MODELING COMPOSITE FLEETS UTILIZING HYBRID AIRSHIPS

Graduate Research Paper

Chris R. Gilbert, Major, USAF

AFIT-ENS-MS-20-J-036

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENS-MS-20-J-036

MODELING COMPOSITE FLEETS UTILIZING HYBRID AIRSHIPS

GRADUATE RESEARCH PAPER

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Operations Management

Chris R. Gilbert, BS, MBA

Major, USAF

June 2020

AFIT-ENS-MS-20-J-036

MODELING COMPOSITE FLEETS UTILIZING HYBRID AIRSHIPS

Chris R. Gilbert, BS, MBA

Major, USAF

Committee Membership:

Dr. Jeffery D. Weir, Ph.D.

Chair

AFIT-ENS-MS-20-J-036

Abstract

This paper examines the potential use and optimum combination of hybrid airships to support large cargo movements related to major war operations across strategic, tactical and last mile distances. The main goal is to determine if hybrid airships can be used in an augmenting role rather than viewing them as a replacement to conventional strategic lift such as the C-17 Globemaster III aircraft and Large Medium Speed Roll-on Roll-off (LMSR) ships or tactical lift such as the C-130 Hercules. The second focus is to determine the optimum size and number of hybrid airships to support a large cargo movement when combined with conventional assets. The final focus is to determine whether hybrid airships should be manned, unmanned or autonomous.

The analysis determined that composite fleets utilizing hybrid airships can be successfully modeled using the Rapid Course of Analysis Tool software. Modeling determined that it is feasible to move large quantities of cargo using combinations of conventional fixed wing aircraft, hybrid airships, and surface ships.

This research simulated the delivery of a Stryker Brigade Combat Team from Ft. Lewis, Washington to Davao International Airport in the Philippines using a composite fleet of assets. The optimum combination for SBCT deployment is 81 C-17s, 50 C-5s, 60 120-ton hybrid airships and 60 30-ton hybrid airships. This fleet closes the TPFDD in 5 days and costs $139.7M. Using a combination of 62 C-17s, 8 C-5s, 40 120-ton hybrid airships, and 1 LMSR ship, an SBCT can be deployed in 17 days at a cost of $70.3M.

Analysis shows that hybrid airships should be either remotely piloted or autonomously controlled in order to lower the personnel requirement for a large fleet.

AFIT-ENS-MS-20-J-036

To my family

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Dr. Jeffery Weir, for his guidance and support throughout the course of this thesis effort. I would also like to thank my sponsor, Brigadier General S. Clinton Hinote, from the Air Force Warfighting Integration Capability for his support.

Chris R. Gilbert

Table of Contents

List of Figures

Page

List of Tables

Page

I. Introduction

Rapid Global Mobility

One of the six key capabilities of the United States Air Force is Rapid Global Mobility. The Air Force maintains and continues to improve its ability to respond quickly and decisively anywhere needed around the globe (United States Air Force, n.d.). During the past twenty years this has meant a persistent presence in the Middle East with occasional force buildups to achieve short-term goals elsewhere. Lessons learned after the first Gulf War highlighted that if the entire military needed to be mobilized the Department of Defense would require civilian augmentation (Air Mobility Command, 2014). The current strategic state of the military is focusing on great power conflict with near-peer adversaries. Gone are the days of uncontested operations and never-ending counterinsurgency operations. Future conflict will require multi-domain dominance, resiliency and innovation. Does the United States possess a capability that can replace conventional cargo lift in the event of major war? Is replacement necessary or can the current inventory be augmented by an existing or emerging technology?

Problem Statement

United States Transportation Command (USTRANSCOM) is the designated distribution process owner for the Department of Defense. Mobility planners fall into two broad categories: strategic and contingency. Strategic planners focus on future conflicts and force packaging to support large cargo and passenger movements associated with Combatant Commander (COCOM) requirements. Contingency planners focus on emerging requirements with current assets and limitations. Two decades of uncontested air operations in support of counter-insurgency missions in Iraq and Afghanistan has led to stagnation of creative planning and critical thought for near-peer competition. The 2018 NDS focuses on rebuilding military readiness as the United States builds a more lethal Joint Force.

The use of balloons and airships in the military is not new. Previous research has focused on the notional cargo capacity that various manufacturers have proposed instead of the optimum cargo capacity required for large Department of Defense cargo shipments such as Time Phased Force Deployment Data (TPFDD) movements in support of an Operation Plan (OPLAN). USTRANSCOM utilizes several programs to model the feasibility and resources required for executing a TPFDD movement. Has consideration been given to utilizing the existing models to conduct analysis on the use of hybrid airships as an augmenting capability to support the Department of Defense? Has consideration been given to exploring the optimum composition of an airship fleet or the manning, operations, and management of that fleet? Has consideration been given to the cost, management, and distribution of helium that fills airships to provide lifting force to determine if there is enough helium in the world to support a fleet of hybrid airships?

Research Focus

No study has focused on defining and utilizing the optimal cargo capacity of a hybrid airship to effectively augment a TPFDD closure. Despite studies showing the feasibility of supporting humanitarian aid and disaster relief missions, research has not been conducted to identify an effective combination of conventional aircraft and hybrid airships to move large amounts of cargo during OPLAN execution. Notwithstanding the use of unmanned aircraft in Intelligence, Surveillance, and Reconnaissance (ISR) missions, research has not explored using unmanned or autonomous hybrid airships to transport large cargo.

Research Question 1

Can current modeling software quickly and accurately model TPFDD closure using hybrid airships with existing and unimproved or nonexistent Ports of Debarkation (PODs)? How do the results of current software compare to previous research models?

Research Question 2

What is the optimum combination of conventional cargo airlifters, surface sealift ships and hybrid airships to support a notional TPFDD closure in the Pacific? How much faster can a TPFDD close by utilizing hybrid airship augmentation?

Research Question 3

What is the optimum cargo capacity for hybrid airships in order to increase capacity and decrease both cost and time for TPFDD closure?

Research Question 4

Should hybrid airships be manned, remotely piloted, or autonomous?

Research Question 5

Is there enough helium in US strategic reserves to support a hybrid airship fleet? How much helium is used in airships, how much is available and what costs are associated with it?

II. Literature Review

Chapter Overview

This review will briefly introduce hybrid airships and explore previous research conducted on hybrid airships. Strategic mobility guidance is presented both in terms of national policy and specific Air Force studies. The strategic nature of helium is discussed to better understand one of the main resources required to operate hybrid airships. Civilian augmentation to mobility lift requirements and the two main programs currently in use by the military are described. Finally, mobility modeling and simulation software used by military planners is explored.

Hybrid Airships

A hybrid airship is a powered aircraft that achieves some of its lift as a lighter-than-air craft like a balloon and some from aerodynamic lift as a heavier-than-air craft like a traditional airplane to create a vehicle that offers short takeoff and landing (STOL) and vertical takeoff and landing (VTOL) characteristics with the cargo capacity, efficiency and range of an airplane. The appeal of a hybrid airship for cargo airlift missions is the tremendous theoretical payload and range combination. Research indicates that payloads of 500 to 1,000 tons could be carried intercontinental distances at approximately 100 nautical miles per hour (Rapp, 2006). Surface ships provide over 310,000 square feet of storage capacity for rolling stock such as armored vehicles and tanks and travel at speeds of 25 knots. Cargo aircraft such as the Boeing 747-8F can carry 154 tons of cargo at speeds of 488 knots (Boeing, n.d.). Where hybrid airships may find a niche is moving cargo capacities close to that of a conventional aircraft at four times the speed of a conventional ship. Additionally, airships offer runway independence with some designs requiring only a clearway for takeoff and landing while others propose the ability to operate to and from water using technology similar to hovercraft (Hybrid Air Vehicles, n.d.) . The ability to carry cargo intercontinental distances faster than a ship, independent from a runway and deliver from original point of origin to final point of need is the most important aspect of hybrid airships. All of these characteristics combine to potentially offer a means to shorten overall TPFDD closure for the DOD.

The first military use of a lighter-than-air vehicle was in 1794 at the Battle of Fleurus during the French Revolution when French forces under General Jean-Baptiste Jourdan used a reconnaissance balloon named l'Entreprenant (Haydon, 1941). The US Navy operated an airship program with 4 rigid airships and over 200 non-rigid airships during the first half of the twentieth century with the program ending in 1962 (Rapp, 2006). Rigid airships were also used for tourism with many successful transoceanic trips made by zeppelins during the 1920s and 1930s (Robinson, 1973). Rigid airships suffered a loss in popularity after the infamous Hindenburg disaster in New Jersey in May of 1937 (Craats, 2009). There has been interest during the past thirty years in the concept of a large airship that could carry significantly more cargo than any current aircraft can. The concept has evolved into discussion of a large vehicle deriving some lift from a lighter-than-air gas and some lift from aerodynamic forces. The government has sponsored research and some private companies have developed proposals or prototypes demonstrating the technology. Lockheed Martin's Skunk Works division developed a 1/3-scale prototype dubbed the P-791 that was 120ft long and flew in 2006. Northrup Grumman developed a similar prototype that was 299 ft long and flew in 2012

(BBC News, 2016). Major Timothy Rapp wrote a thesis in 2006 on the topic of hybrid airships that provides an extensive history.

Emerging Threats, New Technology, Updated Policy

Major Timothy Rapp wrote a paper in 2006 that explored the use of hybrid airships for intertheater cargo delivery. Major Phillip Lynch wrote a paper in 2011 that explored the use of hybrid airships for intratheater cargo delivery. Major Samuel Morgan wrote a paper in 2013 that explored the use of hybrid airships for Joint Logistics over the Shore (JLOTS). These researchers took a broad look at the utility of hybrid airships for cargo movement. Their research examined the feasibility of hybrid airships over strategic distances, tactical distances and the so called "last mile" of delivery. This paper aims to examine what has changed in terms of threats, technology, and policy since the other papers were published and how the DOD can alter its view of hybrid airships to support the 2018 National Defense Strategy (NDS). The focus is on integration with and not replacement of conventional lift capabilities.

Emerging Threats

China has modernized its CSS-5 Medium Range Ballistic Missile (MRBM) to be capable of destroying a moving target such as an aircraft carrier. The new missile, dubbed the CSS-5 Mod 5, or DF-21D, is viewed as a deterrent to prevent the United States from meddling with regional affairs, such as the reunification of Taiwan (National Air and Space Intelligence Center, 2017). China's ability to hold aircraft carriers at risk forces a strategic shift for the United States. The USS Gerald R. Ford is the newest aircraft carrier that the United States possesses. At a cost of $13.3B in FY2008 dollars it is a strategic treasure we cannot afford to lose (O'Rourke, 2020). The

Germans lost World War II because they were unable to prevent the buildup of allied power that led to the invasion at Normandy. The Battle of the Atlantic was the longest campaign of the war taking place between 1939 and 1945. The allied losses were enormous with 3,500 allied merchant ships and 175 allied warships sunk and over 70,000 mariners lost (White, 2006). It would be foolish to assume that China would not attack commercial naval vessels providing military support during major war operations. Though hybrid airships cannot project the same amount of power as an aircraft carrier, they may be able to increase agility and resiliency in the supply and logistics networks of the military at a fraction of the cost of an aircraft carrier. Large numbers of hybrid airships could also supplement the large sealift required for major war operations.

Hypersonic glide vehicles are maneuverable vehicles capable of travelling at speeds greater than Mach 5 at altitudes lower than conventional ballistic missiles. Their high speed, maneuverability and relatively low altitudes make them difficult to defend against. China and Russia are currently developing hypersonic weapons (National Air and Space Intelligence Center, 2017). This new class of weapons provides adversaries with the ability to rapidly attack large supply nodes that the United States maintains such as the prepositioned supply ships operated by Military Sealift Command (MSC) at Diego Garcia in the Indian Ocean and Guam in the Pacific Ocean. Hybrid airships may provide the ability to offer continuously moving supply ships which could complicate an enemy's targeting solution.

New Technology

There have been no developments in Lockheed's P-791 airship since its test flight in 2006. In August of 2012 a hybrid airship prototype developed by Northrop Grumman conducted its maiden test flight at Joint Base McGuire-Dix-Lakehurst, New Jersey. The airship was acquired by Hybrid Air Vehicles after the US Army canceled the Long Endurance Multi-intelligence Vehicle (LEMV) project. The airship was modified and named the Airlander 10 and later flew its first flight in England in August of 2016 (BBC News, 2016). According to Hybrid Air Vehicles, the Airlander 10 prototype was flown seven times (Hybrid Air Vehicles, n.d.). Not only has there been research into manned aircraft, but also unmanned aircraft. The Defense Advanced Research Project Agency (DARPA) has been funding autonomous drone programs with the goal of creating drone swarms. The autonomous cooperative technology could enable drone hybrid airships to act as an autonomous supply network automatically delivering cargo to its destination.

Updated Policy

The United States Army began transforming from a Cold War divisional orientation to a full-spectrum capable brigade force through the adoption of armored brigade combat teams starting in the early 2000s. The size of the various brigade combat teams range from 4,400 to 4,700 troops and include large equipment such as armored tanks, fighting vehicles and troop transports. The Army maintains pre-positioned stocks in the Pacific and in Europe to lower the lift requirement, but supplies and troops will still need to be transported during major war operations. Hybrid airships may help augment this lift requirement.

The Obama administration began a Pivot to the Pacific in 2012. The focus was to strengthen security alliances, increase cooperation and improve trade. Part of the policy also included increasing military presence in the region. The US Navy developed Mobile Landing Platforms (MLP) and designated two of them as Afloat Forward Staging Bases (AFSB). The MLP designation changed and the ships are now referred to as Expeditionary Transfer Docks (ESD) (United States Navy, 2017). The subclass variants of AFSBs were later designated Expeditionary Mobile Bases (ESB). The intent for the ESBs is to take on missions currently tasked to guided missile destroyers and other amphibious ships in order to free up those warships for deployments elsewhere such as the Asia-Pacific region (United States Navy, 2013). There are two ships in the inventory with a 9,500 NM range at 15 knots. They are 80,000 tons, 785-feet long and provide 25,000 square feet of vehicle and equipment stowage and 380,000 gallons of JP-5 storage. As of January 2020 the Navy has decided to designate the ESDs as USS warships which will allow them to employ in accordance with the Laws of Armed Conflict (LOAC) rather than merely transporting supplies and forces (Eckstein, 2020). This paradigm shift in supply and logistics is exactly what is needed to prepare for great power competition. Hybrid airships could fulfill a similar role as mobile logistics nodes.

The 2018 NDS introduced two concepts, Dynamic Force Employment and the Global Operating Model. The current strategic environment requires flexibility and freedom of action. Dynamic Force Employment changes the way the DOD presents forces to combatant commanders. The goal is to maintain capacity for major combat while still providing options for employment of the Joint Force (Mattis, 2018). The Global Operating Model describes how forces will be postured to achieve wartime missions and are established is four distinct layers: contact, blunt, surge, and homeland.

The layers are designed to allow the United States to be more successful in operations below the threshold of armed conflict, delay, deny or degrade enemy aggression, manage conflict escalation and defend the homeland (Mattis, 2018). The 2018 NDS directs a more lethal force and describes resilient and agile logistics in order to sustain American influence and ensure favorable balances of power that safeguard international order (Mattis, 2018). The 2020 National Defense Authorization Act (NDAA) directs military acquisitions and postures of the various services to be in line with 2018 NDS. This verbiage is a change from the 2019 NDAA which makes references to explore the 2018 NDS and provide recommendations to Congress. The newly focused guidance removes ambiguity and addresses the need to prepare for great power conflict. There is an identified shortfall in strategic and tactical lift capacity and hybrid airships could help supplement this shortfall.

In 2005 the Defense Undersecretary for Acquisition, Technology and Logistics established an investigation of capability gaps pertaining to heavy vertical-lift requirements and designated the Army as joint-service lead for the Joint Heavy Lift (JHL) concept. The results of that led to an Initial Capabilities Document (ICD). In 2008 USTRANSCOM produced a Joint Future Theater Airlift Capability Analysis (JFTACA) Functional Needs Analysis (FNA) that would encompass all theater airlift needs. At the same time, the Air Force was investigating a shorter takeoff and landing fixed wing replacement for the C-130. Also in 2008, the Army and Air Force Service Chiefs directed the services to merge the JHL ICD with the requirements identified in the JFTACA FNA into a Joint Future Theater Lift (JFTL) ICD. The results of that study would help inform future budget decisions (United States Air Force, 2013). The stated purpose of the final study was to evaluate the performance, operational effectiveness, operational suitability, and estimated costs of technology alternatives to meet mission capabilities that support theater lift requirements in 2024 and beyond as identified in the JFTL ICD (United States Air Force, 2013). Some of the requirements include the ability to self-deploy 2400nm or more and transport medium weight armored vehicles and personnel with a combat radius between 250nm to >1000nm, within 0-50km of the objective with STOL or VTOL capabilities. One of the technology alternatives explored and considered viable was a 30 ton hybrid airship. A 120 ton hybrid airship was also explored but the members of the study ultimately deemed that the 120 ton variant would be too large based on current technology and engineering practices. The argument that the working group made was that the physical requirements of an airship of that size greatly increased the size, weight, and complexity of the vehicle. Additionally there was no historical data to support the manufacture of an airship that large. The JFTL study results and recommendations for hybrid airships will be explored in further detail in the literature review. The most recent study regarding hybrid airships was focused on the military's Joint Logistics Enterprise.

The Defense Science Board (DSB) Task Force on survivable logistics was established to evaluate the current state of the US military Joint Logistics Enterprise. The purpose of the task force was to assess high-end threats posed by competitors such as China and Russia in order to provide recommendations for securing and sustaining the logistics enterprise in a contested environment (Defense Science Board, 2018). The report provided three recommendations that included hybrid airships. The first was that director of logistics (J4) and USTRANSCOM J5/J4 develop requirements and CONOPs for innovative long-range theater distribution assets such as hybrid airships. The second was to continue Research, Development, Testing and Evaluation (RDT&E) to define the utility and military effectiveness of hybrid airships while specifically exploring potential Civilian Reserve Air Fleet (CRAF) and Voluntary Intermodal Sealift Agreement (VISA)-like programs for airships. The final recommendation was to develop programs to demonstrate the expeditionary utility of artificial intelligence and autonomous systems for long-range theater connectors such as hybrid airships, barges, high-speed vessels and precision airdrop (Defense Science Board, 2018).

National Strategic Guidance

The 2018 National Defense Strategy outlines the strategic direction of the Department of Defense. This newest version of the NDS is a significant departure from previous versions. Rather than making incremental changes in the long-standing war on terror, major threats to the nation are highlighted with an outline of the hard choices that we will face and must prepare for as a nation. The stated intent from the Secretary of Defense is to pursue urgent change at a significant scale (Mattis, 2018).

The NDS speaks of challenges to US military advantage in the global environment. For decades we have operated uncontested or as the dominant force in every domain. The US has been able to deploy our forces whenever we choose, assemble wherever we want and operate unhindered (Mattis, 2018). The NDS highlights that now every domain we operate in is now contested. The NDS outlines eleven objectives for the Defense Department. Three of them are salient points when speaking about hybrid airships. Sustaining Joint Force military advantages, both globally and in key regions; continuously delivering performance with affordability and speed as we change Departmental mindset, culture, and management systems; establishing an unmatched twenty-first century National Security Innovation Base that effectively supports Department operations and sustains security and solvency (Mattis, 2018). The Secretary of Defense makes it very clear that the nation must focus on modernizing key capabilities. The strategic focus of the NDS directly relates to near-term defense budgets. Three key areas highlighted for modernization are forward force maneuver and posture resilience, advanced autonomous systems and resilient and agile logistics. These areas all relate to the future fielding of hybrid airships. There is a shift from large, centralized bases that are vulnerable to resilient, adaptive basing. The Defense Department will start investing heavily in the military application of autonomy, artificial intelligence and machine learning. The current defense logistics supply chain is vulnerable and must be protected. Focus will be on prepositioned stocks, strategic mobility assets and distributed logistics and maintenance to ensure sustainment (Mattis, 2018). Unmanned or autonomous hybrid airships might be a viable way to resupply adaptive bases or act as strategic storage in the Pacific theater

Strategic Mobility Guidance

In 2013 the USAF published the results of a study designed to investigate future airlift requirements and address capability gaps identified in the Joint Future Theater Lift Initial Capability Document. The acknowledged gaps include things such as the inability to operate into austere or unimproved landing areas and the inability to transport forces over strategic distances directly to the point of need in effect bypassing ports of debarkation (United States Air Force, 2013). The JFTL specified the capabilities required to fill the gaps identified in the ICD. Examples include the capability to transport combat configured medium weight armored vehicles and personnel (payloads of 20-36 tons) and the capability to deliver within 0-50 km of the objective area. The study developed planning scenarios to test the hypothetical solutions to four defined mission areas: Joint Forcible Entry Operations (JFEO), Operational Maneuver over Strategic Distances (OMSD), Intratheater Operational Maneuver (IOM), Distributed Maneuver Support and Sustainment (DMSS). The study focused on seven technology alternatives to fill the capability gaps: (1) a baseline (current C-17, C-130 and CH-47 aircraft), (2) conventional turboprop, (3) conventional turbofan, (4) shaped planform turbofan, (5) short takeoff and landing turboprop, (6) tiltrotor, and (7) hybrid airship (United States Air Force, 2013).

Four notable conclusions came from this study regarding hybrid airships. The first is an effectiveness-cost-risk assessment chart that asserts hybrid airships are assessed effective for filling ICD mission area gaps and partially effective meeting gaps for risk. The chart is shown in Figure 1. The second point is a justification for adjusting the planned cargo capacity of a hybrid airship from 120 ton to 30 ton. Third is an investigation of the strategic nature of helium and its long term availability and finally

	Effectiveness	Cost	Risk
Aircraft (Qty)		LCC (BY12$B)	
Baseline (C-130 (63), C-17 (36), CH-47 (20))		$62.1	
[redacted]			
CTP (49)		$63.4	
CTF (84)		$111.1	
SPTF (93)		$120.8	
STP (93)		$110.7	
TR (98)		$128.4	
HA (92)		$84.3	

An assessment of red indicates the technology alternative does not successfully address the ICD gaps. An assessment of amber indicates the technology alternative partially meets the ICD gaps for that mission area, while an assessment of green indicates the technology alternative meets ICD gaps.

Figure 1 - ECR Chart – JFTL Study

the study assesses the industrial base necessary to support hybrid airships. The original recommendation for a 120 ton hybrid airship was based on a simple assumption. If a hybrid airship was 4-5 times slower than a conventional airlifter then its payload should be 3-4 times greater than the desired payload to be transported. Upon further analysis it was determined that the required size of the airship would be larger than anything ever constructed with an estimated length greater than 700 feet, volume greater than 11 million cubic feet and a gross weight greater than 1,000,000 pounds. A revision was made to have a maximum capacity of 120 ton utilizing conventional takeoff but only 60 ton utilizing vertical takeoff. The new requirements led to an estimated size of 650 feet long, 10.6 million cubic feet in volume and a gross weight of 820,000 pounds. The size was still larger than anything built and led to questions in terms of technical feasibility and whether or not the design tools being used for estimation could accurately model something of that scale. The final design change happened after the decision was made to not address all of the ICD areas and instead focus on the DMSS mission, which was expected to make up 85% of the JFTL vehicle usage. Data was analyzed by Air Mobility Command (AMC) A9 and showed that during a one year period, 99% of payloads delivered were 30 tons are less. The final assumption made was that a 500 nm mission radius would support the intent while also delivering a smaller vehicle, with an estimated length of 428 feet and 4.4 million cubic feet in volume. The study continued based on the new 30 ton hybrid airship design (United States Air Force, 2013). It is important to note that the focus of the study was developing a new intratheater lift asset and not something designed to support major power competition between near-peer adversaries.

Previous Research on Hybrid Airships

Major Timothy Rapp's GRP from 2006 titled Analysis of Hybrid Ultra Large Aircraft's Potential Contribution to Intertheater Mobility modeled two deployments of a Stryker Brigade Combat Team (SBCT). One scenario was a short range deployment from Ft. Lewis, WA to Colombia while the other was a long range deployment from Ft. Lewis, WA to Angola. He compared the deployment using four different simulated fleets. The first was a conventional fleet of C-5s and C-17s, the second was a "super conventional" fleet with additional aircraft while the third and fourth fleet represented possible hybrid ultra large airship fleets. His research found that hybrid airships could theoretically outperform conventional aircraft, especially if cost was factored appropriately. He did not recommend a civilian augmentation strategy mainly due to the timelines associated with deployment and the lack of ability to modify airships to meet certain military requirements as technology evolved. He recommended an acquisition strategy be pursued for 40 hybrid ultra large airships in the 500-ton payload class. He noted the limitations in current modeling software and the likelihood that a smaller hybrid airship would most likely be built before the much larger models that he simulated. His research reveals an opportunity to model smaller hybrid airships and a combination of either conventional aircraft and hybrid airships or conventional aircraft, hybrid airships and surface ships.

Major Phillip Lynch's GRP from 2011 titled Hybrid Airships: Intratheater Operations Cost-Benefit Analysis looked at a USTRANSCOM study that outlined four priorities for mobility. In 2010 USTRANSCOM was tasked to lead an effort to develop a long term concept of operations for the use of hybrid airships. The task outlined four objectives for USTRANSCOM: identify the use/need/capability gaps for hybrid airship employment, determine required hybrid airship capabilities, identify partner organizations, and develop a timeline for implementation (United States Transporation Command, 2010). Using an excursion from a base scenario methodology Maj Lynch explored the first priority of identifying gaps for hybrid airship employment. He developed a model that explored using hybrid airships in a humanitarian aid/disaster relief role, specifically in an intratheater role. The model reflected a response in support of a natural disaster in Haiti. His research showed that hybrid airships with a capacity between 30 ton and 50 ton can successfully support humanitarian aid missions. He demonstrated that hybrid airships could replace strategic airlift capacity if C-17s and C-5s were not available. He also demonstrated that tactical airlift C-130 missions could be successfully replaced by using hybrid airships (Lynch, 2011).

Major Samuel Morgan's paper titled Hybrid Airships in Joint Logistics over the Shore explored the use of hybrid airships in supporting the final delivery of equipment, supplies and personnel. His focus was on near-port operations to assembly areas, not direct delivery. Specifically he looked at ~150NM range once in theater. His modeling compared hybrid airships to traditional Army LOTS using large ships and lightering vessels to transfer cargo at sea and deliver to the beach, then a trucking network to deliver cargo to the final tactical assembly area inland. His focus was on replacing the lightering vessels and trucking network with hybrid airships to deliver from either the large ships at sea or nearby intermediate staging bases directly to the point of need. What he did not focus on was using hybrid airships to take the cargo from point of origin all the way to point of need. His research looked at multiple hybrid airships ranging in size from 40 ton to 1000 ton. The relatively faster speed of hybrid airships did not prove advantageous over ships when looking at single airships due to the larger payload capacity of lightering vessels. His research did show however, that a fleet of hybrid airships could deliver a Stryker Brigade Combat Team (SBCT) to the point of need faster than the conventional LOTS construct (Morgan III, 2013). He established a baseline LOTS network using one Logistics Support Vessel (LSV) and eight Landing Craft Utility (LCU) ships to unload three Large Medium Speed Roll-on Roll-off (LMSR) ships. His data revealed faster delivery times with various notional hybrid airship fleets. The notional fleets in order from fastest to slowest that still outperformed the conventional LOTS were either four 500 ton, seven 200 ton, four 1,000 ton, eight 80 ton or eight 40 ton hybrid airships (Morgan III, 2013).

Lt Col Donald Ryan's School of Advance Airpower Studies thesis from 1992 titled The Airship's Potential For Intertheater and Intratheater Airlift argues that a gap in strategic intertheater airlift exists and used the Gulf War logistics flow as a model to identify a Million-Ton-Mile per Day (MTM/D) shortfall and demonstrate that the US cannot meet wartime needs, much less wants. His thesis argues that a hybrid airship is the answer to the US intermediate strategic transportation shortfall (Ryan, Jr., 1992). Lt Col Ryan highlighted the following six points in his argument that hybrid airships could fill a void: marshalling delays, transit time, conventional transporter availability and vulnerability, APODs and direct delivery, cost, and attrition. He acknowledges that hybrid airships will not replace jet aircraft but points out that they could provide an adjunct capability which would relieve stresses imposed upon strategic airlifters during the early stages of a force buildup and he argues that the additional capability would enable the US to rapidly project massive combat power directly to the place of need until sealift can become established to support the large logistical requirement of war (Ryan, Jr., 1992).

Strategic Use of Helium

A basic understanding of helium is important when discussing hybrid airships. This section will discuss the strategic nature of helium, where it comes from, how it is processed, where it is stored and where is it used. This information is helpful when answering whether or not enough helium exits to support a hybrid airship fleet.

Early use of gas as a lifting medium for lighter-than-air craft saw hydrogen as the primary choice since it is the lightest known gas in existence. Balloons used for reconnaissance during the Civil War initially used coal gas but eventually switched to hydrogen gas created with portable hydrogen generators (Bowen, 1977). Hydrogen was easier and cheaper to procure compared to other gases in the early 1900's. The use of hydrogen was widely accepted throughout Germany where rigid airships originated; the Hindenburg disaster of 1937 highlighted the dangers of working with large volumes of hydrogen and ultimately led to the decline in hydrogen use in airships. The Hindenburg was originally designed to use helium, but at the time the United States controlled the helium supplies and refused to export it, claiming it was a strategic war resource (Robinson, 1973). In addition to inflammability, helium has the lowest boiling point of any element which makes it very useful with industries requiring large amounts of cooling. One common use is cooling the superconducting magnets used in Magnetic Resonance Imaging (MRI) machines. Since the gas is inert, it is also used in welding as a shielding gas and as a protective layer used for growing the silicon wafers used in electronics. The Large Hadron Collider (LHC) at CERN uses helium to cool the electromagnets to 1.9 K (-271.3 C) for scientific research (CERN, 2020).

Helium production is generally the result of collecting the byproducts of natural gas extraction from underground reserves. Most helium production in the United States occurs in Kansas, Oklahoma and Texas. See Appendix 1 – Helium Information for additional helium information. The United States Geological Survey monitors helium production, usage and storage and reports statistics annually. Helium use in 2019 was categorized as follows: 30% MRI, 17% lifting gas, 14% analytical and laboratory use, 9% welding, 6% engineering and sciences, 5% semiconductor manufacturing and 14% various other (Peterson, 2020). The United States possesses an underground strategic reserve known as the Federal Helium Reserve which is located near Amarillo, Texas that is in the process of a long-term transfer of ownership from the government to private companies. The Helium Conservation Act of 1925 established federal control over the production, refining and storage of helium including the construction of the underground stockpile (Secretary of the Interior, 2020). The purpose was to responsibly manage the supply of helium for the United States. US law directs that the Bureau of Land Management must sell off the stockpile in order to repay the US Treasury for the debt incurred creating the reserve. The Helium Stewardship Act of 2013 is the most recent legislation directing the transfer (Secretary of the Interior, 2020). Helium is still being produced, refined, stored and sold, the work is just transferring to private companies as the government gets out of the helium business. The USGS reported domestic helium consumption in 2019 at 1.4 billion cubic feet. Private producer exports were 2.25 billion cubic feet and imports were 882 million cubic feet.

US law requires the USGS to complete a national helium gas assessment which is expected to be complete by mid-2020. Until that study is complete the most current estimate is from a 2006 study. In 2006 the USGS estimated total reserves and resources of helium for the United States to be 744 billion cubic feet. It is important to note that 153 billion cubic feet comes from actual reserves available. The other 591 billion cubic feet are made up nearly equally of probable, possible and speculative sources (Peterson, 2020). The estimate for total world resources, excluding the US is 1.13 trillion cubic feet. The top five countries controlling large helium resources in order are Qatar, Algeria, Russia, Canada and China.

The overall size of an airship is related to the purity level of helium used. Impurities in helium result in less lifting capability than pure helium. Grade-A helium is >99.997% pure. Pure helium results from 98% purity levels. Crude helium ranges from 50-90% pure helium. If an airship was designed for 98% pure helium use, the volume would be 1.4% larger, the empty weight 1.5% greater and the takeoff weight 1.1% more than compared to a Grade-A design. A crude helium design would have a volume 80% larger, an empty weight 84% heavier and takeoff weight 63% more when compared to the Grade-A design (United States Air Force, 2013). The purity level and designated user also determines the price. Crude helium for government users in FY19 dollars is $86 per thousand cubic feet and for non-governmental users is $119 per thousand cubic feet. Private industry Grade-A helium is $210 per thousand cubic feet.

Civilian Augmentation to Military Cargo Capacity

The Department of Defense augments airlift capacity through cooperation and partnership with civilian air carriers in a program known as the Civil Reserve Air Fleet (CRAF). USTRANSCOM oversees the program that will augment Department of Defense airlift requirements in emergencies when the need for airlift exceeds the capability of military aircraft (Air Mobility Command, 2014). Military Sealift Command operates a program similar to CRAF that utilizes civilian mariners. The program is known as the Voluntary Intermodal Sealift Agreement (VISA) and a variety of specialized U.S.-flag vessels agree to volunteer their time and intermodal capacity during wartime in exchange for Cargo Preference during peacetime (United States Department of Transportation, 2019). These programs provide access to capacity for the DOD for a cost without the accompanying requirement to invest in and maintain capital. Civilian ownership and augmentation of fleets of hybrid airships might be the appropriate avenue to implement required capability.

Mobility Modeling and Simulation

In 2015 NASA Ames Research Center conducted a study on behalf of USTRANSCOM to investigate available modeling software that could be used to model lighter-than-air vehicles (Hochstetler, Chachad, Hardy, Blanken, & Melton, 2016). The study did a capability gap analysis of all the currently available software. The report that was produced cited a lack of standardization and a desire of private companies to create and maintain their own software tools with proprietary information concerns preventing collaboration. The lack of standardized tools led this researcher to determine if current software used for modeling cargo airlift could be used to simulate hybrid airships.

The Analysis of Mobility Platform (AMP) is a federated suite of software tools used by USTRANSCOM to model end-to-end deployment and distribution. It has been a program of record used for analysis since 1995 (US Army SDDC, n.d.). The AMP modeling environment allows models to run in parallel and transfer back and forth during model execution. The advantage is that it provides an organized approach to modeling in a single environment operated on a single hardware platform (JDPAC, 2010). Within AMP is the AMP Port Analysis Tool (AMP-PAT) which is a suite of tools that simulate airport and seaport analysis (JDPAC, 2010). The Model for

Intertheater Deployment by Air and Sea (MIDAS) is another tool that operates within AMP. The tool allows individual aircraft to be loaded and fly independently as opposed to producing an average flow rate across multiple sorties. This type of modeling provides greater fidelity (Rapp, 2006). AMP allows planners to produce highly detailed results of Time Phased Force Deployment Data (TPFDD) movements. AMP-PAT allows planners to then study the embarkation and debarkation ports to better understand throughput issues. The final model to mention is the Rapid Course of Action Analysis Tool (RCAT) that allows planners to quickly consider various Courses of Action (COAs) and make decisions based on movement requirements (US Army SDDC, n.d.). RCAT allows planners to quickly produce feasibility reports for large movements utilizing a graphical interface that allows planners to rapidly develop multiple COAs and determine from a macro level whether or not the proposed solution is viable. Once a COA is validated in RCAT, more detailed analysis can be completed in within AMP. RCAT allows planners to produce an answer in a short amount of time to the question of whether or not a movement can happen. It provides highly granular data initially before additional detail can be developed using the other software tools.

Gabrielli von Kármán Diagram

In an article published in 1950 by Theodore von Kármán and Giuseppe Gabrielli titled What Price Speed? Specific Power Required for Propulsion of Vehicles, the authors discuss the efficiency of various forms of transportation. Their argument was that in any form of transportation, a balance must be struck between cost of transportation and the value of the time required for transport (Yong, Smith, Hatano, & Hillmansen, 2005). Their study produced a chart listing various forms of transportation and is shown in Figure 2. The chart related the specific power required of a form of transportation compared to the speed of that form of transportation. A gradient line on the chart, known as the GvK line represents the expected best performance across the range of transportation modes. In 2005 the article was revisited and updated with Système International (d'unités) (SI) units by engineers from the Railway Research Group from the Department of Mechanical Engineering of Imperial College London. The chart can roughly be broken into three portions representing sea, land and air

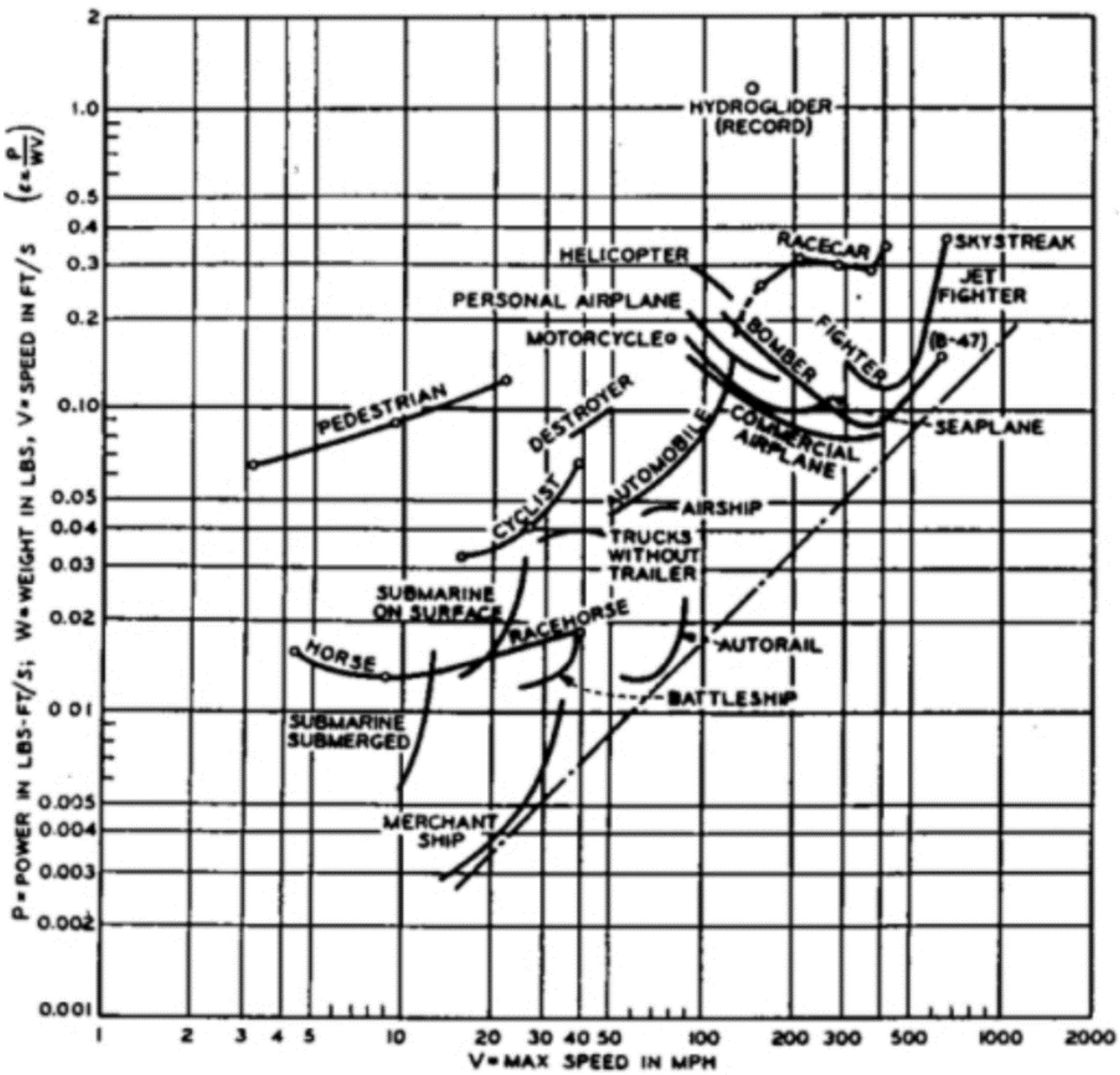


Figure 2 - Gabrielli von Kármán Diagram

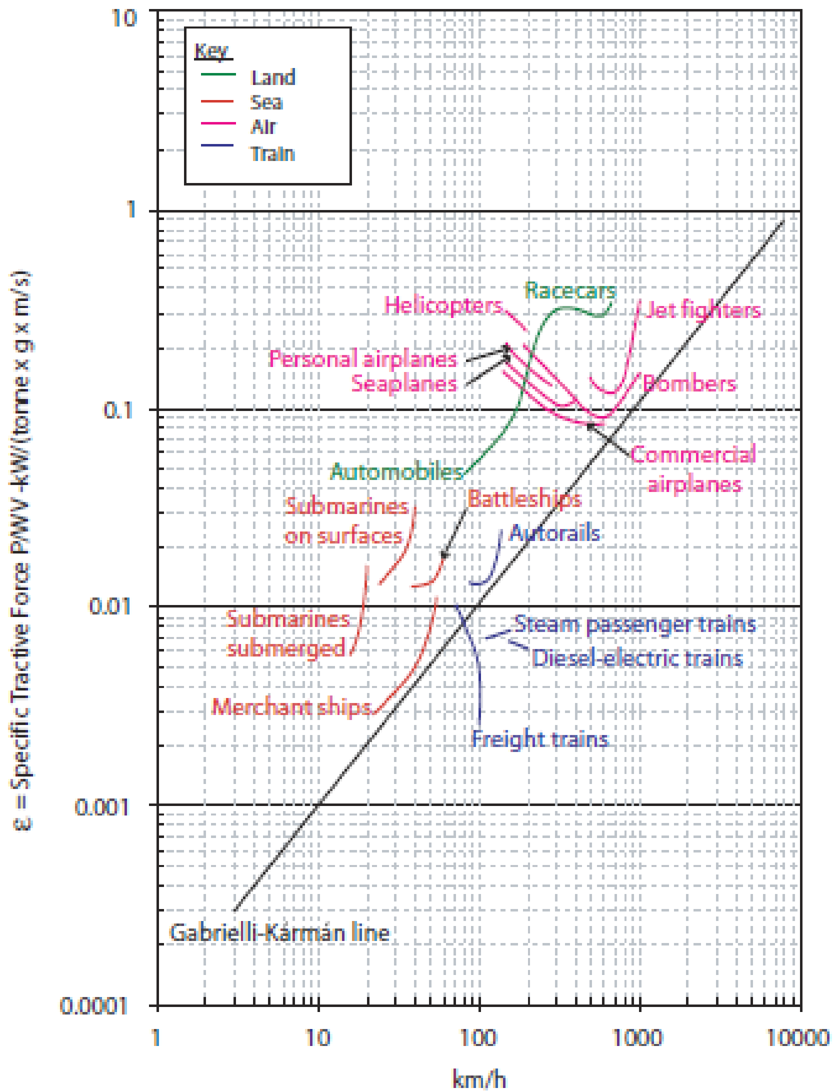


Figure 3 - Updated GvK Diagram

transportation methods and is shown in Figure 3. Movement below the GvK line represents transportation efficiencies such as long freight trains that provide increased transportation with a negligible increase in resistive force. A modern GvK diagram was produced and shifts to the right along the x-axis represent design efficiencies gained in various methods of transport. These improvements are shown in Figure 4. If the different methods are categorized by similarity an argument can be made that there is a capability gap. The gap exists between the high speed and low capacity of air transport and the low speed and high capacity of sea transport. Freight trains offer larger capacity than trucks but are limited to established rail lines while trucks are able to travel anywhere roads exist but provide low capacity. Hybrid airships can fill this gap by offering more capacity than some aircraft and more speed than ships. Lockheed Martin developed their own version of the GvK diagram to depict where a hybrid airship might fill a need. It is shown in Figure 5. The depiction is common with hybrid airships. They can carry more cargo than and are slightly faster than trucks, they are faster than ships and slower than jet aircraft.

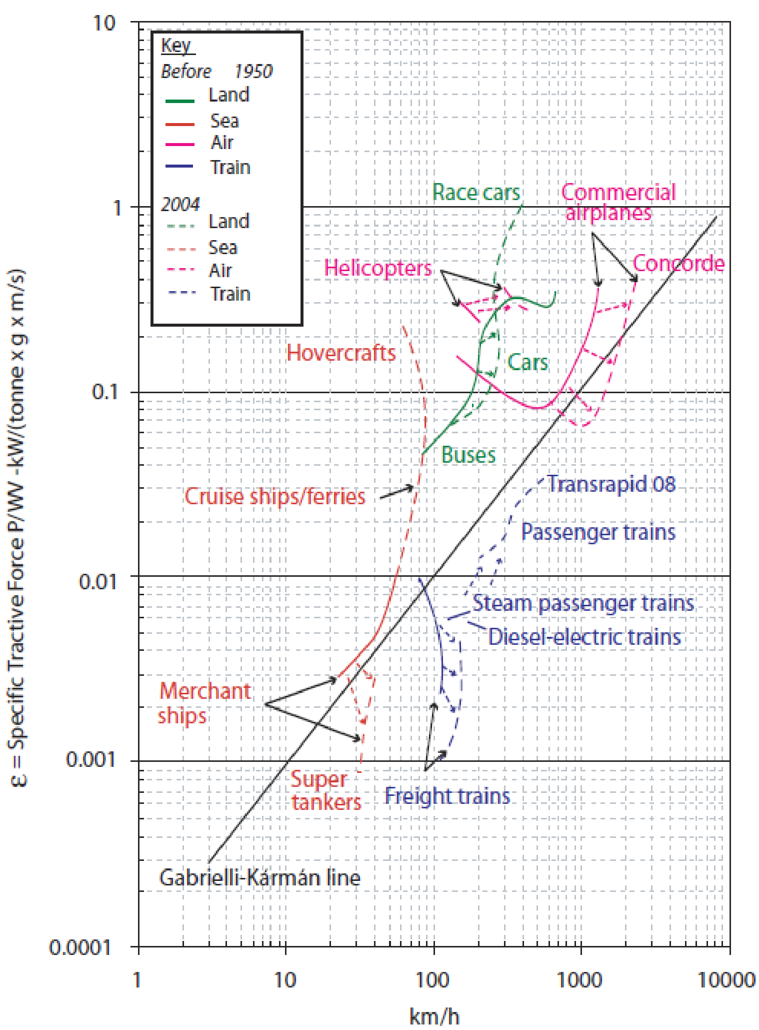


Figure 4 - Modern GvK Diagram

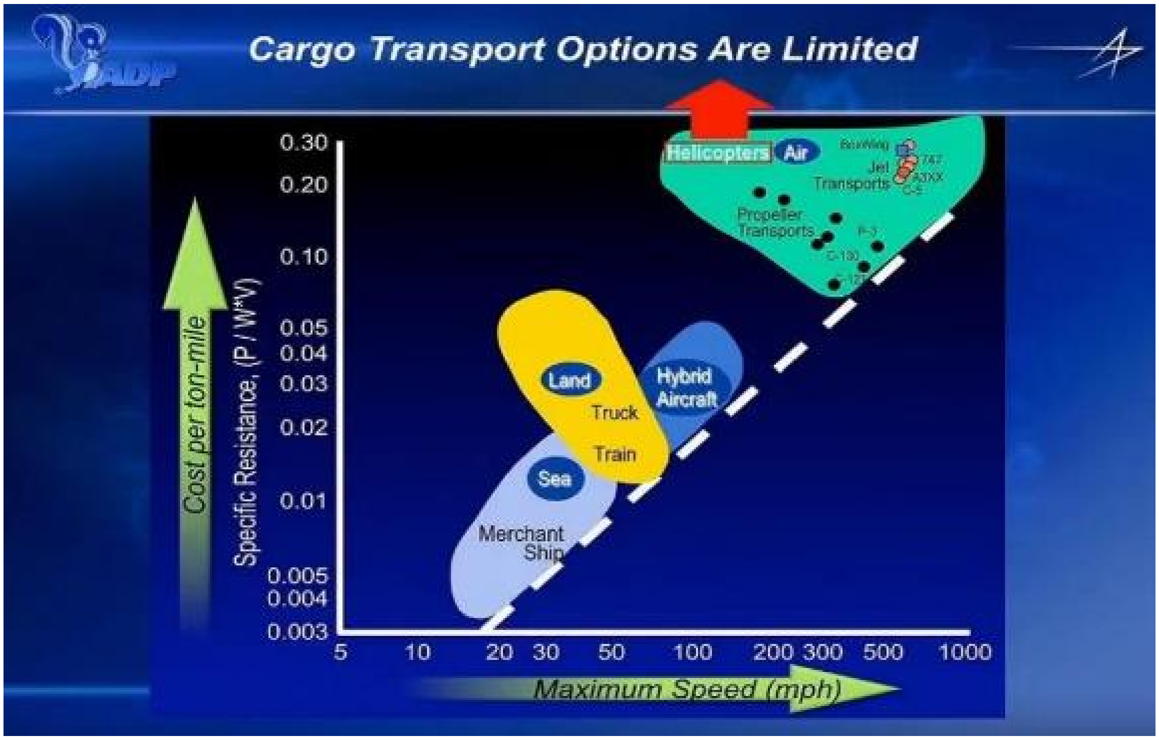


Figure 5 - Hybrid Airships along GvK line

Summary

This section introduced hybrid airships and the most recent military strategy guidance. National mobility strategic guidance was presented and the results of the JFTL study were presented that explored using hybrid airships to support national military objectives. Four important research papers were highlighted in order to establish a framework for this research through an exploration of intertheater airlift, intratheater airlift, last-mile delivery and the notion that hybrid airships could serve an augmenting and not replacement role for the mobility enterprise. The strategic nature of helium, how it is collected, refined and stored was next. The civilian cargo augmentation programs that utilize surface ships and commercial aircraft were then discussed to describe a way in which hybrid airship fleets could be managed. Current mobility modeling software and the Gabrielli von Kármán line and how it relates to hybrid airships were the final points discussed. The next section will describe the specific methodology used to answer the research questions.

III. Methodology

Background

This section explains the methodology used in this research to develop a simplified model in RCAT to simulate the integration of hybrid airships with conventional cargo lift assets. Previous research focused on replacing conventional assets with hybrid airships whereas this research looks at integrating hybrid airships. The methodologies used in previous research will be explained to highlight where gaps exist. The previous research mentioned spans the years from 1992 to 2013. As should be expected, technology and policy have changed since these works were published. For this research, an emphasis is placed on implementation of the 2018 National Defense Strategy and the 2019 National Defense Authorization Act. Current mobility modeling software is utilized to analyze the ability of hybrid airships to augment airlift and sealift. Analysis of current Air Force regulations is conducted to explain and quantify the limitations of manned flight in order to determine the savings that unmanned or autonomous aircraft may offer to the mobility enterprise.

Basic Methodology

The focus of this research is to combine the lessons learned from previous research efforts and apply it to the strategic inclusion of hybrid airships to support rapid global mobility. The focus is to determine if hybrid airships should augment, not completely replace conventional lift assets. RCAT is used to develop a model that presents an optimum combination of conventional airlift and sealift assets plus hybrid airships to move a notional TPFDD. The first step in developing the working model is to compare the output to previous research efforts. If identical or similar results can be achieved using RCAT, it is assumed that the new model adapted to hybrid airships is valid. The next step is to focus on optimizing the combination of airlift, sealift and hybrid airship assets to minimize the time and cost associated with TPFDD closure. The final step explores the advantages gained by using the runway independent attribute of hybrid airships, specifically the ability to operate on water and unimproved surfaces. The emphasis is on maximizing throughput by increasing the number of Aerial Ports of Embarkation (APOEs) and Aerial Ports of Debarkation (APODs) available for TPFDD closure, thus limiting Maximum On Ground (MOG) issues.

The first model comes from Maj Rapp's 2006 thesis that simulated intertheater airlift. His model used two scenarios that had been studied by USTRANSCOM, both a short and long distance deployment of a Stryker Brigade Combat Team (SBCT) from Ft. Lewis, WA. He assumed 13,989.6 short tons of cargo and 3,837 passengers. The short distance scenario went to Colombia, covering a distance of 3,800NM. The long distance scenario went to Angola and covered 8,500NM. He used a normal fleet consisting of 84 C-17 and 60 C-5 aircraft based on projected aircraft that could be made available at the time (Rapp, 2006). He created two additional fleets made up of enough 1,000 ton and 500 ton hybrid airships to carry the entire TPFDD in one trip.

The second model comes from Maj Lynch's 2011 thesis that simulated intratheater airlift in support of a humanitarian aid mission from the United States to Haiti. He assumed 200 tons of cargo per day originating from either Charleston, SC or Jacksonville, FL, which was based on actual cargo throughput during the crisis response. He assumed one way delivery, with no cargo leaving Haiti and a requirement to make the entire 2,500NM roundtrip unrefueled in an effort to reduce MOG in Haiti. He modeled four main scenarios: (1) Sealift, strategic and tactical airlift plus 50-ton hybrid airships, (2) no strategic airlift, (3) no sealift, (4) C-130 and 30-ton hybrid airships.

The third model is from Maj Morgan's 2013 thesis that looks at utilizing hybrid airships for last-mile delivery to replace conventional JLOTS assets. His analysis centered on determining the minimum size of a hybrid airship fleet and the cost effectiveness compared to watercraft. He assumed the movement of all the rolling stock of a Stryker Brigade Combat Team plus 200 containers of cargo. He modeled three distance scenarios simulating final delivery to the tactical assembly area, between 1-5km, 25 NM, and 1,500 NM. The distances represented a ship anchored just off the coast, a ship anchored just beyond the horizon and the approximate distance from an intermediate staging base just outside the objective area.

Specific Methodology

This paper models the delivery of a Stryker Brigade Combat Team from Ft. Lewis, WA (KTCM) to Davao International Airport in the Philippines (RPMD) with an available intermediate stop at Wake Island Airfield (PWAK). The distance from Washington to Wake Island is 3,794 NM and the distance from Wake Island to the Philippines is 2,499 NM. These distances are chosen only to replicate intertheater and intratheater transportation distances as previously discussed. The distances are important, the specific airports used are not.

Any aircraft designed to carry cargo can carry bulk cargo. Bulk cargo is considered any cargo that fits the dimensions of a 463L pallet. The pallet measures 104 x 84 inches and can carry 10,000 pounds. Oversize cargo is any cargo that exceeds either the length or width dimensions of the 463L pallet but does not exceed 1,000 inches in length or 117 inches in width. Outsize cargo exceeds the dimensions of oversize cargo and requires the use of either the C-17 or C-5 (Surface Deployment and Distribution Command, 2011). The default SBCT unit in RCAT 4.8.0 has 18,766 tons of total cargo, consisting of 2% (375.3 tons) of bulk cargo, 50% (9,383 tons) of oversize cargo and 48% (9,007.7 tons) of outsize cargo, plus 4,390 passengers. RCAT automatically assigns cargo to aircraft based on the size. For example, outsize cargo for airlift will not be allocated to an available C-130, instead it is assigned to either a C-17 or C-5, based on a built-in ranking system.

For this research, models of hybrid airships are created in RCAT and simulations are run to investigate the capability of hybrid airships to augment conventional lift assets. The variables used to create the hybrid airship models are explained below.

In order to model aircraft performance and characteristics, RCAT creates virtual objects that represent aircraft based on parameters published in AFPAM 10-1403 – Air Mobility Planning Factors. The stated intent of the pamphlet is to provide planners with gross estimates about the mobility requirements in the early stages of the planning process. The pamphlet encourages detailed computer simulation for extensive calculations (Air Mobility Command, 2018). The parameters for each aircraft are input as variables that affect cargo utilization, speed, fuel consumption, total cost and airfield suitability in the simulation. The default values for most of the required variables of the military cargo aircraft used in RCAT are depicted in Figure 6. The same implementation is used, albeit with different parameters to define surface ships. The source of data for the ship variables comes from SDDC Pamphlet 700-4, published by the Transportation Engineering Agency. The version of RCAT used for this research is 4.8.0 and uses planning factors from the 2011 version of AFPAM 10-1403. A newer version of the

CREATE MEMORY TABLE CVAO_REFERENCE.AIRCRAFT			
ACTYPE VARCHAR(15) NOT NULL PRIMARY KEY	'C-130'	'C-17'	‘'C-5'
CIVMIL VARCHAR(10) DEFAULT NULL	'Military'	'Military'	‘'Military'
CARGOCLASS VARCHAR(10) DEFAULT NULL	'Oversize'	'Outsize'	‘'Outsize'
SIZE VARCHAR(10) DEFAULT 'NARROW'	'NARROW'	NARROW'	‘'WIDE'
DEFMOG DOUBLE DEFAULT NULL	5.00E-01	1.00E+00	2.00E+00
ONLOADHOURS DOUBLE DEFAULT NULL,	2.25E+00	3.25E+00	4.25E+00
ENROUTEREFUELONLYHOURS DOUBLE DEFAULT NULL	1.50E+00	2.25E+00	3.25E+00
OFFLOADHOURS DOUBLE DEFAULT NULL	2.25E+00	3.25E+00	4.25E+00
MINCREWRESTHOURS DOUBLE DEFAULT NULL	1.63E+01	1.65E+01	1.70E+01
EXPEDITEDHOURS DOUBLE DEFAULT NULL	7.50E-01	1.75E+00	2.00E+00
UTESURGE DOUBLE DEFAULT NULL	2.40E+01	2.40E+01	2.40E+01
UTECONTINGENCYSUSTAINMENT DOUBLE DEFAULT NULL	6.00E+00	1.25E+01	8.10E+00
FUELBURNRATE INTEGER DEFAULT NULL	4533	21097	24033
BLOCKSPEED2000 INTEGER DEFAULT NULL	273	405	415
CARGOPAYLOADPLANNING DOUBLE DEFAULT NULL	1.20E+01	4.50E+01	6.10E+01
PAXPAYLOADPLANNING DOUBLE DEFAULT NULL	0.00E+00	0.00E+00	5.10E+01
MAXOPERATINGTIME INTEGER DEFAULT NULL	100	100	100
MAXPAYLOADRANGE INTEGER DEFAULT NULL	2868	3900	3900
MAXFUELLOADRANGE INTEGER DEFAULT NULL	2870	5220	6200
MAXRANGE INTEGER DEFAULT NULL	2870	5840	6556
PROVENANCE VARCHAR(40) DEFAULT NULL	'AFPAM10-1403 12Dec2011'	'AFPAM10-1403 12Dec2011'	'AFPAM10-1403 12Dec2011'
PAXASSIGNMENTRANK INTEGER DEFAULT NULL	0	0	8
BULKASSIGNMENTRANK INTEGER DEFAULT NULL	4	6	7
OVERSIZEASSIGNMENTRANK INTEGER DEFAULT NULL	4	1	3
OUTSIZEASSIGNMENTRANK INTEGER DEFAULT NULL	0	2	1
MILITARYASSIGNMENTRANK INTEGER DEFAULT NULL	3	1	2

Figure 6 - Default Aircraft Variables in RCAT, 2011 Numbers

pamphlet was released in 2018 and several of the planning factors changed. Most calculations made by RCAT 4.8.0 will not match the 2018 planning factors. Some fields are user editable to adjust certain planning factors but each field must be changed with each new calculation. In order to reflect the changes automatically in RCAT 4.8.0, the databases used by the software need to be modified to match the new guidance. The changes require editing files in the data subdirectory that RCAT is installed in. The Air Force Standard Desktop Configuration (SDC) does not allow users to modify files in this directory. Another option is to manually adjust the appropriate calculations that RCAT produces with the updated planning factors. The point of this research is to determine if a software tool exists to quickly and accurately model hybrid airships so the researcher chose to use a non-SDC computer without permission restrictions to modify the files and utilize the built-in functionality of RCAT rather than complete multiple calculations by hand. The variables used to model different hybrid aircraft in RCAT are explained in the next section and shown in Figure 7. To produce the results for his research, Maj Rapp developed custom variables that would simulate the performance of hybrid airships. He utilized fuel burn diagrams and range-payload charts that were the result of a hybrid airlift study as the baseline for his models. He extrapolated the data to create instantaneous fuel burn charts and maximum range charts. The data he used was from a proposed 1,000 ton hybrid airship, the SkyCat 1000. He used that data to develop variables to model a notional 500 ton Hybrid Ultra Large Airship (HULA) as well. His research details four separate variants of each hybrid airship size, for eight total models

CREATE MEMORY TABLE CVAO_REFERENCE.AIRCRAFT		
ACTYPE VARCHAR(15) NOT NULL PRIMARY KEY	30T Airship	120T Airship
CIVMIL VARCHAR(10) DEFAULT NULL	Military	Military
CARGOCLASS VARCHAR(10) DEFAULT NULL	Outsize	Outsize
SIZE VARCHAR(10) DEFAULT 'NARROW'	WIDE	WIDE
DEFMOG DOUBLE DEFAULT NULL	3.00E+00	8.00E+00
ONLOADHOURS DOUBLE DEFAULT NULL,	2.50E+00	1.00E+01
ENROUTEREFUELONLYHOURS DOUBLE DEFAULT NULL	4.00E+00	4.00E+00
OFFLOADHOURS DOUBLE DEFAULT NULL	2.50E+00	1.00E+01
MINCREWRESTHOURS DOUBLE DEFAULT NULL	1.70E+01	1.70E+01
EXPEDITEDHOURS DOUBLE DEFAULT NULL	2.25E+00	8.75E+00
UTESURGE DOUBLE DEFAULT NULL	2.40E+01	2.40E+01
UTECONTINGENCYSUSTAINMENT DOUBLE DEFAULT NULL	8.00E+00	8.00E+00
FUELBURNRATE INTEGER DEFAULT NULL	5406	9563
BLOCKSPEED2000 INTEGER DEFAULT NULL	105	105
CARGOPAYLOADPLANNING DOUBLE DEFAULT NULL	3.00E+01	1.20E+02
PAXPAYLOADPLANNING DOUBLE DEFAULT NULL	1.00E+02	1.00E+02
MAXOPERATINGTIME INTEGER DEFAULT NULL	100	100
MAXPAYLOADRANGE INTEGER DEFAULT NULL	9711	10979
MAXFUELLOADRANGE INTEGER DEFAULT NULL	9711	10979
MAXRANGE INTEGER DEFAULT NULL	10711	11979
PROVENANCE VARCHAR(40) DEFAULT NULL	Researcher	Researcher
PAXASSIGNMENTRANK INTEGER DEFAULT NULL	5	6
BULKASSIGNMENTRANK INTEGER DEFAULT NULL	8	9
OVERSIZEASSIGNMENTRANK INTEGER DEFAULT NULL	4	5
OUTSIZEASSIGNMENTRANK INTEGER DEFAULT NULL	2	1
MILITARYASSIGNMENTRANK INTEGER DEFAULT NULL	3	4

Figure 7 - Hybrid Airship Variables Used in RCAT

consisting of high and low altitude and high and low speed variants. Based on data available, the SkyCat speeds are either 80 knots or 105 knots. The HULA speeds are either 70 knots or 105 knots. Both airship altitude ceilings are either 4,000' or 9,000' MSL. To create the data for all four regimes of the 500 ton model he took the average of the instantaneous fuel burn rates of the appropriate regimes of the 1,000 ton model and divided by two (Rapp, 2006). His resulting fleet summary is shown in Table 1. Note that F is fast, S is slow, and H is high altitude. Example: SKY-FH is the SkyCat 1000 airship, fast and high altitude variant.

Table 1 - Maj Rapp's Fleet Summary

Name	Number	Max Payload Range	Max Fuel Load Range	Max Range	Max Fuel Load	Max Cargo Payload	Cargo Payload Max Fuel	Fuel Burn Rate	Def Hrs Upload	Def Hrs Enroute	Def Hrs Download	Pax	Pax Wt
C17ER	84 / 125	2,240	5,220	5,840	245,208	164,900	57,292	19,643	3	2	3	24	550
C5	60 / 76	1,130	5,630	5,960	332,500	270,000	56,500	23,132	4	3	4	71	550
SKY-F	18	4,800	4,800	5,400	992,000	2,200,000	2,200,000	19,500	11	11	11	300	1,000
SKY-S	18	5,500	5,500	7,200	992,000	2,200,000	2,200,000	13,000	11	11	11	300	1,000
SKY-FH	22	3,900	3,900	5,400	992,000	1,772,000	1,772,000	24,000	11	11	11	300	1,000
SKY-SH	22	3,900	3,900	7,200	992,000	1,772,000	1,772,000	18,250	11	11	11	300	1,000
HULA-F	35	9,900	9,900	10,900	992,000	1,000,000	1,000,000	9,563	6	6	6	250	1,000
HULA-S	35	9,999	12,100	15,700	992,000	1,000,000	1,000,000	5,406	6	6	6	250	1,000
HULA-FH	39	8,300	8,300	10,900	992,000	900,000	900,000	11,313	6	6	6	250	1,000
HULA-SH	39	8,200	8,200	15,700	992,000	900,000	900,000	8,125	6	6	6	250	1,000

Assumptions/Limitations

This section describes the assumptions used to accurately model hybrid airships and develop an optimum mix of mobility assets. It also describes some of the limitations imposed on this research.

Hybrid airship prototypes have been built and flown but there are currently no commercial or government produced airships in service. Historically there has not been significant interest to warrant large-scale economic investment and most projects fail due to a lack of funding. It is assumed that if the Department of Defense advertised a sufficient demand, the industrial base would respond in kind to build hybrid airships.

This limitation of actual flying production airships makes modeling and simulation challenging but not insurmountable. The rational for variables used is described next.

Critical numbers that RCAT uses to model aircraft relate to cargo and fuel loading times, crew rest time, aircraft speed, fuel usage and cargo capacity. The next set of variables relate to passenger carrying capacity, ranking and MOG. The ranking determines what aircraft should get the next available compatible cargo. For example, only the C-5 and C-17 are capable of carrying outsize cargo. RCAT has three sub-variants of the C-17 that are described in the next section. RCAT ranks the priority for outsize cargo as the C-5 first, the C-17 cargo only variant second and the C-17 cargo and passenger combination third. The order is based on the fact that the C-5 can carry more total outsize cargo than either the C-17 with cargo only or the C-17 with cargo and passengers. The same ranking structure exists for both bulk and oversize cargo as well as passenger movement. Finally there is a ranking for all military aircraft, to include tankers. These variables represent what needs to be input to accurately model a hybrid airship.

The default value for MOG used in RCAT is ‘1’ and is based on the C-17. The square footage of the C-17 using overall length and wingspan is 29,580 ft^2. The square footage of the C-130 is 13,034 ft^2 and the square footage of the C-5 is 55,081 ft^2. RCAT uses ‘0.5’ to represent MOG for a C-130 and ‘2’ to represent MOG for the C-5. The default MOG value determines what size parking spot an aircraft can occupy. For example, a C-17 can occupy either one narrow parking spot or one wide parking spot equivalent but a C-5 can only occupy one wide parking spot equivalent. If an airfield has a parking MOG of one wide and one narrow, the following combinations are possible: 2 C-130s, 1 C-130 and 1 C-17, 1 C-130 and 1 C-5, 2 C-17s, or 1 C-17 and 1 C-5. Table 2 shows the possible parking combinations.

Table 2 - Parking Options Based on MOG

Parking Options	Narrow Spot	Wide Spot
COA 1	C-130	C-130
COA 2	C-130	C-17
COA 3	C-130	C-5
COA 4	C-17	C-130
COA 5	C-17	C-17
COA 6	C-17	C-5

The proposed 30 ton hybrid airship described in the JFTL study would be 428 feet long compared to 247 feet for a C-5 and 174 feet for a C-17. An approximation of the 30 ton hybrid airship square footage is 91,592 ft^2 so a value of ‘3’ is used for MOG. Note, one of the main objectives of using a hybrid airship is operating at unprepared locations. MOG will still be an issue at unprepared locations but will not be the same as at an airport. MOG for conventional aircraft at an airfield is based on the useable paved surface that is appropriately stressed to support aircraft. Hybrid airships can operate on grass, dirt, sand, gravel or water. At an airport where conventional aircraft are limited to runways, taxiways and parking aprons, hybrid airships can operate on the grass in between runways and taxiways and clear areas surrounding parking aprons or even outside the airport perimeter completely. The main limitation is the ability of support assets such as cargo handling and refueling equipment to reach the airships operating off a prepared surface. RCAT uses airfield data that specifies working and parking MOG in terms of either wide body or narrow body. C-17 and C-130 aircraft are considered narrow body and C-5s are considered wide body. This is only based on paved surfaces that can support large aircraft so additional analysis of the operating locations for hybrid airships is done to determine appropriate MOG capacity at each location. Analysis of current satellite imagery at all three scenario locations reveals potential parking locations that are independent of taxiways or runways. McChord AFB has open areas covered in grass throughout the airfield. Wake Island surrounds a lagoon that measures nearly three miles long and one mile wide which provides airship parking locations on water. Davao International airport is surrounded by a city and less than ½ mile from water and the facilities of Sasa port. In addition to the grass infield areas at the airport that provide airship parking, additional airships could park on water at the port.

Figure 8 - Parking Example McChord AFB

Figure 9 - McChord AFB MOG Example

Rectangles that represent parking spots for hybrid airships are added to the imagery as polygons to determine optimum placement. Figure 8 uses green rectangles to show the parking spaces that could be utilized and represents six 30 ton hybrid airships parked south of the Juliet ramp at McChord AFB without interfering with fixed wing taxi operations. Notice all the C-17s in the figure for size reference. Looking at the entire airfield it becomes obvious that the space between the ramps is not the only area that is useable for airship parking. Figure 9 shows an example of parking 30 ton hybrid airships between the parking ramps as well as between the main runway and parallel taxiway at McChord AFB. This example shows thirteen airships parked with additional space to park twelve more airships northeast of the runway. McChord AFB represents the initial onload location of the scenario. Using the methodology described to determine parking spaces, the 30 ton airship wide body MOG is set to ’25’ at the APOE to represent 25 equivalent parking spots. The next location to review is the enroute location in the Pacific Ocean at Wake Island. Twelve airships are shown in the lagoon near the west end of the runway at Wake Island in Figure 10 to demonstrate how airships can be parked in water but still remain close to paved surfaces. The lagoon at Wake Island provides enough square footage for parking approximately nine hundred 30 ton airships. The 30 ton airship MOG is set to ‘25’ for this scenario to represent 25 parking spots. Wake Island is not the only airfield in the Pacific Ocean that provides ample parking for airships. The lagoon at Midway Island provides enough square footage for approximately six hundred 30 ton airships and the southern portion of the

Figure 10 - Wake Island MOG Example

lagoon at Kwajalein Atoll has enough square footage for approximately one thousand two hundred airships to park. The final location in the scenario is Davao International airport in the Philippines. The airport was chosen strictly based on distance from Wake Island, not strategic significance. The location demonstrates how hybrid airships can be used at an airfield in close proximity to both a city and a large port. In this case airships could be parked both on grassy open areas at the airport and close by at the sea port. Figure 11 shows three airships parked at the airport and three more parked at the sea port. Due to the large amount of parking space on the water, the MOG is set to '25' to represent 25 parking spots for 30 ton airships at Davao. Parking airships in the water is similar to using lay berths to temporarily lay-up surface ships. This allows ships to be anchored with minimum support to keep them operational until ready for loading or unloading. It is a technique to keep ships protected from open waters while waiting for

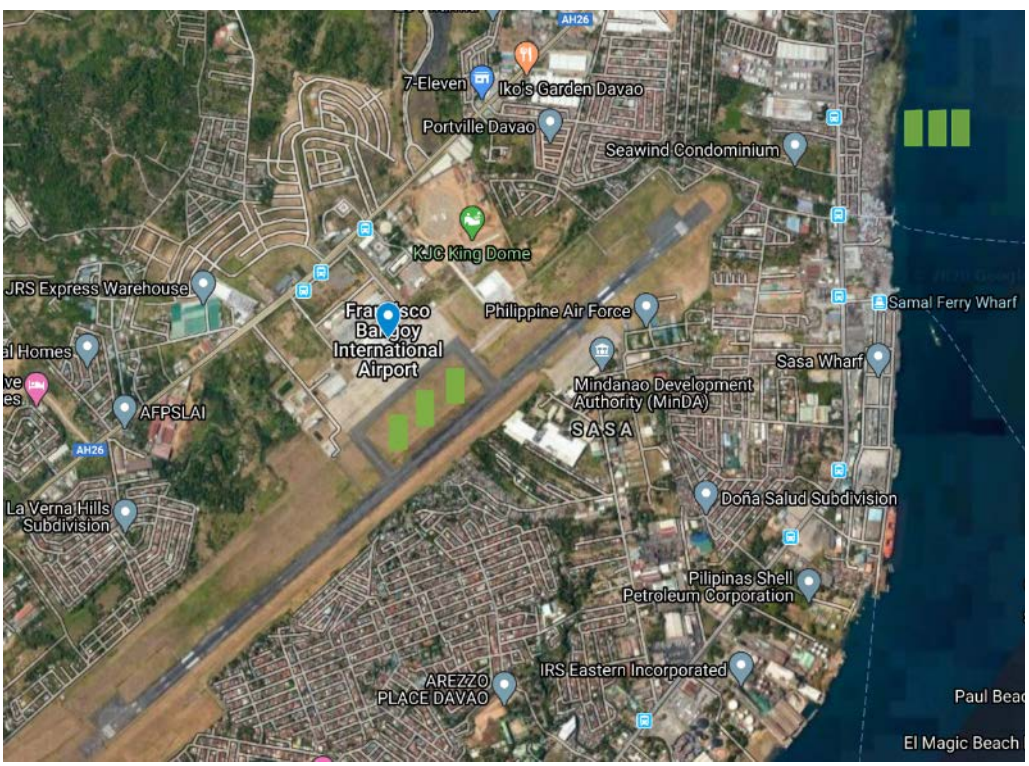


Figure 11 - Davao International MOG Example

space to moor at a dock (Det Norske Veritas AS, 2012). Maj Rapp cited a study that determined 11 hours would be required to load and unload a 1,000 ton airship (Rapp, 2006). It is assumed that loading and unloading times for a 30 ton airship would be closer to a conventional aircraft so a different metric is necessary. Dividing the time for loading and unloading by the total planned cargo as defined in AFPAM 10-1403 gives an hours/ton metric. Averaging this between the C-130, C-17 and C-5 gives the average hours/ton to load and unload cargo aircraft. This number multiplied by 30 tons gives the expected time in hours to load and unload the hybrid airship, 2.47 hours, which is rounded up to '2.5' hours. An R-11 fuel truck holds 40,200 pounds of fuel and is designed to transfer fuel at a rate of 4,020 pounds per minute (Genys, n.d.). The study cited by Rapp assumed that two fuel trucks simultaneously refueling an airship would take four hours to onload up to the maximum of 992,000 pounds of fuel (Rapp, 2006). This equates to 2,067 pounds per minute per truck. This is a conservative estimate based on the refueling rate of a standard R-11 fuel truck but allows for connection and disconnection of hoses as well as repositioning fuel trucks. If only two trucks are available this time is a better estimate assuming refill time for the trucks. If fuel trucks were not a constraint it would take 24 trucks to fill up one of the 1,000 ton airships. The amount of fuel the 30 ton airship holds is not specified so before the refueling time is set, the required fuel must be estimated. The fuel burn rate parameter is described below. Using that rate, 992,000 pounds of fuel provides an unrefueled range of 19,215 NM. 500,000 pounds of fuel provides an unrefueled range of 9,711 NM and 250,000 pounds of fuel provides an unrefueled range of 4,855 NM. For this scenario the 30 ton airship model is built with a fuel capacity of 500,000 pounds. Based on two refueling trucks simultaneously refueling the time required for an enroute refuel is set to '2' hours. The minimum recommended ground time of 17 hours based on the C-5 is the most conservative so ‘17’ is used for the 30 ton airship. The same method of calculating hours/ton is used to determine a metric for expedited cargo upload or download only with no concurrent fueling or reconfiguring. This results in 2.18 hours and is rounded up to ‘2.25’ hours. The same methodology used by Rapp for determining fuel burn rates is used to approximate the fuel burn of a 30 ton airship. The resulting numbers are lower than the fuel burn rate of a C-130. The JFTL study that ultimately recommended a 30 ton airship calculated that an airship of that size would require eight 42 foot propellers to power it. Compared to the 13.5 foot diameter of the C-130 propellers the proposed airship’s propellers would be over three times larger. To be conservative, the lowest fuel burn rate of ‘5406’ pounds/hour from Maj Rapp’s calculations is used. The cruising speed is ‘105’ knots. Cargo capacity in tons is ‘30’ for the airship. An argument can be made that the passengers of the SBCT should travel with the cargo that will carry them into battle in an attempt to reduce the overall Reception, Staging, Onward movement and Integration (RSOI) process. The hybrid airship is assumed to carry ‘100’ passengers in this model. One unique characteristic of hybrid airships regarding range is that the maximum range is not affected by the amount of cargo carried because they are designed to simultaneously carry maximum fuel so maximum payload range and maximum fuel range are identical and ‘9,711’ nautical miles is used. Maximum range is slightly greater and accounts for a light airship with just enough ballast onboard to prevent the airship from achieving positive buoyancy with continued fuel burn off and is set to ‘10,711’ nautical miles. The final variables determine the ranking for cargo and passengers. The logic is that the aircraft best designed for large cargo should be the last one chosen to move passengers because it lowers the overall system capacity if passengers are exchanged for cargo. Similarly the aircraft least suited for outsized cargo should be a lower ranking than the aircraft best suited for it. The 30 ton airship is ranked '5' for passengers, '8' for bulk cargo, '4' for oversize cargo, '1' for outsize cargo, and '3' for military assignment. This research focuses on the 30 ton airship but the addition of a 120 ton airship model is easily made. The only change affecting the 30 ton airship if a 120 ton airship is added is the reduction in outsize ranking from '1' to '2' since the 120 ton airship offers the largest capacity.

United States Transportation Command uses information provided by Air Mobility Command to set the rates charged for cargo aircraft use. The current rates for Special Assignment Airlift Missions (SAAM) are used to calculate estimated COA costs for conventional fixed wing assets in RCAT (Air Mobility Command, 2019). The hourly cost of a C-17 in FY20 dollars is $17,068 and for a C-130 it is $8,852. The operating costs of hybrid airships must be estimated in order for RCAT to calculate COA costs. Comparative fuel burn and cruise speed are used to provide rough cost estimates for both 30 ton and 120 ton hybrid airships. The estimated fuel burn of the 30 ton hybrid airship is divided by the fuel burn of a C-130 to establish a C-130 fuel multiplier. This number is multiplied by the hourly cost of the C-130 to set the cost multiplier compared to a C-130. The 30 ton fuel burn is then divided by the C-17 fuel burn to establish a C-17 fuel multiplier. This number is multiplied by the hourly cost of a C-17 to set the cost multiplier compared to a C-17. These two costs are then averaged to provide the baseline cost multiplier of the 30 ton hybrid airship. The next step is incorporating a cruise speed multiplier. Due to the slow travel speed of airships, cost must be reduced to account for the longer total mission time in order for airships to be cost competitive. First the cruise speed of the 30 ton airship is divided by the cruise speed of the C-130 to establish a C-130 speed modifier. Then the 30 ton airship cruise speed is divided by the speed of the C-17 to establish a C-17 speed modifier. These two modifiers are averaged to set the 30 ton airship baseline speed multiplier. Estimated hourly cost of the 30 ton airship is then the product of baseline cost multiplier and baseline speed multiplier, which is \$2,403/hr. The same process provides an estimated hourly cost of \$4,251/hr for the 120 ton airship.

$$30\ ton\ cost_{(C-130)} = \frac{5{,}406\ {}^{lbs}/_{hr}}{4{,}533\ {}^{lbs}/_{hr}} * \$8{,}852 = \$10{,}557/hr$$

$$30\ ton\ cost_{(C-17)} = \frac{5{,}406\ {}^{lbs}/_{hr}}{21{,}097\ {}^{lbs}/_{hr}} * \$17{,}068 = \$4{,}374/hr$$

$$30\ ton\ cost\ multiplier\ = (\$10{,}557/hr + \$4{,}374/hr)/2 = \underline{\$7{,}465/hr}$$

$$30\ ton\ speed_{(C-130)} = \frac{105\ knots}{237\ knots} = 0.385$$

$$30\ ton\ speed_{(C-17)} = \frac{105\ knots}{405\ knots} = 0.259$$

$$30\ ton\ baseline\ speed\ multiplier = (0.385 + 0.259)/2 = \underline{0.322}$$

$$30\ ton\ hourly\ cost = cost\ multiplier * speed\ multiplier = {}^{\$7{,}465}/_{hr} * 0.322$$

$$\boxed{30\ ton\ hourly\ cost = {}^{\$2{,}403}/_{hr}}$$

Cargo movements are constrained to the Pacific Area of Responsibility (AOR) to support the 2018 NDS focus of competing long-term with China. Commercial applications of hybrid airships are ignored in this paper. All material handling equipment is assumed available at the destinations. Personnel required for cargo upload and download of hybrid airships are not counted toward aircrew manning. The use of prepositioned cargo and ships stationed at Diego Garcia and managed by Military

Sealift Command are not considered. All sealift cargo and vessels originate in Washington State. Contingency Response Elements or Groups (CRE/CRG) are deployed to increase working MOG at Wake Island and Davao International. Each team increases capacity by two aircraft for a twenty-four hour period (2/24) (Department of the Air Force, 2015). Notional water based and unimproved terrestrial facilities for hybrid airships are assumed to provide all necessary requirements for landing, mooring, cargo handling and launching. Hybrid airships are fully filled with helium prior to deployment from the US and do not require helium refills.

AFPAM 10-1403 provides a definition of cycle time which is shown below. Round trip ground time is sometimes referred to as total ground time.

$$Cycle\ Time = Round\ Trip\ Flying\ Time + Round\ Trip\ Ground\ Time$$

One of the limitations with RCAT is that it does not include preflight time, only onload and offload time when calculating cycle times. When total ground time is displayed, it assumes all time is used for onload and offload when in reality a single aircraft would not offload and onload the same cargo at an enroute stop. For initial planning purposes the onload time can be counted as preflight time and the overall calculations will match. To reduce the amount of error this discrepancy adds, all locations will be configured as crew changes, not refuel only or crew rest locations. This increases the overall personnel requirement but better simulates stage operations during large cargo movements. Another limitation is that the maximum number of any specific aircraft in RCAT is 60. This prevents matching the fleet size described in some of the models discussed previously.

Surface ships are included in the combined model but limited to the LMSR. The LMSR is specifically designed to be a larger and faster version of a RORO ship. The LMSR has a capacity of 317,510 square feet and is designed to transit at a speed of at least 24 knots. There are 19 ships in the fleet with 8 assigned to the MSC prepositioning fleet (Surface Deployment and Distribution Command, 2007). RCAT 4.8.0 does not allow passenger movement for COAs involving surface ships. If cargo is added to a COA with a sea leg, the passenger requirement is automatically removed. This prevents a true comparison of COAs deploying the SBCT. A version of the SBCT with no passengers is included for simulation completeness when surface ships are utilized.

RCAT allows creation of composite COAs. Examples of composite COAs include two types of aircraft splitting the same cargo requirement, two types of aircraft moving separate cargo requirements, multiple POEs generating cargo to one POD or one POE delivering cargo to multiple PODs. There are, however, several limitations to the use of composite COAs in RCAT. The composite COAs cannot have different POE and PODs simultaneously, only one sea leg is allowed per COA, only one transload location (port to airfield, airfield to port) is allowed per leg and finally the transload cannot be the last leg of the segment. These limitations prohibit the full simulation of a true multimodal COA. One method employed to mitigate these limitations is to create a custom airfield for hybrid airships near the destinations. MOG is increased at the APOE to allow the appropriate number of conventional aircraft and hybrid airships, then the fixed wing aircraft depart for the conventional airfield while the hybrid airships depart for the custom airfield. Since COAs must have the same POE or POD and a transload segment cannot be the last leg of the segment the simulation of multimodal delivery with surface ships and aircraft cannot be completed in one step. Ships can still be simulated with aircraft COAs, they just display as separate efforts and the results must be assimilated.

To simulate the use of LMSR ships in the baseline scenario the port of Tacoma in Washington State and the port of Barranquilla in Colombia are used. They represent the closest seaports to the airports used. To simulate ships in the Pacific scenario the port of Tacoma and the port of Cagayan de Oro in the Philippines are used.

Methodology Summary

Background information shows that historical research focused on utilizing only hybrid airships while this research uses a combination of hybrid airships and conventional lift assets. Three different historical models describe intertheater, intratheater and last-mile delivery methods using hybrid airships. The deployment of an SBCT from Ft Lewis, WA to Davao International airport in the Philippines is simulated using a detailed model in RCAT with updated planning factors. The next section describes how the model is calibrated to match the performance of historical models. Once performance is verified the planning factors are updated to match current guidance and the historical performance is recalculated. The final step applies the most current model to the notional deployment scenario in the Pacific.

IV. Analysis and Results

Introduction

This chapter provides the results of software modeling and the analysis of those results. The chapter begins with a comparison of a new model developed in RCAT to an older model developed in AMP by another researcher. The next part updates the new model with current planning factors. The next part examines the applicability of the new model to intertheater deployment distances. After the model is verified using intertheater and intratheater scenarios it is used to simulate the full deployment of an SBCT using a combination of conventional airlift assets, sealift vessels and hybrid airships. After the model simulates the full deployment with a combination of assets an attempt is made to optimize the total combination of assets to decrease the total time and cost of TPFDD closure. Finally, the research questions are answered.

Developing and Comparing a Baseline Model

First, a baseline model is developed to replicate the results Maj Rapp produced using AMP to model a short-range deployment (3,800 NM) of an SBCT consisting of 13,989.6 tons of cargo and 3,837 passengers. The goal is to get this new baseline model close to Maj Rapp's movement that resulted in a closure of 6.8 days utilizing 84 C-17s flying 306 total missions and 29 C-5s flying 29 missions (Rapp, 2006). RCAT allows users to quickly change input parameters and see the results. Multiple runs of this baseline model are conducted in RCAT to match the performance of Maj Rapp's model. The number of each aircraft type is changed for each run with the total number of missions flown and total cost recorded for comparison. Figure 12 shows an example run

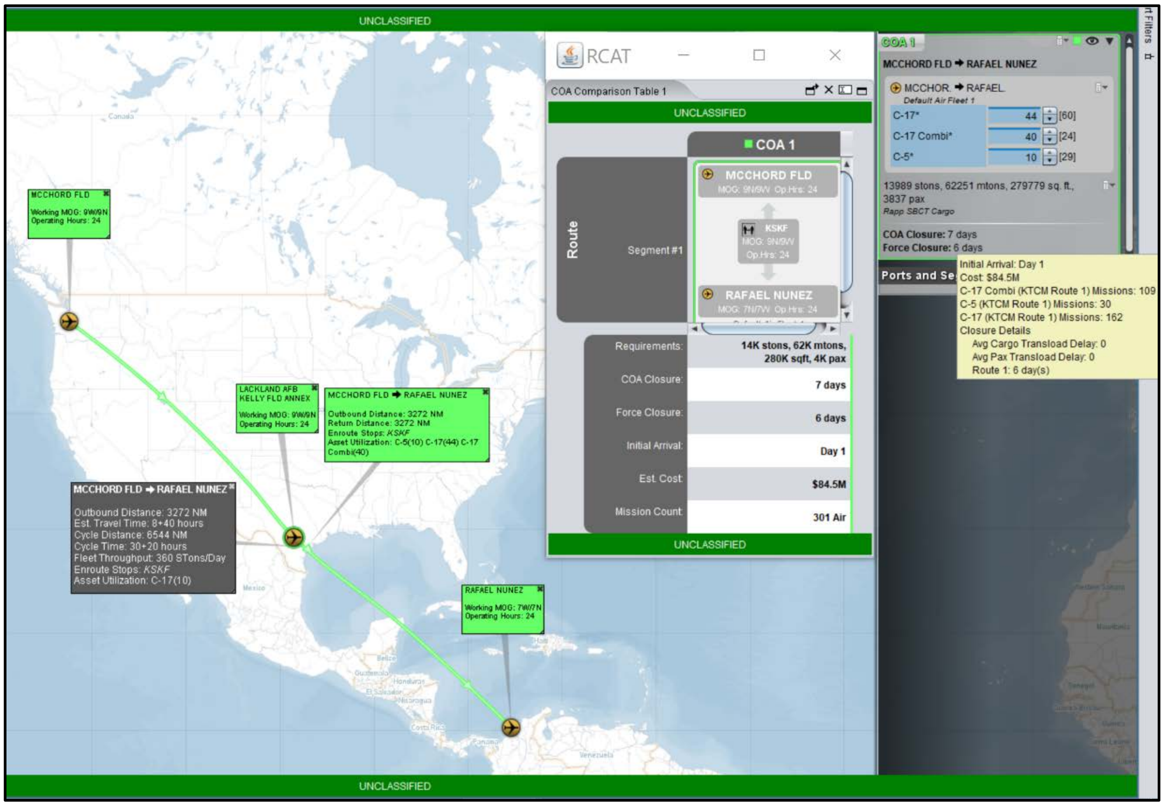


Figure 12 - Baseline Model Calibration

during initial model calibration. The C-17 passenger parameter used in Maj Rapp's fleet had a maximum passenger load of 24. There are 3 different versions of the C-17 available in RCAT, a pure cargo version labeled "C-17", a pure passenger version labeled "C-17 PAX" and a combination version labeled "C-17 Combi." The default cargo capacity for the first model is 45 tons, the default passenger load for the second is 90 passengers and the combination aircraft defaults to 27 tons and 45 passengers. The cargo capacity of the C-17 Combi is changed to 45 tons to match the cargo only version because the original planning factor of 27 tons is conservative and the sidewall seats in the C-17 are always installed which allows for an average load of 45 tons with 45 passengers. Additionally the cargo only planning factor has been updated in the newer version of the AFPAM. The new factors are explained later in this section. A software limitation in RCAT that affects the baseline model is that the maximum limit for a single aircraft type is 60. To closely match the original model with 84 C-17s, both the C-17 and C-17 Combi aircraft are used. An effort is made to keep the C-17 and C-17 Combi fleet as equal as possible to represent a homogenous C-17 fleet. A fleet consisting of 36 C-17 and 48 C-17 Combi aircraft has the closest number of missions flown between aircraft, 139 and 132, respectively. Using 10 C-5s in RCAT most closely replicates the 29 original missions. Using additional C-5s results in an increase in C-5 missions flown but a simultaneous decrease in C-17 missions flown. Table 3 shows the results of the baseline model runs. The highlighted row shows a closure time of 6 days is achieved with 84 C-17s (36 C-17 and 48 C-17 Combi) flying 271 missions and 10 C-5s flying 30 missions for a total of 301 missions flown at a cost of $84.5M.

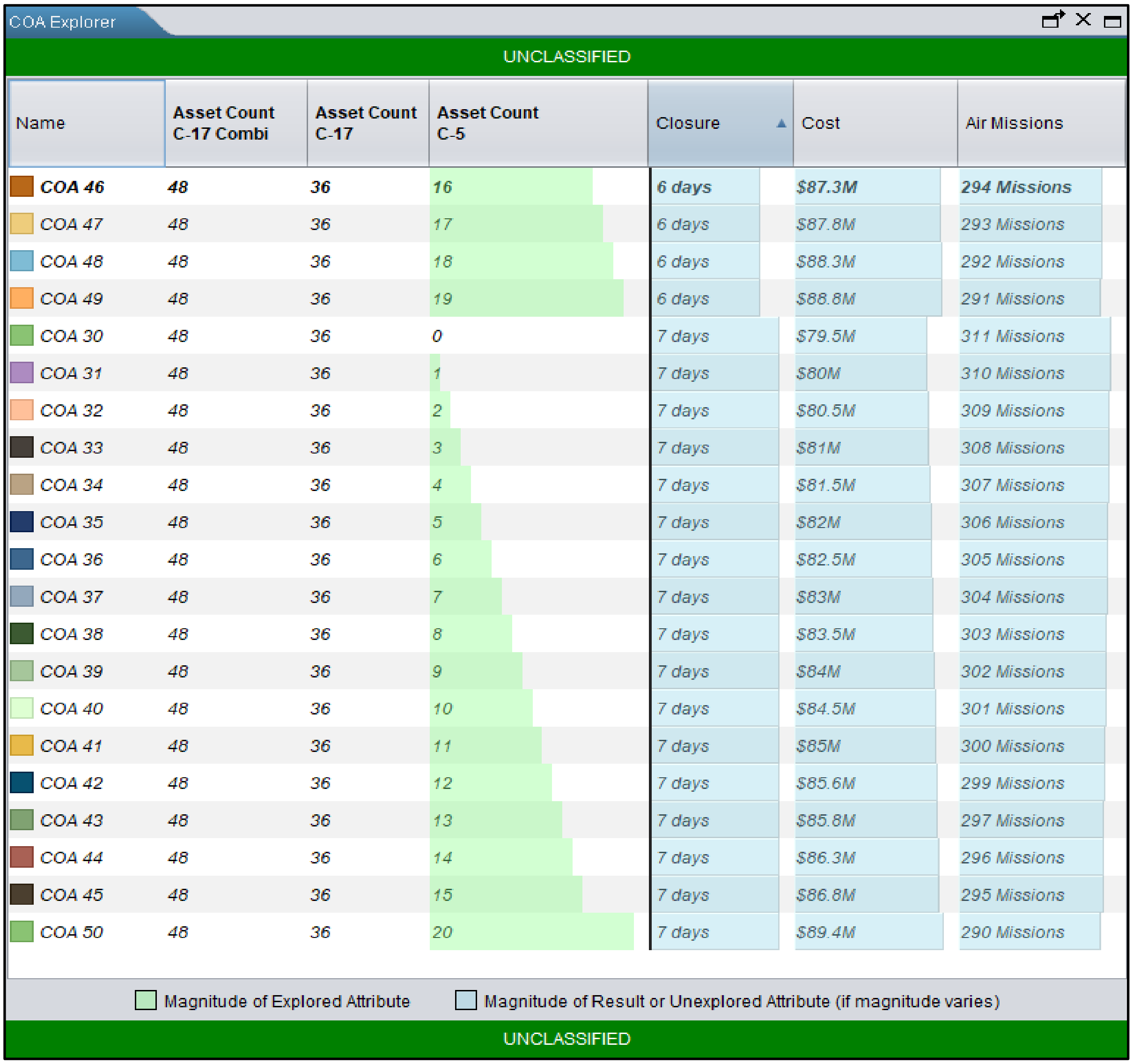
Table 3 - RCAT Baseline Model vs. Maj Rapp Model

Closure (days)	# of Aircraft Type / # of Missions Flown			COA Cost
	C-17	C-17 Combi	C-5	
6.8	84 / 306	N/A	29 / 29	Rapp Baseline
6	60 / 155	24 / 48	29 / 80	$92.6M
6	40 / 111	44 / 88	29 / 83	$93.1M
6	24 / 72	60 / 132	29 / 79	$92.4M
6	60 / 123	60 / 110	29 / 58	$89.1M
6	60 / 196	0 / 0	29 / 85	$93.4M
7	60 / 227	0 / 0	18 / 76	$96.7M
6	60 / 160	0 / 0	60 / 112	$98.0M
6	60 / 173	60 / 120	5 / 14	$82.0M
6	60 / 163	60 / 120	9 / 21	$83.0M
6	60 / 160	60 / 120	10 / 23	$83.3M
6	60 / 211	24 / 60	10 / 30	$84.5M
6	24 / 96	60 / 175	10 / 30	$84.5M
6	0 / 0	60 / 196	29 / 85	$93.4M
6	24 / 109	60 / 202	0 / 0	$79.5M
6	40 / 153	44 / 118	10 / 30	$84.5M
6	41 / 157	43 / 114	10 / 30	$84.5M
6	42 / 157	42 / 114	10 / 30	$84.5M
6	43 / 159	41 / 112	10 / 30	$84.5M
6	44 / 162	40 / 109	10 / 30	$84.5M

Table 3 (Continued)

6	45 / 165	39 / 106	10 / 30	$84.5M
6	30 / 120	54 / 151	10 / 30	$84.5M
6	31 / 124	53 / 147	10 / 30	$84.5M
6	32 / 128	52 / 142	10 / 30	$84.5M
6	33 / 130	51 / 141	10 / 30	$84.5M
6	34 / 134	50 / 137	10 / 30	$84.5M
6	35 / 139	49 / 132	10 / 30	$84.5M
6	36 / 139	48 / 132	10 / 30	$84.5M
6	37 / 141	47 / 130	10 / 30	$84.5M
6	38 / 143	46 / 128	10 / 30	$84.5M
6	39 / 145	45 / 126	10 / 30	$84.5M
6	50 / 182	34 / 89	10 / 30	$84.5M

For most of the iterations with the number of C-5s held at 10, the various combinations of C-17s resulted in 271 missions flown. The cost to operate the C-17 and C-17 Combi is the same since it is simply a different model of the same aircraft. If total cost is also important for determining a desired course of action, more iterations need to be run to determine the effects of fleet size. The iterations could be manually accomplished to attempt to find the lowest total cost. Software simulation provides results quickly, but manual entry is still time consuming. RCAT has some automated functionality built in that is useful in making decisions about different plans. One of these tools is the "COA Exploration" tool that allows multiple variables to be changed while holding others constant. The output of the comparison ranks the results in terms of shortest COA closure time followed by lowest cost. Results indicate that with 36 C-17 and 48 C-17 Combi aircraft, the optimum number of C-5s is 16 as represented by the line labeled "COA 46" in Figure 13. Note, the closure time indicated is COA closure, not just force closure. This includes the final missions required to return the aircraft back to their starting location after all cargo and passengers have been delivered. The



COA Explorer

UNCLASSIFIED

Name	Asset Count C-17 Combi	Asset Count C-17	Asset Count C-5	Closure	Cost	Air Missions
COA 46	48	36	16	6 days	$87.3M	294 Missions
COA 47	48	36	17	6 days	$87.8M	293 Missions
COA 48	48	36	18	6 days	$88.3M	292 Missions
COA 49	48	36	19	6 days	$88.8M	291 Missions
COA 30	48	36	0	7 days	$79.5M	311 Missions
COA 31	48	36	1	7 days	$80M	310 Missions
COA 32	48	36	2	7 days	$80.5M	309 Missions
COA 33	48	36	3	7 days	$81M	308 Missions
COA 34	48	36	4	7 days	$81.5M	307 Missions
COA 35	48	36	5	7 days	$82M	306 Missions
COA 36	48	36	6	7 days	$82.5M	305 Missions
COA 37	48	36	7	7 days	$83M	304 Missions
COA 38	48	36	8	7 days	$83.5M	303 Missions
COA 39	48	36	9	7 days	$84M	302 Missions
COA 40	48	36	10	7 days	$84.5M	301 Missions
COA 41	48	36	11	7 days	$85M	300 Missions
COA 42	48	36	12	7 days	$85.6M	299 Missions
COA 43	48	36	13	7 days	$85.8M	297 Missions
COA 44	48	36	14	7 days	$86.3M	296 Missions
COA 45	48	36	15	7 days	$86.8M	295 Missions
COA 50	48	36	20	7 days	$89.4M	290 Missions

Magnitude of Explored Attribute   Magnitude of Result or Unexplored Attribute (if magnitude varies)

UNCLASSIFIED

Figure 13 - Baseline Model COA Exploration

main COA summary window in RCAT lists both times but the COA explorer tool does not include an option to display force closure.

TPFDD Closure Using the Baseline Model

The baseline fleet identified earlier is now used to simulate the total time and cost required to close the notional TPFDD. The model indicates that all cargo and personnel can be delivered in 6 days. This consists of 271 C-17 sorties flown by 36 cargo only variants and 48 combination cargo and passenger variants, and 30 C-5 sorties flown by 10 aircraft for a total of 301 sorties and 94 aircraft. The total estimated cost in FY17 dollars is $84.5M.

The next step is updating the aircraft variables in RCAT so that the baseline fleet represents FY20 dollars and 2018 AFPAM planning factors. Specifically the planning factors for cargo handling times are reduced, cargo capacity is increased and hourly cost increased. The resulting model predicts a closure time of 4 days with an estimated cost of $72.5M. For comparison, the updated model requires 219 C-17 sorties (108 C-17 sorties, 111 C-17 Combi sorties) and 21 C-5 sorties for a total of 240 sorties with the same 94 total aircraft. Note the decrease in 61 missions and $12M is a result of using more accurate planning data that reflects a recent trend of increased capacity utilization and faster loading times.

The final step is to update the baseline model cargo requirements to reflect the size of an SBCT used in the current version of RCAT 4.8.0. The updated SBCT represents 2017 data and contains 18,766 tons of total cargo and 4,390 passengers. Rerunning the simulation with the updated cargo requirement results in a closure time of 5 days and a cost of $97.7M. For comparison this requires 278 C-17 sorties (135 C-17 sorties, 143 C-17 Combi sorties) and 37 C-5 sorties for a total of 315 sorties with 94 aircraft. All future modifications to the model represent the most current fiscal year prices and AFPAM planning factors available at the time of publishing. Figure 14 shows the simulation of the baseline model with the current SBCT parameters and Figure 15 shows the COA Cost tool indicating total hours flown and the updated hourly costs.

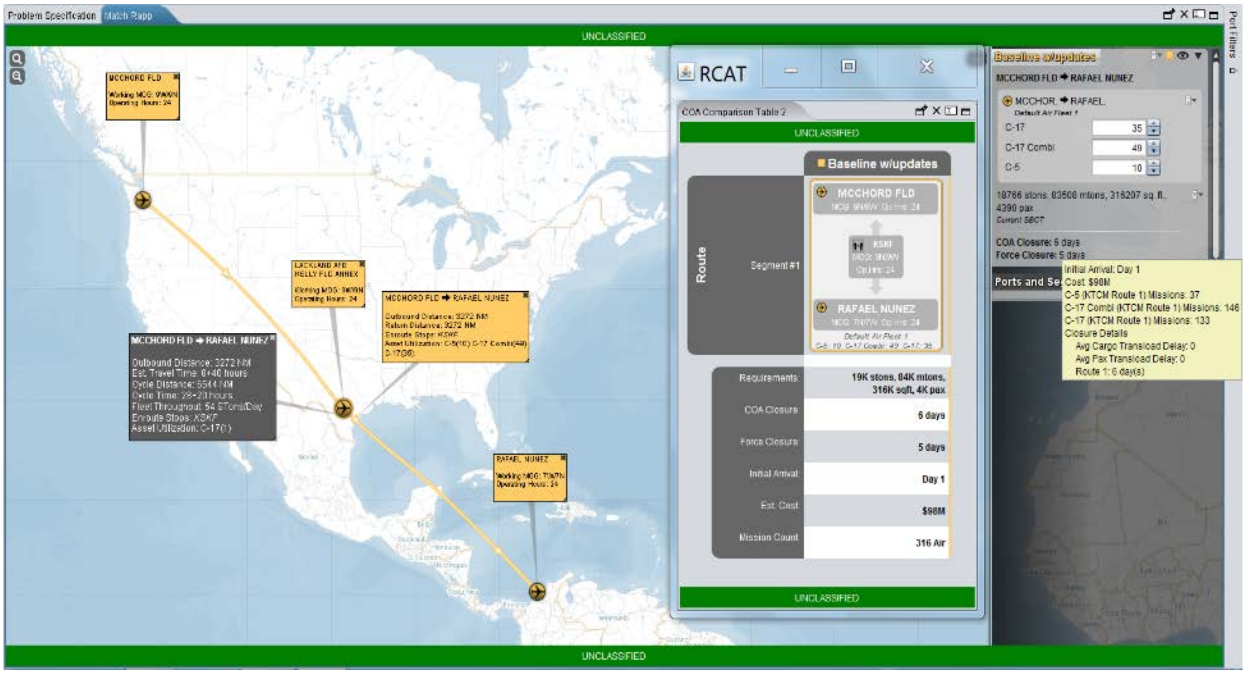


Figure 14 - Baseline Model with Current SBCT

Figure 15 - Baseline Model COA Cost

Table 4 shows the results from Maj Rapp's original model, the newly created RCAT baseline model and the baseline model updated with current planning factors.

Table 4 - Baseline Model Comparison

Parameter	Maj Rapp's Fleet	Baseline Model Fleet	Baseline w/current factors
COA Closure	6.8 days	6 days	4 days
C-17 Cargo Only Aircraft	N/A	36	36
C-17 Combi Aircraft	N/A	48	48
Total C-17 Aircraft	84	84	84
Total C-17 Missions	306	271	219
C-5 Aircraft	29	10	10
Total C-5 Missions	29	30	21
Estimated Cost (FY20)	N/A	$84.5M	$72.5M

Adding C-130s to the Baseline Model

Careful consideration must be taken when including C-130s in the model. MOG becomes an issue at enroute locations because the shorter maximum range of the C-130 does not allow the same intertheater delivery capability that the C-17 and C-5 offer and more crew rest stops are necessary. RCAT considers C-17s and C-130s both narrow body aircraft for parking calculations so either aircraft occupies the same equivalent parking spot. A C-130 takes up the same parking spot whether it is actively loading or unloading cargo or parked for the night as the crew rests. Additional crews could be prepositioned to ensure the aircraft continues to move regardless of crew endurance but less total cargo is delivered if C-130s displace C-17s at an airfield. For these reasons, the C-130 should not be used for intertheater planning such as a large TPFDD movement in the Pacific. However, for completeness the C-130s will be simulated using the baseline model. For the deployment to Colombia, adding 50 C-130s creates MOG issues at each location and increases the total deployment time to 7 days and costs $115.2M. The model with C-130s requires 265 C-17 sorties (121 C-17 sorties, 144 C-17 Combi sorties), 33 C-5 sorties, and 110 C-130 sorties for a total of 408 sorties with 144

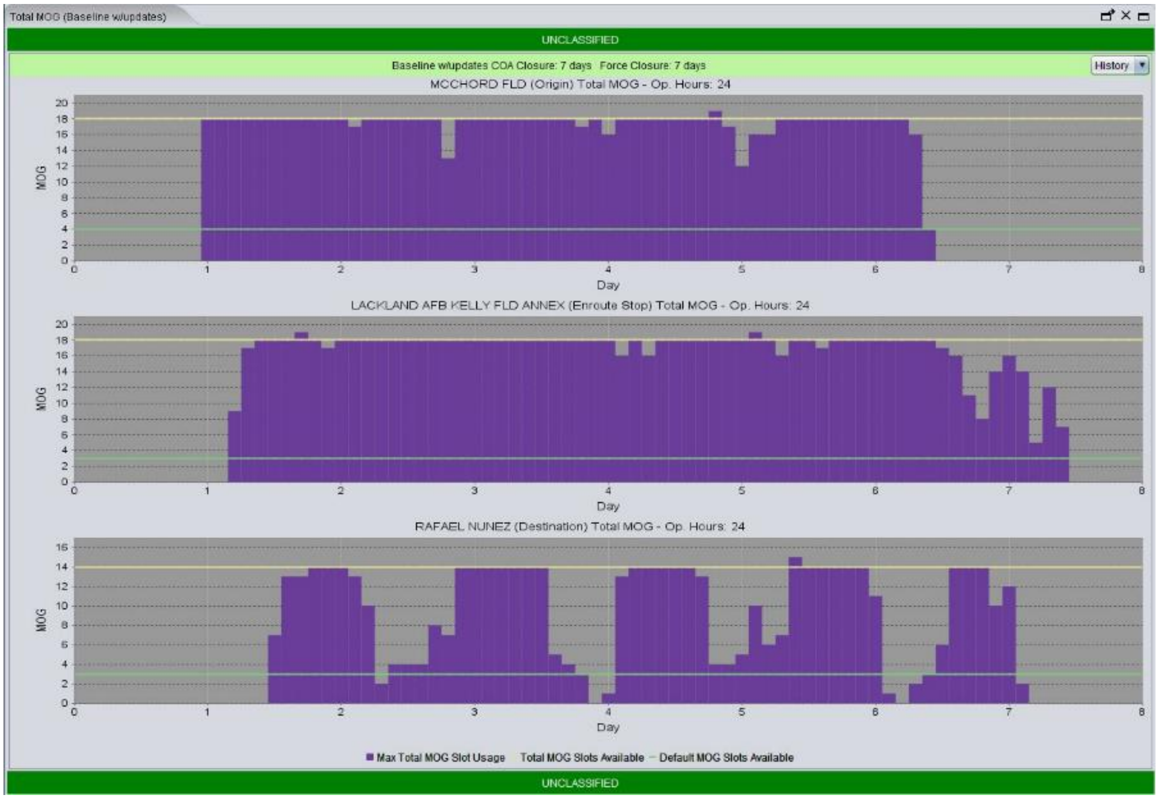


Figure 16 - Baseline Model MOG Report

aircraft. Figure 16 shows the MOG at each location after C-130s are added to the model. The yellow line depicts the maximum total MOG at each location.

Adding Sealift Vessels to the Model

Using surface ships to deliver cargo from Washington State to Colombia is not expeditious since the ships must transit the Panama Canal. As long as enough airplanes are available, fixed wing aircraft can make the multiple trips required to move an entire SBCT faster than even the Fast Surface Ship (FSS) traveling at 27 knots can make one voyage. If aircraft availability is limited then surface ships are a feasible solution for rapid deployment. Three FSS can deploy an SBCT from Tacoma to Colombia in 12 days for $14.4M. Two Large Medium Speed Roll-on Roll-off (LMSR) ships travelling at 19 knots can deliver all the cargo in 15 days for $7.1M. For comparison with conventional aircraft, to conduct an air bridge that matches the 12 days the FSS takes, 30 C-17s flying 286 sorties (143 C-17 sorties, 143 C-17 Combi sorties) and 4 C-5s flying 32 sorties for a total of 318 sorties with 34 aircraft are required, but at the increased cost of $97.2M. To conduct the air bridge in 15 days like the LMSR, 20 C-17s flying 245 sorties (120 C-17 sorties, 125 C-17 Combi sorties) and 5 C-5s flying 55 sorties for a total of 300 sorties with 25 aircraft are necessary at a total cost of $98.5M. Table 5 summarizes the comparison of surface ships to conventional aircraft. The effectiveness of surface ships becomes apparent at greater deployment ranges and increased cargo loads. Examples are shown in a future section when the SBCT deployment to the Philippines is modeled using conventional airlift as well as sealift. Figure 17 shows the workaround for investigating a multimodal COA. One uses only surface ships while the other uses only conventional aircraft and the results are summed.

Table 5 - Surface Ships and Air Bridge Comparison

Asset	# of Assets	# of Missions	Force Closure	Total Cost
FSS	3	1	12 days	$14.4M
C-17 Cargo	15	143	12 days	$97.2M
C-17 Combi	15	143		
C-5	4	32		
LMSR	2	1	15 days	$7.1M
C-17 Cargo	10	120	15 days	$98.5M
C-17 Combi	10	125		
C-5	5	55		

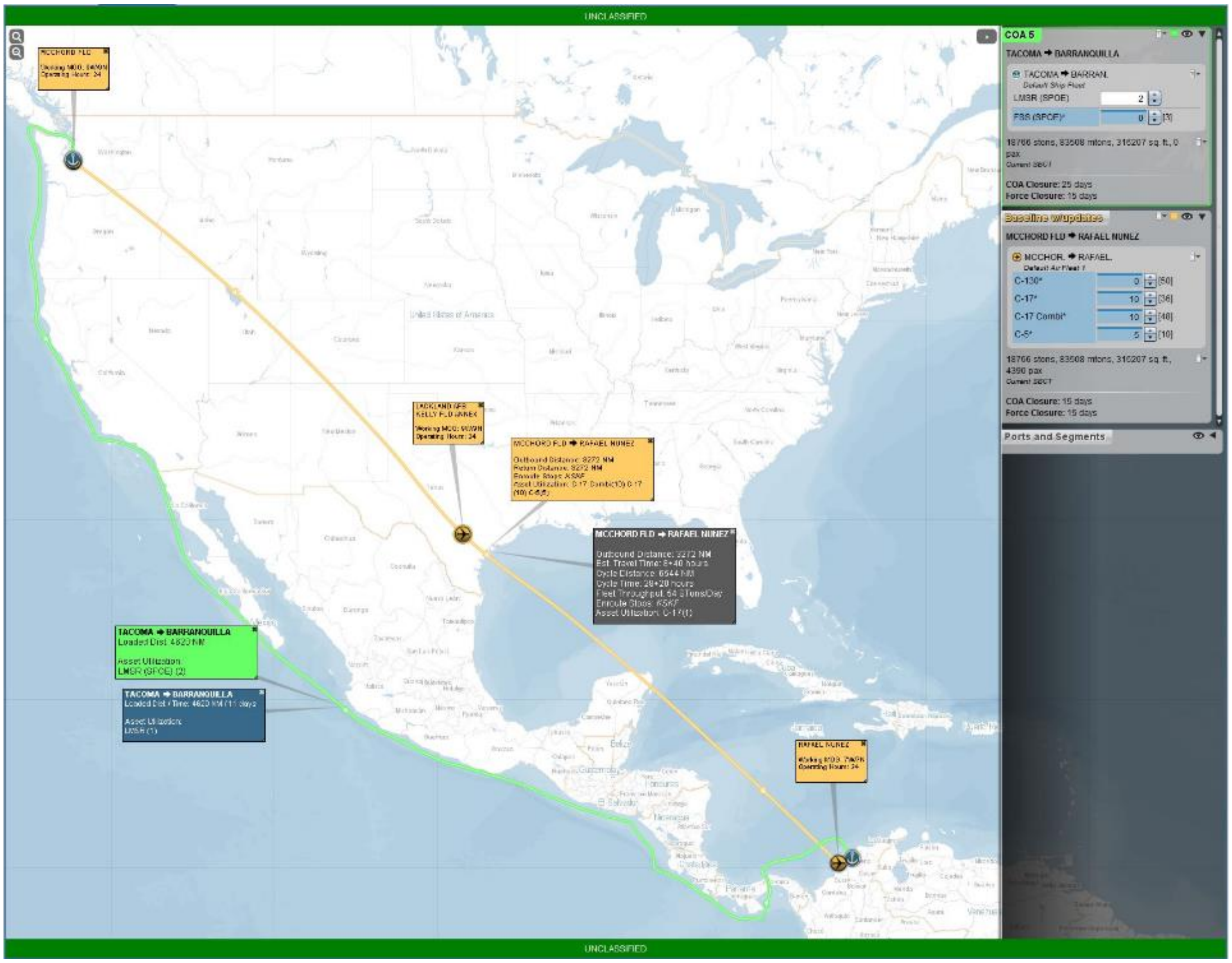


Figure 17 - Comparing Sealift and Airlift COAs

Adding Hybrid Airships to the Model

This section details the addition of hybrid airships to the model. As discussed earlier, the theoretical advantage of hybrid airships is the ability to move more cargo than an airplane at speeds greater than a surface ship. When simulating hybrid airships, the total amount of cargo and total distance that the cargo is to be delivered must be carefully considered. Too short of a distance and the slow speed of the airships will never exceed the capacity of faster aircraft making frequent trips with smaller loads of cargo. Too great a distance and the capacity of cargo ships cannot be matched by even the largest proposed hybrid airships.

Four variants of the baseline model will be discussed: only strategic aircraft plus hybrid airships, both strategic and tactical aircraft plus hybrid airships, only strategic aircraft and surface ships plus hybrid airships, and finally both strategic and tactical aircraft and surface ships plus hybrid airships.

RCAT provides the ability to manage multiple fleets for COA development. Multiple fleets can split a cargo requirement which allows planners to better choose the right mix of assets for the mission. Using a conventional unit deployment as an example, a planner can select military gray tail aircraft to deliver all of the unit's cargo from home station to the deployed location. Then civil carriers are chosen to deliver all the passengers of the unit to their destination. In this research, fleet management is used to compile one fleet with conventional fixed wing aircraft and another with hybrid airships. Once the initial route is built the number of each aircraft type and breakdown of the cargo load can be quickly adjusted to determine the best mix of assets for short delivery time and low cost. The first version uses the same mix of 94 strategic fixed wing assets and evenly splits the SBCT cargo and passengers between conventional and airship fleets. Multiple iterations are run and the COA closure time and cost are recorded. The results are summarized in Table 6. The fastest and cheapest COA is highlighted.

The next version adds C-130 aircraft to the fleet in order to see the effect tactical fixed wing aircraft have on the model. The strategic aircraft fleet is kept the same while C-130, 30 ton and 120 airships numbers are changed. The force closure and cost results are recorded and shown in Table 7.

Table 6 - Strategic Aircraft plus Hybrid Airships

Test	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	Cost
1	36	48	10	10	0	88 days	$94.7M
2	36	48	10	20	0	45 days	$94.7M
3	36	48	10	30	0	31 days	$94.7M
4	36	48	10	40	0	23 days	$94.7M
5	36	48	10	50	0	19 days	$94.7M
6	36	48	10	60	0	16 days	$94.7M
7	36	48	10	0	10	28 days	$69.0M
8	36	48	10	0	20	15 days	$69.0M
9	36	48	10	0	30	10 days	$69.0M
10	36	48	10	0	40	8 days	$70.1M
11	36	48	10	0	50	8 days	$70.1M
12	36	48	10	0	60	8 days	$70.1M
13	36	48	10	10	10	22 days	$74.9M
14	36	48	10	20	20	13 days	$76.0M
15	36	48	10	30	30	9 days	$74.9M
16	36	48	10	40	40	9 days	$75.2M
17	36	48	10	50	50	12 days	$73.6M
18	36	48	10	60	60	33 days	$74.2M

Table 7 – Strategic and Tactical Aircraft plus Hybrid Airships

Test	C-17	C-17 Combi	C-5	C-130	30 ton	120 ton	Force Closure	Cost
1	36	48	10	10	20	20	12 days	$77.5M
2	36	48	10	20	20	20	12 days	$78.1M
3	36	48	10	30	20	20	12 days	$79.6M
4	36	48	10	40	20	20	12 days	$80.4M
5	36	48	10	50	20	20	12 days	$80.4M
6	36	48	10	60	20	20	12 days	$81.8M
7	36	48	10	10	40	40	8 days	$75.3M
8	36	48	10	20	40	40	8 days	$78.5M
9	36	48	10	30	40	40	8 days	$78.2M
10	36	48	10	40	40	40	8 days	$81.1M
11	36	48	10	50	40	40	8 days	$81.7M
12	36	48	10	60	40	40	8 days	$83.4M
13	36	48	10	10	60	60	8 days	$75.6M
14	36	48	10	20	60	60	7 days	$78.2M
15	36	48	10	30	60	60	8 days	$78.5M
16	36	48	10	40	60	60	8 days	$80.2M
17	36	48	10	50	60	60	8 days	$81.8M
18	36	48	10	60	60	60	8 days	$83.6M

The next version simulates strategic aircraft, hybrid airships and surface ships. In order to simulate the composite COA within the limitations of RCAT the model is separated into two parts. Half the cargo requirement of an SBCT is loaded on one LMSR while the remainder of the cargo is evenly split between conventional aircraft and hybrid airships. This equates to 9,383 tons of cargo (158,102 square feet) for the LMSR and 4,691 tons for each aircraft fleet. Recall that no passengers are used due to the limitation of the surface ships in RCAT. Figure 18 shows this version of the model. The cost of each COA is summed and the greater closure time is recorded as the total composite time. Table 8 shows the results of the simulations.

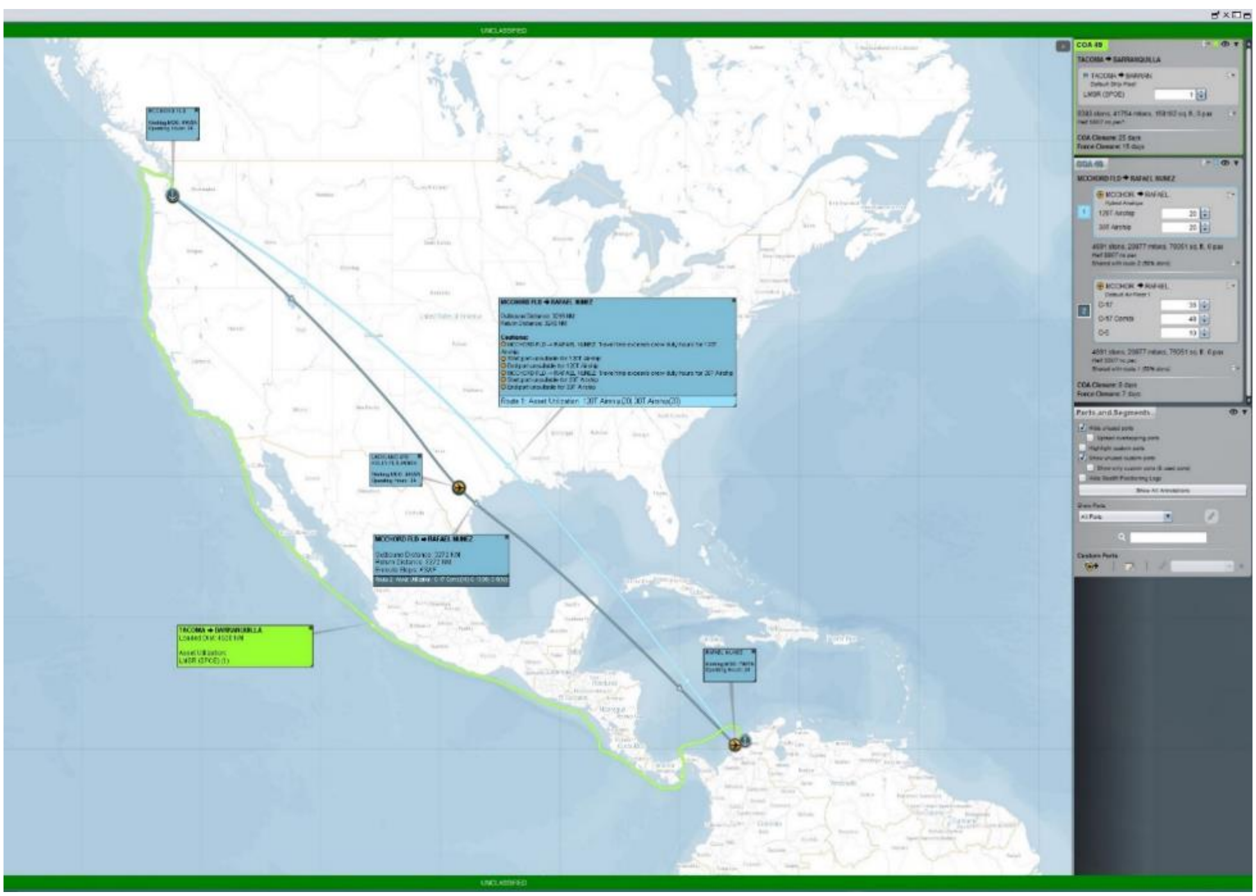


Figure 18 - C-5, C-17, and LMSR plus Hybrid Airship

Table 8 - Strategic Aircraft and Surface Ships, plus Hybrid Airships

Test	C-17	C-17 Combi	C-5	30 ton	120 ton	LMSR	Force Closure	Cost
1	36	48	10	10	10	1	15 days	$41.3M
2	36	48	10	20	20	1	15 days	$41.3M
3	36	48	10	30	30	1	15 days	$41.2M
4	36	48	10	40	40	1	15 days	$40.9M
5	36	48	10	50	50	1	15 days	$41.5M
6	36	48	10	60	60	1	15 days	$42.2M

The last version simulates both strategic and tactical aircraft, surface ships, plus hybrid airships. The same methodology of splitting the cargo is used. This combination represents the total theoretical capacity available to deliver an SBCT. Table 9 shows the results of the simulations. An observation from this simulation is that the C-130 was never utilized. This is most likely due to the inability to carry outsize cargo and the lowest ranking for oversize cargo and assignment ranking compared to the other assets.

Table 9 - All Available Assets

Test	C-17	C-17 Combi	C-5	C-130	30 ton	120 ton	LMSR	Force Closure	Cost
1	36	48	10	20	20	20	1	15 days	$41.3M
2	36	48	10	40	20	20	1	15 days	$41.3M
3	36	48	10	60	20	20	1	15 days	$41.4M
4	36	48	10	20	40	40	1	15 days	$41.3M
5	36	48	10	40	40	40	1	15 days	$42.0M
6	36	48	10	60	40	40	1	15 days	$40.9M
7	36	48	10	20	60	60	1	15 days	$40.9M
8	36	48	10	40	60	60	1	15 days	$42.2M
9	36	48	10	60	60	60	1	15 days	$42.2M

Applying the Model to the Pacific Scenario

Now that all facets of the model are integrated, the Pacific deployment scenario with an SBCT travelling from Ft. Lewis to the Philippines is simulated. The first iteration is shown in Figure 19 and this only includes strategic aircraft and hybrid

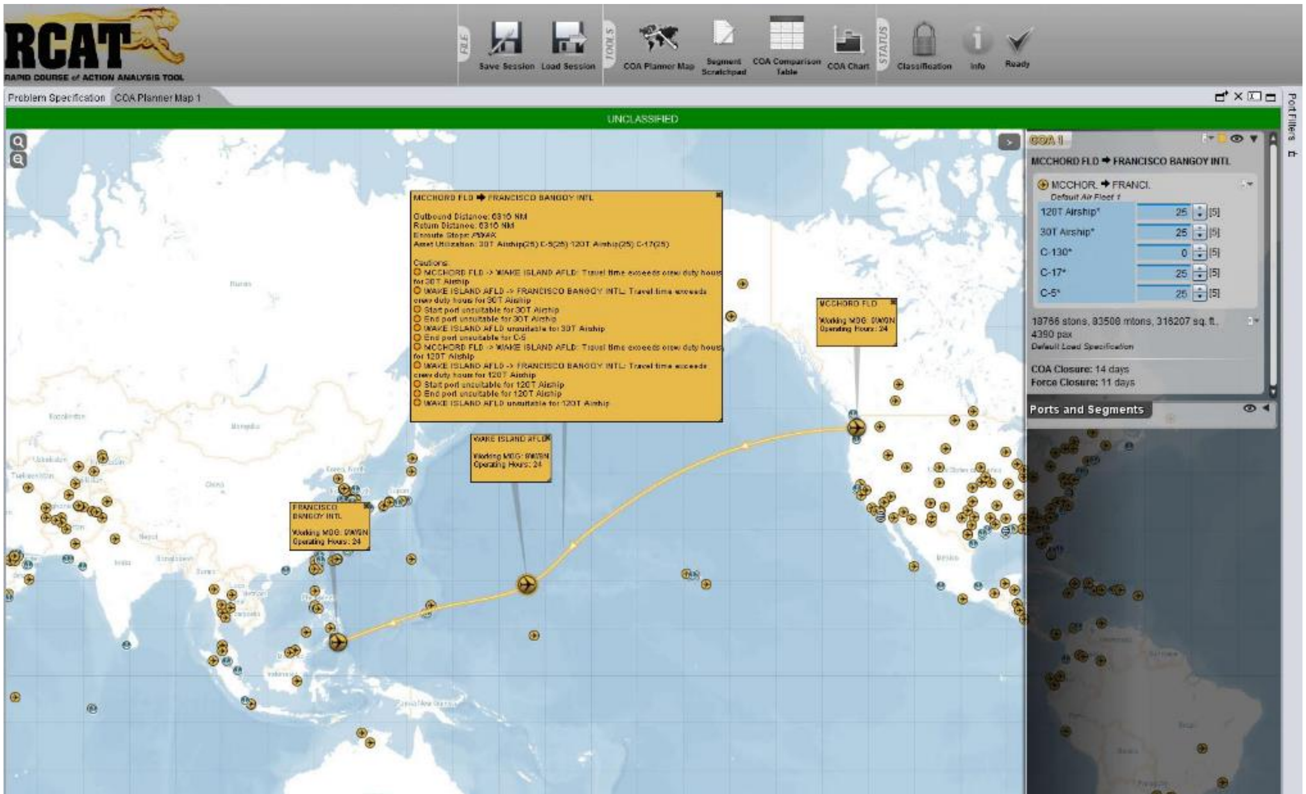


Figure 19 - First Test Using Hybrid Airships

airships. There are multiple cautions in the orange box that can be grouped in two categories. The first set of cautions are airfield suitability notes since there is no suitability code for hybrid airships. The second set of cautions are crew duty day limitations since the approximately 6,000NM trip requires over 60 hours traveling at 105 knots. RCAT is able to complete the simulation with cautions present, so total COA closure time and cost are still calculated. The cautions are displayed because RCAT identifies that aircrew flying limits are violated based on the long distance and slow speed of the hybrid airships. Figure 20 shows the cautions regarding hybrid airships and the expected time to make the journey in an airship travelling at 105 knots.

Another limit that is violated but not displayed is the 7/30/90 day time limits. This is discussed further in another section, but aircrew are only allowed to fly a certain number of hours cumulatively in 7 days, 30 days and 90 days. Once any limit is reached

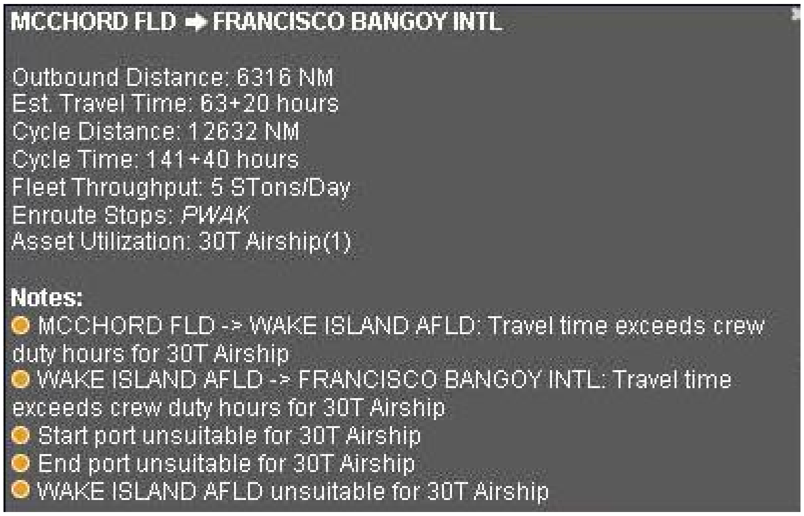


Figure 20 - Cautions from First Hybrid Model Test

the member must be grounded until the oldest hours “drop off” and the cumulative total falls below the appropriate limit. Aircrew will consistently exceed these limits if flying long missions at a cruising speed of 105 knots.

Note that similar cautions regarding crew duty limits were not displayed when surface ships were added to the model. The expectation for surface ships is that the crew will live onboard during the entire mission. Mariners experience different working conditions based on the type of ship, the position occupied, and whether or not the ship is underway. Some jobs have multiple crew members performing the same tasks while working separate shifts and other jobs only employ one person that works a shift and remains on call. Some positions dictate work 5 to 7 days in a row followed by time off. Other positions have no time off while at sea and instead earn time off for when the ship returns to port. The Chief Engineer usually works an 8 hour shift and remains on call 24 hours per day. Oiler positions are usually filled by more than one worker and shifts of 12 hours each are normal. The Captain of a ship typically works 3 months in a row overseeing the ship, then receives 3 months off. Their working shifts depend on what is

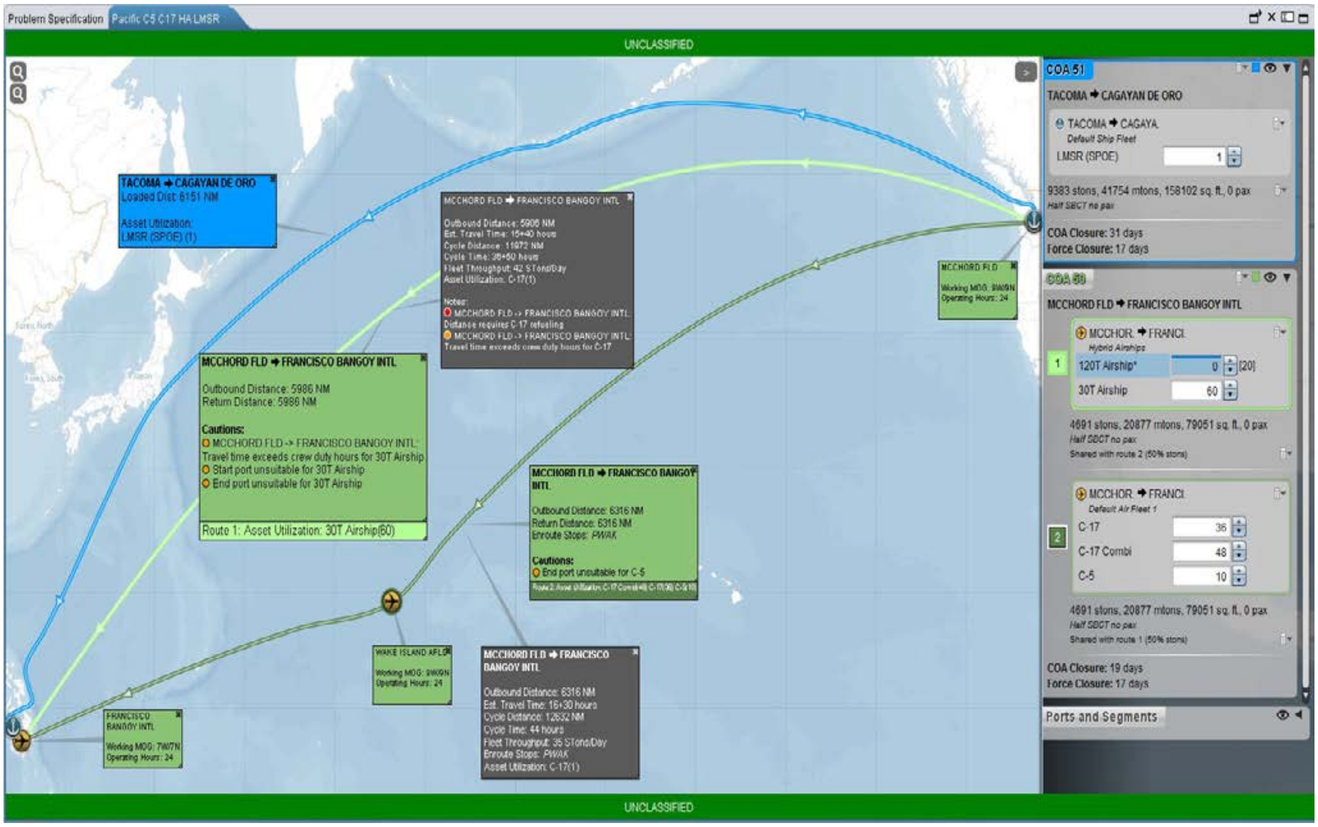


Figure 21 - Multi modal Pacific COA

happening during any given time and they seek rest whenever they can. Deckhands typically conduct shift work ranging from 5 to 16 hours per day (M & L Research, Inc., n.d.). The relatively slow speed of a hybrid airship means some facets of operations are more similar to surface ships while others are more similar to conventional aircraft. Management of crewmembers onboard a hybrid airship is important but beyond the scope of this paper. The cautions generated regarding crew duty limitations are acknowledged, but are ignored for the remainder of this research.

The first multi modal run of the simulation is shown in Figure 21. The simulation uses 60 of the 30 ton hybrid airships flying 157 sorties, 10 C-5s flying 8 sorties, 84 C-17s (36 C-17 and 48 C-17 Combi aircraft) flying 73 sorties (33 C-17, 40 C-17 Combi) and 1 LMSR sailing once. The total time for TPFDD closure is 17 days and costs $95.7M. Both the air COA and the sea COA take 17 days to achieve force closure. Adding 60 of the 120 ton airships decreases the air COA closure to 7 days. The resulting simulation uses 60 of the 30 ton hybrid airships flying 36 sorties, 60 of the 120 hybrid airships flying 31 sorties, 10 C-5s flying 8 sorties, 84 C-17s (36 C-17 and 48 C-17 Combi aircraft) flying 73 sorties (33 C-17, 40 C-17 Combi) and 1 LMSR sailing once. The total time for TPFDD closure is still 17 days because of the LMSR but cost is reduced to $75.6M.

Airship Runway Independence

This section shows the results if hybrid airships operate directly to the point of need to see if runway independence increases capability for a large TPFDD movement. This is simulated in RCAT by adding a custom airfield and restructuring the COA so conventional aircraft fly to the conventional airport and hybrid airships fly to the custom airfield. MOG constraints at a traditional airport are reduced if hybrid airships do not use the same parking spaces as conventional aircraft. There are still limits to the amount of personnel available to conduct cargo and refueling operations but it is assumed that if hybrid airships can operate at an airfield or location without displacing conventional aircraft, additional personnel and equipment can be brought in to increase capacity and throughput. Since RCAT allows composite COAs, the total cargo and passengers can still be split between fleets operating to different destinations. The effects on throughput are demonstrated by using the mix of 94 strategic airlifters operating to Davao International and 40 of the 120 ton airships operating to a custom airfield created in the port near the airfield. Wide body MOG is set to ‘7’ at Davao International for the conventional aircraft and ‘25’ for the hybrid airships at the custom airfield. Results of the simulation are shown in Table 10. Note the minimum number of 120 ton airships required to allow the simulation to complete is 4. Anything less results in an error message that only partial COA closure was achieved, which is based on the built-in maximum for the required delivery date duration, which is greater than four months. A second simulation is run with half the cargo to match the scenario when a ship is used and the remaining cargo is split between conventional aircraft and airships. The results of this simulation are shown in Table 11. The same observation is made regarding missions flown, cost, and closure time. Note the total duration is still 17 days when an LMSR is used.

Table 10 - Airship Runway Independence (18,766 tons, 4,390 pax)

APOD	C-17	C-17 Combi	C-5	120 ton	Closure	Cost
Same	36	48	10	40	13 days	$133.9M
Separate	36	48	10	4	111 days	$131.8M
Separate	36	48	10	10	45 days	$131.8M
Separate	36	48	10	20	24 days	$131.8M
Separate	36	48	10	30	17 days	$131.8M
Separate	36	48	10	40	13 days	$131.8M
Separate	36	48	10	50	11 days	$131.3M
Separate	36	48	10	60	11 days	$130.2M

Table 11 - Airship Runway Independence (9,383 tons 2,195 pax)

APOD	C-17	C-17 Combi	C-5	120 ton	Closure	Cost
Same	36	48	10	40	8 days	$66.2M
Separate	36	48	10	3	76 days	$66.2M
Separate	36	48	10	10	24 days	$66.2M
Separate	36	48	10	20	13 days	$66.2M
Separate	36	48	10	30	10 days	$66.2M
Separate	36	48	10	40	7 days	$66.2M
Separate	36	48	10	50	7 days	$66.2M
Separate	36	48	10	60	6 days	$66.2M

The hypothesis for utilizing hybrid airship runway independence was shorter closure times. The large difference between closure dates led to further exploration into MOG, missions flown and aircraft utilization. These assumptions are described in the next section regarding model optimization.

Optimizing the Model

The focus of this section is optimizing the model with two points of emphasis. The most important criteria is time, the second is cost. In both cases a lower number is desired. The model is manipulated by limiting the use of assets that are expensive to operate and have lower total units of cargo delivered per unit of time. For example, one LMSR can move about 400 C-17 equivalents worth of cargo but travels at 19 knots (Surface Deployment and Distribution Command, 2011). The C-17 can only move 1 C-17 equivalent of cargo but travels at 405 knots. The LMSR costs the same and takes the same amount of time to move 1 C-17 equivalent as it does to move 400 C-17 equivalents of cargo an identical distance. The LMSR takes 17 days and costs $1.9M to move 1 C-17 equivalent from Ft. Lewis to Davao International. That price does not include the return voyage, which costs an additional $1.7M. The C-17 takes 21 hours and costs $358,000 to move 1 C-17 equivalent of cargo the same distance, again not counting the required crew rest and return flight. If additional crews are prepositioned in order to keep the entire mission duration low, the total time and cost is about 47 hours and $529,000. Simply extrapolating, one C-17 would take 783 days and cost $211.6M to move 400 C-17 equivalents of cargo.

The way airlift planners view conventional airlift assets is important to understand when discussing optimization. The assumptions affect utilization rates and closure times. AFPAM 10-1403 defines the total number of missions required as the total cargo requirement divided by the average payload being transported:

$$Number\ of\ cargo\ missions\ required = \frac{Requirement\ (short\ tons)}{Average\ Payload\ (short\ tons)}$$

Simulation software such as RCAT allows planners to estimate the duration, cost, and total missions required to deliver cargo. The assumption is that aircraft will be loaded as full as possible and continue to make trips back and forth until all the cargo is delivered. However when making plans utilizing ships, due to their slower speed and larger capacity, one way delivery is assumed. Hybrid airships were compared to surface ships when considering crew rest and duty limitations. To realize the benefit of high volume cargo delivery that hybrid airships provide, the way they are utilized also has to be compared to ships.

During several of the earlier simulations a break point was observed when 40 of the 120 ton airships were added to the model. When the total cargo is divided between surface ships and aircraft the cargo required to be lifted by air is 9,383 tons. When further divided in half this is 4,691.5 tons. The total cargo capacity provided by 40 hybrid airships capable of carrying 120 tons is 4,800 tons. Combining the total average capacity of the conventional fleet of 36 C-17, 48 C-17 Combi, and 10 C-5 gives 5,464 tons. The maximum number of 120 ton airships provides 7,200 tons of capacity while the maximum number of 30 ton airships provides a total capacity of 1,800 tons. Using RCAT to simulate delivery of an SBCT entirely by air means that the maximum number of hybrid airships provides a total capacity of 9,000 tons. The initial cargo assumption evenly split the cargo requirement with 9,383 tons for each fleet, invalidating the concept that hybrid airships only make one trip. This offers support to the notion that if enough airships are utilized to only require one trip to deliver cargo, their slow speed can be offset by the total cargo they can deliver. For this to be effective, a more critical method for distributing cargo between the fleets is required. Two issues need to be addressed. The first deals with utilization while the second deals with cargo allocation.

Though the equation above determines the number of missions required, it does not factor in utilization rates or travel time. Initial simulation runs did not result in hybrid airships arriving at the same time, even when a separate airfield was created with unlimited MOG. The following example will explain the reason. Assume 1,200 tons of cargo needs to be moved from Ft. Lewis to Davao using only 120 ton airships. The equation for number of missions gives:

$$Number\ of\ missions = \frac{1{,}200\ tons}{120\ tons/mission} = \boxed{10\ missions}$$

This can be accomplished with 1 airship flying 10 missions, 2 airships flying 5 missions or 10 airships flying 1 mission. For this example the assumption for one way delivery is that 10 hybrid airships will be required, each carrying 120 tons of cargo and flying 1 mission each. If all the cargo is expected to be delivered at the same time, then the average throughput must equal 1,200 tons/day. AFPAM 10-1403 provides a planning equation for throughput:

$$Fleet\ Capability\ Short\ Tons\ delivered\ to\ theater\ per\ day$$
$$= \frac{(Average\ Payload) * (\#\ of\ aircraft) * (Utilization\ Rate)}{(Round\ Trip\ Flight\ Time)}$$

Utilization rate is the capability of a fleet of aircraft to generate flying hours in a day and examples for mobility aircraft are provided in AFPAM 10-1403 (Air Mobility Command, 2018). The round trip travel time for this example is 140.33 hours which includes 10 hours for loading, 60 hours and 10 minutes for the departure flight, 10 hours for unloading, and another 60 hours and 10 minutes for the return flight. Substituting the values and using 10 airships gives:

$$Fleet\ Capability = \frac{(120\ tons) * (10\ aircraft) * (24)}{140.33\ hours} = \boxed{205.23\ tons/day}$$

which is less than the required 1,200 tons/day. Rearranging terms to solve for the number of aircraft required to deliver 1,200 tons/day gives:

$$\#\ of\ aircraft = \frac{(1{,}200\ tons/day) * (140.33\ hours)}{(120\ tons) * (24)} = \boxed{58.5\ aircraft}$$

It is important to note that these 58.5 aircraft provide an aggregated average throughput of 1,200 tons per day assuming they make multiple trips. These planning equations are how RCAT calculates the resource throughput and determines the number of missions flown per day. The total number of missions required is calculated accurately, but the program does not allow a planner to specify how many sorties each aircraft flies. RCAT generates a chart that shows the number of sorties per day as well as the total cargo throughput at each location. During initial simulations, this chart showed that hybrid airships were not arriving at the same time, but were instead flying multiple trips. To ensure hybrid airships are only used for one trip in RCAT, the travel time must not be factored in. This is achieved by making the utilization rate equal to or greater than the round trip flight time. When they are equal, this cancels the two terms in the number of aircraft equation. When the utilization rate is greater, the number of aircraft required decreases, but based on the average payload, less aircraft are not chosen since this prevents all cargo from being delivered. To prevent having to change the utilization rate any time the trip duration changes, an arbitrarily high number of ‘1000’ is used for the utilization rate for both the 30 ton and 120 ton airships. Multiple simulations are run to verify that this does not affect the total closure time, and that one way delivery times are still calculated accurately.

The second issue to address is how cargo is allocated in RCAT. If multiple fleets are used, the planner must decide how to distribute the cargo. In order to estimate an optimum fleet for this research, spreadsheet software is utilized to test multiple combinations of aircraft. The Solver function of Microsoft Excel is used to choose an optimum combination of aircraft by solving linear equations that describe cargo capacity and aircraft cost. Solver changes the number of each aircraft used and compares total capacity to cargo remaining. Aircraft with greater capacity will be chosen over aircraft with smaller capacity while simultaneously attempting to keep total cost down. The goal is to choose a combination that can transport all the cargo in one trip. Constraints include a maximum of 60 of any type of aircraft, except the C-5. To reflect current inventory in 2020 the maximum is set to 52. One iteration uses the entire TPFDD load of 18,766 tons and spreads it evenly across all available aircraft. This reflects a COA designed to only use aircraft. Another iteration tests approximately half the cargo with the conventional fleet and the remainder with the hybrid airship fleet. The conventional fleet is matched to 9,766 tons of cargo and hybrid fleet gets 9,000 tons. 9,000 tons represents the maximum one way delivery capacity of the maximum number of hybrid airships in RCAT. The results are compared to the first iteration. The third iteration uses half the cargo, 9,383 tons, evenly distributed between all available aircraft. This simulates half the cargo moving by ship and the remaining half by air. A final iteration tests one fourth of the cargo with fixed wing only and one fourth with the hybrid airships only. Each fleet is matched against 4,692 tons of cargo and the number

Total Cargo Requirement (tons)	18766

Aircraft Type	C-17	C-17 Combi	C-5	30 ton	120 ton
Individual Cargo Capacity (tons)	64	45	100	30	120
Hourly Cost	$17,068	$17,068	$34,846	$2,403	$4,251
Round Trip Mission Duration (hours)	33	33	32.33	120.33	120.33
Maximum number of aircraft	60	60	52	60	60
Optimized number of aircraft	59	22	50	60	60

	C-17	C-17 Combi	C-5	30 ton	120 ton
Fleet Capacity (tons)	3776	990	5000	1800	7200

	C-17	C-17 Combi	C-5	30 ton	120 ton
Individual Mission Cost	$563,244	$563,244	$1,126,571	$289,153	$511,523
Total Asset Cost	$33,231,396	$12,391,368	$56,328,559	$17,349,179	$30,691,370
Total COA Cost	$149,991,872	<--			

Total Fleet	251
Total Fleet Capacity (tons)	18766
Remaining SBCT Cargo (tons)	0

Figure 22 - Solver Output Using Microsoft Excel

is compared to the previous iteration. The output from each iteration is used to modify the COA in the Pacific scenario. One set of simulations is run with the MOG constraints previously used and another set is run with the MOG at each location set artificially high to ‘1000’ to simulate no constraints. Force closure, total cost and number of missions flown is recorded. The output from the first iteration is shown in Figure 22. The numbers in the green boxes represent the optimum number of each aircraft while the number in the yellow box represents the estimated total cost. The remaining iterations are shown in Appendix 2 – Fleet Optimization.

The RCAT simulation results of the full SBCT movement optimization are shown in Figure 23. Both iterations of the optimization tool calculate the same number of aircraft per fleet with this total amount of cargo because the maximum capacity of the airships is 9,000 tons, leaving 9,766 tons for the fixed wing assets. Allocating more than 9,000 tons to the airship fleet in RCAT results in multiple missions being flown.

Full SBCT - 18,766 evenly distributed

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**59**	**22**	**50**	**60**	**60**		
Normal MOG	66	18	44	72	61	9 days	$139.6M
No MOG Limit	69	22	40	73	60	8 days	$138.9M

Full SBCT - 9,766 fixed wing, 9,000 airship

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**59**	**22**	**50**	**60**	**60**		
Normal MOG	66	17	48	60	60	5 days	$139.5M
No MOG Limit	75	22	40	60	60	3 days	$138.5M

Figure 23 - Full SBCT Fleet Optimization

The RCAT simulation results of the half SBCT movement optimization are shown in Figure 24. The optimization tool calculates different fleet sizes because the 120 ton airship offers the cheapest way to move large amounts of cargo. When all the cargo is split evenly the maximum number of 120 ton airships chosen because they are cheaper than C-5s. This leaves 2,183 tons for the conventional fleet. Putting 76% of the total air cargo on 120 ton airships increases closure by 13 days. However when 25% of the cargo is allocated for the hybrid airship fleet only 40 of the 120 ton airships are required because they provide 4,800 tons of capacity. Note in both cases the LMSR is still required for this movement which adds $3.6M to the total cost. Furthermore the total closure time remains 17 days for this COA.

Half SBCT - 9,383 evenly distributed

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**32**	**3**	**0**	**0**	**60**		
Normal MOG	70	25	-	-	40	17 days	$69.4M
No MOG Limit	68	25	-	-	40	16 days	$68.3M

Half SBCT - 4,692 split fixed wing and airship

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**58**	**4**	**8**	**0**	**40**		
Normal MOG	60	4	13	-	40	4 days	$66.7M
No MOG Limit	59	7	11	-	40	4 days	$65.6M

Figure 24 - Half SBCT Fleet Optimization

The cheapest way to deliver the SBCT is entirely by ship, which requires either 2 LMSRs or 1 LMSR making two trips. The sealift only COA closes the TPFDD in 17 days and costs $7.1M using 2 LMSRs.

One final change to the model requires modifying payloads based on range-payload charts. RCAT provides planners with initial feasibility calculations. The mobility planning equations used in the program come from AFPAM 10-1403. The purpose of the AFPAM is to provide planners with initial gross estimates with the expectation that computer simulation will be used to further refine a solution. The updated numbers used in this research come from the 2018 version of AFPAM 10-1403, not range-payload charts. For completeness, one final adjustment to RCAT is made for this research. Since the planning factors used in RCAT are adjusted to the new numbers

Table 12 - Maximum Allowable Cabin Load From AFPAM 10-1403

	C-17	C-17ER	C-5M	C-130H/J	C-130J-30	KC-135R/T	KC-46A	KC-10A
NM	WEIGHT[3]							
1500	81	80	140	15.5	21	28	32	77
2500	81	80	130	8	15	28	32	77
3250	68	67.5	111	3	N/A	28	32	73
5000	N/A	37.5	67	N/A	N/A	28	32	47

NOTES:
1. The maximum allowable cabin load can be used for planning with concurrence of 618 AOC (TACC) Mission Planners, Flight Managers, or Combatant Commander's Air Operations Center/Air Mobility Division in conjunction with detailed mission information (critical mission leg, winds, weather, terrain clearance, runway limitations, and diplomatic clearance). For cargo load planning, verify size and dimensions and input data into Integrated Computerized Deployment System for an accurate load plan.
2. Key Assumptions: Standard day, no wind, sea level, dry runway, zero obstacles, sufficient runway length
3. Weight expressed in Short Tons.

in the AFPAM, the planning payloads for conventional airlifters is adjusted to be more accurate. Analyzing the range and accompanying maximum payload that is listed in AFPAM 10-1403 provides the slope and intercept of a line that fits this data. The slope and intercept is then used to determine the updated planning cargo weight based on the actual distances used in the Pacific scenario. Table 12 shows the range-payload chart and Figure 25 shows the resulting planning numbers. The distance from McChord to Wake Island is the limiting factor for both the C-17 and C-5. The weight listed is the maximum average weight that can be transported. The simulation is run with these weights and the results are listed in Figure 26.

	C-17	
	Range (NMs)	Payload (tons)
Assumed Average Planning Distance, 2011	4562	**45**
Assumed Average Planning Distance, 2018	3454	**64**
KTCM-PWAK Distance	**3816**	57.8
PWAK-RPMD	**2499**	80

	C-5	
	Range (NMs)	Payload (tons)
Assumed Average Planning Distance, 2011	5161	**61**
Assumed Average Planning Distance, 2018	3687	**100**
KTCM-PWAK	**3816**	96.8
PWAK-RPMD	**2499**	130

Figure 25 - Updated Planning Weights – Range Specific

Full SBCT - Updated Average Payload Capacities

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**59**	**22**	**50**	**60**	**60**		
Normal MOG	76	17	48	60	60	5 days	$144.7M
No MOG Limit	59	51	42	60	60	3 days	$147.4M

Figure 26 - Full SBCT - Updated Planning Weights

Comparing Conventional and Composite Fleets

Now that the model is optimized, the composite fleet is compared to a conventional fixed wing fleet, a non-optimized fleet operating to one APOD, and a non-optimized fleet operating to two APODs. This comparison does not include the lower payload capacity from the range-payload charts mentioned, it uses the AFPAM 10-1403 planning factors. The analysis compares moving the entire SBCT by air with only C-17s and C-5s to moving the entire SBCT with a composite fleet of C-17s, C-5s, 120-ton hybrid airships and 30-ton hybrid airships. The maximum amount of aircraft are used for the conventional airlift fleet. In all cases one simulation is run with normal MOG constraints and one simulation is run with no MOG constraints. The RCAT simulation results are presented in Figure 27. The arrivals and total throughput of the composite fleet with no MOG constraint are shown in Figure 28. Note the vertical bar in the lower chart representing all airships arriving the same day, as desired for one way delivery. Figure 29 shows the same COA with normal MOG constraints. When comparing COAs with normal MOG constraints, the optimized composite fleet utilizing two APODs is able to close the TPFDD 2 days faster and $39.6M cheaper than the conventional fleet.

Full SBCT - C-17s and C-5s, 1 APOD

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**60**	**60**	**52**	**0**	**0**		
Normal MOG	130	19	96	-	-	7 days	$179.1M
No MOG Limit	120	120	57	-	-	4 days	$186.1M

Full SBCT - C-17s, C-5s, 120 ton HA, 30 ton HA, 1 APOD

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**60**	**60**	**52**	**60**	**60**		
Normal MOG	47	49	42	73	60	8 days	$143.6M
No MOG Limit	47	49	42	73	60	8 days	$143.6M

Full SBCT - C-17s, C-5s, 120 ton HA, 30 ton HA, 2 APODs

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**60**	**60**	**52**	**60**	**60**		
Normal MOG	67	7	48	73	60	8 days	$138.3M
No MOG Limit	69	22	40	73	60	8 days	$138.9M

Full SBCT - C-17s, C-5s, 120 ton HA, 30 ton HA, 2 APODs, Optimized

	Missions Flown						
	C-17	C-17 Combi	C-5	30 ton	120 ton	Force Closure	COA Cost
# of Aircraft	**59**	**22**	**50**	**60**	**60**		
Normal MOG	66	17	48	60	60	5 days	$139.5M
No MOG Limit	75	22	40	60	60	3 days	$138.5M

Figure 27 - Conventional Fleet vs. Composite Fleets

`

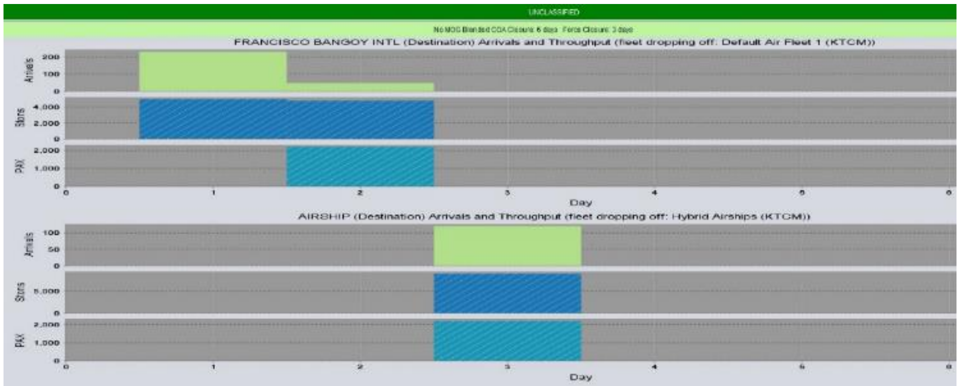


Figure 28 - Arrivals and Throughput with No MOG Constraints

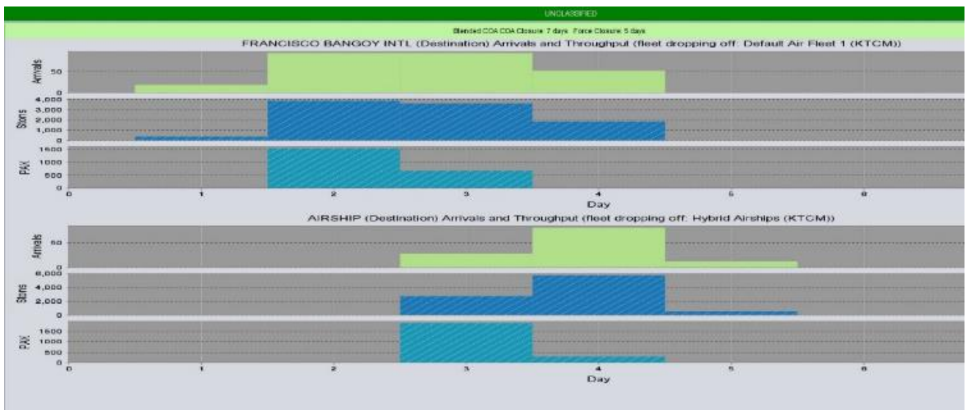


Figure 29 - Arrivals and Throughput with Normal MOG Constraints

The Price of Aircrew

This section reviews the limitations of aircrews in terms of operating conventional manned and unmanned aircraft. Factors such as crew duty day, flight duty period and crew rest are discussed. The limitations that planners face regarding crew rest, flight duty period and crew duty time are lessened or eliminated if aircraft are operated autonomously. This discussion is meant to focus on autonomous hybrid airships, not autonomous conventional assets.

AFI 11-202 Volume 3 defines general flight rules for the Air Force. Basic aircrews are defined by an aircraft technical order as the minimum amount of crewmembers required to operate the aircraft or mission. Augmented aircrews are basic crews supplemented with additional aircrew members to allow for in-flight resting. Unmanned aircraft do not operate with augmented crews.

Flight Duty Period (FDP) is the maximum amount of time that a crewmember can be performing official duties related to flying. For manned aircraft it starts at initial show time and ends after final engine shutdown. For unmanned aircraft it ends after final engine shutdown, final in-flight handover briefing or final crew swap, whichever is last. Table 13 lists the flight duty periods for conventional aircraft in the US Air Force inventory.

AFMAN 11-2C-17 Volume 3 defines Crew Duty Time (CDT) as the maximum time that aircrew members can perform both flight and ground duties. CDT for a basic crew is 18 hours and for an augmented crew it is 24 hours and 45 minutes.

AFI 11-202V3 defines a maximum amount of flying hours in a consecutive amount of time. Maximum flying time is 56 hours in 7 days, 125 hours in 30 days and 330 hours in 90 days. As discussed earlier, aircrew members operating hybrid airships for long durations will exceed these limits. In the Pacific deployment scenario, just one

Table 13 - Flight Duty Period From AFI 11-202V3

Aircraft Type	**Basic Aircrew**	**Augmented Aircrew**
Single Piloted Aircraft	12	NA
Fighter, Attack or Trainer (Dual Control)	12	16
Bomber, Reconnaissance, Electronic Warfare, or Battle Management (Dual Control)	16	24
Tanker/Transport	16	NA
Tanker/Transport with Sleeping Provisions[1]	16	24
Rotary Wing (without Auto Flight Control System)	12	14
Rotary Wing (with Auto Flight Control System)	14	18
Utility	12	18
Unmanned Aircraft System (Single Control)	12	NA
Unmanned Aircraft System (Dual Control)	16	NA
Tilt-rotor	16	NA
NOTE 1: *Sleeping provisions are crew bunks or other MAJCOM-defined rest facilities aboard the aircraft. Rest facilities should provide adequate privacy and noise levels to obtain suitable rest.*		

mission requires 120 hours and is intended to be one continuous trip totaling six days. This limitation cannot be applied to airship crews and is an argument for either unmanned or autonomous operations or flying rules more in line with sailing regulations.

The final consideration discussed is crew rest. AFI 11-202V3 mandates a minimum of 12 hours of crew rest for aircrews immediately prior to performing duties. The time provides an opportunity to get food and travel to and from lodging and includes time for at least 8 hours of uninterrupted sleep. Additional regulations specify recommended minimum crew rest times for mobility aircraft. AFPAM 10-1403 consolidates these and lists the recommended minimum of 16 hours for C-130s, 16 hours and 30 minutes for C-17s and 17 hours for C-5s.

An example mission will highlight what a planner has to consider. For this example time is listed as follows: 1 hour and 45 minutes is depicted as 1+45. AFPAM 10-1403 specifies the standard amount of time allotted for a crew to make a C-17 ready for departure is 2+45. For one C-17 mission flown from Ft. Lewis to Davao International the total distance is 5,986NM and at normal cruise speeds and altitudes would take 15+40. Assuming constant speed, the total time from initial crew show to landing is 18+25. This exceeds a basic crew duty day and would require an augmented crew. For the C-17 this means 5 people are required, 3 pilots and 2 loadmasters. However, this distance exceeds the C-17 maximum range and would require either in-flight refueling or an enroute stop to refuel. If in-flight refueling is utilized, assuming a KC-135 could fly from Wake Island, refuel the C-17, then recover to Wake Island during a basic crew day, the total aircrew required grows to 8 with the 2 additional pilots and 1 boom operator for the tanker. If Wake Island is the enroute refuel location, the total distance is 6,316NM and the total flight time is 16+30. Standard ground refueling time for a C-17 enroute stop is 1+45 so the total time would be 21+00 and require an augmented crew of 5. Both scenarios only allow the aircraft to arrive in the Philippines, there is not enough time to download cargo, refuel, and depart the Philippines in order for the aircraft to be used again the same day. The crew must enter a minimum of 12+00 but recommend 16+30 crew rest period before departing the next day. To deliver one load of cargo from Washington to the Philippines and return it to Washington ready for the next load of cargo, assuming normal planning factors, requires a minimum of 1 aircraft and 5 aircrew members with a total time of 58+30 assuming the crew rest happens in the Philippines. If the situation requires the crew rest location be at Wake Island, an additional crew rest period would be required and the total time increases to 77+00. An additional option to get the aircraft back to Washington faster would be to stage crews at each location. Stage crews are additional basic or augmented crews fully crew rested and ready to fly the aircraft to the next location once it arrives while the incoming crew enters crew rest. For simplicity it can be assumed that the stage crews arrive via commercial air, otherwise their initial travel would have to be account for. The use of stage crews increases the total aircrew requirement to 16 but decreases the time to 36+50. Just to halve the total mission time requires doubling the number of aircraft and tripling the number of aircrew. RCAT determines total flight hours used and only counts cargo handling towards ground time. In this sense it is focused on mission execution and does not factor in total crew time to prepare the aircraft. For this research the total crew time is important for discussing unmanned and autonomous operations. The routes that are planned can be manipulated to reflect the preflight times by adding notional crew changes or enroute fuel stops. This workaround is less than ideal and if personnel factors were the focus of future research then RCAT should be modified to be more user friendly when determining crew usage. The planning factors from this example are depicted in Table 14.

Table 14 - Planning Factors for Example C-17 Mission

	Enroute Stop, RON Wake Island	Enroute Stop, RON Philippines	In-Flight Refuel, RON Philippines	In-Flight Refuel, w/Stage Crew
Aircraft	1	1	2	2
Aircrew	5	5	8	16
Crew Rests	2	1	1	0
Time	77+00	58+30	53+20	36+50

An example displaying 2 COAs simultaneously is shown in Figure 30 and the cycle time assumptions for enroute refueling plus one crew rest COA are shown in Figure 31. Note the blue highlighted lines in the figure showing adjusted onload and offload time of 2+45 instead of 3+15. This reflects the updated planning factors in AFPAM 10-1403. Not changing this manually results in a one hour discrepancy from the times listed above.

For the sake of discussion, consider that a C-17 was able to operate remotely, not counting ground crew responsible for launch and recovery but assuming cargo loading responsibilities could be transferred to port personnel. A basic crew of only 1 pilot could operate in the ground station for basic duty periods of 12 hours before a changeover was necessary. A remotely operated cargo aircraft with the same performance characteristics of the C-17 could deliver the same cargo and be made ready for a new mission with fewer total aircrew required. Assuming in-flight refueling could be conducted it would require 3 basic crews and take 36+50. If the enroute refueling was necessary, the trip would take 42+00 and require 4 basic crews. If the same aircraft could be completely autonomous then it can be assumed that one person could monitor multiple aircraft simultaneously and be independent of the launch and recovery or cargo handling processes. This leads to a potential reduction of 15 people just to execute one mission.

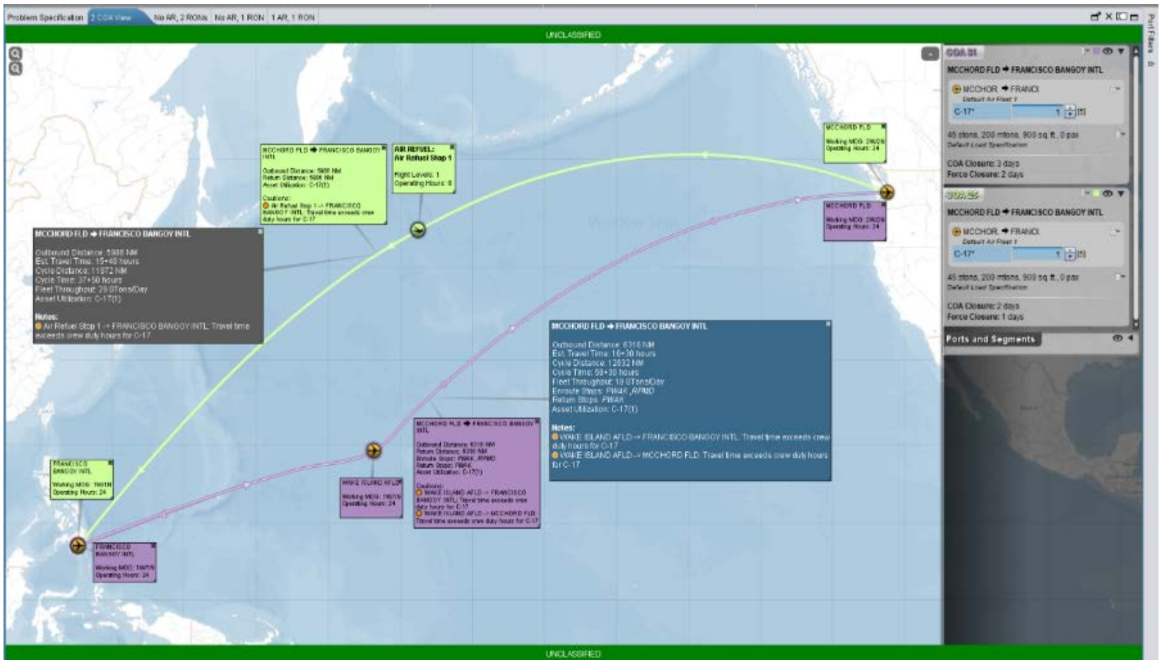


Figure 30 - Two COA Comparison View

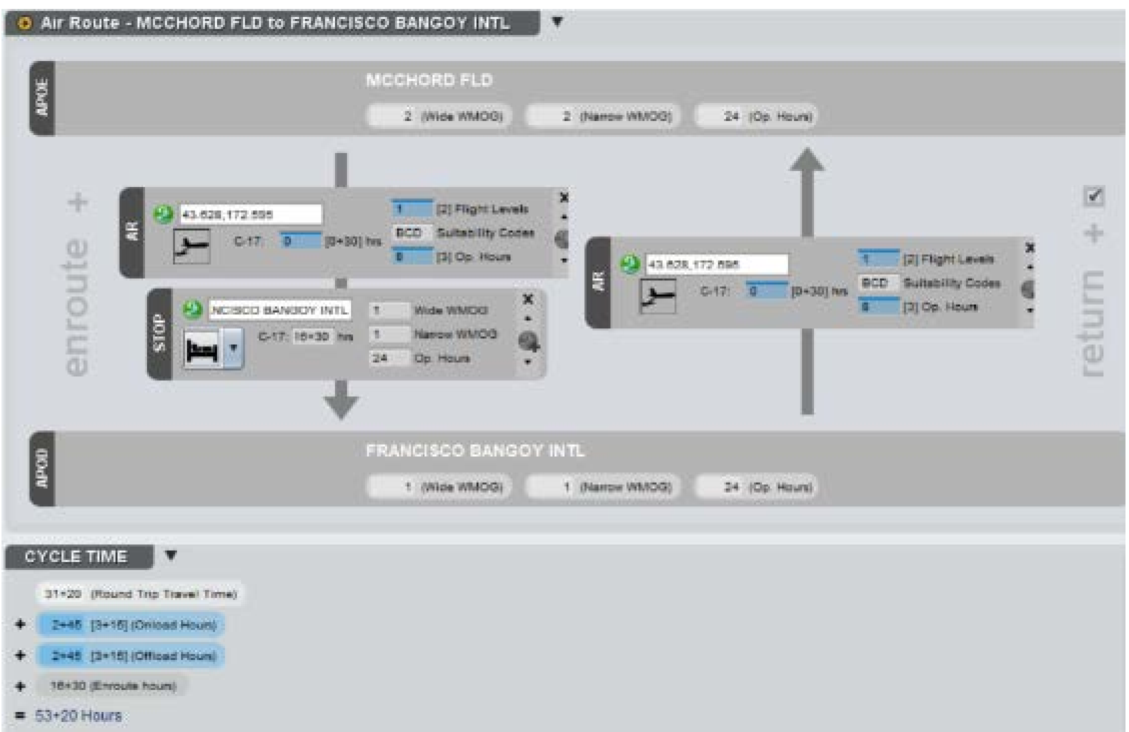


Figure 31 - Example COA Assumptions Showing Cycle Time

These theoretical planning factors are summarized in Table 15.

Table 15 - Planning Factors for Notional Cargo Aircraft

	Remotely Operated Cargo Aircraft		Autonomous Cargo Aircraft	
	Enroute Stop, Wake Island	In-Flight Refuel	Enroute Stop, Wake Island	In-Flight Refuel
Aircraft	1	1	1	1
Aircrew	4	3	1	1
Time	42+00	36+50	42+00	36+50

Answering the Research Questions

Based on the analysis, answers to the five research questions are provided below.

RQ1: Can current modeling software model TPFDD closure using hybrid airships with existing and unimproved or nonexistent Ports of Debarkation (PODs)?

A1: RCAT was used to model a notional Army SBCT TPFDD that matched Maj Rapp's short-range SBCT movement. The movement consisted of 13989.6 tons of cargo and 3,837 passengers moving approximately 3,800 NM from Ft. Lewis, WA to Colombia. Maj Rapp's research modeled a baseline conventional fleet (84 C-17s and 60 C-5s) and two theoretical hybrid airship fleets. His results are shown below in Figure 32. His model determined that with no constraints on MOG the SBCT can be moved in 4.3 days with a conventional strategic airlift fleet. With normal constraints on MOG the movement takes 6.8 days. This research paper created a model using RCAT and duplicated Maj Rapp's scenario. Results from RCAT show the same fleet of aircraft moving the same cargo takes 6 days. The output of RCAT does not offer more resolution than whole days. The baseline model is modified to include hybrid airships and demonstrates the ability to model COAs with conventional and runway independent APODs for hybrid airships. This research shows that it is possible to model TPFDD closure using hybrid airships operating at both existing and nonexistent PODs. TPFDD closure of an SBCT from Ft. Lewis to Davao International took 5 days and cost $139.5M using unimproved locations for hybrid airships and normal MOG constraints. If MOG constraints are removed at each location, TPFDD closure takes 3 days and costs $138.5M.

Run	Fleet	MOG Level	RSOI Delta	Airship Mode	Closure (days)	Aircraft Used / Missions		
						C-17	C-5	Airships
1 A	Base Conventional	1 (unrestricted)	0		4.3	84 / 261	55 / 55	
B			5		9.3			
C			10		14.3			
2 A		2 (normal)	0		6.8	84 / 306	29 / 29	
B			5		11.8			
C			10		16.8			
3 A		3 (hot cargo)	0		7.9	84 / 312	35 / 35	
B			5		12.9			
C			10		17.9			
4 A	Super Conventional	1 (unrestricted)	0		4.8	124 / 206	76 / 142	
B			5		9.8			
C			10		14.8			
5 A		2 (normal)	0		6.5	124 / 283	62 / 62	
B			5		11.5			
C			10		16.5			
6 A		3 (hot cargo)	0		8.0	124 / 273	76 / 76	
B			5		13.0			
C			10		18.0			
7 F	SkyCat 1000	1 (unrestricted)		Fast Low	4.1			18 / 18
S				Slow Low	3.8			18 / 18
FH				Fast High	3.6			22 / 22
SH				Slow High	4.7			22 / 22
8 F		2 (MOG = 5)		Fast Low	4.5			18 / 18
S				Slow Low	5.4			18 / 18
FH				Fast High	5.2			22 / 22
SH				Slow High	5.7			22 / 22
9 F		3 (MOG = 3)		Fast Low	5.5			18 / 18
S				Slow Low	6.3			18 / 18
FH				Fast High	6.3			22 / 22
SH				Slow High	8.8			22 / 22
10 F	HULA 500	1 (unrestricted)		Fast Low	3.2			35 / 35
S				Slow Low	4.0			35 / 35
FH				Fast High	3.2			39 / 39
SH				Slow High	4.0			39 / 39
11 F		2 (MOG = 5)		Fast Low	3.9			35 / 35
S				Slow Low	4.7			35 / 35
FH				Fast High	4.0			39 / 39
SH				Slow High	4.9			39 / 39
12 F		3 (MOG = 3)		Fast Low	5.0			35 / 35
S				Slow Low	5.7			35 / 35
FH				Fast High	5.4			39 / 39
SH				Slow High	5.9			39 / 39

Figure 32 - Maj Rapp Short Range Model Reseults

RQ2: What is the optimum combination of conventional airlifters, sealift ships and hybrid airships to transport a Stryker Brigade Combat Team at intertheater distances in the Pacific? How much faster does the TPFDD close with hybrid airship augmentation?

A2: Based on lowest total time required to close a TPFDD, the optimum combination for SBCT deployment is 59 C-17s, 22 C-17 Combi, 50 C-5s, 60 120-ton hybrid airships and 60 30-ton hybrid airships delivering to two APODs, one for conventional aircraft and one for hybrid airships. This closes the TPFDD in 5 days and costs $139.5M. Surface ships do not prove effective at reducing the timeline based on this scenario's distance and cargo requirements. Using a combination of 58 C-17s, 4 C-17 Combi, 8 C-5s, 40 120-ton hybrid airships, and 1 LMSR, the TPFDD can be closed in 17 days and costs $70.3M. The cheapest method is moving the SBCT entirely by ship which requires 2 LMSRs and closes in 17 days at a cost $7.1M. It is 29% faster and 22% cheaper to deliver an SBCT if hybrid airships are added to a fleet of C-17s and C-5s and utilize an airship specific APOD.

RQ3: What is the optimum cargo capacity for hybrid airships to increase capacity, and decrease cost and time for TPFDD closure? Does this fall in line with the 30 ton recommendation of the JFTL study?

A3: An analysis of the optimum cargo capacity was ultimately beyond the scope of this research due to time constraints and the limitations of RCAT. The baseline assumption of 30 tons is valid for initial analysis due to the fact that no full scale hybrid airships have been developed to date. 30 ton capacity is a decent starting point since it logically compares to current tactical airlift capability and historical strategic airlift utilization. However, the data shows that transporting 30 ton payloads across intertheater distances is not efficient and leads to MOG issues. This research proved better results when the 120 ton airship was simulated. It is the belief of the researcher that hybrid airships must be designed with a much larger payload than 30 tons to achieve the strategic benefits required in a great power competition. Additionally, the rationale provided for changing the size of the airship in the JFTL study was based on AMC/A9 data that looked at conventional airlift available at the time. This myopic focus is valid for determining new planning factors when updating publications such as AFPAM 10-1403, but should not be used for forward projecting the expected payload utilization of a still yet to be developed ultra large lift capacity airship.

RQ4: Should hybrid airships be manned, remotely piloted or autonomous?

A4: The conventional aircrew manning requirement to support the fleet able to deliver an entire SBCT by air described in this research is 805 total augmented aircrew members. 405 augmented C-17 crewmembers for 81 C-17s and 400 augmented C-5 crewmembers for 50 C-5s. This is only the number of crews required to operate all the airplanes at once and does not count staged crews at each location. Assuming each location in this scenario has one crew on standby so the airplanes never stop, the total number of crews can be multiplied by 4, requiring 3,220 total crew members to continuously operate in a stage environment supporting wartime operations. If hybrid airships require three crewmembers for a basic crew and six for an augmented crew, the total number of augmented airship crewmembers required is 720, 360 each for the 120 ton and 30 ton variants. This assumes one airship commander, one copilot and one loadmaster on a basic crew. If airships are remotely piloted the number of crewmembers required is 360. This assumes one person remotely operating an airship per 8 hour shift followed by a 16 hour crew rest period. If the airships are autonomous, the number of potential crewmembers is 3, which is based on one operator monitoring all 120 airships per 12 hour shift in a command center followed by 24 hours off. The Air Force has relayed to Congress a desire to increase the number of operational squadrons. The Secretary of the Air Force says one additional airlift squadron and fourteen air refueling squadrons are needed in Air Mobility Command alone to meet the requirements levied upon the force (Secretary of the Air Force Public Affairs, 2018). These squadrons need people and aircraft. Autonomous hybrid airships would increase global cargo airlift capacity without adding a manpower requirement to the Air Force. There is a ground handling requirement for loading, launch and recovery operations but addressing this manpower requirement is beyond the scope of this paper.

RQ5: Is there enough helium to support a fleet of hybrid airships?

A5: The USGS estimates total worldwide resources of helium, not including United States resources, to be 1.13 trillion cubic feet. US resources are estimated to be at 153 billion cubic feet, with an additional 591 billion cubic feet in probable, possible and speculative reserves. For size comparison purposes, the Goodyear Blimp requires 300,000 cubic feet of helium. The Airlander 10 requires 1.34 million cubic feet of helium which compares to the largest soft-skin airship ever built, the ZPG-3W, which required 1.5 million cubic feet of helium. The proposed 30 ton airship would have a volume of 4.4 million cubic feet. The Hindenburg, which was 500 feet longer than the Airlander 10, required 7 million cubic feet of hydrogen. There is enough helium estimated in worldwide resources to fill over 256,000 30 ton airships. There is enough helium estimated in current United States resources to fill over 34,000 30 ton airships. If additional resources are utilized, over 169,000 30 ton airships could be filled. The estimated cost to fill a single airship with helium based on the different prices is indicated in Table 16.

Table 16 - Estimated Cost to Fill a Single Airship

Vehicle	Government: Crude ($86/thousand ft^3)	Non-Govt: Crude ($119/thousand ft^3)	Private: Grade-A ($210/thousand ft^3)
Goodyear Blimp	$25,800	$35,700	$63,000
Airlander 10	$115,408	$159,692	$281,810
Proposed 30 ton Airship	$378,400	$523,600	$924,000
Hindenburg	$602,000	$833,000	$1,470,000

Using the three different prices mentioned, the estimated cost to fill a simulated fleet of airships with helium in FY19 dollars is shown in Table 17.

Table 17 - Estimated Cost to Fill Airship Fleets

Fleet Size	Government: Crude ($86/thousand ft^3)	Non-Govt: Crude ($119/thousand ft^3)	Private: Grade-A ($210/thousand ft^3)
Goodyear Blimp			
10 ships	$258,000	$357,000	$630,000
100 ships	$2,580,000	$3,570,000	$6,300,000
1000 ships	$25,800,000	$35,700,000	$63,000,000
Airlander 10			
10 ships	$1,154,080	$1,596,920	$2,818,100
100 ships	$11,540,800	$15,969,200	$28,181,000
1000 ships	$115,408,000	$159,692,000	$281,810,000
Proposed 30 ton Airship			
10 ships	$3,784,000	$5,236,000	$9,240,000
100 ships	$37,840,000	$52,360,000	$92,400,000
1000 ships	$378,400,000	$523,600,000	$924,000,000
Hindenburg			
10 ships	$6,020,000	$8,300,000	$14,700,000
100 ships	$60,200,000	$83,300,000	$147,000,000
1000 ships	$602,000,000	$833,000,000	$1,470,000,000

V. Conclusions and Recommendations

Conclusions of Research

The purpose of this research was to explore the utilization of hybrid airships to augment TPFDD closure. The research attempted to identify the optimum combination of conventional fixed wing aircraft, hybrid airships and surface ships to move large amounts of cargo during OPLAN execution. The research also attempted to explain the personnel impacts and requirements for manning a hybrid airship fleet. Planning software that is currently available and in use was modified in order to simulate cargo movement using hybrid airships.

Significance of Research

Previous research shows that hybrid airships can offer significant advantages and capabilities to the United States military. This research has shown that RCAT can be used to quickly simulate cargo movement utilizing hybrid airships. The analysis above has shown what an optimized fleet of conventional sealift, airlift and hybrid airship vehicles looks like. Hybrid airships may prove useful in niche mission sets but the best utilization for wartime efforts would be to augment conventional assets executing a TPFDD movement. It should not be assumed that a fleet of hybrid airships could be supported with Air Force aircrew and future efforts should be made to advance remotely piloted and autonomous airships. Future research of the work and rest cycles of aircrew and mariners will help shape the desired personnel requirements.

The advantage of remotely piloted or autonomous hybrid airships is that personnel requirements would be kept to a minimum. During major conflict the will of the public to accept aircraft losses may be increased if America's sons and daughters were not onboard those aircraft.

Another point of significance is the resiliency that hybrid airships could add to our military logistics networks. An enemy could sabotage an airfield to prevent large aircraft from operating there. Vertical lift aircraft and aerial delivery via fixed wing aircraft could deliver runway repair assets that could eventually open the airfield. Despite the speed of airlift, the bulk of American supplies will be delivered via surface ships which means an enemy could prevent large ships from ever arriving by sabotaging a port. This would slow the process by requiring JLOTS assets to deliver supplies from large ships anchored at sea. Hybrid airships could prevent both of these problems by offering delivery of large amounts of supplies directly to the point of need, either inland or at the beach. Another plan could have large hybrid airships augment the prepositioned supply ships operating in Guam and Diego Garcia. Since hybrid airships are able to remain airborne for extended periods of time they could slowly move around either the Pacific or Indian Oceans in an effort to complicate enemy targeting while increasing the survivability of supplies onboard. They could essentially be large supply warehouses that constantly move.

Recommendations for Future Research

The US Navy proposed a concept of an arsenal ship in 1995 that would contain hundreds of missiles and could be controlled by an Aegis cruiser (Driesbach, 1996). The Air Force also envisioned a form of an arsenal ship, instead opting for an airborne version (May & Pietrucha, 2016). Future research could determine the feasibility of using hybrid airships as a form of kinetic weapons delivery platform, able to deploy standoff munitions, jammers or autonomous drones. Areas of focus could be the Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities, and Policy (DOTMLPF-P) considerations for using hybrid airships in an offensive role.

Joint All Domain Command and Control (JADC2) is how the Air Force envisions it will fight and win in the future (Hitchens, 2020). The system will require a large number of sensors able to collect and share data. In 2020 the Air Force began testing radio connections with SpaceX Starlink satellites as part of larger exercises (Tirpak, 2020). Future research could explore the ability of a fleet of hybrid airships to participate in the JADC2 network as they transit across the globe delivering equipment and supplies. Research could focus on the improved capability of in-transit visibility (ITV) of cargo that participation by mobility assets might offer in such a network.

Two emerging concepts support great power competition and could be supported by hybrid airships. The first is the loyal wingman concept of autonomous drones and the second is standoff munitions concealed in plain sight. Future research could look at the feasibility of delivering weapons that are stored in and operated from shipping containers. Kratos Unmanned Aerial Systems is developing the ability to launch their XQ-58A Valkyrie drones from a standard shipping container. They displayed their current work at the 2019 Association of the United States Army convention. The drone is stored in the shipping container with the wings removed and is capable of being launched within a few hours. Rails are built into the container that allow the drone to slide out so the wings can be installed and the drone angled up for launch. The model on display at the convention is shown in Figure 33 (Mizokami, 2020). The Russians have already developed standoff weapons hidden in shipping containers. A variant of an anti-

Figure 33 - Kratos XQ-58A Valkyrie Deployable Launcher Mockup

ship and land attack cruise missile known as the Club-K has been observed on display at military weapons trade shows. The Club-K concealed in a shipping container is shown in Figure 34 (Kuzmin, 2011). Either of these capabilities could force an adversary to consider any shipping container as a potential threat and could be transported by hybrid airships. Both of these concepts could use shipping containers to create a large shell game in the Pacific. Some containers could house loyal wingmen or standoff munitions but most would be empty or holding other supplies. Either way, enemy targeting solutions would be complicated.

If large numbers of hybrid airships are acquired it might be more efficient to manage and operate the fleet through a program such as CRAF or VISA. Future research could perform a cost-benefit analysis showing the potential savings achieved with various sizes of hybrid airships. Focus should be in terms of dollars per ton-mile spent to move cargo with a consideration for total time of delivery.

If future research identifies the routine missions flown by C-17s and C-5s that hybrid airships could fly instead, those conventional fixed wing aircraft could be held back to form a sort of ready reserve in order to support a fleet dedicated to Dynamic

Figure 34 - Club-K Anti-Ship Missile Shown in a Shipping Container

Force Employment as outlined in the 2018 NDS. Even if the fixed wing aircraft were not allocated to a ready reserve fleet, flight hours could be saved by lowering their utilization and potentially extending their service life. One area of focus could be determining if the speed of hybrid airships compared to surface vessels is fast enough to prevent spoilage of perishable goods. An example of goods transported by different modes based on value and shelf life is discussed in the Journal of the Transportation Research Forum article titled "The Rebirth of Airships" and is shown in Figure 35 (Prentice, Phillips, Beilock, & Thomson, 2005).

One final area of future research could be the potential use of hybrid airships to support the West African Logistics Network (WALN) that currently facilitates cargo delivery in Western Africa. Planners at AFRICOM face the challenges of great distance and poor infrastructure when delivering equipment and supplies to Africa. The WALN was developed to implement a form of hub-and-spoke cargo distribution network. Hybrid airships could provide much needed lift capacity to the region. Focus areas could be the optimum cargo capacity and fleet size of hybrid airships necessary to support operations in Africa.

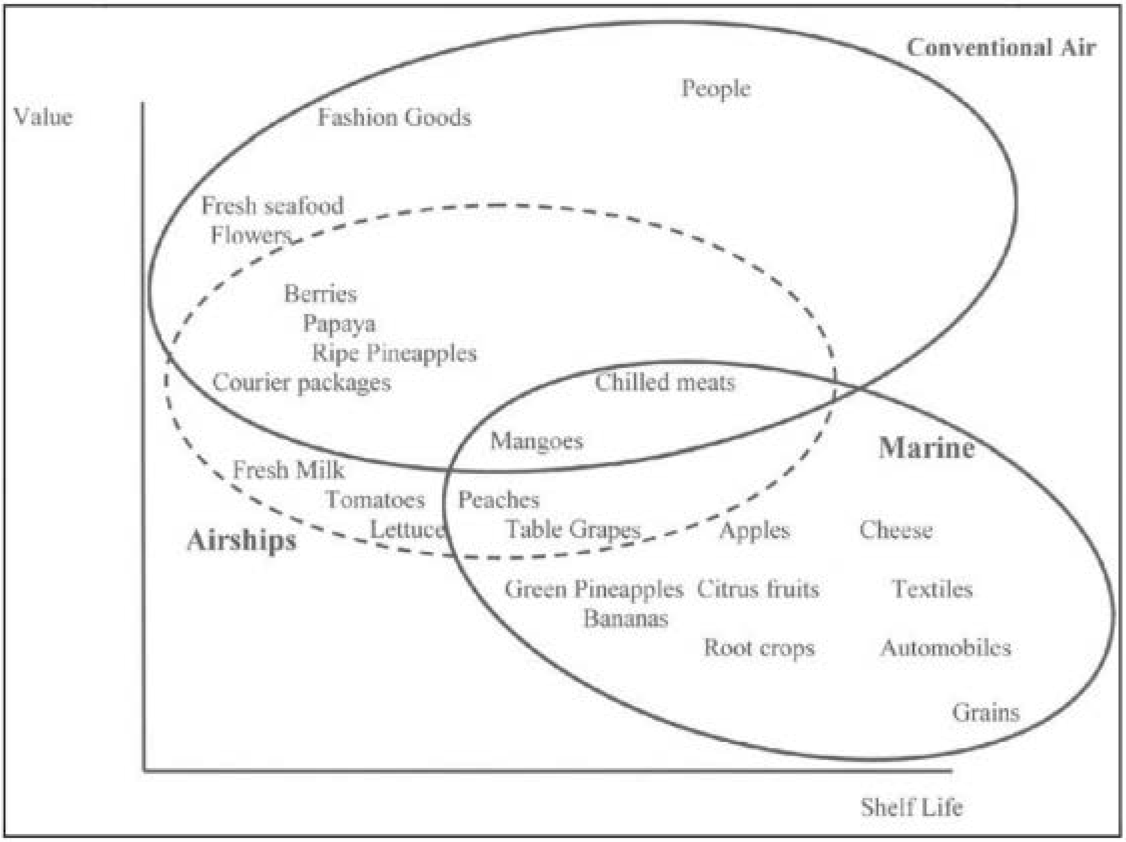


Figure 35 - Proposed Transportation Mode Based on Value and Shelf Life

Summary

The idea of large hybrid airships is not new. Conditions have not yet been met to warrant large investment into the technology by industry. Research and development has shown that the technology is feasible and benefits are real. The lack of funding and construction of actual production aircraft should not hamper future research and the development of new ways to solve old problems using hybrid airships. One day if hybrid airships become common place, society should not have to wonder how best to employ them.

Appendix 1 – Helium Information

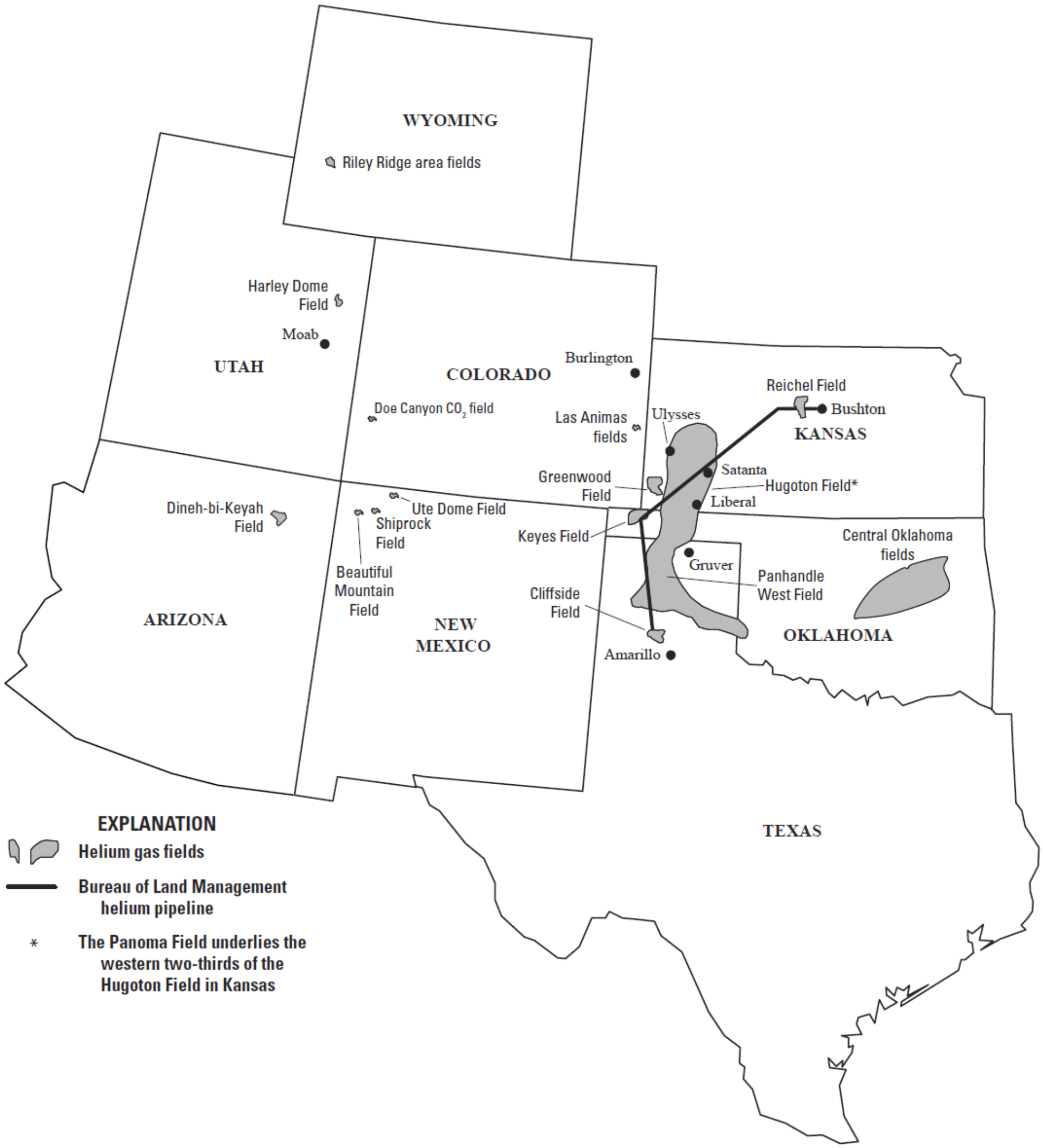


Figure 1. Major helium-bearing natural gas fields in the United States.

From the USGS Minerals Yearbook

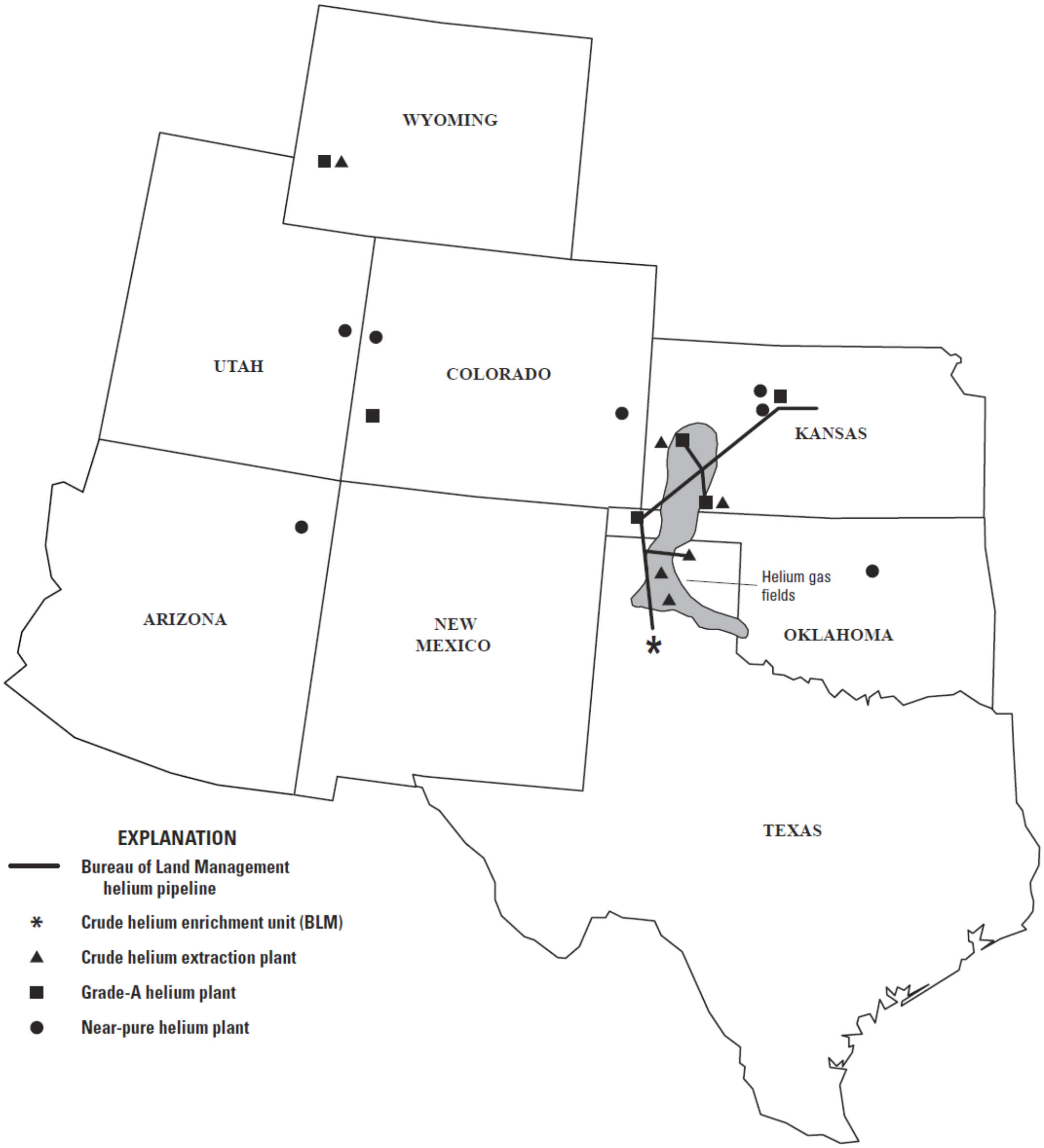


Figure 2. Helium extraction and refining plants in the United States.

From the USGS Mineral Yearbook

Appendix 2 – Fleet Optimization

Full SBCT

This table adjusts the number of individual aircraft to optimize total cargo capacity required to transport a full SBCT
This represents moving an entire SBCT via airlift only

Total Cargo Requirement (tons)	18766

Aircraft Type	C-17	C-17 Combi	C-5	30 ton	120 ton
Individual Cargo Capacity (tons)	64	45	100	30	120
Hourly Cost	$17,068	$17,068	$34,846	$2,403	$4,251
Round Trip Mission Duration (hours)	33	33	32.33	120.33	120.33
Maximum number of aircraft	60	60	52	60	60
Optimized number of aircraft	59	22	50	60	60

	C-17	C-17 Combi	C-5	30 ton	120 ton
Fleet Capacity (tons)	3776	990	5000	1800	7200

	C-17	C-17 Combi	C-5	30 ton	120 ton
Individual Mission Cost	$563,244	$563,244	$1,126,571	$289,153	$511,523
Total Asset Cost	$33,231,396	$12,391,368	$56,328,559	$17,349,179	$30,691,370
Total COA Cost	$149,991,872	<--			

Total Fleet	251
Total Fleet Capacity (tons)	18766
Remaining SBCT Cargo (tons)	0

The green cells are changed
To minimize the yellow cell

Full SBCT - Fixed Wing Only

This table adjusts the number of **fixed wing** aircraft to optimize total cargo capacity required to transport a full SBCT
This represents moving an entire SBCT via airlift only

Total Cargo Requirement (tons)	9766

Aircraft Type	C-17	C-17 Combi	C-5		
Individual Cargo Capacity (tons)	64	45	100		
Hourly Cost	$17,068	$17,068	$34,846		
Round Trip Mission Duration (hours)	33	33	32.33		
Maximum number of aircraft	60	60	52		
Optimized number of aircraft	59	22	50		

	C-17	C-17 Combi	C-5		
Fleet Capacity (tons)	3776	990	5000		

	C-17	C-17 Combi	C-5		
Individual Mission Cost	$563,244	$563,244	$1,126,571		
Total Asset Cost	$33,231,396	$12,391,368	$56,328,559		
Total COA Cost	$101,951,323				

Total Fleet	131
Total Fleet Capacity (tons)	9766
Remaining SBCT Cargo (tons)	0

The green cells are changed
To minimize the yellow cell

Full SBCT - Airships Only

This table adjusts the number of **hybrid airships** to optimize total cargo capacity required to transport a full SBCT
This represents moving an entire SBCT via airlift only

Total Cargo Requirement (tons)	9000

Aircraft Type				30 ton	120 ton
Individual Cargo Capacity (tons)				30	120
Hourly Cost				$2,403	$4,251
Round Trip Mission Duration (hours)				120.33	120.33
Maximum number of aircraft				60	60
Optimized number of aircraft				60	60

				30 ton	120 ton
Fleet Capacity (tons)				1800	7200

				30 ton	120 ton
Individual Mission Cost				$289,153	$511,523
Total Asset Cost				$17,349,179	$30,691,370
Total COA Cost	$48,040,549				

Total Fleet	120
Total Fleet Capacity (tons)	9000
Remaining SBCT Cargo (tons)	0

The green cells are changed
To minimize the yellow cell

Half SBCT

This table adjusts the number of individual aircraft to optimize total cargo capacity required to transport half of an SBCT
This represents moving half an SBCT via airlift and half via sealift

Total Cargo Requirement (tons)	9383

Aircraft Type	C-17	C-17 Combi	C-5	30 ton	120 ton
Individual Cargo Capacity (tons)	64	45	100	30	120
Hourly Cost	$17,068	$17,068	$34,846	$2,403	$4,251
Round Trip Mission Duration (hours)	33	33	32.33	120.33	120.33
Maximum number of aircraft	60	60	52	60	60
Optimized number of aircraft	32	3	0	0	60

	C-17	C-17 Combi	C-5	30 ton	120 ton
Fleet Capacity (tons)	2048	135	0	0	7200

	C-17	C-17 Combi	C-5	30 ton	120 ton
Individual Mission Cost	$563,244	$563,244	$1,126,571	$289,153	$511,523
Total Asset Cost	$18,023,808	$1,689,732	$0	$0	$30,691,370
Total COA Cost	$50,404,910				

Total Fleet	95
Total Fleet Capacity (tons)	9383
Remaining SBCT Cargo (tons)	0

The green cells are changed
To minimize the yellow cell

Half SBCT - Fixed Wing Only

This table adjusts the number of **fixed wing** aircraft to optimize total cargo capacity required to transport half of an SBCT
This represents moving half an SBCT via airlift and half via sealift

Total Cargo Requirement (tons)	4692

Aircraft Type	C-17	C-17 Combi	C-5		
Individual Cargo Capacity (tons)	64	45	100		
Hourly Cost	$17,068	$17,068	$34,846		
Round Trip Mission Duration (hours)	33	33	32.33		
Maximum number of aircraft	60	60	52		
Optimized number of aircraft	58	4	8		

	C-17	C-17 Combi	C-5		
Fleet Capacity (tons)	3712	180	800		

	C-17	C-17 Combi	C-5		
Individual Mission Cost	$563,244	$563,244	$1,126,571		
Total Asset Cost	$32,668,152	$2,252,976	$9,012,569		
Total COA Cost	$43,933,697				

Total Fleet	70
Total Fleet Capacity (tons)	4692
Remaining SBCT Cargo (tons)	0

The green cells are changed
To minimize the yellow cell

Half SBCT - Airships Only

This table adjusts the number of **hybrid airships** to optimize total cargo capacity required to transport half of an SBCT
This represents moving half an SBCT via airlift and half via sealift

Total Cargo Requirement (tons)	4692

Aircraft Type				30 ton	120 ton
Individual Cargo Capacity (tons)				30	120
Hourly Cost				$2,403	$4,251
Round Trip Mission Duration (hours)				120.33	120.33
Maximum number of aircraft				60	60
Optimized number of aircraft				0	40

				30 ton	120 ton
Fleet Capacity (tons)				0	4800

				30 ton	120 ton
Individual Mission Cost				$289,153	$511,523
Total Asset Cost				$0	$20,460,913
Total COA Cost	$20,460,913				

Total Fleet	40
Total Fleet Capacity (tons)	4800
Remaining SBCT Cargo (tons)	-108

The green cells are changed
To minimize the yellow cell

Bibliography

Air Mobility Command. (2014, July 28). *Civil Reserve Air Fleet*. Retrieved from U.S. Air Force Fact Sheets: https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104583/civil-reserve-air-fleet/

Air Mobility Command. (2018). *AFPAM 10-1403 - Air Mobility Planning Factors.* Washington, D.C.: United States Air Force.

Air Mobility Command. (2019). *Charter Guidance and Rates for Special Mission Assignment Airlift Missions, Joint Exercise Transportation Program, and Contingency Missions for the Transportation Working Capital Fund.* Scott Air Force Base: Air Mobility Command.

BBC News. (2016, August 17). *Airlander 10: Maiden flight at last for longest aircraft*. Retrieved from BBC: https://www.bbc.com/news/uk-england-beds-bucks-herts-37111527

Boeing. (n.d.). *Boeing Freighter Family*. Retrieved from Boeing Commercial: http://www.boeing.com/commercial/freighters/#/family

Bowen, D. (1977). *Encyclopedia of War Machines: An Historical Survey of the World's Great Weapons.* London: Octopus Books.

CERN. (2020, March 13). *Cryogenics: Low Temperatures, High Performance*. Retrieved from CERN: Engineering: https://home.cern/science/engineering/cryogenics-low-temperatures-high-performance

Craats, R. (2009). *USA: Past, Present, Future-Economy.* New York: Weigl Publishers.

Defense Science Board. (2018). *Task Force on Survivable Logistics Executive Summary.* Washington, D.C.: Office of the Secretary of Defense.

Department of the Air Force. (2015). *AFI 10-202 - Contingency Response Forces.* Washington, D.C.: HQ USAF.

Det Norske Veritas AS. (2012). *Lay-up of Vessels.* Oslo: Det Norske Veritas.

Driesbach, D. H. (1996). *The Arsenal Ship and the US Navy: A Revolution in Military Affairs Perspective.* Monterey: United States Naval Postgraduate School.

Eckstein, M. (2020, January 21). *Navy Will Commission All Expeditionary Sea Bases as USS Warships*. Retrieved from USNI News: https://news.usni.org/2020/01/21/navy-will-commission-all-expeditionary-sea-bases-as-uss-warships

Genys, A. (n.d.). *Kovatch R-11 Aircraft Refueler*. Retrieved from Military Today: http://www.military-today.com/trucks/kovatch_r11.htm

Haydon, F. S. (1941). *Military Ballooning During the Early Civil War.* Baltimore: The Johns Hopkins University Press.

Hitchens, T. (2020, February 12). *All-Domain C2 Key to Air Force Ops: Lt Gen Kelly*. Retrieved from Breaking Defense: https://breakingdefense.com/2020/02/all-domain-c2-key-to-air-force-ops-ltg-kelly/

Hochstetler, R., Chachad, G., Hardy, G., Blanken, M., & Melton, J. (2016). *Modeling and Simulation Tools for Heavy Lift Airships.* Norfolk: MODSIM World.

Hybrid Air Vehicles. (n.d.). *Our Technology*. Retrieved from Hybrid Air Vehicles: https://www.hybridairvehicles.com/our-aircraft/our-technology/

JDPAC. (2010). *Joint Distribution Process Analysis Center (JDPAC) Software Catalog.* Scott Air Force Base: United States Transportation Command.

Kuzmin, V. V. (2011). *International Aviation and Space Salon MAKS-2011*. Retrieved from Vitaly V Kuzmin: https://www.vitalykuzmin.net/Military/MAKS-2011/i-RxhnWT2

Lynch, P. W. (2011). *Hybrid Airships: Intertheater Operations Cost-Benefit Analysis.* Wright Patterson Air Force Base: Air Force Institute of Technology.

M & L Research, Inc. (n.d.). *The Maritime Work Schedule*. Retrieved from Cruise Job Finder: https://www.cruisejobfinder.com/members/maritime/schedule/

Mattis, J. (2018). *Summary of the 2018 National Defense Strategy of the United States of America.* Washington D.C.: United States Department of Defense.

May, T. J., & Pietrucha, M. (2016, June 22). *We Already Have An Arsenal Plane: It's Called the B-52*. Retrieved from War on the Rocks: https://warontherocks.com/2016/06/we-already-have-an-arsenal-plane-its-called-the-b-52/

Mizokami, K. (2020, March 8). *The Air Force's New Weapon Is...Shipping Containers?* Retrieved from Popular Mechanics: https://www.popularmechanics.com/military/aviation/a31263609/air-force-shipping-containers/

Morgan III, S. W. (2013). *Hybrid Airships in Joint Logistics Over the Shore (JLOTS).* Fort Leavenworth: U.S. Army Command and Staff College.

National Air and Space Intelligence Center. (2017). *Ballistic and Cruise Missile Threat.* Wright-Patterson Air Force Base, OH: NASIC Public Affairs Office.

O'Rourke, R. (2020). *Navy Ford (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress.* Washington, D.C.: Congressional Research Service.

Peterson, J. B. (2020). *Mineral Commodity Summaries, Helium.* Reston: United States Geological Survey.

Prentice, B. E., Phillips, A., Beilock, P. R., & Thomson, J. (2005). The Rebirth of Airships. *Journal of the Transportation Research Forum*, 173-190.

Rapp, T. J. (2006). *Analysis of Hybrid Ultra Large Aircraft's Potential Contribution to Intertheater Mobility.* Wright-Patterson Air Force Base: Air Force Institute of Technology.

Robinson, D. H. (1973). *Giants in the Sky: History of the Rigid Airship.* UK: G. T. Foulis & Co Ltd.

Ryan, Jr., D. E. (1992). *The Airship's Potential for Intertheater and Intratheater Airlift.* Maxwell Air Force Base: Air University.

Secretary of the Air Force Public Affairs. (2018, September 17). *The Air Force We Need: 386 Operational Squadrons*. Retrieved from AF.mil: https://www.af.mil/News/Article-Display/Article/1635070/the-air-force-we-need-386-operational-squadrons/

Secretary of the Interior. (2020, March 13). *Helium Stewardship Act of 2013.* Retrieved from US Senate Committee on Energy & Natural Resources: https://www.energy.senate.gov/public/index.cfm/files/serve?File_id=494b2f9e-c8f5-4a44-962d-de4e83397d6b

Surface Deployment and Distribution Command. (2007). *Vessel Characteristics for Shiploading.* Scott Air Force Base: Transporation Engineering Agency.

Surface Deployment and Distribution Command. (2011). *Logistics Handbook for Strategic Mobility Planning.* Scott Air Force Base: Transporation Engineering Agency.

Tirpak, J. A. (2020, February 21). *Roper Aims for 50 Percent Failure in Next ABMS Experiment*. Retrieved from Air Force Magazine: https://www.airforcemag.com/roper-aims-for-50-percent-failure-in-next-abms-experiment/

United States Air Force. (2013). *JFTL Appendix - 120 Ton to 30 Ton Rationale.* Washington, D.C.: United States Air Force.

United States Air Force. (2013). *JFTL Appendix - Helium Availability & Impacts.* Washington D.C.: United States Air Force.

United States Air Force. (2013). *Joint Future Theater Lift.* Scott Air Force Base: Headquarters Air Mobility Command.

United States Air Force. (n.d.). *Key Capabilities*. Retrieved from Air Force Mission and Vision: https://www.airforce.com/mission/vision

United States Department of Transportation. (2019, December 11). *Voluntary Intermodal Sealift Agreement*. Retrieved from United States Department of Transportation - Maritime Administration: https://www.maritime.dot.gov/national-security/strategic-sealift/voluntary-intermodal-sealift-agreement-visa

United States Navy. (2013). *US Navy Program Guide 2013.* Washington D.C. : United States Department of the Navy.

United States Navy. (2017). *United States Navy Program Guide 2017.* Washington D.C.: United States Department of the Navy.

United States Transporation Command. (2010, July). Hybrid Airship Gameplan. *PowerPoint presentation*. Scott AFB, IL.

US Army SDDC. (n.d.). *Analysis of Mobility Platform*. Retrieved from Transporation Engineering Agency: https://www.sddc.army.mil/sites/TEA/Functions/SystemsIntegration/ModelingAndSimulation/Pages/AMP.aspx

US Army SDDC. (n.d.). *Rapid Course of Action Analysis Tool (RCAT)*. Retrieved from Transporation Engineering Agency: https://www.sddc.army.mil/sites/TEA/Functions/SystemsIntegration/ModelingAndSimulation/Pages/RCAT.aspx

White, D. F. (2006). *Bitter Ocean: The Battle of the Atlantic, 1939-1945.* New York: Simon and Schuster Paperbacks.

Yong, J., Smith, R., Hatano, L., & Hillmansen, S. (2005, March). What Price Speed - Revisited. *Ingenia*, pp. 46-51.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
06/05/2020	Graduate Research Paper	July 2019 - June 2020

4. TITLE AND SUBTITLE
Modeling Composite Fleets Utilizing Hybrid Airships

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Gilbert, Christopher R, Maj, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way
Wright-Patterson AFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT-ENS-MS-20-J-036

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Warfighting Integration Capability
Deputy Director, Brig Gen S. Clinton Hinote
1010 Defense Pentagon
Washington, DC 20301-1010
samuel.c.hinote.mil@mail.mil

10. SPONSOR/MONITOR'S ACRONYM(S)
AFWIC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A. Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
This work is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

14. ABSTRACT
This paper examines the potential use and optimum combination of hybrid airships to support cargo movements across strategic, tactical and last mile distances. The main goal is to determine if airships can be used to augment conventional strategic assets. The second focus is to determine the optimum size and number of airships to support a cargo movement when combined with conventional assets. The final focus is to determine whether airships should be manned, unmanned or autonomous. The analysis determined that composite fleets utilizing airships can be successfully modeled using the Rapid Course of Analysis Tool software. This research simulated the delivery of a Stryker Brigade Combat Team from Washington

15. SUBJECT TERMS
Hybrid Airships, Airships, Modeling and Simulation, Intertheater, Intratheater, JLOTS, TPFDD

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Dr. Jeffery D. Weir, AFIT/ENS
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	122	(937) 255-3636, ext 4523 Jeffery.Weir@afit.edu

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18