydrogen-filled *Hindenburg* Zeppelin that crashed spectacularly in 1937. The public consciousness seems to ignore that airships achieved a number of significant aviation and transport milestones before fading into relative obscurity. Furthermore, modern airships are undergoing a renaissance that promises to deliver new capabilities relevant to the 21st century. Indeed, development of composite materials, vectoring engines, fly-by-light technology, and revolutionary new hybrid designs have renewed commercial interest in airships.[7] As opposed to conventional lighter-than-air airships, which relied exclusively

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[4] Department of National Defence, *Strategic Capability Roadmap Version 1.0 – Sustain Capability Alternative Report 2008* (Ottawa: DND Canada, 2008), 9.

[5] Department of National Defence, *Canada First Defence Strategy* (Ottawa: DND Canada, 2008), 4.

[6] Department of National Defence, B-GJ-005-404/FP-000 *Joint Movement Support*. (Ottawa: DND Canada, 2002), 1-13.

on buoyant gases for lift, these so-called hybrid airships are slightly-heavier-than-air and use an aerodynamic design and vertical thrusters in addition to helium lift. As a result, they have a much greater manoeuvrability and payload capacity than legacy airships.[8] For example, the British company Hybrid Air Vehicles advertises that their heavy-lift model *HAV 606* can carry a 200 tonne payload over 3225 nautical miles.[9] However, while a prototype model exists, these heavy-lift airships have yet to come to market.

This paper will argue that modern hybrid airships show promise in providing routine, high-volume, heavy-weight strategic lift, but that this capability is not yet viable for the CF as it remains under development. This argument will be developed in four sections. First, in order to help define the problem space, this paper will provide a description of strategic lift, the CF Strategic Capability Roadmap, the strategic environment, and the operational environment. Second, in order to help establish the possible solution space, this paper will provide an overview of airship basics, airship development and historical milestones, the modern airship resurgence, and an introduction to the notional airship to be used for analysis. Third, in order to provide an authoritative framework for this analysis, the notional airship's capabilities and limitations will be examined from the perspective of current CF Aerospace, Joint Movement, and Air Movement Support doctrine. Finally, in order to determine the

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[7] Barry Prentice, Barry, Al Phillips, Richard P. Beilock, and Jim Thomson, "The Rebirth of Airships." *Journal of the Transportation Research Forum* Vol. 44, no. 1 (Spring 2005): 173. Journal on-line; available from http://journals.oregondigital.org/trforum/article/viewFile/806/701; Internet; accessed 16 January 2011.

[8] Irene A. Collin, "Future Air Platforms – Preliminary Analysis," *The Canadian Air Force Journal* Vol. 4 no.1 (Winter 2011): 39.

[9] Hybrid Air Vehicles, "Heavy Lift Vehicles – HAV 606," http://www.hybridairvehicles.com/hav606.aspx ; Internet; accessed 15 March 2011.

feasibility and merits of bringing airships to the strategic lift market, this paper will provide a comparison of airship's advantages and disadvantages in relation to conventional sealift and airlift. Such an approach is aimed to provide a broad and fundamental understanding of modern airships and their potential to conduct strategic lift.

Undoubtedly, the idea of an airship solution to strategic lift challenges may seem far-fetched to some. However, the growing worldwide cargo demand, coupled with increasingly evident conventional transport limitations such as congestion problems and fuel efficiency, give merit to examining creative solutions.[10]

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[10] Prentice *et al*, "The Rebirth…", 173.

Chapter 2 – Establishing the Problem Space: Strategic Lift

In order to assess the viability of an airship solution for CF strategic lift needs, the nature of the problem needs to be understood. This appreciation will be developed in four sections. First, in order to establish context, CF strategic lift will be defined and its capabilities and limitations explored. Second, in order to appreciate the spectrum of possible alternatives, the CF Strategic Capability Roadmap will be explored. Third, in order to provide perspective, the CF's strategic environment will be reviewed. Finally, in order to provide further perspective, strategic lift's operating environment will be described. In such a manner, a fundamental understanding of the problem space will be achieved.

Strategic Lift

As defined in CF Aerospace Doctrine, strategic lift missions "are those operations conducted to move personnel and material between theatres."[11] This air mobility capability of the Air Force Move function exploits the global reach of aerospace power. Indeed, this is a fundamentally important air force role that can rapidly deploy and sustain a joint force so that it may generate and maintain capabilities in support of operations.[12] While this inter-theatre logistic support normally requires a combination of

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[11] Department of National Defence, B-GA-400-000/FP-000 *Canadian Forces Aerospace Doctrine* (Winnipeg: DND Canada, 2010), 44.

[12] Department of National Defence, B-GJ-005-300/FP-001 *CFJP 3.0 Operations* (Ottawa: DND Canada, 2010), 1-6.

sealift and airlift, the latter can provide unmatched speed and reach in providing this key support function.[13]

While the CF has two Auxiliary Oiler Replenishment (AOR) ships in its fleet, each capable providing limited logistics support, it does not have an organic sealift capacity.[14] However, in addition to opportunity sealift charter, the CF has secured a full-time charter of the Polish Cargo ship Maritime Vessel (MV) *Wloclawek*. Based out of Montreal, this Roll-On/Roll-Off (RORO) cargo ship has a 1600 linear metre cargo capacity and has supported the CF since October 2009. Under command of CANSOCOM, the MV *Wloclawek* has transported CF equipment destined for Afghanistan and in support of Op HESTIA.[15] Furthermore, the planned Joint Support Ship (JSS) is intended to provide a limited sealift capability.[16]

With respect to airlift, the CF uses a mix of integral and chartered fleets. For example, the CF has a fleet of five CC150 Polaris aircraft, which are modified Airbus A310-300 aircraft. One aircraft is configured for VIP transport, one for passengers, and three for a combination of passengers and freight. Furthermore, in 2007 and 2008, the CF procured four Boeing C-17 military aircraft designated as the CC177 Globemaster III. This purchase brought an organic CF capability for strategic lift of outsize cargo such as the LAV III fighting vehicle. However, even-bulkier and heavier explosive-resistant

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[13] *Ibid.*, 1-5.

[14] Ray Szeto and Barry Cooper, "The Need for Canadian Strategic Lift," *Studies in Defence & Foreign Policy* No. 5 (August 2005): 11.

[15] Gord Lovelace, "Full-time Charter Key Link in Supply Chain," *The Maple Leaf* Vol. 12 no. 9 (4 March 2009), 18; Steve Fortin, "Massive Vessel to Support Op HESTIA," *The Maple Leaf* Vol. 13 no. 4 (3 February 2010): 5.

armoured vehicles exceed even the CC-177's capabilities and the CF has made use of chartered aircraft such as Antonov An-124.[17] However, there have been concerns about the latter's reliability and guaranteed availability, and North Atlantic Treaty Organization countries have not certified them for passenger use.[18]

Due to ongoing expeditionary operations, demand for strategic lift is on the rise.[19] 8 Wing Trenton, the home of Canadian Forces air mobility, has seen a proportionally increased operational tempo. For example, 2 Air Movement Squadron (AMS) processed 10.5 million pounds of freight in 1998; by 2007, that number had more than doubled to 24.7 million pounds. Given this rising demand for service in an era of fiscal restraint and environmental concerns, the CF and other air forces around the world have begun to consider unorthodox means to provide effective and efficient strategic lift.[20]

Strategic Capability Roadmap

Formal guidance for planning for future CF capabilities is provided by the Strategic Capability Roadmap (SCR). In order to give rigour and logic to this process, the SCR uses capability based planning, which involves future security environment

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[16] Department of National Defence, News Release 10.074 "Government of Canada to Acquire New Joint Support Ships," (Ottawa: DND Canada, 14 July 2010).

[17] Department of National Defence, *Air Force Strategy – The Flight Plan for Canadian Forces' Aerospace Power* (Version 3.0) (Ottawa: DND Canada, 2007), 47.

[18] Paul Dickson, "Air Options: How Much Airlift and What Type," in *Strategic Lift Options for Canada and the Allies*, edited by David Rudd, Ewa Petruczynik, and Alexander Wooley, 57-76 (Toronto: Canadian Institute of Strategic Studies, 2005), 65.

[20] Gareth Jennings, "Theatre lift takes centre stage as missions and cargoes increase," http://www4.janes.com/subscribe/idr/doc_view.jsp?K2DocKey=/content1/janesdata/mags/idr/history/idr2011/idr13795.htm@current&Prod_Name=IDRQueryText=; Internet; posted 10 March 2011, accessed 15 March 2011.

analysis, concept development, scenario analysis, and deficiency and alternative identification. The product is a prioritized list of capabilities that balances capital fleet replacement with emerging technologies. [21]

Amongst this list of capabilities, the SCR identified the following deficiency: insufficient capacity to provide routine, high volume, heavy weight strategic lift to and from theatre. Ranked by the SCR as number 272 of 319 priorities, this project is targeted for the 2019 to 2023 time period.[22] As part of developing the SCR, The Sustain Capability Alternative Report 2008 further amplified this deficiency. While noting that the CF has recently procured CC-177 *Globemaster III* and CC-130J *Hercules* aircraft, and is planning a new multi-role joint ship, this report identified continuing deficiencies with CF lift into theatre. Specifically, there remains a requirement to move high-volume or heavy weight items too large to fit in a CC-177, such as tanks and other armoured vehicles.[23]

Developing such joint support capabilities is one of the Canadian Operational Support Command's (CANOSCOM) responsibilities.[24] Indeed, CANSOCOM project staff for the Canadian Forces Operational Support Capability Project have further articulated that this high volume, heavy weight strategic lift capability must include the ability to operate in Arctic and austere environments that lack well established airports

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[21] Department of National Defence, *Strategic Capability Roadmap Version 1.0* (Ottawa: DND Canada, 2008), iii.

[22] *Ibid.*, 61.

[23] Department of National Defence, *Strategic Capability Roadmap Version 1.0 – Sustain Capability*…, 9.

[24] Department of National Defence, B-GJ-005-300/FP-001 ..., 3-8.

and seaports. Such a capability would allow the CF to better fulfill the Government of Canada's interests at home and abroad.[25]

The Security Environment

Indeed, as articulated in the *Canada First Defence* Strategy (*CFDS*), the CF is depended on to support the Government's national security and foreign policy interests. This has been challenging, as the early 21st century has been defined by volatility. Recent security challenges have included terrorist attacks, ethnic and border conflicts, fragile states, global criminal networks, tensions stemming from globalization, and natural disasters. In order to formally address its responsibility for defending Canadians from such threats, the *CFDS* provided guidance for modernizing the CF by detailing clearly defined military missions and capabilities. Specifically, the Government listed expectations that the Canadian Forces would be able to conduct daily domestic and international operations, support a major international event in Canada, respond to a major terrorist attack, support civilian authorities during a crisis in Canada, lead and/or conduct a major international operational for an extended period, and deploy forces in response to crises elsewhere in the world for shorter periods. In order to support this ambition, the *CFDS* revealed increased defence funding over twenty years in order to address the needs of four key military capabilities: personnel, equipment, readiness, and

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[25] Major Julie Lycon, Canadian Forces College 2010 Research Symposium Organization Information Form, "Strategic Lift: The Airship Solution," (Ottawa: DND Canada, 2010), 1.

infrastructure. In doing so, the *CFDS* attempts to balance what the CF needs today with what it will likely need in the future.[26]

This long-term vision prompts an understandable question: what will the future security environment be like? Published in 2009, the Chief of Force Development document *The Future Security Environment 2008-2030* addresses this very issue. This analytic document is intended to drive capability development and serve as a means to inform CF concept development. While this document does not predict future conditions, it does seek to anticipate them.[27]

Among others, the document identified several following broad trends relevant to strategic lift. Specifically, negative social and economic trends, fuelled by globalization, may increase tension and hostilities in underprivileged regions. These factors could result in humanitarian crises that call for stabilization and/or reconstruction missions. Furthermore, regional instability will also worsen due to competition for food, water, and natural resources, possibly leading to humanitarian and economic crises. In addition, the projected decline in fossil fuels, combined with rising oil prices, will force the CF to feed alternative sources of power for its vehicles. In this environment, asymmetric attacks will pose the main security threat, but state-on-state conflict cannot be discounted. Therefore, the CF must be prepared to operate in a full-spectrum conflict. Finally, science and technology will continue to drive defence capabilities, but will require massive investments from private and multinational companies. It will be critical for the CF to exploit technological innovations in order to maintain relevant and effective military

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[26] Department of National Defence, *Canada First Defence Strategy*…, 2,6,10,21.

capabilities.[28] Such a future security environment will challenge the military and new capabilities and approaches will be called for in order to conduct domestic and international operations.

The Operational Environment

While any future strategic airlift solution would be expected to deploy globally, CF Operational Support Capability project staff made specific mention of an Arctic and austere field capacity. These operating conditions, particularly in combination, are among the most demanding and dangerous in the world.[29]

Canada's Arctic is defined by its vastness and isolation. Communities and airfields are few and far between, and the majority lack access to connecting road infrastructure.[30] One of the most extreme locations is Canadian Forces Station (CFS) Alert, the world's most northerly permanently inhabited settlement. Situated at latitude 82 degrees North, CFS Alert spends alternating period four and a half months each of complete darkness and daylight. Temperatures are below freezing for the majority of the year, with monthly winter means of -32ºC and summer of +2ºC.[31] Strong winds and

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[27] Department of National Defence, *The Future Security Environment 2008-2030* (Ottawa: DND Canada, 2009.), 2.

[28] *Ibid.*, 5-8.

[29] Lycon, "Strategic Lift…", 1; The author served at 440 (Transport) Squadron Yellowknife from 2007 to 2010, where he was qualified as a CC-138 Twin Otter Aircraft Commander and Ski Pilot and has Arctic experience with austere wheel and ski operations.

[30] Ahmed Ghanmi and Sokri Abderrahmane, "Airships for military logistics heavy lift – A performance assessment for Northern applications," (Ottawa: Defence R&D Canada, 2010,) 2.

[31] Ed Hudson, David Aihoshi, Tim Gaines, Gilles Simard, and John Mullock, *The Weather of Nunavut and the Arctic – Graphic Area Forecast 36 and 37* (Ottawa: NAV CANADA, 2001), 86.

drifting snow can reduce visibility to zero during the winter, as can freezing fog during the spring melt. Such conditions pose significant aviation challenges, and scheduled resupply flights can be delayed for days at a time. These delays can affect the Station significantly, as airlift is the only means to deliver cargo such as fresh foods and critical equipment parts. Given the likelihood of any future CF airlift capability of being tasked to support this remote Station, it must be capable of operating in this extreme environment.[32]

These Arctic flight operations can carry even more risk when operating away from the safety and support of an established airfield. When operating on unprepared strips such as abandoned runways, tundra, beaches, gravel bars, or sea ice, consideration must be given flight path obstacles, wind and sun direction, as well landing area size and hazards.[33] "Reading" sea ice can be particularly challenging and requires experienced operators. Furthermore, given the lack of local weather reporting and instrument approach procedures at austere fields, crews often depart for an austere location without knowing the probability of successful visual approach and landing. This requires carrying sufficient fuel to divert to an alternate field, impacting aircraft range and/or cargo load. Indeed, while an austere capability gives an airframe great flexibility for Arctic operations, this must be balanced with the operational environment, crew experience, aircraft performance, and flight safety considerations.[34] It must be

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[32] Further to his service at 440 (Transport) Squadron, the author served as the Commanding Officer of Canadian Forces Station Alert from January to July 2009.

[33] Department of National Defence, SMM 60-138-0747 *CC138 Twin Otter Standard Manoeuvre Manual* (Ottawa: DND Canada, 15 March 2009), 11-3.

[34] *Ibid*., 11-3.

understood that austere Arctic operations do not enjoy the predictability of routine flights elsewhere in the world.

Nonetheless, the CF is expected to continue to be involved in sustain-heavy operations where normal, peacetime, commercial forms of sustainment are unavailable or impractical.[35] A review of the current and future security environment suggests that flexibility will be critical to operational success. Indeed, the CF will be expected to operate globally, conduct extended international operations, and deploy in response to crises. Furthermore, future CF capability planning has noted a deficiency in routine, high volume, heavy weight strategic lift to and from theatre. The operational environment for such a capability, particularly in Arctic and austere locations, will be very demanding. However, emerging aircraft such as hybrid heavy lift airfield-independent airships show potential to deliver this capability. The following chapter will explore this possible solution space.

[35] Department of National Defence, *Strategic Capability Roadmap…*, 5.

Chapter 3 – Exploring the Solution Space: Airships

As we enter the second decade of the 21st century, it may seem counter-intuitive to consider airships as an alternative to existing strategic lift options. Indeed, it has been almost seventy-five years since the Hindenburg disaster effectively marked the end of the airship era. The iconic newsreel footage of that historic crash, along with Herbert Morrison's passionate live radio broadcast, shattered public faith in the airship industry. That stigma lingers today, even though the various accidents of the 1930s were as often due to weather as to intrinsic limitations of airship technology.[36] However, airships did not completely disappear and recently emerging technology suggests that they may once again be relevant. In order to establish this premise, airship basics and history will be explored along with contemporary technology and developments.

Airship Basics

Airships are lighter-than-air (LTA) aircraft.[37] As opposed to heavier-than-air (HTA) aircraft such as airplanes and helicopters, which generate aerodynamic lift by moving air over a wing or rotor, airships generate aerostatic lift by filling a large cavity with a lifting gas such as helium or hydrogen. Fully steerable, airships typically use propellers or other thrust-generating devices for propulsion. However, while aerodynamic lift comes at the cost of fuel and horsepower due to induced drag, aerostatic

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[36] Keith Hayward, *The Military Utility of Airships* (London: Royal United Services for Defence Studies, 1998), 1.

[37] Collin, "Future Air Platforms …," 39.

lift only has parasitic drag. In other words, airships are highly efficient, as the engines only have to move the airship, not lift and move it.[38]

Structurally, airships are typically constructed in one of two ways: rigid and non-rigid. With rigid airships, such as the *Hindenburg*, an envelope covers a large aluminum hull. Individual unpressurized gas cells are lined from front to back and lift the hull by floating against it. However, due to the complexity of the structure, rigid airships are very expensive and are no longer produced.[39] On the other hand, non-rigid airships such as the *Goodyear Blimp* have a hull structure made of material that served doubly as the envelope containing the lifting gas. As this requires pressurization, the stresses involved limit non-rigid airships size in relation to the strength of fabric used.[40]

Airships are further limited by their maximum operating altitude, known as pressure height. This limitation stems from the properties of gas, which expands due to decreased atmospheric pressure as the airship climbs. Rigid airships, which typically used hydrogen, vented this lifting gas in to avoid pressure on the envelope. While this resulted in a loss of lift, hydrogen was cheap and easily produced on site. In contrast, non-rigid airships use rare and expensive helium, as it is less volatile. As a matter of economy, however, it is not desirable to vent this gas. In lieu, the main gas envelope includes separate, small air-filled envelopes called ballonets. Filled with ambient air at the surface, these ballonets collapse as the airship rises, in order to accommodate the expanding helium. The pressure height is the altitude at which these ballonets are fully

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[38] Colonel Walter O. Gordon and Colonel Chuck Holland, “Back to the Future: Airships and the Revolution in Strategic Airlift,” *Air Force Journal of Logistics* Vol. 29 no. 3 (Fall/Winter 2005): 49.

[39] *Ibid*., 50.

collapsed and the entire main envelope is filled with helium. This is a design compromise, as larger ballonets allow for a greater pressure height but consequently less lifting gas in the main envelope.[41]

Another technical challenge for airships is buoyancy compensation. When taking off with neutral buoyancy, the airship's aerostatic lift is equal to its total weight, which includes the aircraft, the cargo, and the fuel. As fuel is burned enroute, however, the ships gains positive buoyancy as time progresses, resulting in control difficulty. In order to create ballast en-route, some airships use a complicated engine exhaust water condenser and recovering unit, which attempts to keep the overall airship weight constant. Furthermore, when offloading cargo at destination, equivalent weight ballast and/or cargo must be uploaded simultaneously in order to maintain neutral buoyancy.[42] Clearly, while traditional airships have some advantages over conventional aircraft, they also suffer from some unconventional limitations.

Airship History

The history of lighter-than-air travel spans nearly two and half centuries, one hundred and twenty years longer than heavier-than-air flight. The related aviation developments and milestones were numerous and significant, but are generally not well known. Reviewing this history will provide an appreciation of the airship's legitimacy as a long-range aircraft and speak to its potential today.

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[40] Ghanmi and Abderrahmane, "Airships for military…", 7.

[41] Gordon and Holland, "Airships and the Revolution…", 50.

[42] Ghanmi and Abderrahmane, "Airships for military…", 8.

Lighter-than-air vehicles are not a new concept; in the thirteenth century, early pioneers such Franciscan monk Roger Bacon described the possibility of human flight using a thin-walled metal sphere filled with rarefied air, or 'liquid fire'. In 1670, Italian Jesuit priest Francesco Lana di Terzi recorded the first design of an aerial ship. He proposed that the boat-like ship would be lifted by air-evacuated copper globes and propelled by sails. However, this hypothetical design was flawed due to structural limitations; had this vacuum ship been built, the globes would have collapsed from atmospheric pressure. [43]

Practical progress towards lighter-than-air travel was made in the late 1700s when experiments with gases by scientists such as Henry Cavendish, Joseph Priestley and Antoine Lavoisier led to several attempts to lifting balloons with "inflammable air", or hydrogen. Difficulty lay in finding a suitable material for the balloon envelope; one that was light enough to facilitate lift, yet dense enough to prevent hydrogen from escaping. Building on these experiments, brothers Joseph and Étienne Montgolfier conducted a number of hot-air balloon trials culminating in the first manned flight on 21 November 1783. Modern-day hot-air balloons, also known as Montgolfières, which rely exclusively on air heated by propane burners for lift, are direct descendants of the original balloon.[44]

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[43] Basil Collier, *The Airship: A History* (London: Hart-Davis, McGibbon, 1974), 15.

Despite early optimism about balloon passenger transport networks, their lack of steerability and ability travel into wind made this dream impractical. In the following years, a succession of scientists, engineers, aristocrats, and fools attempted to solve this challenge. Proposed solutions included paddle wheels, flapping mechanical wings, steam jets, and even a team of harnessed eagles.[45] In 1774, Jean-Baptiste Meusnier, a young French Army engineer, produced the first airship design that would appear familiar today. His 260-foot long dirigible was ellipsoid-shaped, was steered horizontally and vertically with a rudder and elevator, and was propelled by three airscrew propellers. As no suitable engine yet existed, his airship had to be manually propelled using a rope and pulley mechanism connected to these screws.[46] It was not until 1851 that wealthy Frenchman Henri Giffard designed a steam engine that was light enough to be carried, yet powerful enough to propel a useful load. Incorporated into a 144-foot long cigar-shaped airship, this three horsepower engine propelled Giffard on 24 September 1852 for seventeen miles over Paris on the first successful powered flight. With a maximum speed of five miles per hour, however, this ship was useful in only calm winds. As a result, designers continued to pursue other propulsion means such as gas engines, steam jets, and battery-stored electrical power, albeit without meaningful success.[47]

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[44] Jack A. Jones, James A. Cutts, Jeffrey L. Hall, Jiunn-Jenq Wu, Debora Ann Fairbrother, and Tim Lachenmeier, "Montgolfiere Balloon Missions for Mars and Titan," available from http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/38360/1/05-1506.pdf; Internet; accessed 13 April 2011.

[45] Louis C. Gerkin, *Airships: History and Technology* (Chula Vista, California: American Scientific Corp, 1990), 10.

[46] Collier, *The Airship:…,* 22.

Designers eventually concluded that only the newly invented internal combustion engine provided the vital characteristics of light weight, sufficient power, and reasonable safety.[48] Using a gasoline-powered single-cylinder two-horsepower engine built by Gottlieb Daimler, German inventor Karl Wölfert successfully flew an airship for nearly three miles in 1888. Further collaboration culminated in a disastrous demonstration flight on 12 June 1897 when the fuel tank exploded and engulfed the ship in flame, resulting in a crash that killed its crew. While this disaster put airships out of public favour for several years, interest was rekindled in 1901 when wealthy Brazilian Alberto Santos-Dumont won the l00,000 franc la Meurthe prize for flying from the Aéro Club de France at St Cloud to the Eiffel Tower and back in under half an hour. Known as “le petit Santos,” he captured the public imagination with his numerous stunts and public demonstrations over Paris. Furthermore, he wrote predictions that there would someday be luxury cruise airships, flights over the North Pole, and huge transport airships that would carry hundreds of passengers and tons of cargo around the world. However, Santos was not able to pursue these goals, as he was forced to retire from aviation in 1910 due to failing health caused by multiple sclerosis.[49]

That same year marked the first passenger flight by the *Deutsche Luftschiffahrts-Aktien-Gesellschaft* (the German Airship Transport Company, known by its acronym DELAG). Founded in 1909 by Count Ferdinand von Zeppelin, DELAG was the world’s first passenger transport airline. Zeppelin had first experienced being airborne in 1863,

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[47] Gerken, *Airships:…*, 19.

[48] *Ibid.*, 26.

when he had travelled to the United States as German military observer of the American Civil War. His interest was further piqued when he witnessed hundreds of successful balloon flights transporting mail during the 1870 siege of Paris. Upon retiring as a Brigadier-General in 1890, he was finally able to pursue this interest in a serious manner. His experiments led to the development and the perfection of the rigid airship, whose generic name has become synonymous with his own: the Zeppelin.[50]

Unlike the previous non-rigid airships, the rigid Zeppelins maintained their form in all wind conditions, which minimized the chance of a catastrophic leak of lifting gas. Furthermore, rigid airships could be much larger than non-rigid ones, allowing them to mount larger engines and carry heavier loads. Zeppelin's successive design evolutions improved performance and reliability; however, ground-handling challenges were never fully overcome. Indeed, rigid airships remained buoyant after landing, and required either large ground handling teams to carry it to large hangars, or a mooring mast to which the airship could be tethered. Even with these measures, airships were often damaged (or even destroyed) while moored in poor weather. Nevertheless, DELAG enjoyed an enviable safety and performance record. From its founding to the outset of the First World War, more than 30,000 passengers flew 107,000 incident-free miles over Germany during 1588 flights.[51] This consistency was remarkable, particularly in a time when other nations had but nascent airship capabilities and the thought of passenger airplanes was but wishful thinking.

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[49] *Ibid.*, 43.

[50] *Ibid.*, 67.

Indeed, at the outbreak of the First World War, only Germany, Great Britain, and France had an airship capability.[52] While the British used their airships in a maritime reconnaissance role, the German and French used airships to conduct reconnaissance missions and tactical bombing missions in support of their land forces. However, their vulnerability to ground fire became quickly evident; unable to fly much above six thousand feet, the large airships were easy targets for small arms and artillery fire when flying daylight tactical missions. In response, the German High Command began a shift in airship operations from over the Western Front to the skies over England; this decision marked the beginning of the first strategic bombing campaign.[53] By 1916 Zeppelins could fly as high as twenty thousand feet, but remained vulnerable to newly introduced night fighter squadrons using incendiary bullets. Furthermore, crew exposure to hypoxia and extreme cold temperatures at these altitudes resulted in loss of judgement and performance that reduced mission effectiveness.[54] A series of failed raids culminated on the night of 19 October 1917, when five of the newest Zeppelins were lost during a raid against London. Although sporadic and limited raids carried on until August 1918, this defeat effectively ended the strategic bombing campaign.[55]

Perhaps the greatest Zeppelin feat of the war occurred in a very different theatre of war and did not involve bombing.[56] In November 1917, German troops stationed in

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[51] Edward Horton, *The Age of the Airship* (London: Sigwick & Jackson, 1974), 34.

[52] *Ibid.,* 42.

[53] Gerken, *Airships:…,* 114, 116.

[54] Collier, *The Airship:…*, 135.

[55] Horton, *The Age of…,* 57.

German East Africa, now a part of Tanzania, were being pressed by British Forces and were in desperate need of replenishment. With no other means to deliver the needed material, a Zeppelin was tasked with the desperate resupply mission. The 3600-mile direct flight was unprecedented and modifications were made to an airship already in production in order to create the largest airship yet built: the 743-foot long Zeppelin *LZ-59*. Since there were no fuel or hydrogen reserves at destination, no return flight was expected. On 21 November 1917, *LZ-59* launched from Bulgaria with 14 tons of medical supplies and weapons aboard. Guided by celestial navigation, the ship successfully crossed the Mediterranean and the Libyan Desert. The crew was only 400 miles from their destination when they were ordered by radio to turn back, as the German Admiralty had received (faulty) intelligence that the German positions had been overtaken. Disappointed, the crew landed in Turkey, having covered 4,225 miles over a 95-hour non-stop flight. Notably, there was enough fuel in the tanks for an additional 64 hours of flight (or approximately 3800 miles). Had the crew headed west instead of south on their journey, this range would have taken them as far as San Francisco.[57] Notably, it would be thirty years before any airplane could have accomplished the same feat.[58] While the mission itself was a failure, it demonstrated the rigid airship's potential to deliver cargo between continents.

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[56] *Ibid.*, 166.

[57] Collier, *The Airship:…*, 139.

[58] Gordon and Holland, "Airships and the Revolution….", 48.

Following the Great War, however, this potential for intercontinental transport was slow to develop. As per the provisions of the Treaty of Versailles, Germany was prohibited from maintaining military air forces and also faced restrictions on its civilian aircraft industry. While the Allies seized existing airships, many new owner nations such as France saw these fleets quickly dwindle due to operational losses and were not prepared to invest resources to further developing the capability.[59]

An exception to this reluctance, the British Air Ministry used a Zeppelin design to develop an airship capable of transatlantic crossing. On 2 July 1919, the *R-34* launched from Scotland bound for Roosevelt Field, New York. Some 108 hours later it landed, with only fumes of fuel remaining, having completed the first ever east-west Atlantic crossing and having established a new endurance record. This flight occurred only two weeks after the first successful west-east Atlantic crossing, completed by Alcock and Brown in a modified Vickers Vimy bomber. The relative ease of *R-34*'s crossing (including the return flight) in comparison to Vimy's crash landing on arrival in Ireland gave confidence to the British airship industry. However, British airship interest collapsed in 1921 following the loss of the ambitious successor *R-38* along with forty-four of its forty-nine crew during its inception trials.[60]

The United States was also interested in developing rigid airships. In lieu of demanding financial war reparations from Germany, it commissioned a new Zeppelin airship for American use. Completed in 1924, the *LZ-126* was re-christened the *Los Angeles* and served with the US Navy for eight years in a variety of research and

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[59] Gerken, *Airships:…*, 201.

[60] Horton, *The Age of…*, 72.

operational roles before being withdrawn from service. The year 1924 also saw the launch of the American-built *Shenandoah*, the first helium-inflated airship. Notably, helium was quite rare at the time and there was only enough of the gas available for the Navy to inflate one ship at time. Nonetheless, the *Shenandoah* completed a round-trip of North America and spurred interest in attempting the first overflight of the North Pole. However, on 2 September 1924 the *Shenandoah* was destroyed in a thunderstorm, crushing hopes for an American polar expedition.[61]

Nonetheless, the fascination with polar flight was not limited to the United States. Famed Norwegian explorer Roald Amundsen, who had been the first to reach the South Pole in 1912, had already made unsuccessful attempts to reach the North Pole by ship and by flying boat. Undeterred, Amundsen purchased a semi-rigid airship named *Norge*, which was designed, built, and operated by Italian Colonel Umberto Nobile. Racing against American Commander Richard Byrd and his Fokker monoplane, the expedition left Italy on 10 April 1926. The two expeditions met in the Svalbard Archipelago on 7 May at King's Bay, Spitzbergen. Two days later Byrd launched and returned after a sixteen-hour flight, claiming to have reached the Pole. This claim has subsequently been disputed due to the lack of range of his aircraft, and Amundsen and Nobile are now recognized as having been the first to reach the Pole on 12 May 1926.[62]

Further airship milestones would soon follow, as the greatest airship to be built was nearing completion.[63] On 8 July 1928, Von Zeppelin's daughter christened the *LZ-*

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[61] Gerken, *Airships…*, 263.

[62] *Ibid*., 269.

[63] Horton, *The Age of…,* 86.

127 Graf Zeppelin. At 775 in length, 100 feet in diameter, and some 3,700,000 cubic feet in volume, it was the largest airship that had ever been built. Appointed with a fully equipped kitchen, a luxurious dining saloon, and two-berth staterooms, the *Graf Zeppelin* was designed to transport passengers in a comfort and style unparalleled in its day. Driven by five powerful engines, it could cruise at seventy-three miles per hour. Notably, these engines were fed with Blaugas, a gaseous fuel with nearly the same weight as air. As a result, it was no longer necessary to release hydrogen to compensate to weight loss due to fuel burn, extending the airship's range by a third.[64] Indeed, on its first flight to North America the *Graf Zeppelin* broke the flight distance record by covering 6,200 miles non-stop. Notably, this was also the first intercontinental passenger airship flight. In an effort to raise money to fund fleet expansion, a series of spectacular demonstration flights followed, culminating in an attempt to fly around the world. Backed by American financing, the *Graf Zeppelin* left Lakehurst, New Jersey on 7 August 1929. Some twenty-one days, thirty thousand miles, and four fuel stops later, the circumnavigation had been completed at an average speed of 70.7 miles an hour. Furthermore, in addition to a polar expedition research flight and two trips to the Middle East, the *Graf Zeppelin* conducted passenger flight between Germany and Brazil. During its service life, it flew 590 flights, made 144 ocean crossings, and carried 13,100 passengers with a perfect safety record.[65]

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[64] *Ibid.,* 88.

[65] Daniel G. Brewer, *Hydrogen Aircraft Technology* (Boca Raton: CRC Press, 1991), 2.

However, the *Graf Zeppelin* was permanently grounded in 1937 due to the spectacular crash of its sister ship, the *Hindenburg*. Completed in May 1936, the *Hindenburg* set a new standard in terms of size, speed, safety, comfort, and economy.[66] With a fifty passenger capacity, it had an 11,000 miles range at a cruising speed of 84 miles per hour. While designed to fly with helium, the 7,000,000 cubic foot ship had to be filled with hydrogen due to the refusal of the United States to export the extremely rare helium to Germany. [67] Nonetheless, the *Hindenburg* made seventeen successful round trips to United Stated and Brazil before its final fateful flight. It was scheduled to make eighteen further flights to the United States that year, and the *Graf Zeppelin* another twenty round-trips to Brazil. Work on the next airship, the LZ-130 *Graf Zeppelin II*, was underway and the Zeppelin company appeared poised for stable commercial success.[68] That hope crashed along with the *Hindenburg* on 6 May 1937 at Lakehurst, New Jersey. As thunderstorms approached, the crew dropped lines to the ground to prepare for mooring. The landing was proceeding normally when a flash of fire burst in one of the aft cells and quickly spread to the rest of the ship. Within thirty-two seconds, the ship dropped to the ground from a height of seventy-five feet and was engulfed in a fire that continued to burn for three hours. Incredibly, sixty-two of the ninety-seven people on board survived the highly publicized disaster.[69]

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[66] Gerken, *Airships:…*, 331.

[67] Collier, *The Airship:…*, 212.

[68] Horton, *The Age of…*, 115.

[69] Gerken, *Airships:…,* 353.

Among all airship crashes, the *Hindenburg*'s was the most mysterious and contentious.[70] It rivalled the *Titanic* with the feeling of horror and awe that it evoked; each vessel's name itself is synonymous with its disaster.[71] Indeed, Herbert Morrison's cry "Oh the humanity!" during his eyewitness radio report was one of the most famous moments in broadcasting.[72] Theories as to the crash's cause included a gas leak sparked by static electricity, venting gas sparked by a snapped wire, and sabotage by either explosive device or incendiary bullet. While the weight of evidence at the board of enquiry suggested that the accident was the result of a freak set of circumstances, the dramatic sabotage theory could not be disproved and seemed plausible in the anti-German sentiment of the time. Whatever the cause, the *Hindenburg* crash marked the end of intercontinental flights by hydrogen-filled airships.[73]

Indeed, heavier-than-air jet aircraft came to dominate the skies following the Second World War.[74] Rigid airships no longer existed and blimps were relegated to primarily advertising and sightseeing roles.[75] So long as no urgent need for an alternative

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[70] *Ibid.*, 353.

[71] Horton, *The Age of…*, 122.

[72] *The Nelson Mail*, "Historical Failures," (18 January 2011): 11; http://web.ebscohost.com/ehost/detail?vid=5&hid=10&sid=8fccedeb-9fea-4df0-a73c-e1b1db46e929%40sessionmgr13&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=n5h&AN=NEM1101180011133195587-CY; Internet; accessed 14 April 2011.

[73] Collier, *The Airship:…*, 216.

[74] Hayward, *The Military Utility…*, 5.

[75] Gerken, *Airships:…,* 387.

to heavier-than-air passenger and cargo transport could be identified, airships remained on the periphery. Despite this marginalization, a number of ambitious developers believed that airships could establish a cargo-carrying niche.[76]

During the 1970s and 1980s, companies from Britain and the United States produced designs capable of carrying up to 500 tonne payloads. However, these companies failed to secure sufficient commercial funding and the designs withered on the vine. During this time, military funding was similarly insufficient to convert hypothetical designs into operational aircraft. For example, in 1987 the US Navy awarded study contracts to Boeing Military Airplane Division, Goodyear Aerospace Corporation, and Westinghouse Defence Electronics System Corp to develop a surveillance and reconnaissance blimp for the Navy Airship Program. However, the program was terminated in 1995 due to severe funding restrictions.[77]

A theme emerges from this review of airship development: despite enthusiasm inspired by technological promises, airships never fully established themselves commercially. This stigma has lingered and has hampered investor confidence.[78] Indeed, despite achieving a number of significant aviation milestones, airships have been unjustly characterized as "a tragic detour in the history of transportation."[79]

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[76] Collier, *The Airship:…*, 227.

[77] Gerken, *Airships:…,* 402.

[78] Lane Wallace, "Dirigible Dreams," *Atlantic Monthly* Vol. 305, no, 3 (April 2010): 27; http://web.ebscohost.com/ehost/detail?hid=105&sid=fcf0d8b4-43ee-4fe6-aba9-be40d485c25b%40sessionmgr115&vid=15&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=48758344; Internet; accessed 23 January 2011.

[79] Prentice *et al*, "The Rebirth…," 173.

Modern Airships

Nonetheless, fuelled by a growing demand for air cargo, the early 21st century saw a resurgence of interest in airship use.[80] Furthermore, technological advances such as fly-by-light technology, composite materials, vectoring engines, and computer-assisted design promised to set the stage for the comeback for airships.[81] As opposed to prior airships, however, this latest generation of vehicles combines both heavier-than-air and lighter-than-air technology. Indeed, traditional aerostatic lift is combined with aerodynamic lift derived from an airfoil-like envelope and vertical thrusters. As a result, such aircraft can gain as much as 40 percent of their lift aerodynamically; this additional lift source provides so-called hybrid airships with an increased load capacity and/or enhanced endurance.[82] Furthermore, hybrid airship designs feature buoyancy management systems that balance aerodynamic and aerostatic lift. As fuel is burned during flight, the nose of the hybrid airship is proportionally lowered using ballonet trim. Due to the airship's airfoil-shaped envelope, this causes the aerodynamic lift to decrease in balance with the reduced weight of the aircraft. Due to this elegant design, hybrid airships will be slightly heavy when landing and will not require ballast, since the aerostatic lift will be insufficient to lift it airborne. There is a performance cost, however, as this design also prevents hybrid airships from vertical take-offs.[83]

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[80] Gordon and Holland, "Airships and the Revolution…", 48.

[81] *Ibid*., 173.

[82] *Defence Daily* Vol. 246, no. 54 (June 16, 2010): 3; available from http://web.ebscohost.com/ehost/detail?hid=105&sid=fcf0d8b4-43ee-4fe6-aba9-be40d485c25b%40sessionmgr115&vid=23&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=tsh&AN=52290164; Internet; accessed 16 January 2011.

[83] Gordon and Holland, "Airships and the Revolution…", 50.

Despite these advances that propose to address conventional airship limitations, hybrid airships are not yet available for purchase. In recent years several manufacturers have designed and tested prototypes; a review of these efforts reveals that challenges remain in successfully bringing airships to the market.

Indeed, since the turn of the century a number of companies have attempted to produce hybrid airships. In 2000, British company *Advanced Technology Group* (ATG) flew the first hybrid airship prototype, the *Skykitten*.[84] The full-scale mode, known as *Skycat*, was to have three variants capable of carrying 20, 50, or 200 tonnes. The largest model was designed with a cruise speed of 80 knots and a 3,250 nautical mile range. Designed to take off from any reasonable flat terrain, including water, without the need for runways, hangars, or ground crew, the *Skycat* was marketed as the ideal air cargo vehicle for transporting cargo long distances to remote locations.[85] However, while production was scheduled for 2008, ATG went bankrupt in 2005.[86]

In 2004, the US Department of Defence Advanced Research Projects Agency (DARPA) sponsored one of the most ambitious heavy-lift airship projects ever. The WALRUS HULA (Hybrid Ultra-Large Aircraft) project studied the feasibility of carrying 500-1000 tons over a distance of roughly 22,000 kilometres without the need for ballast

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[84] World Skycat, "Skykitten," http://www.worldskycat.com/skycat/skykitten.html; Internet; accessed 15 January 2011.

[85] World Skycat, "Key Features," http://www.worldskycat.com/skycat/features.html; Internet; accessed 15 January 2011.

[86] John Tagliablue, "Why Fly When You Can Float?" *New York Times*, 5 July 2008, available from http://www.nytimes.com/2008/07/05/business/worldbusiness/05dirigible.html?_r=1; Internet; accessed 23 January 2011

or ground-handling equipment. Lockheed Martin Corporation and Aeros Aeronautical Systems were each granted approximately 3 million USD to develop a design concept.[87] The winning design team was to have built a demonstration prototype, however, funding for the program was cancelled in 2006.[88]

Furthermore, in 2006 Lockheed Martin also tested a secretive hybrid airship known as *P-791*. Believed to be a heavy-lift airship, this project was part of a development project by the Skunk Works.[89] Capable of taking off and landing within 360 metres, 20-, 50-, and 500- ton capacity models were planned. However, the P-*791* and *Skykitten* appeared similar in design, and a lengthy legal battle ensued. That issue now settled, Lockheed Martin is reported to be ready to build prototypes for the two smaller versions, with the largest version still in final design.[90]

In 2008, Canadian-based Skyhook International teamed with Boeing to develop a hybrid airship for tactical airlift. The Skyhook Jess Heavy Lift (JHL) design combined a neutrally buoyant airship with four Chinook helicopter rotors. Design to carry a 40-ton slung payload over 200 miles, the *JHL-40* airship was targeted for sale to the northern oil

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[87] Joe Bacchus, . "Lockheed and Aeros Aeronautical both studying feasibility of blimp-based transport," *The Daily Record (Baltimore, MD), September 13 2005; http://web.ebscohost.com/ehost/detail?hid=105&sid=fcf0d8b4-43ee-4fe6-aba9-be40d485c25b%40sessionmgr115&vid=6&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=n5h&AN=L54136215DRMD; Internet; accessed 16 January 2011.*

[88] Bill Sweetman, "WALRUS Project Runs Out of Air," Jane's Defence Weekly Vol. 43 No. 10 (29 March 2006): 10; http://web.ebscohost.com/ehost/detail?vid=11&hid=10&sid=793cb3c6-a371-4652-9ea5-5508d87c5c37%40sessionmgr13&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=tsh&AN=20542341; Internet; accessed 13 April 2011.

[89] Jennings, "Theatre lift takes centre stage …,".

[90] Michael A. Dornheim, "Quietly Built Airship Makes Unannounced Spin Above the Desert," *Aviation Week*; Vol 164 No 6: 24; http://web.ebscohost.com/ehost/detail?vid=37&hid=10&sid=793cb3c6-a371-4652-9ea5-5508d87c5c37%40sessionmgr13&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=19746407; Internet; accessed 8 April 2011.

industry in order to carry heavy equipment to remote sites inaccessible by road.[91] Design hurdles have been surpassed and the cost for developing a prototype was estimated at 200 to 250 million dollars. As of summer 2010, reluctant credit markets and unsupportive governments have stalled the project and production has been pushed at least three years to 2015.[92]

The current leading edge developer is British company Hybrid Air Vehicles (HAV), which arose from the defunct ATG. HAV is currently developing persistent surveillance and heavy lift logistics airships. Their 1/6th scale prototype dubbed *HAV3*, based on the *Skykitten*, has successfully flown and three production models are under development. Each model incorporates recent technology developments such as hover cushion landing system, vectored thrust for take-off and landing, and lifting body hull design. The largest proposed model, depicted in the figure below, the *HAV 606* has a payload of 200 tons with a roll-on/roll-off cargo ramp, a range of 3225 nautical miles (5,972 kilometres), a cruise speed of 75 knots, and a pressure ceiling of 9000 feet. Furthermore, "crane" type operations capable of a 90-tonne vertical lift is advertised.[93] An even larger 1000-tonne vehicle has been proposed but has not yet been fully

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[91] Boeing, News Release. "Boeing Teams With Canadian Firm to Build Heavy-Lift Rotorcraft"; http://www.boeing.com/news/releases/2008/q3/080708c_nr.html; Internet; posted 8 July 2008; accessed 17 March 2008.

[92] Markus Ermisch, "Skyhook CEO Calls For Government Funding For Plane Project." *QMI Agency*; http://money.canoe.ca/money/business/canada/archives/2010/08/20100823-143710.html; Internet; posted 23 August 2010; accessed 08 April 2011.

[93] Hybrid Air Vehicles, "Military Heavy Lift," http://www.hybridairvehicles.com/militaryheavylift.aspx; Internet; accessed 18 March 2011.

developed due to envelope material limitations; such a vehicle offers even greater potential for future strategic lift.[94]

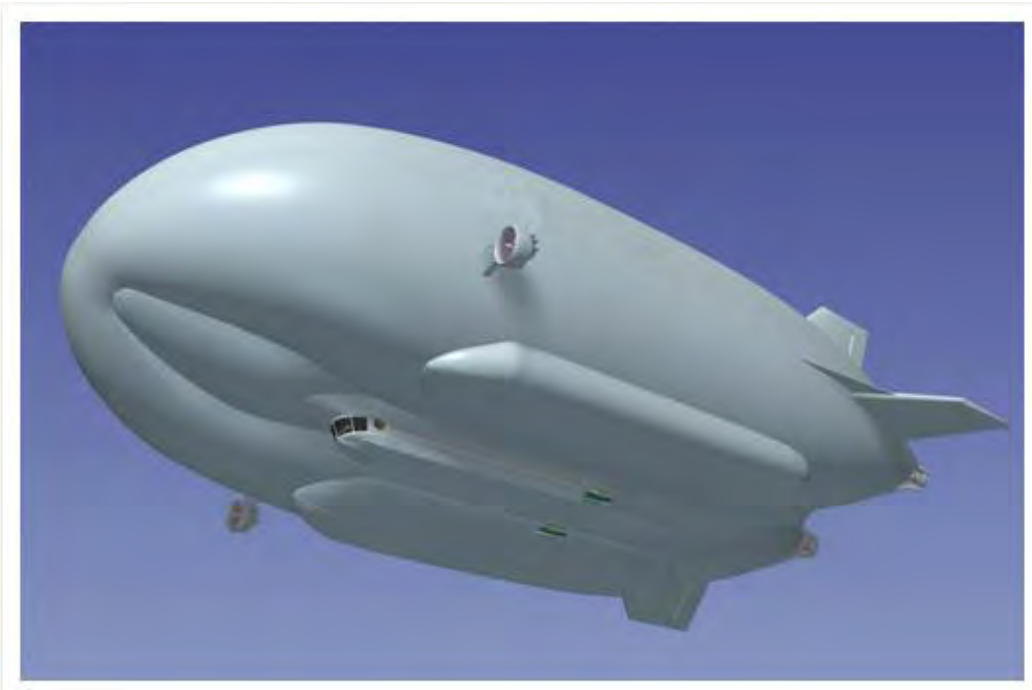

Figure 1.1: Hybrid Air Vehicles - Heavy Lift Airship
Source: Hybrid Air Vehicles, "Image Gallery," http://hybridairvehicles.com/imagegallery.aspx; Internet; accessed 15 April 2011.

A Notional Airship

Indeed, despite intensive design and marketing, such full-scale hybrid airships remain speculative only. However, given the *HAV 606's* status as the only design under development that matches the CANOSCOM project staff requirements, its characteristics will be used for the purpose of analyzing the viability of an airship solution for strategic lift. While this notional airship remains under development, the sub-scale prototype

[94] Hybrid Air Vehicles, "Heavy Lift Vehicles.

vehicle has made 22 flights as of mid-2009.[95] Furthermore, Hybrid Air Vehicles (partnered with Northrop Grumman) has won a $517 million dollar contract for the US Army Long-Endurance Multi-Intelligence Vehicle (LEMV) slated for deployment to Afghanistan in early 2012.[96] Should the LEMV succeed, this may bring much-needed legitimacy to hybrid airships and possibly help the heavy-lift variant to market. Given no known viable competitors at this time, this paper will use the *HAV 606* as the basis for a notional heavy-lift airship to be used for feasibility analysis. A summary of its principal data and design features is provided below.

Table 1.1: Notional Airship - Principal Data and Design

Characteristic	Specification
Envelope volume	457,500 m3 (16.1 m ft3)
Payload	200 tonnes
Length	185 m (607 ft)
Width	77 m (253 ft)
Height	47 m (154 ft)
Range	3225 NM (5972 km)
Pressure Altitude	2745 m (9000 ft)
Payload Deck Length	49.4 m (162 ft)
Payload Deck Width	7.5 m (24.5 ft)
Payload Deck Height	5.0 m (16.5 ft)
Cruise Speed	75 KTAS (139 km/h)
Maximum Speed	90 KTAS (167 km/h)
Envelope	Laminated fabric construction hull with 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 lifting needs. The internal diaphragms required to support this shape allow for a limited amount of compartmentalization further enhancing the fail-safe nature of the vehicle. Pressure control is provided by multiple

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[95] Jane's, "HAV SkyCat," http://client.janes.com/K2/doc.jsp?t=B&K2DocKey=?conent1/janesdata/yb/jawa/jawa5315.htm@current&Prod_Name=JAWA& ; Internet; posted 24 January 2011; accessed 15 March 2011.

[96] Hybrid Air Vehicles, "About Us," http://hybridairvehicles.com/About.aspx; Internet; accessed 17 March 2011.

	ballonets located fore and aft in each of the hulls.
Landing System	Hover skirts on the underside of the two outer hulls provide an amphibious capability with an enhanced (compared to conventional airships) ground handling ability. Hover skirts are 'sucked in' for a clean in-flight profile and enhanced all-round visibility. System shares use of ballonet fans with hull pressure system.
Power plant	4 x 8000 shaft horsepower (6000 shaft horsepower max cont) turboprop gas turbines. An engine within each stern duct drives a propeller. An engine is configured forward on either side of the hull also within a duct. The forward engines are for ground handling and take-off. All four ducts are configured with blown vanes to allow vectored thrust for take-off, landing, and ground handing operation.
Payload Module	Located on centerline providing roll-on/roll-off capability. Primary features are as follows: flight deck forward on centerline above the forward cargo ramp; flight deck provides side-by-side pilot stations along with 200 ft2 of accommodation for off-duty crew members; main load deck provides clear space for cargo/freight on a military rated floor structure; mezzanine decking can be provided to give multiple lower load area; rear cargo ramp provides roll-on/roll-off access to load deck; Above door aperture is a further 400 ft2 of accommodation space. Crane-type operations with a lift capacity of up to 90 tonnes vertically.
Flight controls	Dual-channel, optically signed, flight control system.

Source: Hybrid Air Vehicles, "Heavy Lift Vehicles…".

As the historical record revealed, airships achieved a number of significant milestones and competed with heavier-than-air aircraft for several decades. From the first manned flight by the Montgolfier brothers in 1783, to the first passenger airline in 1909, to the first round-trip trans-Atlantic flight in 1919, to the first polar overflight in 1926, to the first circumnavigation of the world in 1929, ligher-than-air vehicles have been at the vanguard of aviation. Despite the cultural memories of the *Hindenburg* disaster, lighter-than-air travel has nonetheless enjoyed an enviable safety record. While the dawn of the jet-engine age marked the decline of airships, modern hybrid technology and increasing need for heavy lift transport have opened the field once again. While manufacturers have faced financial challenges in bringing airships to market, they offer great potential. The *HAV 606* hybrid airship has been submitted as the basis of a notional airship used for analysis. However, any conclusions drawn will have to be verified once a production model is ready for operational use. Nonetheless, in order to determine the airship's theoretical effectiveness for military strategic lift, the following chapter will examine this potential from a doctrinal perspective.

Chapter 4 – Airship Suitability: Doctrinal Perspective

According to the CF doctrine development manual, military doctrine "…represents the distilled insights and wisdom gained from experience."[97] Furthermore, the CF Aerospace Doctrine manual states that doctrine is "…instrumental in establishing priorities and acts as a critical sounding board for testing and evaluating new concepts and policies."[98] Therefore, using a doctrinal framework to assess the viability of an airship solution to strategic airlift will allow for a critical evaluation based on an authoritative foundation. This examination will be developed in three parts. The first part will use the recently revised CF Aerospace Doctrine to assess the notional airship's strengths and weaknesses as a generic aerospace vehicle. The second part will use CF Joint Doctrine for Movement Support to assess how the use of airships could affect the flow of personnel, equipment, and goods. The third part will use CF Air Movement Support doctrine to examine how the notional airship's strengths and weaknesses affect airlift planning. Such a balanced doctrinal approach aims to provide a fundamental appreciation of the airship's military utility.

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[97] Department of National Defence, A-GJ-025-0A1/FP-001 *CFJP A1 Doctrine Development Manual* (Ottawa: DND Canada, 2010), v.

[98] Department of National Defence, B-GA-400-000/FP-000 *Canadian Forces Aerospace Doctrine* (Winnipeg: DND, Canada, 2010), 1.

Aerospace Doctrine

The Canadian Forces Aerospace Doctrine manual establishes the framework for the effective use of aerospace forces. Within this framework, strategic lift forms a part of Air Mobility and therefore falls under the Air Force "Move" function. This function results in the deployment and positioning of personnel and material in order to achieve desired effects. Indeed, strategic airlift allows a Joint Task Force (JTF) to deploy, maintain, and regenerate its capabilities in support of operations.[99] While strategic airlift and force sustainment are not glamorous military activities, they are critical capabilities that enable operational success. This importance is captured in the military cliché "amateurs talk tactics; professionals talk logistics."[100]

For optimal use of aerospace forces, an understanding of the following basic doctrinal characteristics of air power are required: elevation, fragility, impermanence, payload, precision, reach, sensitivity to environmental conditions, sensitivity to technology, speed, stealth, and support dependency.[101] In order to achieve this understanding, each of these characteristics will be examined in turn as they apply to the notional airship and assessed as being strong, moderate, or weak.

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[99] Department of National Defence, B-GA-400-000/FP-000…, 4, 46.

[100] As noted in Mitch Free, "Amateurs Talk Tactics; Professionals Talk Logistics," *Production Machining* Vol.9 No. 11 (November 2009): 20; http://web.ebscohost.com/ehost/pdfviewer/pdfviewer?vid=28&hid=10&sid=793cb3c6-a371-4652-9ea5-5508d87c5c37%40sessionmgr13; Internet; accessed 13 April 2011.

[101] Department of National Defence, B-GA-400-000/FP-000…, 25.

The ability for aerospace vehicles to operate the Earth's surface provides the ability to observe and influence activities on the surface and below the sea.[102] Within the framework of Air Force functions, this characteristic applies primarily to the Sense function and the Shape sub-function. However, airships engaged in strategic lift could conceivable have integrated surveillance sensors that allow it to fulfill multiple functions concurrently. This potential flexibility means that elevation may indeed be pertinent to a heavy-lift airship.

Conventional, airships were typically low altitude vehicles, seldom operating above 3000 feet unless forced higher by military or navigation necessity.[103] In contrast, hybrid airships can operate higher as they are buoyed by both aerodynamic lift from its envelope shape and by buoyant lift from helium. More specifically, the notional airship has a pressure altitude of 9000 feet.[104] Notably, this elevation is much less than fixed-wing aircraft and specialized high-altitude airships. Therefore, the notional heavy-lift airship is only moderately able to exploit elevation.

As compared to surface vehicles, aerospace vehicles tend to be more fragile and require special handing to keep them operational.[105] With computer-assisted design and modern materials, however, modern air vehicles are less affected by catastrophic design

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[102] *Ibid*., 25.

[103] Hayward, *The Military Utility…,* 15.

[104] Hybrid Air Vehicles, "Heavy Lift…,".

[105] Department of National Defence, B-GA-400-000/FP-000…,, 25.

and construction failures than their predecessors. However, they remain vulnerable to equipment failure and to enemy air defences.[106]

Fuelled by the graphic images of the *Hindenburg* disaster and of popping balloons, there is an unfounded myth about the fragility of airships.[107] However, nearly two-thirds of the passengers survived – a survival rate that would be highly unlikely today for any exploding jet airliner.[108] Furthermore, a number of technological developments have enhanced modern airship safety. For example, the use of inert helium has reduced the chance of explosion and new envelope materials make airships lighter and more robust.[109]

Nonetheless, airships are large, relatively slow moving vehicles that are susceptible to ground fire.[110] However, unlike a child's balloon, which holds air at high pressure, airships hold helium at a very low pressure. As a result, holes result in slow leaks as opposed to catastrophic failure. Feasible studies indicate that a large airship could sustain thousands of holes from small arms fire and still be able to operate for a number of hours.[111] This theory is supported by the 1998 example of rogue 80-metre

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[106] Charles E. Newbegin, "Modern Airships: A Possible Solution for Rapid Force Projection of Army Forces" (PhD Thesis, School of Advanced Military Studies, US Army Command and General Staff College, 2003), 31.

[107] Hayward, *The Military Utility…*, 26.

[108] Barry Prentice, "Question and Answer Forum," in *Strategic Lift Options for Canada and the Allies*, edited by David Rudd, Ewa Petruczynik, and Alexander Wooley, 91-104. (Toronto: Canadian Institute of Strategic Studies, 2005), 93.

[109] Barry Prentice, "Airship Applications," in *Strategic Lift Options for Canada and the Allies*, edited by David Rudd, Ewa Petruczynik, and Alexander Wooley, 33-48. (Toronto: Canadian Institute of Strategic Studies, 2005), 38.

[110] Prentice, "Question and Answer…", 93.

[111] Newbegin, *Modern Airships*…, 32.

high weather balloon that drifted across the North Atlantic, surviving more than 1000 cannon shells being fired at it by CF-18 fighter aircraft.[112] Furthermore, vulnerability trials established that a Surface-to Air Missile (SAM) missile would pass through the envelope, leaving relatively small holes that would take three and a half hours for the vehicle to deflate.[113]

However, engineering studies indicate vulnerability in the crew cabin, engines, and cargo compartments.[114] Heat signatures from the engine could attract man portable air defence system (MANPADS) fire, although the loss of one or two engines of eight 8000 hp engines would only degrade performance and not ‘kill’ the airship outright.[115] However, barring the use of armour, hazardous cargo in the cargo compartment remains vulnerable to fire or explosion caused by explosive or incendiary rounds. Similarly, the crew compartment is vulnerable to ground-based fire unless armour protection such as Kevlar is installed.[116]

While vulnerable to sustaining battle damage, the survivability of the notional airship is higher than other aircraft due to the smaller likelihood of explosion and the greater ability to conduct low speed off-airfield forced landings.[117] Therefore, the notional modern airship is deemed moderately fragile.

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[112] Bruce Poulin, “Balloons Away!” *Airforce* Vol. 28 No. 4 (Winter 2005): 60.

[113] Jennings, “Theatre lift takes centre stage …,”.

[114] Ghanmi and Abderrahmane, “Airships for …”, 15.

[115] Newbegin, *Modern Airships*…,, 31.

[116] Hayward, *The Military Utility…,* 29.

Another aircraft characteristic is impermanence. Indeed, aerospace platforms cannot stay aloft indefinitely; this limitation may be offset by rotating a number of platforms in order to maintain a posture of relative permanence, or by repeating missions as needed.[118] The notional airship has a published endurance of 43 hours, which significantly exceeds that of fixed- and rotary-wing aircraft. Greater endurance is certainly possible, as current efforts to integrate thin membrane solar collectors into the upper envelope promise to increase an airship's power supply even further.[119] Therefore, notional heavy-lift airships have moderate aerospace endurance.

Compared to maritime and land vehicles, aerospace vehicle payloads are limited. However, due to faster speed, this constraint may be offset by a high sortie rate. Furthermore, a smaller payload of critical equipment (such as ammunition or medical supplies) delivered quickly may contribute to mission success more effectively than a larger payload delivered later.[120]

However, heavy-lift airships promise to deliver payloads that exceed that of all other aircraft, not only in terms of absolute volume but also in terms of cargo size.[121] For example, the C17 Globemaster has a maximum payload of 75 tons that must fit in a

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[117] Newbegin, *Modern Airships…*, 33.

[118] Department of National Defence, B-GA-400-000/FP-000…, 25.

[119] Prentice, "Airship Applications", 39.

[120] Department of National Defence, B-GA-400-000/FP-000…, 25.

[121] Congress of the United States Congressional Budget Office Study, *Options for Strategic Military Transportation Systems* (Washington, DC: Congressional Budget Office, 2005), 22.

compartment measuring 18 feet (5.49 m) wide by 68.2 feet (20.78 m) long, by 12.3 feet (3.76 m) under the wing.[122] In contrast, the notional airship design allows for a cargo of 200 tons in a compartment measuring 25 feet (7.5 m) wide, 162 feet (49.4 m) long, and 16.5 feet (5.0 m) high. This calculates to roughly two and half times the weight, and four and half times the volume, in favour of the notional airship. In addition to providing a roll-on/roll-off capability on a military rated floor structure, the notional airship also allows for mezzanine decking in order to provide multiple load areas.[123] This would allow the carriage of every category of military land vehicle up to main battle tank size.[124] Therefore, the notional airship has a strong aerospace payload capacity.

Aerospace power can deliver kinetic effects with great accuracy (and minimal collateral damage) due to the inherent qualities provided by surveillance satellites and precision guided munitions. However, precision is also a navigational consideration for Move missions. Indeed, heavy-lift airships are capable of as much navigational precision as other aircraft, as equipment such as Global Positioning System (GPS) and Inertial Navigation System (INS) are not dependant on platform type. Furthermore, in terms of delivering 90 tonnes of slung cargo to a specific location, the crane-operations capable

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[122] Boeing. "C-17 Globemaster III – Technical Specifications," http://www.boeing.com/defense-space/military/c17/c7spec.htm; Internet; accessed 17 March 2011.

[123] Hybrid Air Vehicles, "Heavy Lift Vehicles…,".

[124] Jennings, "Theatre lift…,".

notional airship has the precision of a helicopter.[125] Therefore, the notional airship is deemed to have strong precision.

Aerospace vehicles can be projected globally, relatively unimpeded by surface features such as mountain barriers or water expanses.[126] The non-stop, non-refuelled circumnavigation of the world by the Voyager in December 1986 demonstrated the potential for aircraft reach.[127] Indeed, air vehicle range is limited only by fuel and, for manned vehicles, crew endurance. Air-to-air refuelling and/or the use of ‘deadhead’ crews on board can mitigate these limitations. Indeed, the notional airship design provides for extra crew birthing, allowing for flight limited only by fuel. However, no mention of air-to-air refuelling for airships can readily be found in literature at this time, suggesting that this reach extension is not being pursued.

The notional airship’s range of 3,225 nautical miles would allow it to fly directly from Halifax, Nova Scotia to Vancouver, British Columbia (2400 nautical miles) and from Alert, Nunavut to Windsor, Ontario (2450 nautical miles); a superior range capacity. Furthermore, this range just meets the “strategic distance” of 6000 km specified by the WALRUS project.[128] Therefore, the notional airship has moderate strategic reach.

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[125] Hybrid Air Vehicles, “Military Heavy Lift,”.

[126] Department of National Defence, B-GA-400-000/FP-000…,, 25.

[127] Michael A. Dornheim, “Solo Ambitions,” *Aviation Week* Vol. 162 No. 1 (1 March 2005): 46; http://web.ebscohost.com/ehost/detail?vid=34&hid=10&sid=793cb3c6-a371-4652-9ea5-5508d87c5c37%40sessionmgr13&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=15592159; Internet; accessed 13 April 2011.

Aerospace power is sensitive to environmental conditions. For example, bad weather can create difficulties with take-offs and landings, navigation, target acquisition, and weapons delivery.[129] Indeed, most historic airship losses were due to extreme weather such as thunderstorms. Lacking satellite-fed weather predictions and on-board weather, legacy airships inadvertently flew into storm tracks from which they were too slow to escape.[130] In contrast, modern weather forecasting and advanced weather radar systems would allow modern airships to avoid potentially dangerous weather systems.

Even when confronted by winds at departure and/or destination points, the notional airship is less susceptible to strong and/or gusty winds than its predecessors, due to its slightly-heavier-than-air design combined with its air cushion landing system.[131] Furthermore, fly-by-light flight control systems and pneumatic flight-control actuators provide low susceptibility to lightning strike and electromagnetic interference.[132]

Restricted to operating in the low level environment, the notional airship may be susceptible to ice accumulations, which increase the aircraft's weight and increase drag. In extreme cases, this can result in the stall and crash of an aircraft. While in-flight anti-icing and de-icing systems such as electric heaters and pneumatic inflating boots may be used, these systems are not yet proven on the notional airship. Furthermore, ground de-icing may be very difficult due to the enormous envelope size. Indeed, the CFAWC

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[128] Gordon and Holland, "Airships and the Revolution…", 53.

[129] Department of National Defence, B-GA-400-000/FP-000…, 25.

[130] Ghanmi and Abderrahmane, "Airships for Military Logistics…", 15.

[131] Newbegin, *Modern Airships*…, 26.

[132] Jane's, "Heavy Lift Vehicles…".

Future Air Platform Preliminary Analysis assessed the hybrid airship to be highly vulnerable to weather.[133] Therefore, pending definitive studies of how snow and ice affect hybrid airships, the notional airship is conservatively estimated to have high sensitivity to environmental conditions.

Aerospace power effectiveness can be significantly affected by relatively small technological innovations. Such advances drive an ongoing requirement for continuous improvement and development of aerospace forces.[134] Indeed, airship history has been highly affected by technological innovations. For example, developments in lifting gases, materials, and internal combustion engines fuelled the development of airships. Furthermore, the slower pace of development relative to airplanes contributed to their decline following the Second World War.

Modern airships attempt to take advantage of technological milestones such as vectored thrust, composite structures, fly-by-light flight control systems, laminated hull fabrics, turbine propulsion, lifting body hull designs, and air cushion landing systems.[135] Even so, these airships remain at the prototype stage at best and their effectiveness can only be determined once a successful production model integrates these technological

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133 Ghanmi and Abderrahmane, "Airships for Military Logistics…", 17; Collin, "Future Air Platforms…", 41.

134 Department of National Defence, B-GA-400-000/FP-000…,, 26.

135 Hybrid Air Vehicles, "About Us," http://hybridairvehicles.com/About.aspx; Internet; accessed 17 March 2011.

solutions to legacy airship issues. Indeed, CFAWC analysis concludes that technological risk is moderate for hybrid airships.[136]

Aerospace power has an inherent characteristic of speed, which provides a rapid response capability that can be projected across a great distance. Furthermore, survivability in hostile theatre can be increasing by using speed to achieve surprise.[137] Compared to airplanes, however, airships have much lower cruising speeds. In addition, airship cruising speeds have not appreciably increased since they 1930s. Higher speeds can be achieved, however at an unacceptable fuel penalty due to increased power to overcome aerodynamic drag. A 2005 Congressional Budget Office concluded that achievable speeds for hybrid airships range from 80 to 120 knots. Indeed, the planned cruising speed for the notional airship is 75 knots, with a maximum speed of 90 knots.[138]

Due to this relatively low cruise speed, the notional airship may be negatively affecting by low level winds. For example, frontal low-level jets in a developing low pressure system, typically located between 500 and 5000 feet, can produce winds as high as 100 knots.[139] While this is unusual, airships will nonetheless be affected more than airplanes by headwinds and have limited options in seeking more favourable winds at different altitudes. Therefore, the notional airship is considered to have weak speed.

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[136] Collin, "Future Air Platforms…", 45.

[137] Department of National Defence, B-GA-400-000/FP-000…,, 26.

[138] Hybrid Air Vehicles, "Heavy Lift Vehicles…".

[139] Ed Hudson *et al*, *The Weather of Nunavut…*, 21.

Aerospace power can use stealth tactics and/or technology to increase survivability by minimizing the risk of detection. Indeed, due to its structure, the notional airship has an intrinsically lower radar signature that conventional aircraft, resulting in lower risk of radar detection.[140] Furthermore, trials suggest that it would be inaudible at a slant range of 3500 feet and use could low-visibility or camouflage paint blend to help blend into the background sky.[141] Nonetheless, a 600 foot-long vehicle operating at 9000 feet in open sky is not covert.[142] Therefore, the notional airship is deemed to have a weak stealth capability.

Aerospace power requires high levels of technical and logistical support that must be provided from an operations support base.[143] Indeed, strategic lift aircraft typically require long runways, large hangars, and extensive movement teams. However, since the notional heavy-lift airships uses hover skirts for air-cushioned landings, airfields and associated infrastructure are not required.[144] Indeed, this design allows for amphibious operations. However, hybrid airships still need a landing/take-off zone with approach and departure paths clear of obstacles such as trees, wires, and other man-made structures. When taking off from the APOE with a full load, up to 8000 feet of runway of open space is required to gain enough speed (and aerodynamic lift) for take-off. This

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[140] Hayward, *The Military Utility…*, 27.

[141] Hayward, *The Military Utility…*, 27.

[142] Collin, "Future Air Platforms…", 41.

[143] Department of National Defence, B-GA-400-000/FP-000…,, 26.

could be a runway or a large drop zone at an army base. Upon arrival in theatre, with most of the fuel burnt, only an estimated 1500 feet is required for landing due to the slow approach speeds combined with air cushion landing system. Once the cargo is unloaded, the airship would be nearly neutral buoyant and would be able to take off almost vertically.[145] While an aircraft ground handling team is not required, a cargo movement team will be required for all cases except for self-loading/unloading cargo such as personnel and their associated land vehicles. Therefore, the notional airship is deemed have strong support dependency characteristics.

In summary, the notional airship demonstrates a balance of strengths and weaknesses in basic aerospace characteristics. Specifically, the notional airship has strong payload, precision, and support dependency characteristics. Furthermore, it has moderate elevation, fragility, reach, and sensitivity to technology. Finally, it has weak speed, stealth, and sensitivity to environmental conditions. Some of these characteristics are better than other aircraft, some are worse, and some are simply different. The following section will examine how these intrinsic aerospace characteristics affect air movement support planning.

Joint Movements Doctrine

Indeed, while the review of the notional airship's aerospace characteristics revealed operational aerospace characteristics suitable for conducting strategic lift, the

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[144] Hybrid Air Vehicles, "Heavy Lift Vehicles…,".

[145] Gordon and Holland, "Airships and the Revolution…", 53.

picture is not complete with considering the logistics aspect of these operations. The joint doctrine manual Joint Movement Support provides guidance on this issue. Specifically, a review of the typical generic flow of movements from origin to final destination will provide an appreciation of how airships could expedite this process.

Indeed, the movement flow of a Task Force from home to an operational theatre involves planning and execution by several levels of command and normally involves stops at several intermediate locations.[146] The typical movement flow is depicted in the table below.

Table 2.1: Logistics Movement Flow

Key Location	**Routine Use**
Home Base	Where individual units or components of a Task Force normally reside and from where movement begins
Staging Base	Where units are located far from Ports of Embarkation, staging bases may be required between Home Base and Port of Embarkation locations
Assembly Base	Where individual units or components of the Task Force consolidate in order to complete movement within Canada to a Mounting Base
Mounting Base	Where the Task Force gathers for final preparation prior to loading for strategic transport (is some cases, it may be at the Port of Embarkation
Port of Embarkation	Where strategic air (APOE) or sea (SPOE) transportation begins
Forward Staging Base	In cases where the Ports of Disembarkation and Embarkation are distant, a forward staging base facilitates refuelling, crew changes, and re-configuration of the Task Force
Port of Disembarkation (POD)	Where the strategic transportation requirement for forces is completed, generally a large airport (APOD) or seaport (SPOD
Marshalling Area	Where personnel are reunited with their vehicles and

[146] Department of National Defence, B-GJ-005-404/FP-000 *Joint Movement Support* (Ottawa: DND, Canada, 2002), 3-5.

	equipment prior to moving forward in-theatre (passengers normally move by strategic air, and vehicles and equipment by sea
Staging Area	In cases where it is a considerable distance from the Marshalling Area to an Assembly Area, a staging area facilitates vehicle re-fuelling, minor repairs, food, rest, consolidation of vehicles/equipment into packets
Assembly Area	Where vehicles are refuelled, minor repairs are completed, final briefing and training completed, vehicles loaded with combat supplies, and vehicles/equipments are formed into unit and directed to their final destination
Final Destination	Where a unit or capability is required to be within their intended area of operations (AO

Source: Department of National Defence, B-GJ-005-404/FP-000 *Joint Movement Support*, 3-5.

The possibility of nine enroute stops from home base to final destination seems to contract the principle of maximum utilization, which emphasizes minimizing turn-around times and avoiding congestion en route.[147] Indeed, SPODs can be easily become choke points and APODs in land-locked areas of operation can be subject to congestion due to insufficient infrastructure to accommodate large surges in flow.[148]

With its long reach and low support dependency due to airfield independence and roll-on/roll-off capability, the notional airship shows potential to eliminate a number of these intermediate stops and thus improve movement flow. For example, airships could embark personnel and equipment at training areas located at home base, effectively consolidating staging, assembly, mounting bases and ports of embarkation into the same location. Depending on the distance to the area of operations, a staging base may or may not be needed during travel to destination. Further consolidation may be possible,

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[147] *Ibid.,*, 1-1.

[148] Congressional Budget Office, “Options for Strategic…”, 16.

particularly if passengers and vehicles travel together. Indeed, with use of mezzanine decking, personnel could be berthed above the vehicle stored below. If this is the case, the port of disembarkation, forward staging base, assembly and staging areas might also be consolidated. Thus, despite the notional airship's slow relative speed, in certain circumstances it may nonetheless be able to deliver troops and their equipment quicker than any other method.[149]

Indeed, the notional airship's potential ability to embark troops and equipment at home base and deliver them directly to an assembly area in theatre promises to maximize the generic movement principle of maximum utilization. Building on this logistics analysis, the following section will explore how the notional airship affects specific planning considerations for air movement support.

Movement Support – Air

The Joint Doctrine manual *Movement Support – Air* provides CF overall guidance in planning and executing air transport missions.[150] This document notes that aircraft provide the fastest movement of personnel and cargo, albeit at a high cost. In certain cases, however, there may be no other option. In all cases, though, the advantages and disadvantages of air transport must be considered before it is used. The major planning considerations are: security, speed, load, resources, flexibility, weather, over-flight and

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[149] *Ibid.,* 24.

[150] Department of National Defence, B-GJ-005-404/FP-040 *Joint Doctrine Manual: Movement Support – Air* (Ottawa: DND Canada, 2003), i.

diplomatic clearances, joint planning, support requirement, and flight safety.[151] In order to assess the notional airship's effectiveness as an air transport vehicle, each of these considerations will be examined in turn and operational conclusions drawn.

Transport aircraft are particularly vulnerable to ground-based air defence and air interdiction.[152] Indeed, given the notional airship's weak speed and moderate elevation, it has been assessed as being at high risk of interception.[153] Despite the notional airship's relatively strong survivability, exposing such a high payoff target to such threat should be minimized. Therefore, the notional airship should not be operated into high-intensity operations, well-defended areas, or over enemy positions.

On the other hand, air transport's speed provides an unmatched capability to move cargo quickly over long distances. However, for larger heavily equipped forces, it may not be the most effective.[154] Indeed, the CFAWC analysis concluded that a hybrid airship was too slow for strategic transport.[155] However, as just explored in the Joint Doctrine section, while the notional airship has a lower relative speed than aircraft, it may be able to deliver cargo direct to destination faster than other means. Indeed, in case of complicated conventional movement flow, an airship may be as much as ten times faster

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[151] Department of National Defence, B-GJ-005-404/FP-040, 1-1.

[152] Department of National Defence, B-GJ-005-404/FP-040, 1-1.

[153] Collin, "Future Air Platforms…", 41.

[154] Department of National Defence, B-GJ-005-404/FP-040, 1-1.

[155] Collin, "Future Air Platforms…", 42.

time than standard multi-modal means.[156] Therefore, an accurate time-space appreciation comparing conventional airlift and the notional airship should be conducted for time-critical missions.

Despite transport aircraft's speed, it has limited cargo capacity in terms of bulk and/or weight.[157] Indeed, the CFAWC analysis also concluded that hybrid airships were not suitable for strategic lift due to insufficient payload.[158] However, it appears that this conclusion was based on a 50-ton load, which is much less than the notional airship's 200-ton over-size capacity.[159] Indeed, based on the notional airship specifications, this paper has concluded that the notional airship has an excellent aerospace payload capacity. This discrepancy highlights the challenges of analyzing capabilities based on a 'paper aircraft'; any conclusions drawn with will have to be revisited once a production model hybrid aircraft become available. Nonetheless, the notional airship shows potential be the preferred air platform when tasking mission involving over-size and/or overweight cargo.

However, air transport can be expensive, particularly when compared to surface delivery options. Allocating this scarce resource should be made at the highest possible

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[156] Lieutenant Colonel Christopher Thurrot and Major Shane Jennings. "The Dirigible – A Phoenix Rising from the Ashes," *The Army Doctrine and Training Bulletin* Vol. 5, no. 3 (Fall 2002): 56..

[157] Department of National Defence, B-GJ-005-404/FP-040, 1-1.

[158] Collin, "Future Air Platforms…", 42.

[159] *Ibid*., 39.

level, and the resulting decisions should be based on operational priorities.[160] Notably, the notional airship promises a unique operational capability due to its unmatched combination of payload, range, and short-field austere capabilities.[161] While a more detailed modal comparison with sealift and conventional airlift will be made in the following chapter, planners should task the notional airship on missions that best fit its niche capabilities.

Indeed, air transport is flexible and can carry out a wide variety of tasks.[162] In fact, an often-referenced Air Force tenet states "Flexibility is the key to air power."[163] With an austere field capability, the notional airship appears to be highly flexible. However, the notional airship's 9000 foot pressure altitude may limit this flexibility. For example, in cases such as mountain flying, visual meteorological conditions may be required in order to navigate over valleys floors and passes in order to cross a mountain range. Indeed, on a cloudy day, the airship may not be able to climb to a safe instrument flying altitude. In fact, since military flying orders dictate as much as 2000 feet clearance above all terrain within 5 miles of aircraft track to ensure safety, a CF notional airship may therefore be limited when operating in terrain reaching 7000 feet above sea level.[164]

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[160] Department of National Defence, B-GJ-005-404/FP-040, 1-1.

[161] Gordon and Holland, "Airships and the Revolution…", 52.

[162] Department of National Defence, B-GJ-005-404/FP-040, 1-1.

[163] Lieutenant Colonel Brian Dickerson, "Adaptability: A New Principle of War," in *National Security Challenges in the 21st Century* (10 January 2003): 212; http://web.ebscohost.com/ehost/pdfviewer/pdfviewer?vid=41&hid=10&sid=793cb3c6-a371-4652-9ea5-5508d87c5c37%40sessionmgr13; Internet; accessed 13 April 2011.

Within Canada, this includes large portions of British Columbia and the Yukon, and well as eastern portions of Nunavut. As a result, this may mean delaying for suitable weather or diverting to alternate routes (if available). In some cases, they may negatively affect mission accomplishment.[165] While the notional airship is highly flexible, planners should consider the notional airship's maximum operating altitude when assigning missions.

Notwithstanding modern navigation systems and instrument approach aids, weather is still a consideration for air movement. Indeed, operating from austere fields may not be possible in low visibility and/or ceiling conditions.[166] Furthermore, the notional airship's pressure altitude may put it at increased risk to experience weather conditions such icing conditions. This is particularly true is areas where the surface temperature is near freezing and there is extensive low level moisture in the air. Such areas include much of Canada's Arctic during periods of the spring and fall, where layer cloud is common.[167] In this type of weather, the most severe icing is generally found to 0º to -15º Celsius temperature range.[168] With surface temperatures within a few degrees of either side of freezing, this translates to a risk of severe icing in cloud from the surface

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164 Department of National Defence, B-GA-100-001/AA-000 *National Defence Flying Orders – Book 1 of 2 – Flight Rules* Change 8 (Ottawa: DND, Canada, 2009), 8-4/12

165 The author served with 442 (Transport and Rescue) Squadron at 19 Wing Comox, British Columbia, from 2002 to 2007. Qualified as a Search and Rescue (SAR) Aircraft Commander on the CC115 Buffalo, he had extensive mountain flying experience.

166 Department of National Defence, B-GJ-005-404/FP-040, 1-1.

167 Ed Hudson *et al,*. *The Weather of Nunavut*…, 52.

168 *Ibid.*,12.

through to 5000 to 10000 feet above sea level.[169] While the notional airship's pressure altitude of 9000 feet might allow for some manoeuvring space above the most severe icing, this room for altitude change is limited. As when facing mountain barriers, evasion options are limited to delaying for suitable weather or diverting up to hundreds of miles around the weather system.[170]

Despite this consideration, a study conducted for the Boeing Company concluded that airships could generally operate in northern weather conditions for up to 310 days a year, with January and February being the limiting period.[171] As with some of the other planning considerations, empirical evidence is required before drawing decisive conclusions. As the very least, planners should account for the fact that the notional airships will not always be able to operate to a fixed schedule in the Arctic.

However, there are also planning considerations when operating in higher density airspace. For example, over-flight and diplomatic clearances are required internationally, even when working with allies.[172] However, due to the notional airship's weak speed, stealth, and moderate elevation characteristics, non-committed nations may hesitate to grant such clearances. Indeed, the potential for public plausible deniability for the

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[169] Based on a standard temperature lapse of 2 degrees per 1000 feet, as noted in Department of National Defence. B-GA-007-001/PT-D01 *Air Command Weather Manual* (Ottawa: DND Canada, 2008): 3-1.

[170] The author was qualified as an Aircraft Commander on the CC138 Twin Otter from 2008 and 2010 and flew extensively across the Arctic. As the CC138 is not pressurized and does not carry oxygen, aircrews have an operational ceiling of 10000 feet - very similar to that of the notional airship. Based on this experience, the consideration of low level icing should not be underestimated or discounted until the notional airship's de-icing capacity has been determined.

[171] Ghanmi, "Airships for Military Logistics…", 16.

[172] Department of National Defence, B-GJ-005-404/FP-040, 1-1.

notional airship's passage is much lower than an anonymous jet aircraft flying overhead above thirty thousand feet. As a result, planners must be prepared adjust routes to accommodate nations who do not want to be seen to be facilitating military-related Allied flights over their country.[173]

Furthermore, air transport tasks are assigned at high-level headquarters in conjunction with stakeholder organizations.[174] The airship's unique capacity to deliver large amounts of cargo to austere locations within the operating area may require more tactical-level coordination than has been typical for air transport bound for Air Ports of Disembarkation (APODs) established at main operating bases (MOBs). For example, the possible need for customs clearance for international cargo moves at austere locations may be complicated.[175] Should the notional airship be brought into military service, air and joint logistics doctrine and planning procedures would have to be revised in order to appropriately account for a new strategic asset capable of deploying into tactical areas.

In addition, personnel deployed in support of air operations at austere locations may not have access to local rations, quarters, and transport.[176] Provided that the notional

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[173] Congressional Budget Office, *Options for Strategic…*, 24.

[174] Department of National Defence, B-GJ-005-404/FP-040, 1-2.

[175] Ian Putzger, "Global Warming and Emissions Concerns Strengthen Case for Airships for Moving Cargo, Especially in Canada's North" Canadian Transportation and Logistics Vol. 110, no. 11 (Nov/Dec 2007): 41; http://web.ebscohost.com/ehost/detail?hid=105&sid=80c5ed0c-152c-41c6-a22f-cff8bc5fab79%40sessionmgr115&vid=8&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=bth&AN=28096115; Internet; accessed 16 January 2011.

airships delivers personnel and cargo such as vehicles than can roll-on and roll-off to austere locations, the support footprint required is minimal.[177] However, refuelling, de-icing, and/or first-line maintenance for the notional airship and its delivered vehicles may be difficult to complete on-site.[178] Furthermore, should the notional airship become an organic CF asset, extremely large hangars may be required at home base in order to conduct first- and second-line maintenance out the elements. Operational research is required before drawing any firm conclusions, however, planners should at least consider that support requirements may be higher than advertised by developers.

Finally, modern aircraft are valuable resources that are not easily replaced. Planning must weigh operational necessity against flight safety considerations.[179] Given that hybrid airships are an entirely new type of aircraft, it is reasonable to expect a heightened level of risk during the early employment phase. Should the CF procure the notional airship, this risk should be mitigated by incorporating lessons learned from recent fleet acquisitions. Considerations should include, but are not limited to, operational and technical airworthiness, test and evaluation, initial cadre selection, as well as standards and training development. Until the notional airship's capabilities and limitations are well understood, planners should be conservative when tasking its missions.

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[176] Department of National Defence, B-GJ-005-404/FP-040, 1-2.

[177] Collin, "Future Air Platforms…", 41.

[178] Putzger, "Global Warming and Emissions…", 41.

This air movement doctrinal review has revealed a number of insights on the notional airship's suitability for strategic transport. Specifically, airships are vulnerable to interdiction and should not operate in high-intensity tactical operations, well-defended areas, or over enemy positions. While the airship is a relatively slow aircraft, it may nonetheless be able to deliver personnel and equipment quicker than aircraft by expediting the movement flow; a time-space appreciation is recommended to confirm this for time-critical missions. Furthermore, the notional airship has an unparalleled load capacity for aircraft and should be exploited accordingly. However, traditional lift options should not be discounted due to their inherent advantages in certain aspects. Planners should consider the notional airship's operating altitude when tasking missions involving high terrain and/or low-level weather systems enroute. Due to this altitude limitation, in conjunction with the notional airship's slow speed and large size, planners will also have to consider that non-committed nations may be reluctant to issue over-flight and diplomatic clearances. Indeed, planners at all levels may have to adjust their templates in order to accommodate the unique capabilities that the notional airship may bring. This is particularly true for operations at austere locations, where support requirement may be reduced in some areas, but also complicated by the possible need for customs and first-line maintenance facilities. Finally, extensive planning and consideration will be required to safely introduce the notional airship as a new CF operational fleet or leased capability.

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[179] Department of National Defence, B-GJ-005-404/FP-040, 1-2.

This chapter has explored in depth the notional airship's aerospace characteristics, its impact on the flow of movement, and its influence on air movement support planning. While the notional airship shows strong potential to deliver effective strategic lift, the issue of efficiency has not yet been fully explored. In order to assess the airship's economic feasibility, the following chapter will conduct a market analysis.

Chapter 5 – Airship Feasibility: Market Analysis

Strategic lift is a vital capability needed to accomplish Canadian foreign policy and to defend Canada's interests.[180] Traditional methods involve either shipping by sea or air. While the notional hybrid airship may be doctrinally suitable in providing strategic lift, its true capabilities remain unproven. As final development, procurement, and operating costs for the hybrid airship remain speculative, a proven and accurate cost-benefit analysis comparing hybrid airships to sealift and conventional cargo aircraft is not possible at this time. Nonetheless, a comparison of the generic strengths and weaknesses of sealift, conventional airlift, and the notional airship may provide insights into the desirability of pursuing an airship solution for strategic lift. Indeed, the greatest risk to airship development lies not with technical ability, but rather with weak commercial demand.[181] In order to explore this issue, this chapter will review the advantages and disadvantages of each mode in turn, along with its niche capabilities. In such a manner, the full potential of the notional airship may be revealed.

Sealift

While jet aircraft dominate the global passenger market, sealift is the principal means of overseas cargo delivery. Indeed, ninety percent of the world's trade is carried by sea. Furthermore, many of the world's militaries rely on this same network of

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[180] Szeto and Cooper, "The Need for …", 19.

[181] Prentice *et al*, "The Rebirth…", 14.

commercial sealift.[182] The main advantage of sea transport is large carrying capacity and endurance. Consequently, sealift is the most economical overseas mode of transport for material.[183] Furthermore, modern ships with built-in ramps allow a roll-on/roll-off capacity (RORO) that allows vehicles to be driven on and off the ship. Since this can be accomplished much faster than on other ships, and with less need for port infrastructure, these ships are preferred for vehicle cargo. Also known as Large, Medium-Speed Roll-on/Roll-off Ships (LMSRs), such ships are typically 900 feet long, have a beam of 100 feet, a draft of 35 feet, and cargo capacity of 17,000 to 21,000 tons. In response to mobility studies after operation DESERT STORM, the US Navy procured 19 such ships between 1997 and 2003.[184]

However, sealift is limited by its slow speed and its vulnerability to interference. The average cargo ship speed is 15 to 25 knots, which may be reduced in adverse weather or if operating under convoy security. Furthermore, cargo ships are subject to interdiction by enemy submarines and mines.[185] What is more, most sea transport depends on the suitability and availability of port and cargo terminal facilities.[186] Ports must have sufficient depth to accept large container ships and not all coastal countries

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[182] P Kaluza, A Kölzsch, MT Gastner, and B Blasius, "The Complex Network of Global Ship Movements," *Journal of the Royal Society* Vol 7 No 48 (July 2010):Abstract; http://web.ebscohost.com/ehost/detail?vid=42&hid=10&sid=793cb3c6-a371-4652-9ea5-5508d87c5c37%40sessionmgr13&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=mnh&AN=20086053; Internet; accessed 7 April 2011; David Rudd, "Strategic Lift: The Neglected Dimension of Canadian Defence Policy," (Master's Thesis, Dalhousie University, 1995), 21.

[183] Department of National Defence, B-GJ-005-404/FP-000…, 1-12.

[184] Congressional Budget Office, *Options for Strategic*…., 4,5.

[185] Newbegin, "Modern Airships…", 18.

[186] Department of National Defence, B-GJ-005-404/FP-000…,, 1-12.

have the required major ports.[187] Furthermore, infrastructure such as piers and cranes are required along with movement teams to offload cargo.[188] In the case of disaster zones such as the Haiti earthquake in 2010, such facilities may be damaged and/or congested with other ships. For example, the MV *Wloclawek* was unable to secure a berth at Port-au-Prince and was too large to tie up at Léogâne and Jacmel. In lieu, it sailed to Barahonas, Dominican Republican, from where final delivery was completed intra-theatre by air and road.[189] Such intermodal transfers add time and complexity to the movement flow and reduce throughput capacity.

Despite these limitations, sealift delivers the bulk of inter-theatre lift.[190] Indeed, marine transport is ideally suited for high capacity intercontinental delivery of non-perishable goods.[191] Furthermore large RORO ships currently have a valuable capability to move outsized armoured vehicles and are preferred for deploying high-readiness ground units.[192] These well-established niche capabilities suggest that sealift will remain a desirable option for strategic lift for the foreseeable future.

Conventional Airlift

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[187] Newbegin, "Modern Airships…", 19.

[188] Congressional Budget Office Study, *Options for Strategic*…., 14.

[189] Fortin, "Massive Vessel…", 5.

[190] Newbegin, "Modern Airships…", 19.

[191] Prentice *et al*, "The Rebirth…", 177,

[192] Congressional Budget Office , "Options for Strategic….", 4.

In contrast, it was not until the Second World War that significant military cargoes could be delivered by air.[193] This nascent capability was tested in early 1948, when Stalin ordered a land route blockade of Berlin. This action spurred the Berlin Airlift, the greatest airborne relief operation in history. Indeed, during the 462 days of Allied flying more than 2 million tonnes of food, clothes, and coal were delivered. This airlift demonstrated the effectiveness of strategic lift and influenced Stalin to end the blockade.[194] During the Cold War strategic air transport played a more modest role in supporting Allied troops deployed to forward locations against the Soviet threat. With the post-Cold War rise of regional conflicts, however, the need for more timely and flexible air movements became clear.[195]

Indeed, the inherent speed and range of transport aircraft allows rapid force deployment over long distances.[196] For example, the C-17 has a speed of 410 knots, some twenty times faster than most cargo ships.[197] Furthermore, it has a range of 3200 nautical miles, which can be extended by air-to-air refuelling and augmented crews.[198] The C-17 can carry forces and equipment over ocean-land boundaries and terrain barriers to inland airports, which may be less congested than typically less numerous seaports.[199]

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[193] *Ibid*., 2.

[194] Clayton K.S. Chun, *Aerospace Power in the Twenty-First Century: A Basic Primer* (Montgomery: United States Air Force Academy in cooperation with Air University Press, 2001), 196.

[195] Congressional Budget Office, "Options for Strategic…", 2.

[196] Department of National Defence, B-GJ-005-404/FP-000…, 1-14.

[197] Congressional Budget Office, *Options for Strategic*…., xi.

[198] Szeto and Cooper, "The Need For…", 7.

[199] Prentice *et al*, "The Rebirth…", 178.

Furthermore, for specialized troops and cargo, delivery via airdrop may also be an option.[200] Indeed, the flexibility of air power allows delivery to almost anywhere on the planet.

However, this flexibility is finite as cargo airplanes depend on airfield infrastructure. For example, the CC150 Polaris requires a paved runway with a minimum length of 7000 feet. Furthermore, due to elevated side cargo door, it requires special handling equipment to load and off-load cargo.[201] In contrast, during Op HESTIA relief efforts, the C-17 was able to avoid the congestion at the Port-Au-Prince airport and operate on the more austere dirt strip at Jacmel. However, the C-17 has an extremely limited payload in comparison to sealift. For example, its 75 tonne payload is only approximately 1/240th of LMSR ships.[202] This results in a very high lift cost ratio, approximately .38 $/tonne x km. With this compares very favourably with other cargo aircraft, it is very high when compared with sealift.[203] Air transport is also expensive in terms of the number of highly qualified aircrew and technicians need to operate and maintain complex modern aircraft.[204]

Despite the costs, air transport is favoured for deliveries of time-critical cargo over long distances. When responding to significant incidents, there may simply be no

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[200] Newbegin, "Modern Airships:…", 15.

[201] Department of National Defence, *Aerospace Capability Framework* (Ottawa: DND, Canada, 2003), 81.

[202] Congressional Budget Office, *Options for Strategic*…., xi.

[203] Ghanmi and Abderrahmane, "Airships for Military Logistics…", 17.

[204] Department of National Defence, B-GJ-005-404/FP-000 …, 1-14.

other option.[205] Similarly, despite some of the inherent inefficiencies, airplanes are preferred for passenger transport due to its timeliness.[206] As with sealift, these well-established niche capabilities suggest that conventional airlift will remain a desirable option for strategic lift for the foreseeable future.

Hybrid Airship

Given the existing strategic lift capabilities, is there a legitimate market niche for hybrid airships? Until tested in commercial and/or military applications, any answer must remain speculative. Indeed, neither the CF nor any other military currently owns or leases a strategic lift-capable hybrid airship. Nonetheless, CF and US Army interest in this emerging market speaks to its potential.

Indeed, airships promise to be much faster and more flexible than sealift, and less expensive with more capacity than airplanes. With a cruise speed of 75 knots, a range of 3225 nautical miles, an oversize payload compartment, and amphibious landing system, the notional airship is ideally suited for bulky non-perishable cargo.[207] Indeed, no other vehicle is capable of such a feat. One estimate suggests that purchasing a hybrid airship would cost the same as a C-17, but would be three times as productive with one-third to one-half the operating cost.[208] Furthermore, with mezzanine decking with vehicles below and living quarters above, airships could transport personnel with their equipment

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[205] *Ibid.,* 1-14.

[206] Congressional Budget Office, *Options for Strategic*…., 2.

[207] Prentice *et al*, "The Rebirth of…", 176.

[208] Gordon and Holland, "Airships and the Revolution…", 48.

directly to a runway-independent location in-theatre, avoiding the additional movement step of reuniting personnel with their equipment.[209] Indeed, being able to deliver cargo directly to destination avoids the potential congestion that ships and airplanes experience at SPODs and APODs. Furthermore, unlike sealift vessels, the airship is immune to mines, torpedoes, suicide speedboats, and pirate boarding.[210] While an airship is more likely to be hit than an aircraft due to lower operating speeds and altitudes, it is nonetheless more survivable in the event of successful attack. For these many reasons, notional airships offer a number of advantages over conventional strategic lift methods.

However, airships may not be a panacea for the strategic lift problem. Despite its inherent advantages, the airship has a number of limitations. They are much slower than airplanes, and much more expensive with less capacity than ships.[211] Furthermore, the airship's relatively low operational ceiling affects its ability to cross mountain ranges, fly over adverse weather systems, and avoid visual detection. Similarly, the low cruising speed makes it vulnerable to strong headwinds and rapidly moving weather systems.[212] Finally, since no hybrid airships have been successfully brought to market, the estimated development and operating costs may be higher than expected, negating predicted efficiencies.[213]

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[209] Newbegin, "Options for Strategic…", 16.

[210] Gordon and Holland, "Airships and the Revolution…", 56.

[211] Prentice *et al*, "The Rebirth of…", 176.

[212] Gordon and Holland, "Airships and the Revolution…", 55.

[213] Ghanmi and Abderrahmane, "Airships for Military…", 13.

Indeed, costing estimates for hybrid airships vary. Furthermore, given the lack of confirmed technical and performance data, there are few such estimates to be found in open literature. For example, in 2005 Prentice *et al* estimated a freight rate of $0.20 per tonne kilometre for its evolutionary predecessor, the *SkyCat 200*, and an estimated purchase price of US$112 million for a smaller 150-ton capacity hybrid airship.[214] Similarly, a 2010 Defence R&D Canada performance assessment estimated cost of $0.22 per tonne kilometre for the *Skycat-200*, as compared to $0.38 for the C-17 and $0.48 for the *AN-124*.[215] In contrast, the 2005 Congressional Budget Office study estimated costs for a fleet of fourteen to sixteen heavy-lift hybrid airships, using 2006 US dollars as a baseline. Specifically, development cost was estimated between 3.0 and 4.0 billion dollars, procurement cost between 4.3 and 4.8 billion dollars (approximately 300 million each), and thirty-year operational cost between 3.0 and 3.4 billion dollars.[216] Such significant estimated development costs, in the face of unconfirmed performance, speak to the challenges that the hybrid airship has faced in securing financing and establishing a commercial presence.

Nonetheless, while precise economic analysis is impossible at this point, the weight of analysis suggests that modern airship technology deserves a second look.[217] Its weaknesses in speed and elevation may be more than compensated by its oversize cargo capacity and ability to operate at austere fields. Indeed, the hybrid airship appears ideally suited for over-size and over-weight air point-to-point deliver to austere destinations. The

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[214] Prentice *et al*, “Re-Birth…”, 178; 186.

[215] Ghanmi and Abderrahmane, “Airships for Military…”, 17.

[216] Congressional Budget Office, “Options for Strategic…”, 42.

notional airship thus promises to fill an operational niche that complements, but not replaces, conventional sealift and airlift. While critics may dismiss hybrid airships as fanciful thinking, they may well offer a valuable third mode of strategic lift.

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[217] Prentice *et al*, "The Rebirth of…", 187.

Conclusion

This study has demonstrated that modern airships show promise in providing routine, high-volume, heavy-weight strategic lift, but also that this capability is not yet viable for the CF as it remains under development. While the word "airship" may evoke images of the 1937 *Hindenburg* disaster, revolutionary new hybrid designs based on modern technology show potential to deliver new capabilities relevant to the 21st century. Indeed, conventional strategic lift delivered by sea and air faces challenges such as growing cargo demand, fuel consumption, and port congestion. Although the idea of an airship solution for strategic lift may seem improbable to some, inventive solutions may be required to address these mounting issues.

As detailed in the *Canada First Defence Strategy*, strategic lift is an essential capability for the CF to meet operational commitments at home and abroad. Indeed, moving personnel and material between theatres is essential to projecting and sustaining joint forces. For example, Canada's humanitarian response to the 2010 Haitian earthquake demonstrated the challenges in moving personnel, equipment, and supplies to austere locations with limited infrastructure. Specifically, material shipped by sea had to be delivered to a neighbouring country and then delivered by road, while some material delivered by commercial air carriers had to be transferred to military aircraft at an intermediate airport. Indeed, despite the recent acquisition of the C-177 *Globemaster III* aircraft and the full-time charter of the MV *Wloclawek*, the CF Strategic Capability Roadmap identified an insufficient capability for routine, high volume, heavy weight strategic lift to and from theatre. As further articulated by CANOSCOM project staff, such a capability should also include an ability to carry a 200 to 500 ton load over long distance, including outsize equipment such as armoured vehicles, and operate in austere and Arctic environments independent of established airfields.

Such capacity and flexibility would be a valuable joint force enhancer in the current security environment. Indeed, the last decade's challenges have included terrorist attacks, ethnic and border conflicts, fragile states, global criminal networks, tensions stemming from globalization, and natural disasters. Negative social and economic trends, natural resource competition, and technological innovations are expected to exacerbate this instability in the coming decades.

Any Arctic airlift operation faces further challenges due to the area's remoteness and extreme climatic conditions such as whiteouts and periods of darkness that can last for months. In particular, flight operations to austere Arctic landing sites such as tundra, gravel beaches, or sea ice demand even further weather, crew experience, aircraft performance, and flight safety considerations. Understandably, such flight operations do not enjoy the predictability or timeliness of routine flights elsewhere in the world.

However, modern hybrid airships show potential to allow the CF to support sustain-heavy operations where normal peacetime commercial forms of sustainment are unavailable or impractical. Unlike legacy rigid and non-rigid airships such as the *Hindenburg* and *Goodyear Blimp*, which derive all of their lift from gases such as helium or hydrogen, hybrid airships also gain aerodynamic lift from their airfoil-shaped design. While still limited to a maximum operating altitude, known as pressure height, hybrid airship designs address the ground handling and buoyancy compensation issues that challenged their predecessors. Indeed, modern airships are undergoing a renaissance that promises to reinvigorate the industry.

Seemingly forgotten by the general public, airships have flown for more than a hundred and fifty years and featured in many aviation milestones. For example, *DELAG*, the world's first passenger airline, safely carried tens of thousands of passengers by Zeppelin over Germany prior to the First World War. In 1917, the German *LZ-59*'s four thousand nautical mile return flight from Bulgaria to Tanzania demonstrated an intercontinental range that fixed-wing aircraft would not achieve for another thirty years. In 1919, the British *R-34* made the first return trans-Atlantic crossing. Seven years later, the Italian *Norge* successfully raced against fixed wing aircraft to be the first to the North Pole. Finally, the *Graf Zeppelin* circumnavigated the world in 1929 with only four fuel stops, and went on to carry thousands of passengers to and from Brazil during the 1930s without incident. However, the *Hindenburg's* spectacular crash in 1937 effectively ended the burgeoning airship age and jet-powered aircraft came to dominate the skies.

Post-Second World War efforts to reinvigorate the airship met with technical and financial failure, hampering investor confidence. However, modern technological advances such as fly-by-light technology, composite materials, vectoring engines, and computer-assisted designs have set the stage for a revival. While a number of companies, such as Advanced Technology Group, Lockheed Martin, and Skyhook International, have attempted to bring the hybrid airship to the market, the British company Hybrid Air Vehicles appears the closest to doing so.

The Hybrid Air Vehicles heavy-lift model, the *HAV 606*, has an advertised a 200-tonne capacity, a range of 3225 nautical miles, a cruise speed of 75 knots, and a pressure altitude of 9000 feet. Furthermore, it promises a hover-skirt landing system for amphibious operations and a large payload module capable of mezzanine decking with roll-on/roll-off access for oversize vehicles. Given the success of its prototype, the sale of its long-endurance sister ship to the US Army, and the lack of competitors, the *HAV 606* was deemed to be the best basis for a notional airship to be used for analysis.

Military doctrine provides an authoritative basis for such an analysis and furthermore serves as a critical sounding board for testing new concepts. With respect to Aerospace Doctrine, the notional airship displayed a balance of aerospace characteristics. Specifically, the notional airship was assessed as having strength in payload, precision, and support dependency. Furthermore, it showed moderate elevation, fragility, reach, and sensitivity to technology. Finally, it was deemed limited by weak speed, stealth, and sensitivity to environmental conditions. Some of these characteristics are better than conventional aircraft, some worse, others simply different. However, the overall balance of these characteristics suggests that the notional airship is a legitimate aerospace platform that has a number of strong capabilities, albeit with some limitations.

With respect to logistics support doctrine, a review of the typical movement flow of personnel and material from home base to final destination revealed as many as nine intermediate stops. In particular, movements to land-locked destinations can suffer from inefficiencies stemming from enroute delays due to modal transfer and congestion at ports of disembarkation. With its unique blend of reach, payload, and low support dependency, the notional airship shows potential to improve this flow considerably.

Furthermore, a review of the planning considerations for air movement support revealed a number of insights. The notional airship is vulnerable to interdiction and should operate in benign tactical environments. Despite its slow speed, in certain circumstances the notional airship may be able to deliver personnel and cargo to destination quicker than any other means. It has a large cargo capacity relative to other aircraft, which should be exploited in consideration of traditional means. However, due the notional airship's relatively low operating altitude, its flexibility is limited as it may be affected by terrain, low-level weather, and/or over-flight clearance denial. Planners will have to account for is unique capabilities, particularly for missions to international austere destinations where fuelling and customs facilities may be lacking. Finally, ensuring flight safety will be a likely challenge when introducing a completely new type of aircraft to a military operational environment.

Following this doctrinal analysis, the notional airship's commercial merits were compared with conventional sealift and airlift. Undeniably, sealift delivers unparalleled amounts of cargo over much over the world's surface. Furthermore, RORO ships provide a critical capability in transporting large and heavy armoured vehicles. Sealift is extremely economical; indeed, it delivers most of the planet's overseas cargo. However, it is limited by slow speed as well as availability and suitability of port and cargo terminal facilities. Nonetheless, marine transport is ideally suited for high capacity intercontinental delivery of non-perishable goods.

Conventional airlift, on the other hand, offers unmatched speed and ability to fly over natural barriers such as terrain and coastlines. However, payloads are much smaller than sealift and are much more expensive to deliver. Much as sealift depends on ports, airplanes depend on airfields and associated infrastructure. Nonetheless, air transport is ideally suited for time-critical cargo over long distances, such as personnel requiring medical evacuation or critical parts needed for urgent equipment or vehicle repair.

While hybrid airships remain in development, they show potential to deliver a capability that fills a niche between the two. Indeed, airships promise to be much faster and more flexible than sealift, and less expensive with more capacity than airplanes. Furthermore, the notional airship's reach, oversize payload compartment, and airfield independence offer a capability that could greatly streamline movement flow from home base to destination. However, the airship is slower than airplanes and more expensive with less capacity than ships. Nonetheless, the hybrid airship appears ideally suited for over-size and over-weight air point-to-point deliver to austere destinations. As the hybrid airship's significant development costs and uncertain performance data remain speculative, further research is required when production models become available for operational testing and evaluation.

The CF should therefore consider hybrid airships as a potentially viable solution for routine, high-volume, heavy-weight strategic lift to and from theatre. While its development and real-world performance must be monitored, the modern airship promises to fill a viable niche that complements conventional sealift and airlift. With such a balanced strategic lift capacity, the CF would be well positioned to deliver the strategic effects required to fulfill its mandate to the people of Canada.

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