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Autonomous Dirigible Airships: a Comparative Analysis and Operational Efficiency Evaluation for Logistical Use in Complex Environments

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MBA PROFESSIONAL REPORT

Autonomous Dirigible Airships: A Comparative Analysis and Operational Efficiency Evaluation for Logistical Use in Complex Environments

By: Brian E. Acton
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June 2012

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The fiscal year 2012 budget resolution forced many agencies to significantly reduce their budget spending and adhere to stricter budgetary policies. The one agency that was hit the hardest was the Department of Defense—it was forced to reduce its budget by $10 trillion over a span of 10 years. With the ongoing War on Terror, the Department of Defense estimated in 2010 that the cost of maintaining a single soldier in a wartime environment grew exponentially—to well over $1 million per soldier.

The U.S. involvement in Iraq and Afghanistan started a major shift, from using manned vehicles to using unmanned vehicles, also known as autonomous vehicles. These autonomous vehicles can be controlled remotely via satellite or radio signals. Currently, the majority of unmanned vehicle usage is in autonomous unmanned aerial vehicles (UAVs) that provide air surveillance, reconnaissance, and assault purposes across all services. This major shift to autonomous vehicles has kept a large number of troops out of dangerous environments such as Iraq and Afghanistan, has reduced the risk of losing soldiers' lives, and, at the same time, has reduced the costs of keeping soldiers in these dangerous environments for long periods of time.

The purpose of this project is to provide a comparative analysis and operational efficiency evaluation of current and in-development airships, or *dirigibles,* to expand the UAV's capability as a viable logistic support platform. This project demonstrates that airships, manned or unmanned, can reduce costs, particularly important with the current budgetary concerns throughout the Department of Defense. The expanded use of airships for logistics could benefit all services due to their flexibility, lift capability, interoperability, and lower cost.

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AUTONOMOUS DIRIGIBLE AIRSHIPS: A COMPARATIVE ANALYSIS AND OPERATIONAL EFFICIENCY EVALUATION FOR LOGISTICAL USE IN COMPLEX ENVIRONMENTS

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Submitted in partial fulfillment of the requirements for the degree of

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The fiscal year 2012 budget resolution forced many agencies to significantly reduce their budget spending and adhere to stricter budgetary policies. The one agency that was hit the hardest was the Department of Defense—it was forced to reduce its budget by $10 trillion over a span of 10 years. With the ongoing War on Terror, the Department of Defense estimated in 2010 that the cost of maintaining a single soldier in a wartime environment grew exponentially to well over $1 million per soldier.

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I. INTRODUCTION

A. PURPOSE OF STUDY

In this research project, we examine the possible use of airships as a viable alternative to current United States Transportation Command (USTRANSCOM) heavy-lift logistics platforms. We compare the estimated operating times of each platform within a given scenario, the number of platforms required to complete a mission, the sorties required to complete a mission, the hourly operating costs, the cost per nautical-ton mile, the overall mission costs, the manning costs, and the cost savings that could be achieved with improved speed and cargo capacity associated with airships. We compare these characteristics against current USTRANSCOM airlift and sealift platform costs.

Our main objective in this project is to establish an operating cost baseline for airships against other platforms. Our second objective is to show the relationship between the number of platforms required with respect to varying mission duration and variable tonnage to transport. In addition, we examine the potential cost savings of using autonomous airships versus manned variants. Our analysis in this project could provide helpful data to allow the Department of Defense (DoD) and USTRANSCOM to evaluate airships currently being designed for potential acquisition.

In this project, we outline the past achievements of airships and the current direction of airship design, and we compare the cost and capabilities of airships against some of the current heavy-lift platforms in use today. Our main belief is that, with proper design and technical capabilities, airships could provide the DoD and USTRANSCOM with a vital asset for accomplishing cost efficient and timely heavy-lift capabilities.

Our first goal in this paper is to examine the history of airships—their successes and failures—and to provide insight on why airships were not used for military purposes following the early 20th century. In addition, we examine the myths that precluded the use of airships in future military operations and the eventual decline of airship use in general.

Our project's second goal is to examine the recent developments and capabilities of modern-day airships and their potential uses in a wide variety of missions. This review provides a better understanding of modern airships and the technological advances that have enabled them to become a viable alternative to current heavy-lift platforms.

Our third goal in this project is to analyze the current costs and operational characteristics of heavy-lift platforms. Using the data obtained from various sources on heavy-lift platforms, we derive cost and operational characteristics that establish a baseline that airships need to achieve, meet, or exceed in order to become a viable alternative to current heavy-lift platforms.

Finally, our project examines whether airships could provide the same operational capabilities while providing the DoD with minimal time and cost characteristics compared to current heavy-lift platforms.

B. PROBLEM STATEMENT

In fiscal year (FY) 2011, the USTRANSCOM conducted over 35,000 airlift missions, transferred over 19 million tons of cargo through sealift, and operated in 75% of the world's countries in support of its mission of delivering and distributing logistics and cargo globally (USTRANSCOM, 2012). The DoD relies on USTRANSCOM's ability to provide a global network of critical surface, sea, and air transportation infrastructure to carry out its global missions. Any disruption or incapacitation of these assets may have devastating effects on the DoD's ability to resupply, equip, and project forces globally (Government Accountability Office, 2008).

The recent budget crisis provided continuing pressure on the DoD and various other departments to cut costs and offer the same level of readiness. The nation's inability to balance budgets and provide an effective long-term budgetary strategy has triggered automatic clauses that will constrain the DoD's budget over the next 10 years. The result of these funding shortfalls will require the DoD to provide tighter controls on the management of operational and acquisition funds. With that in mind, the USTRANSCOM has investigated various new technologies in alternative modes of heavy-lift transportation to ensure the availability of mission-critical infrastructure, including surface, sea, and air transportation assets.

Other considerations, such as aging platforms and maintenance and modernization costs, must be taken into account when discussing new forms of technology used for heavy-lift transportation. Aged equipment in the current fleet of airlift platforms will reach its planned life cycle in coming years. In addition, the Navy's 30-year shipbuilding report does not call for the construction of new strategic sealift platforms. Without a defined, long-term replacement program for these platforms, increasing maintenance costs, parts unavailability, and planned modernization costs will hamper USTRANSCOM's ability to sustain its entire mission.

Airships could provide the DoD with a viable, operationally efficient alternative to current heavy-lift platforms being used by the USTRANSCOM. Airships could also provide better-cost efficiency when transporting logistics to the various military theaters in which our armed forces operate. Additionally, if logistics airships could be designed to provide autonomous point-to-point lift operations, the DoD could potentially save millions of dollars in manning and personnel costs.

C. METHODOLOGY/SCENARIO DEVELOPMENT

This project is designed to investigate the cost effectiveness of airships as viable alternatives to current heavy-lift platforms given varying mission duration time intervals and total tonnage. We formulated two scenarios to analyze each airship in a one-to-one comparison, in a break-even analysis and in a manned versus unmanned comparison in order to assess the potential cost savings airships could provide.

The scenarios in this project are designed to present realistic situations where all platforms can be compared against each other. Scenario 1 consists of a hypothetical re-supply route from Europe to Afghanistan. It is primarily an airlift scenario overland. Sealift is included in this scenario in order to show cost differences in case time is not a critical factor. Scenario 2 consists of a hypothetical re-supply route from Hawaii to Guam. Scenario 2 uses both airlift and sealift, and is constructed to show cost and time calculations of a traditional sea route.

Each scenario provides cost analyses using distance between point of embarkation and point of debarkation, the total cargo movement in short tons, the platform providing support, the number of personnel and manning costs, and overall time to complete a mission.

D. ASSUMPTIONS AND LIMITATIONS

We list specific assumptions and limitations in Chapter V, Methodology, and Chapter VI, Analysis. The project's scope is limited to the variables provided; however, the models are constructed to accommodate any input required for planning purposes. Airships have not yet been procured through the DoD; however, airships in the design or development stages are used in this analysis. All information regarding airships came from the airship manufacturers though various corporate websites or brochures. Data does not yet exist for the cost of maintaining a fleet of airships, but airship hourly operating costs, manning requirements, and maintenance costs are derived, or are factored into our assumptions.

Limitations are not specifically analyzed in this project; however, airships in general are prone to many of the same limitations as conventional logistics aircraft. Specific threats may include other air combatants, surface-to-air missiles, and small arms fire. For the purpose of this paper, we assume the time period for these operations is after the initial mobilization, when air superiority and proper air defense mechanisms are in place, and the missions of each platform are not jeopardized from hostile attack.

E. CURRENT LOGISTICS PLATFORMS

The USTRANSCOM utilizes numerous types of platforms to complete its mission of delivering and distributing logistics and cargo globally. This analysis focuses on two methods of heavy-lift logistics delivery, airlift and sealift. Other forms of transportation, such as rail and trucking, are crucial to USTRANSCOM's mission; however, airlift and sealift fulfill the bulk of transportation needs for the armed forces' heavy machinery and equipment.

Three types of airlift platforms are used in this study for comparison against airships. We chose the C-130J, C-17, and C-5M due to their ability to provide the Air Mobility Command (AMC) with heavy-lift capabilities through numerous types of missions. We chose these aircraft variants to simplify our research scenarios, although most variants are close in specifications—endurance, range, and payload capacities. We did not analyze other forms of fixed-wing aircraft because their missions did not necessarily constitute heavy-lift missions. Rotary-wing aircraft are also not analyzed because of their smaller payload capacity, their maximum range and endurance, and their inability to refuel in the air. Other specific assumptions and limitations are discussed in Chapter V, Methodology, and Chapter VI, Analysis.

Two types of sealift platforms are used in this project for comparison against airships. We selected the Large, Medium Speed Roll-on/Roll-off (LMSR) and Fast Sealift Ship (FSS) are selected due to their ability to transfer large amounts of cargo to any deep draft harbor around the world. Numerous other classes of ships provide Military Sealift Command (MSC) with similar capabilities; however, many of these are commercial assets that are contracted for use and obtaining the cost information for these vessels was infeasible. Sealift platforms will always compare favorably against any airlift platform on a cost-per-ton-mile basis, but if hourly operating and manning costs are reduced, airships can provide better cost efficiencies when time criticality is a driving factor.

F. SCOPE AND ORGANIZATION

This project's primary purpose is to analyze the costs and capabilities of airships against today's current heavy-lift logistical platforms. Our analysis examines the operational capabilities of airships that are currently in design. It determines the hourly costs needed for airships to be a viable alternative to today's heavy-lift platforms and explores if airships can be used to produce a cost-effective method of delivering logistics in manned or unmanned variants.

The project is organized into eight chapters: Chapter I–Introduction, Chapter II–Background, Chapter III–Modern Airship Developments, Chapter IV–Current Logistics Platforms, Chapter V–Methodology, Chapter VI–Analysis of Scenario 1, Chapter VII–Analysis of Scenario 2, Chapter VIII-Additional Airship Analysis, and Chapter IX–Conclusions and Recommendations. The findings are not all encompassing and additional research is needed to further evaluate life-cycle costs, research and development costs, as well as myriad other relevant costs associated with making the technological development of airships a reality. Once airships have been fully developed and data can be collected, additional research will be needed to validate whether airships could be a viable alternative to other forms of airlift and sealift not covered in this analysis.

II. BACKGROUND

A. TECHNOLOGICAL ADVANCES

The 20th century brought about the modernization of air transportation through the use of commercial airships, fixed-wing airplanes, and the development of unmanned aerial vehicles (UAVs). The golden era of airships occurred in the early 20th century; however, airships quickly met their decline following several catastrophic accidents, such as the *Hindenburg*, the U.S. Navy's ZR2, and the British R101 airships. with new technological advances in systems and materials, airships have seen a resurgence—they now provide not only passenger transport, but also other commercial and strategic capabilities.

In recent history, technological advances in aerial systems have allowed a person stationed in the United States to remotely control platforms in other countries, in real time. This step forward has allowed the development of multi-mission platforms that are able to carry out numerous operations with speed, precision, and flexibility. The combination of airships and the possibilities to use them autonomously could provide the DoD a cost-efficient alternative to current logistics transportation platforms.

To understand the future capabilities of autonomous airships, we first need to look at the history of airships and UAVs. In this chapter, we explore the various usages of airships and UAVs in the past, major accomplishments, major disasters, and challenges that lie ahead.

B. THE HISTORY OF AIRSHIPS

A dirigible or airship is a lighter-than-air aircraft that is propelled through the use of lifting gas, rudders, and a thrusting mechanism. Airships differ from aerodynamic aircraft, such as fixed-wing aircraft and helicopters, in that airships have large cavities or balloon-like structures that are filled with noble gases that are "lighter than air." Past airships have used hydrogen as the primary lifting gas, but the majority of modern airships now use helium (Gillett, 1999). Airships have been used since the 1890s, primarily by developed countries—for example, Germany, Great Britain, Italy, and the

United States—in both commercial applications, such as passenger liners, and military applications, such as reconnaissance and intelligence gathering. Airships were attractive at the beginning of the 20th century primarily due to the inexpensiveness of hydrogen gas needed for lift and the relatively low-power engines required for propulsion (Congressional Budget Office [CBO], 2005).

There are three categories of the envelope type or "balloon" used: rigid, semi-rigid, and non-rigid. Rigid envelope airships have an outside frame that keeps the shape of the balloon—for example, the Zeppelins used by Germany. Semi-rigid envelope airships use keel-like structures to distribute the weight of the frame and allow the vessel to maneuver better through the air (CBO, 2005). The airship *Norge* is an example of a semi-rigid airship that was used to travel across the North Pole in 1926. The non-rigid-envelope airships, unlike the previous two categories, lack a frame and use only gas to keep their shape. The Goodyear blimp and various other airships used in sporting events are common examples of non-rigid airships (Toland, 1957).

1. Early Airships and Major Accomplishments

The development of airships was hampered in the late 1890s due to three basic phenomena: the public response to airships, the lack of awareness of airships, and the intrusion of politics into business ventures. These three basic reasons kept many businessmen from investing in and developing airships at the end of the 19th century (Meyer, 2001). The first commercially successful type of airship, called the Zeppelin, or the LZ1, was designed by the German Count Ferdinand von Zeppelin and successfully launched on July 2, 1900. It was the first airship that overcame the three basic phenomena that had previously hampered development of airships by offering promises of speed and luxury for all their passengers (Meyer, 2001). Later, Count von Zeppelin took on a new business associate named Dr. Hugo Eckener and formed the world's first passenger-transport luxury airships. They called their new company Deutsche Luftschiffahrts Aktien Gesellschaft (DELAG) and built air harbors all over Germany, including in Frankfort, Berlin, Hamburg, and Dresden (Toland, 1957).

Unlike luxury cruise liners, locomotives, and sports cars, Zeppelins could maneuver freely without the constraints of roads, rails, or sea routes; this freedom allowed airships to travel anywhere that might have seemed impossible by conventional standards. The greatest achievements of airships happened mainly after the end of World War I (WWI) in 1918. Great Britain and the United States developed military airships of their own from either confiscated, captured, or repatriated German airship designs (Meyer, 2001).

The airship's first major accomplishment happened when the British naval airship R34 left Great Britain on July 2, 1919, and traveled to Mineola, Long Island, United States, on July 6, 1919, crossing the Atlantic Ocean; it also made a successful return trip. Two British corporations manufactured airships during this period. Armstrong-Whitworth manufactured the R33, while William Beardmore & Company Ltd manufactured R34 airships. Both the R33 and R34 were based on the captured German Zeppelin, L33, which was brought down in Great Britain during WWI with its engines intact. Another milestone was achieved when the Germans built and operated the passenger-carrier airship *Graf Zeppelin* (LZ 127), which, in October 1929, was the first commercially operated airship to circumnavigate the globe. The *Graf Zeppelin* included flights to Europe, the United States, and the Middle East, and provided freight, mail, and passenger services to Brazil (Meyer, 2001).

2. Use of Airships in Military

After successful use in the commercial sector, airships were eventually designed for military use. Germany again led the way in the development of airships to be used in various military applications—troop transportation, air surveillance, and reconnaissance. The German army and navy purchased various types of airships from developers such as Gross-Bassenach, Parseval, and Schutte-Lanz. These developers were all competitors of the Zeppelin models (Aeroscraft Corporation, n.d.). The first experimental airship, the LZ3 Zeppelin, was sold to the German army as a school ship and was re-designated as the Z1. The LZ3 was part of a contractual agreement with the German army for the development and later purchase of the LZ4. In August of 1908, the LZ4 broke free from its anchor during a storm and crashed into a tree, creating a large fire in one of the airship's engines.

During WWI, the Germans, the French, and the Italians used airships as a platform for not only reconnaissance and intelligence gathering, but also for tactical bombing. From 1914–1918, Germany used airships to provide stealth night bombings of the British Isles to counteract British naval superiority. The use of airships cost the Germans dearly, as the Zeppelins and various other airships were inaccurate when dropping bombs on targets, due to poor navigation and the difficulty of operating at night (Toland, 1957). In 1918, Germany discontinued the use of airships as bombers due to their vulnerability to the incendiary bullets that the British air defense forces used against them. The British began strategically bombing German airship production lines and hangars in Cologne and Dusseldorf, making airships their primary target. At the end of WWI, and after Germany's defeat in 1919, the Allies demanded that Germany discontinue its airship production for war, and Germany divided amongst the Allies its remaining airships as reparations (Toland, 1957).

Later, the United States and Great Britain used dirigibles for military reconnaissance and intelligence gathering, but discontinued their use due to major disasters. After WWI, Germany continued to produce airships, but rather than producing them for military use, the Zeppelin company believed that airships should be used for peace and created a series of passenger airships that provided services to various cities and other countries (Toland, 1957).

3. Major Catastrophes with Airships

There have been many catastrophes involving airships since their inception in the late 1890s, but three major incidents in airship history limited the usage of airships: the American airship ZR2 in 1921, the British airship R101 in 1930, and the German airship *Hindenburg* (LZ129) in 1937. All three disasters involved heavy loss of the lives of the passengers and crewmembers due to the major fires that erupted from the heat of the engines that ignited the hydrogen gas in the airships' envelopes.

a. *The United States Navy ZR2 Airship Disaster, Hull, England, 1921*

The United States purchased the ZR2 airship from Great Britain in 1921 to be commissioned by the U.S. Navy as a reconnaissance and troop transport airship. The ZR2 was the largest airship during the post-WWI era. During a test flight in Hull, England, on August 24, 1921, the ZR2 was performing high-speed maneuvers at low altitudes when the hull snapped into two pieces, due to structural strains caused by its maneuvering. The rear tail section detached and fell into the Humber River, while the front section caught fire and exploded due to the pockets of hydrogen that ignited because of heat created from the engines. Of the 49 passengers and crewmembers on board, only six passengers survived by parachuting out of the falling airship (Toland, 1957). This disaster marked the first post-WWI airship tragedy that seemed to inhibit future development of airships (ZR2 Airship Disaster, 2012).

b. *The British R101 Airship Tragedy, Beauvais, France, 1930*

The research and development of the R101 commenced in 1924 before the British started construction of the airship. The initial design and construction of the R101 was completed in October 1929, but due to design flaws and performance inabilities, the R101 went through three phases before it was completed in 1930. The R101 moved away from the traditional design of airships during that time and became the largest airship built up to that time (Airship Heritage Trust, 2012). On October 4, 1930, the R101 completed a transit of the English straits, traveling to France to refuel and pick up passengers. The ultimate destination of this trip was India; providing regular service to India was considered monumental to the passenger service and transportation industry. After a series of erroneous weather reports from the meteorological center in Cardington, England, the R101 traveled to Beauvais, France, which had a weather front that the crew did not anticipate. Upon arriving at Beauvais, the R101 began to roll heavily, due to the high winds, and started a steep dive. The R101 continued to dive time and time again until the nose of the airship impacted the ground, causing the starboard engine to wrap around the forward hydrogen gasbag and cause a major explosion. In minutes, the R101 was a raging inferno, killing 48 passengers on board with only eight crewmembers able to flee to safety (Airship Heritage Trust, 2012).

c. *The German Airship Hindenburg, "Titanic of the Skies," Lakehurst Naval Station, New Jersey, 1937*

Germany lost its fleet of military airships to Allied forces at the end of WWI; however, post-WWI Germany allowed companies to continue the use of airships as passenger transport. One of the famous airships that met a disastrous fate was the *Hindenburg*. Between May 3 and May 6, 1937, the *Hindenburg* made its first voyage to the United States. It was business as usual for the passenger airship that made over 10 successful trips between the United States and Germany in 1936 (Toland, 1957). A flame appeared on the upper fin as the *Hindenburg* was landing in Lakehurst Naval Station, NJ, on May 6, 1937, during a stormy evening. Immediately, the *Hindenburg* burst into a raging ball of flame. Luckily, only 35 of the 97 passengers and one ground crewmember were killed in the incident. This major incident had many people calling the *Hindenburg* the "Titanic of the Skies" and marked the abrupt end of the age of airships after 30 years of service (Toland, 1957).

C. *HINDENBURG* MYSTERY

The ZR2, the R101, and the *Hindenburg* disasters marked the end of not only the era of the airship, but also the use of hydrogen gas as the primary lifting mechanism. The *Hindenburg* disaster led to the discontinued use of airships as a means of air transport for over six decades. A professor at the UCLA School of Engineering and Applied Science, William Van Vorst, and former NASA researcher Addison Bain proved in a paper titled "Hydrogen and the Hindenburg" that hydrogen was not the cause of the explosion on that frightful day on May 6, 1937 (Brown, 1998). Two boards of inquiry conducted after the incident, and both concluded that "some hydrogen had, in a manner never explained, become free, was ignited electrostatically and exploded" (Brown, 1998).

Using old photos, videos of the incident, passenger accounts, and old records of the German firm that produced the *Hindenburg,* Van Vorst and Bain conducted thorough research on the real culprit of the fire that started on the fin of the airship. The most compelling evidence that sparked Van Vorst and Bain's curiosity in the *Hindenburg* incident was the eyewitness reports that mentioned the explosion as if it were a fireworks display. These first-hand accounts went against any previous first-hand accounts for other hydrogen airship explosions (Brown, 1998). In addition to photos and videos, the amount of time it took the *Hindenburg* to burst into flames and the amount of debris created after the explosion suggested hydrogen was not the main cause. Van Vorst and Bain concluded that the real culprit in the explosion was not hydrogen or the fuel, but, instead, the material and process, called *doping*, that were used to coat the cotton skin of the airship. Doping is the process of using "a combination of iron oxide, cellulose acetate, and aluminum powder" to make fabrics taunt and durable (Brown, 1998). This process made the skin extremely flammable, needing only a small spark to ignite the substance. The high flashpoint of doping is on par with modern rocket propellant used to send shuttles and satellites into space (Brown, 1998).

D. MODERN AIRSHIPS

Technological developments over the last three decades have sparked new interest in using airships. New developments include helium recovery, composite materials science, vectoring engines, satellite weather forecasting, fly-by-light avionics, and computer-assisted design. Increasing congestion at airports and roads, and long lead times for maritime transport have increased the cost of transportation, making the airship a viable economic option. In addition, the more advanced engines used to propel modern airships burn fuel more efficiently, making it less costly and more economically sound than traditional air transport (Brown, 1998).

In 2004, the DoD, through the Defense Advanced Research Projects Agency (DARPA), requested various companies to provide designs for a modern airship that could be used for heavy airlift capabilities and personnel transport, while at the same time providing a cost-efficient and energy-efficient mode of transportation. This resurgence in the demand for airships has led the *Journal of the Transportation Research Forum* (Prentice, 2005) to believe that new modern airships can "improve service and lower transportation costs [which] can stimulate new commodity flows, diversify industrial activity, and forge new trades routes" (p. 173). Modernized airships could provide lift to various locations on the globe that cannot be reached by car, truck, rail, ship, or fixed-wing aircraft (Prentice, 2005).

Modern conventional airships come in all different categories, but one major modernization of airships is the combination of helium and vector-thrust capabilities, resulting in a new type of airship called a *hybrid*. According to the CBO (2011),

> The combination of three different forms of lift allows hybrid airships to carry heavier loads for a given volume of helium and also provides a greater ability to control upward forces on the aircraft than is the case with conventional airships that rely on buoyancy alone. This new development in hybrid airships eliminated the various problems that plagued earlier models of airships and eventually led to their downfall. (CBO, 2011, pp. 9–10)

E. THE ROLE AND DEVELOPMENT OF THE UAV

The use of UAVs began almost a century ago according to *Unmanned Aviation: A Brief History of Unmanned Aerial Vehicles* (Newcome, 2004). Advancements in technologies, such as satellite navigation, computer processors, and digital cameras, tremendously increased UAVs' capabilities. The next generation of UAVs has been recently deployed to Iraq and Afghanistan to collect intelligence and provide strike capabilities. Countries around the world are continuously developing UAVs and expanding their roles in multiple areas of warfare.

The use of unmanned vehicles began taking shape during both world wars. UAVs, when combined with control stations and data links, are commonly referred to as unmanned aircraft systems (UASs). The United States began developing these remote-guided vehicles to deliver bombs into enemy territories during WWI. The U.S. Army developed drones to provide training for anti-aircraft gunners during WWII. The role of UAVs continued to expand throughout the Cold War as the United States expanded mission requirements for intelligence gathering and reconnaissance purposes.

The conflicts in Iraq and Afghanistan have greatly accelerated the use of unmanned vehicles for combat purposes. The continued development of UAVs and UASs will continue to offer the United States flexibility and the benefits of accomplishing numerous types of missions in a multitude of environments.

F. UAV'S EARLY YEARS

Unmanned Aerial Vehicles: Robotic Air Warfare 1917–2007 describes the early origins of the UAVs used in military applications (Zalgo, 2008). The first attempts with unmanned vehicles for military use can be traced back to an automatic flight control system used in the Curtis flying seaplane developed in 1916 by American inventor Elmer Sperry. The U.S. Navy, after entering WWI, looked into the development of "flying bombs." However, the U.S. Navy's endeavors proved unsuccessful, and the idea of unmanned flight was soon abandoned. The U.S. Army began developing its own "flying bomb" in 1918 when the Army awarded a contract to Charles Kettering for development of the *Kettering Bug*. The *Kettering Bug* was an unmanned aircraft that operated as an aerial torpedo. It was designed to hit targets from a range of 40 miles and was, in essence, a forerunner to modern-day cruise missiles and UAVs. The program met with both success and failure, but the *Kettering Bug* never flew operationally.

The Royal British Navy, along with the U.S. Army, was an early proponent of target drones during WWII. Throughout WWII, Reginald Denny and his company—Radioplane—built over 15,000 various radioplane drones for target use. The Germans led in the development of UAVs as offensive weapons, essentially providing the first cruise missile, called *buzzbombs*. These UAVs had the capability of flying at almost 400 mph at an altitude of up to 1,000 feet. Buzzbombs had devastating effects, causing fear and panic among soldiers and the general public. Germany successfully landed over 9,000 buzzbombs throughout the United Kingdom, causing great death, destruction, and physical and psychological injuries.

The U.S. Army continued to develop target drones in the 1950s and expanded their use by adding cameras to carry out battlefield reconnaissance. The first target drones were designated as SD-1 (Surveillance Drone-1) and were based on earlier versions of the radioplanes that were used during WWII. A pilot launched and controlled the SD-1 drone using a rocket-assisted takeoff before bringing it back to base where it was recovered using a parachute. The SD-1 drone and associated equipment were designated as the AN/USD-1, producing the world's first successful surveillance UAV (Zalago, 2008). The USD-1 program was followed with more sophisticated drones, but the program was cancelled in the early 1960s due to excessive costs.

G. THE MODERN ERA

The modern era of UAVs began in the early 1960s. The impetus for use of UAVs occurred when two U-2 spy planes were downed in Russia and Cuba. During the Cuban Missile Crisis the DoD did not have the capability to effectively use UAVs. This lack of resources provided the necessary momentum to ensure that the UAV program would gain approval. The programs lacked adequate funding, but provided the U.S. military an alternative to the traditional manned airframes that flew over enemy territory (Cook, 2007).

The continued improvement of UAVs consisted of placing cameras and communications equipment aboard target drones. The first substantial use of UAVs occurred during the Vietnam War, where the 100th Strategic Reconnaissance Wing flew more than 3,400 combat UAV sorties over North Vietnam, China, Laos, and other locations throughout Southeast Asia from 1964–1972 (Cook, 2007). During this time, the two main types of UAVs that flew aerial missions were the Lightning Bug and the Buffalo Hunter. Of all the sorties flown during the war, the Lightning Bug and Buffalo Hunter suffered only a 10% attrition rate while providing photographic reconnaissance, battle damage assessments, and electronic intelligence (Cook, 2007).

The development of UAVs continued throughout the 1970s, with the United States and Great Britain developing advanced drones with real-time intelligence, surveillance, and reconnaissance (ISR) and tactical capabilities. The British initiated the Marconi Avionics *Phoenix* program, while Lockheed proposed a new UAV called *Aquila* to the U.S. Army. The *Aquila* UAV provided the Army with real-time intelligence and was fitted with a laser designator meant to illuminate targets with a laser beam and guide artillery rounds that could be used against enemy targets. Although the program was cancelled in 1987 due to cost overruns, *Aquila* showed the breadth and scope of UAVs that could be used in future conflicts.

During the Israeli and Lebanese Conflict from 1981–1982, tactical UAVs showed how valuable they could be in combat environments. The Israelis used unmanned vehicles to saturate Lebanese air defense systems, deplete their missile supplies, and screen Israeli fighters from surface-to- air missiles (SAMs). When the Israelis demonstrated tactical UAVs in action in Lebanon in 1982, Secretary of the Navy John Lehman pushed the services into acquiring new off-the-shelf UAVs rather than waiting for the futuristic *Aquila* (Zalago, 2008). In 1985, the Navy chose the *Pioneer* UAV, which was based on an Israeli design.

The *Pioneer* program proved successful and was used in service for over two decades. The Persian Gulf War saw extensive use of UAVs; the *Pioneer* flew over 523 combat sorties (Zalago, 2008). Additionally, the *Pioneer* provided reconnaissance for U.S. Army Apache attack helicopters. The Persian Gulf War provided the U.S. an opportunity to use UAVs for aerial reconnaissance and to target Iraqi defenses with naval gunfire support.

The development of satellite uplinks and global positioning system (GPS) satellite technology greatly enhanced the use of UAVs in the 1990s. Satellite uplinks provided greater control to UAVs and circumvented the problem of command guidance by using radio signals that limited the range and conditions in which UAVs could fly. The second advancement was in GPS satellite navigation, which provided greater reliability to UAVs, automatically returning the UAV to its forward operating base if the command link was disrupted. These technologies allowed a new generation of long-range UAVs to be developed, such as the *Predator*. An armed version of the *Predator* had been in development since 2000 and was first used tactically in November 2002 when a *Predator* controlled by a Central Intelligence Agency (CIA)/Air Force team in Djibouti destroyed a car carrying Qaed Salin Sinan, an Al Qaeda terrorist, in a remote desert in Yemen using a single Hellfire missile (Zalago, 2008).

Operation Enduring Freedom and Operation Iraqi Freedom expanded the use of UAVs, which performed multifaceted roles over many types of combat environments. The RQ-4 Global Hawk provided continuous surveillance data using state-of-the-art electro optical/infra-red (EO/IR) and synthetic aperture radar (SAR) sensors. Global Hawk provided the Air Force and joint war-fighting commanders near-real-time, high-resolution ISR images, along with the ability to loiter for 24 hours at speeds of 400 mph and at an altitude of 65,000 feet without needing to refuel (Newcome, 2004). The Air Force also developed capabilities that allowed the Global Hawk to be operated from bases in the United States while flying missions over Iraq and Afghanistan.

The development of UAVs has been a relatively slow process since their beginnings as target drones and flying bombs. Many programs have been cancelled due to the cost of drones and the need for greater technological advances. As we move forward in the 21st century, unmanned flight has proven its worth and could very well prove to be the answer to expected logistical needs on future battlefields where unmanned resupply aircraft could exceed the benefits of the current air resupply systems.

H. FUTURE CHALLENGES AND DEVELOPMENT

The DoD has looked to give greater capabilities to smaller forces that could accomplish more than has been possible previously. Unmanned systems have grown exponentially in the hope that they can provide a force multiplier to enhance DoD operations. The current DoD inventory increased from only 167 UASs in 2002 to almost 7,500 by the end of 2010 (Gertler, 2012).

Current UAS capabilities vary and grow with the development of new payload technologies that make their role in future combat operations even more vital. Originally, UASs focused on providing reconnaissance, but their scope has been expanded to include ISR and battle-space awareness missions. Modern UASs are beginning to play larger roles in strike missions as continual developments are made in real-time targeting.

The use of UASs has grown at exponential rates, but challenges remain in order to utilize the full potential of these systems, as outlined in the DoD's (2011) *Unmanned Systems Integrated Roadmap FY2011–2036* and in a Congressional Research Service report, *U.S. Unmanned Aerial Systems* (Gertler, 2012). The challenges include interoperability, autonomy, in-air refueling, and the development of new engine systems; however, new developments within these spheres point to new systems that can accomplish the force multiplication that the DoD is striving to achieve (DoD, 2011; Gertler, 2012).

1. Interoperability

The achievements of unmanned systems over the past decade have led to a significant increase in the number of planned and procured acquisitions. In order to maximize the benefits of unmanned systems, the DoD is integrating unmanned systems with other platforms that will allow UAVs to operate in tandem with other systems across myriad battle space operations, such as air, ground, and maritime domains. The DoD believes that the key to achieving this is to adopt open systems architectures that allow increased flexibility and functionality, and longer system life cycles (DoD, 2011). The current lack of interoperability can lead to a reduction in the effectiveness of unmanned systems, as noted by Dyke Weatherington (Peck, 2004), head of the DoD's UAS planning task force:

> There have been cases where a service's UAV, if it could have gotten data to another service, another component, it may have provided better situational awareness on a specific threat in a specific area that might have resulted in different measures being taken. (Peck, 2004)

In order to help the DoD achieve interoperability, the DoD's (2011) *Unmanned Systems Integrated Roadmap FY2011–2036* provides four processes required to implement an open architecture structure. The first step is to develop service definitions and data models in order to support open architecture concepts. Once the models have been established, the second step is to develop repositories of components, interface standards, and infrastructure services using off-the-shelf technologies that allow all services to adapt, extend, and compose unmanned systems, and that support component reuse. The third component is increased collaboration between the government, industry, and academia to allow proper management and validation of component repositories. Finally, the DoD needs to move all its systems and those in development to the open architecture approach, which may prove costly.

2. Autonomy

The expansion of UASs has brought many new capabilities to military leaders for use on the battlefield. This expansion has also brought the burden of increased manpower needed to operate and maintain these systems. A top priority within the DoD with regard to UASs is to design these systems with greater autonomy. This autonomy would allow cooperative control of multiple UASs by a single operator and reduce the manpower associated with each system. Increased autonomy may reduce the manpower needed to operate UASs, but it may also reduce bandwidth needs, increase its endurance by responding to the outside environmental weather conditions, and better manage the system's onboard sensors.

A fully autonomous system can select the desired goal it is programmed to meet. These systems can define how often operator interface is required to complete missions and can routinely choose behaviors that mimic human directions. In 2010, the Air Force released the results of a yearlong study highlighting the need for increased autonomy in modern weapon systems, especially given the rapid introduction of UASs. Researchers of the study "Technology Horizons" identified the need for greater system autonomy as the "single greatest theme" for future Air Force science and technology (S&T) investments (DoD, 2011). The way ahead for autonomous operations is for systems to operate as effectively as they do when they have undemanding missions and objectives. This can be a daunting task, given the complex environments and operations required of UASs, but the levels of autonomy can be adjusted based on mission requirements, and the systems should be designed to allow operators and the system to interact efficiently.

3. In-Air Refueling

In-air refueling is yet another challenge that the DoD has been focusing on in recent years and is one of the major limitations of UASs. The DARPA has been testing the capability of in-air refueling since 2006 and in 2012 plans to conduct aerial refueling testing of the KQ-X autonomous high-altitude aerial refueling program (Warwick, 2011). The process involves flying unmanned vehicles up to an air tanker, which then uses a fuel line that is inserted into a receptacle. This method is called the "probe and drogue method." Successful testing has also been completed with a modified F/A-18 and could also be used with manned aircraft, relieving the pilots of a difficult and tedious process of flying behind a tanker for extended periods of time.

As of 2007, the DARPA believed in a realistic goal for fielding fully capable UAS autonomous refueling within 10 years (Hockmuth, 2007). Current testing has relied on GPS-based navigation and off-the-shelf digital cameras to determine the UAS's location relative to the tanker. Challenges thus far have revolved around the reliability of GPS data throughout the duration of the fueling operation, which can take in excess of 20 minutes. Further steps are needed to fully develop the concepts of operations and to determine the correct UAS with which the technology can be employed.

4. Propulsion and Power

Vast arrays of propulsion systems have been used since the beginning days of unmanned flight. The dramatic increase of UASs has led to an increased demand for more powerful, efficient, and supportable propulsion systems. As was the case with refueling UASs, endurance and life cycle costs have been two of the most expensive aspects of the program. As technology has increased, the types of propulsion and power plants have grown. One type of system under development is fuel cell-generated electric power plants. Fuel cells work by converting a fuel source into electricity. Fuel cells differ from batteries in that they can produce electricity continually as long as there is a fuel source. The supporters of this technology believe that fuel cells could double the efficiency of mid-sized UAVs compared to those powered by internal combustion engines (Libby, 2005). Other systems under consideration include electrical storage devices, new types of generators, and energy-harvesting devices, such as photovoltaic cells. Hybridization of these systems could also yield greater UAS performance compared to the propulsion and power plants currently in use.

I. AIRSHIPS FROM THE PAST TO THE PRESENT

Airships' early histories have been marked by many accomplishments and operational failures. Major operational failures, such as the *Hindenburg*, were tipping points that led to the decline of research and development for airships. New technologies and the use of UAVs have mitigated many of the risks that past airships encountered, and have revived the DoD's interest in using airships for a multitude of missions.

This renewed interest in airships has led to the development of many types of airships with many usages. In Chapter III, we discuss and differentiate the various modern airships in development today. In addition, we discuss platforms that the DoD currently uses for logistics supply and delivery.

III. MODERN AIRSHIP DEVELOPMENTS

A. RESURGENCE OF AIRSHIPS

The golden era of airships has long passed, and the recent resurgence in the last decade has brought about new roles and missions for airships to fill. Airships have been produced in all shapes, sizes, and colors in the past, but they have followed traditional structural designs, namely non-rigid, semi-rigid, and rigid. Since the development of airships in the early 1900s, new technologies and materials have ushered in a new type of airship called a hybrid. Hybrid airships are the pinnacle of all airship designs and provide future prospects for a multitude of lift capabilities and long-endurance missions.

In this chapter, we outline the various types of modern airships in production and their vulnerabilities and limitations. These airships have a multitude of missions, and each has been designed to meet the growing logistical requirements for the DoD's military strategy. Modernized airships provide the DoD with a possible cost-effective and flexible alternative that may replace or work in tandem with current aging logistical platforms.

B. CURRENT AIRSHIP CAPABILITIES

Non-rigid, semi-rigid, and rigid airships are still being used today for various commercial applications, but hybrid airships can provide a commercial and strategic function. Major companies such as Northrop Grumman and Boeing, along with smaller companies, such as World Skycat Ltd., Discovery Air Innovations, Aeros, Skyhook International, and H2, have been developing heavy-lift hybrid airships to provide various lift capabilities. with the limited data on developing airships, we used four characteristics when comparing various airships. *Lift*, described in units of *short-tons*, is the amount of weight an airship can carry. Because of the variable weights that each airship can carry, the sequential characteristics are based on maximum lift. Speed, described in units of nautical miles per hour or knots, is the maximum velocity at which an airship can move. Endurance, described in nautical miles, is the maximum distance an airship can travel. The last characteristic, altitude, described in units of feet, is the maximum height an airship can travel. Table 1 summarizes the various characteristics of airships currently in development and the best estimates of lift, speed, endurance and altitude that each company publicizes.

Table 1. Airship Characteristics and Early Development Estimates

AIRSHIP NAME	COMPANY	LIFT	SPEED	ENDURANCE	ALTITUDE
Skycat 220	World Skycat Ltd	220 tons	84 kts	3240 nm	10,000 ft
H2 Clipper	H2	200 tons	304 kts	3045 nm	75,000 ft
Aeroscraft	Aeros Inc.	65 tons	120 kts	3100 nm	12,000 ft
HAV 366	Discovery Air Innovations	50 tons	105 kts	3000 nm	9,000 ft
Skyhook	Boeing/Skyhook Int'l	40 tons	70 kts	175 nm	6,000 ft
LEMV	Northrop- Grumman	10 tons	80 kts	1500–2400 nm	22,000 ft

1. Skycat 220, Developed by World Skycat Ltd.

The Skycat airships—developed by World Skycat Ltd.—provide various types of airships for a multitude of uses, such as surveillance, emergency relief, firefighting, passenger transportation, and heavy-lift transportation ("SkyFreight," n.d.). This type of hybrid airship generates more than half its lift by helium buoyancy and by the aerodynamic design of the balloon. The *Skycat 220* (Appendix 7, Figure 37) is one of the heavy-lift hybrids on the higher end of the spectrum that is capable of lifting up to 220 tons, at a maximum speed of 84 knots, and for an endurance of 3,240 nautical miles, before it is required to refuel ("SkyFreight," n.d.). The *Skycat 220* provides a cost-effective alternative to airfreight and a faster means of transportation than sealift. For future developments, World Skycat Ltd. is producing a controlled-atmosphere variant of the *Skycat 220* that can be used to transport fresh produce directly from farms to markets. The capital cost to construct one *Skycat 220* is between $88 million and $95 million, with an operating cost of $1,400 per hour. Because it has fewer moving parts than its fixed-wing aircraft brethren, the *Skycat 220* requires only two weeks per year for maintenance, giving it a short turnaround and possibly better reliability ("SkyFreight," n.d.).

2. H2 Clipper, Developed by H2 Clipper, Inc.

The *H2 Clipper* (Appendix 7, Figure 38) is another hybrid heavy-lift airship that can be used for a multitude of missions, such as ISR; command, control, and communication (C3); and heavy-lift transportation (“The H2 Clipper,” 2011). H2 Clipper, Inc., based the airship’s Teflon-Kevlar-coated balloon design on geodesic domes or interlocking triangles that produce a circle. An American scientist, Richard “Bucky” Fuller, developed this design. This design helps strengthen the balloon and provides better aerodynamic flow against weather, debris, and ice shedding (“The H2 Clipper,” 2011).

The difference between the *H2 Clipper* and other hybrid airships is the type of gas used and the propulsion system developed. Hydrogen makes up the majority of the lifting gas when combined with a helium closed-loop system. A closed-loop system is a control system that is self-regulating and separate from various other systems present. Closed-loop systems can detect any deviations from normal operations and employ self-correcting actions to maintain proper balance. This balance makes the airship neutrally buoyant and allows the airship to take off and land without using its engines. Once the airship is airborne and reaches an altitude of 45,000 feet, the hydrazine engines propel it at high speeds, keeping fuel costs low. Based on these differences, the *H2 Clipper* can lift approximately 200 tons, achieve a maximum speed of 304 knots, and have an endurance of 3,045 nautical miles before it needs to refuel (“The H2 Clipper,” 2011). The capital cost, operating cost, and maintenance period are unknown because the airship is still in development.

3. Aeroscraft, Developed by Aeros, Inc.

The Aeroscraft is a medium-range heavy-lift hybrid airship developed by Aeros, Inc., that addresses future problems with the transportation infrastructure of the various modes of transportation: highway, rail, and water (Appendix 7, Figure 39). Although heavy materials can be lifted to a central hub via traditional methods, it is still necessary to transport heavy material to remote locations that may not have the infrastructure to support this endeavor (Aeroscraft Corporation, n.d.).

The design of the Aeroscraft is based on a rigid-type airship that allows an operator to control the ground and air-lift stages of the Aeroscraft. with its structure, the Aeroscraft can take off vertically, lift a maximum payload of 65 tons, reach speeds of 120 knots, and endure 3,100 nautical miles before it needs to refuel (Aeroscraft

Corporation, n.d.). In addition to providing support to the military, Aeros, Inc., aims to reduce transportation costs for various industries that require heavy-lift capability, such as construction and wind turbine installation (Aeroscraft Corporation, n.d.). The capital cost, operating cost, and maintenance period are unknown while the airship is still in the development stage.

4. HAV 366, Developed by Discovery Air Innovations

The hybrid airship vehicle (HAV) 366, developed by Discovery Air Innovations, is another medium-range heavy-lift airship that belongs to a series of airships that can provide various lift capabilities (Appendix 7, Figure 40). The hull is a laminated fabric construction that is aerodynamically shaped to act like as a wing. Within the hull, an internal catenary system supports the payload module and provides up to 40% of the airship’s lift. In addition, the hull has internal diaphragms to support the wing-shape design and to provide compartmentalization to reduce loss of lifting gas (*Discovery Air Innovations*, n.d.).

The HAV 366 is specifically designed to provide a heavy-lift capability to locations that do not have the transportation infrastructure, and it can endure extreme environments, such as the Canadian Arctic. with its ability to vertically take off and land, the HAV 366 can carry a maximum payload of 65 tons, reach speeds of 100 knots, and endure 3,000 nautical miles before it needs to refuel (*Discovery Air Innovations*, n.d.). For future innovations, Discovery Air Innovations will provide a 400,000-lb payload airship variant in order to diversify its heavy-lift capability. The capital cost of producing an HAV 366 is roughly $40 million, but the operating costs and maintenance period are unknown because this hybrid airship is in the testing stages (*Discovery Air Innovations*, n.d.).

5. Skyhook, Developed by Boeing/Skyhook International

The Skyhook airship, a joint venture between Boeing and Skyhook International, is yet another deviation of hybrid designs (Appendix 7, Figure 41). The major differentiating feature of this airship is that it combines the features of a blimp with a helicopter. The *Skyhook* uses four heavy-duty helicopter rotors located on the four corners of the balloon structure, and it is the only hybrid of its kind that does not have a roll-on/roll-off (RO/RO) hangar to carry cargo. The RO/RO is a design that easily transports heavy machinery and vehicular cargo onto a logistical platform. (We explain the benefits of RO/RO in Chapter IV.) Instead, *Skyhook* uses its rotors to take off while the payload is suspended from the airship via suspending wires. The *Skyhook* can carry a maximum payload of 40 tons, reach a maximum speed of 70 knots, and endure 175 nautical miles before it needs to refuel (Sklar, 2009).

The *Skyhook* is a relatively lighter lift hybrid airship, compared to the others, and caters to industries that transport materials for loggers, miners, oil companies, and pipe builders in remote areas with little or no transportation infrastructure. The first prototype has been scheduled to fly in 2014 and has yet to be certified by Transport Canada and the U.S. Federal Aviation Administration (Sklar, 2009). The capital cost, operating cost, and maintenance period are unknown because this hybrid airship is still in development.

6. LEMV Heavy Configuration Developed by Northrop Grumman

The Long Endurance Multi-Intelligence Vehicle (LEMV) is the last type of hybrid airship in development and is considered to be at the lower end of the heavy-lift capability (Appendix 7, Figure 42). Northrop Grumman developed the LEMV for the U.S. Army to provide ISR and heavy-lift functions. with an aerodynamic balloon and engine, the LEMV can lift a payload of 10 tons, reach a maximum speed of 80 knots, and endure 1,500–2,400 nautical miles before needing to refuel (Northrup Grumman, 2012).

The payload of the LEMV can contain up to 18 vehicles in addition to 24 crewmembers. The LEMV has a multi-mission capability to provide persistent surveillance, force protection, counter-drug operations, humanitarian relief, and heavy-lift logistical support for ground troops. Although the LEMV has a multitude of missions, its main mission is ISR, making all other missions, including heavy-lift, secondary (Northrup Grumman, 2012).

C. VULNERABILITIES AND LIMITATIONS OF AIRSHIPS

All airships have varying levels of vulnerabilities and limitations for a particular class or type of airship, but they also have universal vulnerabilities or limitations. The mission and the environment of operations are key factors in what airships will be exposed to, but a well-thought-out doctrine can help eliminate or mitigate any potential risk that an airship may face.

Airships' vulnerabilities have changed over the last few decades due to improvements in materials, computer systems, and balloon designs. The number one vulnerability, despite all these improvements, is against air defense systems. Airships and various major components aboard the airship can be vulnerable to various air defense systems, such as 7.62mm, 12.7mm, and 14.5mm armor piercing incendiary (API) rounds; 23mm API and high explosive incendiary tracer (HEIT) rounds; man-portable air-defense systems; and long-range surface/ship-to-air missile systems. These threats can severely cripple an airship, especially in vulnerable areas, such as propulsion, navigation systems, crewmembers, cargo, and balloon structure (Newbegin, 2003). In order to negate this vulnerability, it is imperative that air superiority is established prior to airship operations or that the airship operates away from hostile forces before being deployed to certain areas (Newbegin, 2003).

Limitations, unlike vulnerabilities, can hinder airship operations instead of stopping them. Air-defense systems may expose the vulnerabilities of airships, but terrain and weather can provide limitations. According to the technical data each company provided, the majority of the airships we presented can perform a vertical takeoff and landing (VTOL), and a short takeoff and landing (STOL). In order to take off or land, airships require large areas or fields free of obstructions, such as power lines, telephone poles, electrical wires, and so forth (Newbegin, 2003). According to World Skycat, Ltd., the Skycat airships in STOL mode require a landing and takeoff length of five hull sizes. The *Skycat 220* requires a total of 925 meters for STOL and about 185 meters for VTOL ("SkyFreight," n.d.). We assume that all other VTOL/STOL airships follow similar parameters.

Weather is another major limitation and one of the most important planning factors for airships, maritime forces, and fixed-wing aircraft. Despite new technology in aerodynamics and weather forecasting, severe winds can hamper airship operations. There are very few ways to mitigate risks against weather; therefore, weather is a constant limitation (Newbegin, 2003).

D. HELIUM VS. HYDROGEN FOR LIFT

The beginning of the 20th century showed great promise for airship use in passenger and freight transportation, but with safety issues and a series of unfortunate accidents, airships declined in use after World War II. Airships are still being used today and can be seen at various sporting events, giving bird's-eye views of the play-by-play, or simply providing advertisement value, like the Goodyear blimp. The fundamental difference between the Goodyear blimp and the *Hindenburg* does not lie in the design of the airship, but in the type of lifting gas used. Modern airships use helium gas to provide lift, while previous airships, such as the *Hindenburg*, used hydrogen gas. These two gases have defined the past uses of airships and will continue to define their future use.

Hydrogen and helium have similarities in physical properties and many differences in chemical properties. Hydrogen and helium gases are odorless, colorless, tasteless, and nontoxic (Linner, 1985). The hydrogen atom is the first element in the periodic table and consists of one proton and one electron; it is the most abundant element found in the universe and the basic building block for all other elements. Hydrogen helps fuel the combustion of the sun and is estimated to make up three quarters of the mass of the entire universe (Hart, 2011). Hydrogen gas (H_2) was first created in the 16th century by mixing metals with strong acids. Hydrogen gas is 14 times lighter than air, a highly combustible diatomic gas, and rarely found naturally. Current hydrogen gas production is conducted through various methods, such as the steaming of heated carbon, decomposition of hydrocarbons with heat, electrolysis of water, and displacement from acids by metals. The United States alone produces over three billion cubic feet of hydrogen gas per year; the main buyers are in the energy industry (Hart, 2011).

Helium is the second-most-abundant element in the universe and the second element found on the periodic table; it consists of two protons and two electrons.

Although first discovered in space, helium was not discovered on Earth until the end of the 19th century. Helium gas is inert, meaning it does not chemically bond easily with other elements; it is four times lighter than air and is part of the noble gases in the periodic table (Mineral Information Institute, 2008). Similar to hydrogen, helium is rarely found naturally. In fact, helium mines are so rare because helium can only be extracted from the by-product of the production of methane and natural gas liquids, and from trapped helium pockets created by the radioactive decay of heavy elements located in the Earth's crust. It is estimated that United States' helium reserves total 11.1 billion cubic meters, while the world's reserves total 26.2 billion cubic meters. The main buyers of helium include medical, cryogenics, and nuclear industries that use helium as a way to cool machinery (Mineral Information Institute, 2008).

1. The Helium Problem

Helium may seem like a good substitute for hydrogen due to hydrogen gas's combustible properties. The problem occurs with the amount of helium reserves in the world and the growing demand for helium needed in industry. Figure 1 shows the historical demand of helium from 1990–2008 for the United States and foreign buyers. As indicated, the foreign demand for helium increased dramatically from 1990–2008, from 3,200 million cubic feet (MMcf) per year to over 6,000 MMcf/yr.

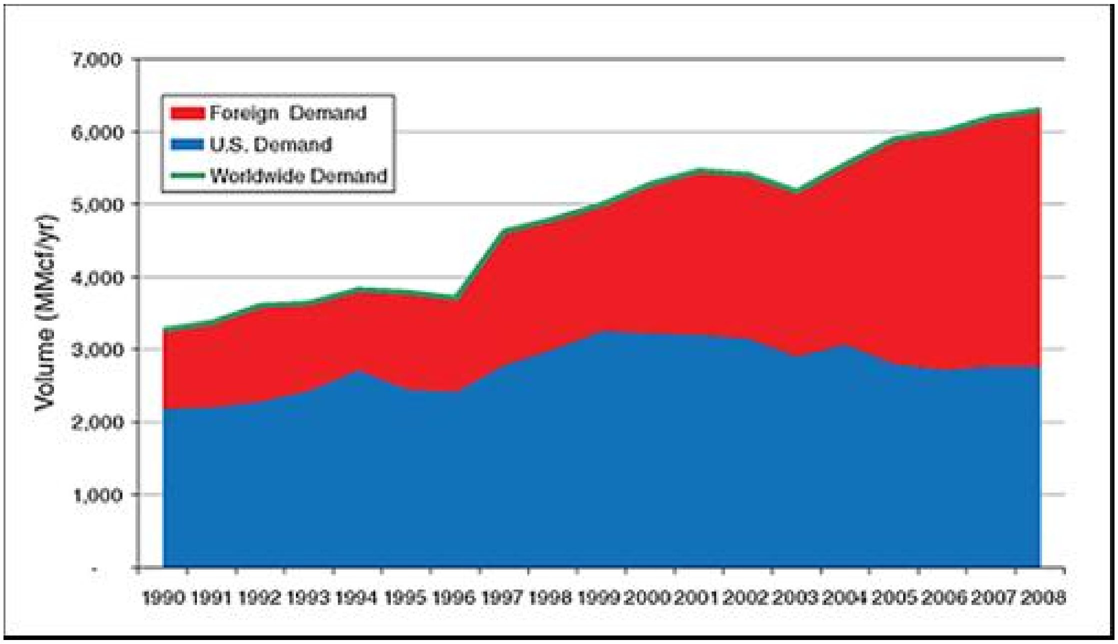

Figure 1. Historical Yearly Foreign, U.S. and Worldwide Demand for Helium (From National Research Council, 2010, p. 35)

The United States is the major supplier of industrial helium, but as industries that use helium move overseas, foreign demand increases exponentially while the United States' relative demand decreases (National Research Council, 2010).

The production of helium is relatively time consuming and expensive, and it relies heavily on other gas processes. Current technologies that extract helium from natural gas have been inefficient in capturing helium before it escapes into the atmosphere. The rising demand for helium, coupled with the inability to produce helium at faster rates, has made helium a scarce resource that is subject to increases in market price. Figure 2 shows previous years' pricing of helium and its projected price through 2015.

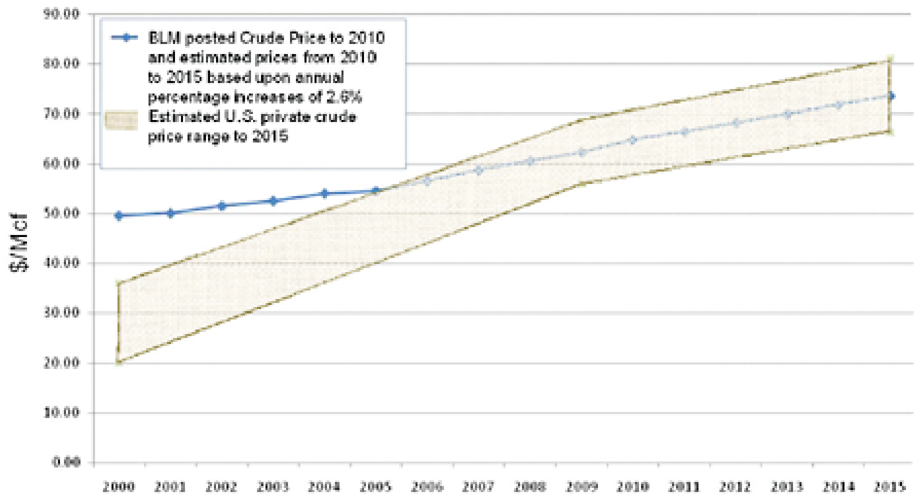

Figure 2. Actual and Projected Crude Helium Prices (Blue Line) with Annual Percent Increases From 2010 to 2015 (From National Research Council, 2010, p. 44)

Airships are just a small market that uses helium as a major portion of airship design. As helium becomes scarcer and prices increase, it can be projected that hybrid airships that use helium will also be subject to an increase in production and maintenance costs. The price and availability of helium is yet another factor that must be taken into account when looking into airships as a viable alternative to other heavy-lift platforms.

E. AIRSHIPS AS A VIABLE ALTERNATIVE

Technological advances have redefined the uses of airships not only in the commercial sector, but also in the government sector. The different types of hybrid airships fulfill many of the missions that the DoD currently performs, and they could perform missions at a fraction of the cost. The hybrids' various vulnerabilities, limitations, and dependency on helium are some of the issues that need to be addressed before the military decides to invest in these platforms.

In Chapter IV, we outline the various heavy-lift logistical platforms and their characteristics. In order to meet the needs of the future logistics delivery, we must understand what is currently available. The heavy-lift logistics platforms we discuss in Chapter IV include what the USTRANSCOM uses to provide strategic transportation through the Air Mobility Command (AMC) and the Military Sealift Command (MSC).

IV. CURRENT LOGISTICS PLATFORMS

A. LOGISTIC PRESSURES

The USTRANSCOM has come under congressional pressure in recent years to provide more cost-effective and efficient ways of delivering logistics. With the recent development of airships, the possibility exists that airships could replace or work in tandem with current logistics platforms to provide strategic transportation. In addition, airships could provide many capabilities that current logistics platforms cannot meet, such as fewer harbor and landing restrictions, and the ability to transport to remote areas with inadequate transportation infrastructures.

In this chapter, we outline the current heavy-lift capabilities that the DoD uses for strategic transportation. These operations are carried out with numerous types of airlift and sealift platforms, depending on the speed and cargo capacity required. These capabilities allow the USTRANSCOM to provide a wide array of operations that supply the strategic transportation needs of the DoD.

B. CURRENT LOGISTICS PLATFORMS

The ability to forward project power across the world has been a stalwart of the United States military since the end of WWII. The past few decades have seen a shift from using overseas bases to using strategic transportation systems to move forces wherever they are needed. The USTRANSCOM's mission is to develop and direct the joint deployment and distribution enterprise to globally project strategic national security capabilities (USTRANSCOM, 2012). With the increased operational tempo of our armed forces, the need to effectively move logistics quickly, easily, and cheaply has become critically and politically important. Airships can easily achieve all three needs and help alleviate pressures that the USTRANSCOM faces.

The USTRANSCOM was established in 1987 to better coordinate mobility operations in alignment with the DoD's strategic transportation requirements. The three major components within the USTRANSCOM are the Air Mobility Command (AMC), the Military Sealift Command (MSC), and the Military Surface Deployment and

Distribution Command. The MSC was originally established in 1949 as the Military Sealift Transportation Service and provided strategic lift of large forces, including armored and support vehicles (CBO, 2005). The AMC was established in 1948 as the Military Air Transport Service and allowed limited amounts of cargo to be transferred over long distances, but at higher speeds than through traditional shipping (CBO, 2005). In addition to cargo transfer, the AMC provides rapid transportation of troops and military personnel.

The strategic transportation systems that deliver logistics can be divided into three broad categories: airlift, sealift, and pre-positioning forces. The U.S. Armed Forces Logistics Support is further divided into 10 classification categories based on what is being transported. The classification system was developed so that categories of logistics could be grouped together for planning and delivery purposes. Each transportation system fits specific roles, with airlift and sealift providing much of the DoD's global transportation needs.

C. AIRLIFT

Airlift is the transportation system best suited for immediate requirements, such as humanitarian relief and troop transportation. Airlift is accomplished through the use of Air Force heavy-lift aircraft as well as commercial crafts from the Civil Reserve Air Fleet (CRAF). The CRAF is a partnership between the DoD and commercial air carriers that supplements the Air Force's airlift when needed (CBO, 2005). The combination of these two elements can effectively deliver logistics overnight to anywhere around the globe. Although effective, airlift also has limitations, such as cost per delivery, cargo volume, life cycle maintenance costs, and airfield restrictions.

1. The C-130 Hercules

The Air Force airlift fleet is composed mainly of three types of aircraft. The oldest and smallest of these aircraft is the C-130 *Hercules* (Appendix 7, Figure 32). The Air Force brought the C-130 into service in the 1950s and currently has specialized variants being flown within the Air Force's inventory of 309 C-130s (United States Air Force [USAF], 2011). The C-130J is the newest variant and has an endurance of 3,000 nautical miles at speeds of over 260 knots (USAF, 2011). One advantage this aircraft has is its ability to take off and land on unprepared runways. Despite its relatively small size, the C-130 can complete a multitude of operations, including troop and cargo transport, search and rescue, and aerial refueling, while hauling up to 22 tons of cargo (USAF, 2011). The total cost of the C-130J program including research, development, test, and evaluation (RTD&E), procurement and acquisition operation, and maintenance totals $14,977,900,000 (Defense Acquisition Management Information Retrieval [DAMIR], 2010b). The total procurement cost of each aircraft is $68,044,000, with 26 more aircraft to be delivered by FY 2016 (DAMIR, 2010b).

2. The C-5 *Galaxy*

The second oldest plane in the airlift fleet is the C-5 *Galaxy* (Appendix 7, Figure 34). The C-5 was introduced in the 1960s and has undergone various improvements throughout the years. At 247.8 feet in length and with a wingspan of 222.7 feet, the C-5 is one of the largest airplanes in the world (CBO, 2005). The Air Force has a total of 83 C-5 A/B/M variants in its inventory; each is designed to carry a large quantity of cargo or heavy pieces of military equipment (USAF, 2011). It has a wide fuselage with low cargo floors, and it is equipped with ramps to allow vehicles to on-load and off-load the 89 tons of cargo it can carry (USAF, 2011). In addition to its payload capability, the C-5 has an endurance of 6,000 nautical miles at speeds over 350 knots (USAF, 2011).

3. The C-17 *Globemaster*

The second largest plane the Air Force has in its airlift fleet is the C-17 *Globemaster* (Appendix 7, Figure 33). This aircraft came into service in the 1990s with 163 planes in service in 2011 (USAF, 2011). The C-17 is smaller than the C-5, but was designed along the same lines as the C-5. It has the ability to carry up to 65 tons of cargo and has an endurance of 4,000 nautical miles at speeds over 400 knots (USAF, 2011). One benefit of the C-17 is that it has special flaps and engine thrust reversers, enabling it to land at much smaller airfields than the C-5. The total cost of the C-17 program, including RTD&E, procurement and acquisition operation, and maintenance totals

$69,497,000,000 (DAMIR, 2010a). The total procurement cost of each aircraft is $244,198,000, with the last of these aircraft being procured in FY 2010 (DAMIR, 2010a).

D. SEALIFT

Sealift is the transportation system category best suited for sustainment requirements following the initial actions of an operation. Sealift is also the system of choice for transporting large amounts of cargo, especially heavy equipment and vehicles. During the course of long operations, sealift transports the majority of all logistics to their destined theaters, which is the most cost-effective way of transporting these logistics. The MSC sealift program transported more than 88 million square feet of combat equipment and more than 8 billion gallons of fuel during the first three years of Operation Iraqi Freedom ("Sealift," 2012). The major disadvantage of sealift is the time needed to transfer from one location to another. The loading and unloading time of sealift ships are relatively slow, which adds to the overall transportation time. Ships are also easily intercepted in the open ocean without escorts. Finally, these ships have limited choice in the ports where they can berth due to their size.

The MSC operates a total of 113 ships worldwide and also has access to 50 additional ships that are kept in the Ready Reserve Force (RRF; MSC, n.d.e). These ships are owned and maintained by the Department of Transportation's Maritime Administration. In addition to MSC and RRF ships, the DoD has the ability to contract the use of commercial shipping vessels via the Voluntary Intermodal Sealift Agreement to supplement MSC ships when additional sealift capability is required. Sealift is accomplished through the use of many types of vessels; however, this analysis will focus on the large medium-speed (LMSR) RO/RO and the fast sealift ship (FSS).

1. Roll-On/Roll-Off

RO/ROs are designed for transporting heavy machinery and vehicular cargo (Appendix 7, Figure 35). As such, RO/ROs are the preferred sealift vessel for U.S. Armed Forces ground units. Besides size, one particular advantage RO/ROs have over other vessels is their ability to transfer much of their cargo without the use of cranes. The MSC has four classes and a total of 19 LMSR RO/RO ships in its inventory; a single

LMSR can carry an entire U.S. Army Task Force consisting of 58 tanks, 48 other tracked vehicles, and more than 900 trucks and other vehicles (MSC, n.d.c; “Large,” 2012). These vessels can contain more than 310,000 square feet of cargo space, depending on the class of ship, and can maintain a speed of 24 knots over 12,000 nautical miles (“T-AK-3008,” 2011). The total acquisition cost, including RTD&E and procurement, was $6,113,000,000, with each ship costing $263,495,000 (DAMIR, 2001). The last of the LMSR ships was delivered in FY 2000.

2. Fast Sealift Ships

Fast sealift vessels (Appendix 7, Figure 36) are the world’s fastest cargo ships (“SS Regulus,” n.d.). The MSC operates eight of these ships as part of its 50 RRF ships under the sealift program office (MSC, n.d.b). Originally built in West Germany in 1973, these vessels were bought by the U.S. Navy in 1981 and converted into RO/ROs. Fast sealift ships are capable of making 33 knots and have 155,000 square feet of cargo space (CBO, 2005).

E. MOVING FORWARD

The USTRANSCOM is the only organization in the world with the ability to transport large quantities of fuel and cargo to any place around the globe. Current airlift and sealift capabilities provide the DoD with the ability to forward project power whenever a crisis occurs; however, there is a need to cost effectively modernize our transportation platforms. The possibilities that modern airships bring, in conjunction with unmanned capabilities, can redefine how the DoD provides future logistical support to the warfighter.

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V. METHODOLOGY

A. OVERVIEW

The idea of using airships for military applications is not new. Many analyses have been conducted to determine their viability over numerous military and civilian applications. With the advent of new technologies and the increased cost of transportation, airships may once again be considered a viable alternative to current heavy-lift platforms. The analysis section of this thesis is designed to provide the cost effectiveness of airships against current heavy-lift platforms using a fixed cargo requirement of 2,500 short tons. In addition, we analyzed varying cargo requirements with fixed time requirements of 168 and 744 hours.

We designed two scenarios to analyze whether airships can be a viable alternative to current heavy-lift platforms over land and sea routes. In each scenario, we applied a break-even analysis that determined an hourly operating cost for airships, derived from current heavy-lift platforms.

1. Data Collection

Data for the current heavy-lift platforms were derived from numerous sources, and are used throughout the two scenarios. Data include ground times and loading times, planned payload capacity, block speeds, ranges, and mission-capable rates. The data for airships were derived from the airships' corporate websites, promotional brochures, and other Internet sources. Data include planned payload capacity, block speeds, and ranges. All other numbers used in the analysis were derived by making reasonable assumptions or were based on other platforms. For the purpose of this analysis the term "airlift" implies the use of the C-130J, C-17, or C-5 aircraft. The term "sealift" will refer to the LMSR and FSS class ships. These platforms were discussed in detail in Chapter IV.

2. Distance

The USTRANSCOM moves cargo throughout the world from numerous locations. The Scenario 1 analysis for airlift is conducted using the distance between

Ramstein Air Base in Germany and Bagram Air Base in Afghanistan, roughly 2,800 nautical miles. This route is shown in Appendix 8. These locations were selected in order to show realistic operations for the delivery of logistics; however, the model can be extended to any situation. Sealift distances, including trucking, were established between Augusta, Italy; Karachi, Pakistan; and Bagram Air Base in Afghanistan, roughly 3,800 nautical miles. As with airlift, these locations were selected to provide a realistic simulation of shipping through the Mediterranean, Red Sea, and Gulf of Aden, and of trucking from Karachi, Pakistan, to Bagram Air Base, but could be altered to include any distance the USTRANSCOM would need to transfer cargo.

The Scenario 2 analysis for airlift and sealift is conducted using distance between Pearl Harbor, Hawaii (U.S.) to Apra Harbor, Guam (U.S.), roughly 3,320 nautical miles. This route is shown in Appendix 8 and was chosen in order to allow a fair comparison between airlift and sealift over a sea route.

3. Time

The analysis throughout each scenario is conducted with time lengths of 168 and 744 hours to complete the delivery of varying amounts of tonnage. The analytical model identifies how many platforms are needed to deliver the given cargo in a certain time span as well as the overall operational cost. Time to complete a mission is a factor when calculating the amount of aircraft needed and the number of sorties required for a particular mission. The total operating time of an aircraft is always the same no matter the mission duration and is based solely off of the block speed of a platform, the sorties or trips a platform is required to do, and the distance traveled. The model is also designed so that platforms not meeting a given time criteria are excluded from those time intervals.

4. Cost

Hourly operating costs for airlift and sealift platforms are used in each scenario to conduct the break-even analysis. The hourly operating rates for airlift platforms are taken from the Air Force's aircraft reimbursement rate table A15–1 (USAF, 2011). The MSC Voyage Calculator, obtained through correspondence with Arthur Clark, calculated the hourly operating rates for sealift platforms (A. Clark, personal communication, March 29, 2012). Hourly operating costs for airships were derived from the lowest operating cost of an airlift platform, the total operating time of the airlift platform, and the total operating time of the airship. The equations for calculating these variables are located in Chapter VI, Analysis. The hourly operating cost for airships is assumed to be the minimum hourly cost derived from each airlift platform. We did this to establish a base so that airships and other platforms could be compared given an hourly rate. In addition to the hourly operating costs of each platform, we added the manning costs of the aircrew and the crew of the ships in order to analyze cost savings if airships could be engineered for unmanned flight.

The break-even analysis multiplied the total number of platforms required, turn-around time for each platform, the sorties required by each platform, and the operating cost of each platform. Overall cost was then determined by adding the total operational cost of conducting a given mission and the manning costs that each mission would require. In order to calculate cost per ton-mile, we divided the overall cost by the total miles covered per mission, per platform.

5. Tonnage

The analysis of airships and heavy-lift platforms uses tonnage in two different forms, as a fixed constant for each platform and as a variable in the break-even analysis. The planned payload capacity of each platform is the fixed constant and can be used for comparison between each of the platforms. The planned payload capacity for airlift platforms is taken from Air Force Pamphlet 10–1403 (USAF, 2011)**.** The planned payload capacity for sealift platforms is taken from the MSC website and a Congressional Budget Office report (MSC, n.d.c; “Large,” 2012; CBO, 2005). The tonnage for sealift platforms is converted from square feet to tonnage. This calculation was provided through e-mail correspondence with Arthur Clark at the MSC (A. Clark, personal communication, March 29, 2012). In order to compute the break-even analysis, a variable amount of tonnage can be used with any formula throughout both scenarios. The planned payload capacity for airship platforms was obtained through the various sources used throughout the thesis (Aeroscraft Corporation, n.d.c; *Discovery Air Innovations*, n.d.c; Northrup Grumman, 2012; “SkyFreight,” n.d.c; Sklar, 2009; “The H2 Clipper,” 2011).

6. Assumptions and Conversions

As in any analysis, we made assumptions in order to devise the models that will compare various platforms. Throughout this analysis, we made certain assumptions in order to study whether airships could be considered a viable alternative to current heavy-lift platforms. In addition, in order to compare various factors of each platform, we made conversions to standardize all units so a valid comparison could be made.

a. General

The following general assumptions are made for all the platforms analyzed throughout this thesis. Airlift and sealift platforms can operate in a variety of weather environments; however, this analysis will assume optimal weather conditions. This allows a straightforward comparison without having to recognize delays from inclement weather. In addition, we assume air superiority and air defense are obtained to allow uninterrupted operations and that we have the diplomatic clearance to fly over allied airspace to the point of debarkation.

The ability to use unprepared airfields or damaged airstrips is one possible benefit airships can provide for heavy-lift operations. The possibility of damage at air or seaports will be of great importance when planning missions. For the purpose of this thesis, however, we assumed that all air and seaports were adequately manned and free of damage and had the proper infrastructure to support all heavy-lift platforms.

b. Airlift

We made the following assumptions for airlift platforms. The speed of all airlift platforms is assumed to remain constant. Platform speeds are derived from Air Force Pamphlet 10–1403 (USAF, 2011). The speed of each platform also assumes a planned payload capacity and distance each aircraft can travel at that speed.

Ground times for each aircraft are drawn from Air Force Pamphlet 10–1403 (USAF, 2011). We assumed on-load and off-load times of the aircraft to be the maximum times listed.   We also factored crew rest times and pre-flight checklists into the analysis. We assumed crew rest would consist of an 8-hour time span and a four-hour flight readiness preparation for a total of 12 hours. In addition to the crew rest period, we assumed a three-hour pre-flight checklist period to be conducted on each platform before each mission.

To achieve the distances required in the various scenarios, we assumed all aircraft have the ability to be refueled mid-air without the requirement of intermediate stops. These mid-air refueling costs were not factored into the operating costs of the aircraft. Fuel costs were assumed to be $3.95 per gallon based on the Air Force's aircraft reimbursement rate table A15–1 (USAF, 2011). We assumed cargo load to be at full platform capacity at all times, as found in Air Force Pamphlet 10–1403 (USAF, 2011). We simplified aircraft manning costs for the analysis and used costs associated with an officer pay grade of O-3 and an enlisted pay grade of E-6 (Office of the Under Secretary of Defense, 2011).

c. Sealift

We made the following assumptions for sealift platforms. The speed of all sealift platforms was assumed to remain constant. The speeds of each platform were derived from the MSC calculator (A. Clark, personal communication, March 29, 2012) and are the maximum economical speed for each platform. We assumed the maximum payload capacity of a sealift ship, despite the tonnage applied to the scenario. In order to compensate for the cost difference between the planned payload and the maximum payload, operating costs were calculated by multiplying the ratio of planned payload by the maximum payload, or the pro-rated costs of just the portion of cargo which is 2,500 tons. Maximum payload capacity for each platform was derived from the square feet of cargo space, which we calculated by converting it to short tons, using 5.5 square feet to one short ton. This information was obtained through correspondence with Arthur Clark at MSC (A. Clark, personal communication, March 29, 2012).

We did not include or calculate activation costs associated with the sealift platforms. We assumed the sealift platforms were already in theater and did not factor in the times or costs to deploy the platform in the area of operations. The availability of all sealift platforms was assumed to be 1.0. The on-load and off-load times were assumed to be the maximum times drawn from the *Logistics Handbook for Strategic Mobility Planning* (SDDCTEA, 2011).

For the purpose of analysis, we assumed all calculations provided by the MSC calculator are correct. These calculations include fuel costs, manning costs, and port costs. The crew size was taken from the MSC webpage and crew costs were based on the MSC calculator (MSC, 2012; MSC, 2012; A. Clark, personal communication, March 28, 2012). For simplicity, we rounded up crew costs for any mission that was less than one month. In addition, we assumed there were no stops between the port of embarkation and the port of debarkation; however, these stops can be calculated into the overall operational costs, if required.

We added trucking costs for land-locked destinations and calculated them using a commercial trucking company from Pakistan (OQab Freight & Logistics Afghanistan Ltd., 2007). For every 30 tons of cargo (one truckload) transport costs are $5,000 per shipment. In Scenario 1, we factored 14 days into the equation for the trucks to complete the mission. Trucking costs do not include the costs to the U.S. military to protect the truck convoys. We assumed the trucking company has enough vehicles available to deliver an entire shipment at one time in convoy.

d. Airships

We made the following assumptions for airship platforms. The estimated minimum hourly operating costs were based on the minimum hourly flight costs of airlift. These minimum hourly operating costs are applied as limits and can be used as a baseline at which airships can be a viable alternative to current heavy-lift platforms.

We assumed the speed of all airship platforms would remain constant. The speeds of each platform were derived from various airship sources and were assumed to be the most economical speed for the given amount of planned payload (Aeroscraft Corporation, n.d.c; *Discovery Air Innovations* n.d.c; Northrup Grumman, 2012; "SkyFreight," n.d.c; Sklar, 2009; "The H2 Clipper," 2011). In calculating each platform's speed, we assumed a planned payload capacity and distance that each aircraft can travel at that speed. We assumed each airship mission flies the same flight patterns as airlift platforms.

We derived ground times for each airship proportionally from the calculated ground times of airlift platforms. We assumed airship on-load and off-load times are the maximum times listed. As with aircraft, crew rest times and pre-flight checklists were factored into the analysis. We used the same aircraft crew rest time and flight readiness preparation of 12 hours. In addition, we assumed a three-hour pre-flight checklist to be conducted on each platform before each mission.

To achieve the distances required in the various scenarios, we assumed all airships have the ability to be refueled mid-air without the requirement of intermediate stops or the airships have been designed with a maximum endurance greater than the maximum distance required in the scenarios. If airships could refuel in mid-air, the costs were not factored into the operating costs of the airship. In addition, we assumed fuel costs to be the same as airlift platforms at $3.95 per gallon based on the Air Force's aircraft reimbursement rate table A15–1 (USAF, 2011). Cargo capacity is assumed to be at full loads at all times and the planned payload capacity is the same as the maximum payload capacity. As with aircraft platform manning costs for aircraft, we simplified crew costs by using a standard officer pay grade of O-3 and an enlisted pay grade of E-6 (Office of the Under Secretary of Defense, 2011).

B. PLATFORM SELECTION

We chose airlift and sealift as the primary platforms to compare against airships for several reasons. Motor vehicles and railroad alternatives were excluded from the analysis, as the majority of USTRANSCOM missions require inter-theater lift; however, trucking costs were added into the Scenario 1 sealift analysis to ensure the best estimate of overall cost and cost per ton-nautical mile

The final port of debarkation will be of great importance for strategic transportation planning considerations. In situations where harbors or airstrips have been damaged or become overcrowded, airships provide a unique alternative for logistics delivery as they require little infrastructure to off-load. Airships also provide better flexibility for transportation when the final port of debarkation is located further inland or a greater distance from conventional airports where other forms of intermodal transportation are needed. For this analysis, the final port of debarkation is not of great importance because the models assume point-to-point delivery.

1. Airlift

We chose the three airlift platforms analyzed due to their ability to perform numerous types of heavy-lift missions. The C-5 and the C-17 are the largest AMC aircraft available, and together they transport the majority of DoD heavy machinery and equipment. The C-130 is the smallest of the airlift fleet, but has much greater flexibility than the other two aircraft due to its size and ability to land in relatively small airfields. The planning payloads of the C-5, C-17, and C-130J are 61, 45, and 18 short tons respectively (USAF, 2011). Other aircraft or rotary-wing aircraft were excluded from this analysis, because of both their lack of cargo capacities and their inability for in-air refueling.

2. Sealift

We chose the LMSR and FSS class ships as two sealift platforms for analysis. These two classes of ships represent the typical assets that MSC deploys to deliver large quantities of cargo and equipment. Due to sealift's relatively inexpensive cost and large capacity, sealift seems the logical choice for logistics transportation over any other type of heavy-lift platform; however, longer lead times are required to complete a mission, keeping other heavy-lift platforms or airships a viable option when time to deliver is a critical factor. Airlift and airships, in particular, are of value when shipping ports are not available, such as when Pakistan closed the Port of Karachi or in underdeveloped countries without an infrastructure.

C. MODELS CONSTRUCTION

Information contained in Chapter V, sections A and B was used to construct the models of analysis for this thesis. In order to effectively evaluate airships against current heavy-lift platforms, the data were initially separated into two scenarios. The first scenario (Appendix 8, Figure 43) evaluates airships against current platforms using over land and sea routes. The second scenario (Appendix 8, Figure 44) evaluates airships against current platforms using only a sea route so that air platforms and sealift platforms travel the exact same distance. Using two scenarios is an advantageous method for military planners because it enables them to view costs associated with each platform over specified distances and in varying geographic locations.

Each scenario is modeled in the same way with the only difference being the distances and geographic locations used. To evaluate each scenario, we provided a one-to-one comparison, break-even data, and analysis sections showing the range of operating costs, potential cost savings, and manned versus unmanned costs for comparison. The main goal of the comparison was to evaluate whether airships, given specified operating costs, were a viable option to replace or work in tandem with current heavy-lift platforms, and whether the DoD should pursue airship technology as a means of logistics delivery in the future.

1. Excel Model

A basic Microsoft Excel model was based off information found in the various sources for AMC, MSC, and airship platforms. Using the performance characteristics of each platform, various models were created to extrapolate useful information that could answer the question of whether dirigibles could be a viable alternative to current heavy-lift platforms. The Excel model was divided into a data information section and five models: single-unit model, break-even model, replacement operating cost model, autonomous platforms model, and airship characteristics model.

2. Data Information Section

The data information section is part of the Excel file that contains all the basic information for each platform. It acts as the central location from which all five models pull their information. The Excel file is dynamic, meaning a user can change information on the data within this section and all the other models would reflect that change. This provides flexibility within the Excel file, allowing future users to correct any mistakes made in this analysis or to input new data collections. The data information section is divided into three portions: manning, general characteristics, and scenario information.

In the manning portion, the military and civilian personnel, as well as their hourly wage rates, are given in order to approximate manning costs in all five models. In the general characteristics portion, ground, loading, unloading, pre-check, and crew rest times are given for each platform in order to derive the different turn-around times required in further analysis. In addition, the general characteristics of the platform, such as payload capacity, block speed, range of operation, and altitude, are given in order to extrapolate more information in the models. Lastly, scenario information shares the general information of Scenario 1 and 2, such as the distance traveled and the total cargo to be moved.

The data information section also serves as the main input of information for the scenarios. Users can input the distance of the mission for both air and sea platforms and provide a given mission duration time for a platform to complete a mission. These values are used with the three sections mentioned previously and apply to the five models.

3. The Five Research Models

The five models fall in line with the various sections of the analysis to help answer the thesis question. The single-unit model uses the various characteristics found in the data information section and applies them to a single platform to complete a mission without a time constraint. In addition, tables are created in this model that show the various changes in total time to complete a mission over varying tonnage movement requirements.

The break-even model uses the same calculations as in the single-unit model, with the exception that, instead of one platform, various platforms will be used to complete a mission. In addition to calculating the number of platforms to perform these missions, an hourly cost is assigned to airships, using the various operating costs from current logistic platforms. The break-even model also shows the impacts of the requirements of varying tonnage to be moved, similar to the calculations in the single-unit model.

The replacement operating cost model shows the various break-even hourly costs between each airship and other logistics platforms. Using these hourly operating costs, the model shows the cost savings of each airship if hourly operating costs were reduced by a $100. It also provides the cost savings if hourly operating costs were reduced to that of a C-130J aircraft.

The autonomous platforms model shows the difference between manned airships and unmanned airships. Manned airship costs were derived from the break-even model and compared to the autonomous platform model when manpower was removed from the original equation. The model outputs the cost savings per mission of implementing unmanned airships and compares the cost savings from manned AMC and MSC platforms against unmanned airships.

Finally, the airship characteristic model allows the user to change the input variables of plan payload and block speed of each airship in order to show improvements in total operating and manpower hours. Pivot tables were used to compare the effects of total operating and manpower hours based on an increase of block speed and plan payload by 25%, 50%, 75%, and 100% of the original values. The model gives airship companies and the DoD the ability to build or modify requirements of each airship and determine the point of diminishing returns.

4. MSC Calculator

Hidden in the Excel model is the MSC voyage-planning calculator that MSC uses in order to plan budgets for various logistics transportation mission requirements. Using fuel curves, block speed calculations, and historical data, the voyage planning calculator provides a near-accurate budget plan for the MSC to use. The MSC voyage-planning calculator is integrated into our model to better portray the MSC platforms and to ensure more accurate results.

D. ANALYSIS AND MODEL EXPLANATION

1. One-to-One Comparison

The goal of the one-to-one comparison spreadsheet is to provide a threshold of associated costs when analyzing each of the current platforms in use. The data contained within the model show hourly operating costs and manning costs per platform. The data contained in this model are shown throughout the tables located in the analysis section of Chapters VI and VII.

2. Break-Even Analysis

The goal of the break-even analysis is to calculate the number of airships required to complete the same mission that current heavy-lift platforms provide, and to show the maximum costs an airship can have and be a viable alternative to the current lift platforms. Missions are based on the time durations mentioned previously and on varying total lift requirement tonnage. The models output hourly operating costs per platform, the number of platforms required to complete a mission, and overall cost per ton-nautical mile.

To obtain the desired analytical results, time durations and total tonnage are variable throughout the calculations. Each time variable can be changed, depending on the platform, for planning purposes. The variables include pre-checklist hours, crew rest hours, ground and loading times, total inter-/intra-theater distances, speed of each platform, the planned payload, and total delivery tons. From these variables, the model outputs the number of sorties, aircraft, and crews required for each mission. Using these outputs, we can then calculate the total average manning costs, total operating costs, and total overall costs. The total overall costs, the total tonnage, and total distance traveled are then used to calculate the cost per ton-nautical mile.

3. Hourly Operating Cost Savings

The goal of the hourly operating cost savings was to determine a "one-size-fits-all" hourly operating cost to compare airships against current heavy-lift aircraft. The hourly operating costs were calculated by using the aircraft total operating costs for a particular mission and the required airships to complete the same mission. The hourly operating costs of airships was determined by taking the total operating cost of the aircraft and dividing it by the total number of operating hours of an airship needed to complete a particular mission. These equations are further explained and delineated in chapters VI and VII, in the Scenario 1 and 2 analyses. The lowest aircraft operating cost was used with the airship's total operating time to establish a baseline that provides the one-size-fits-all hourly operating cost.

a. Replacement Operating Costs

In certain cases, it might not be prudent to judge the viability of airships against all three aircraft platforms combined. The following section of analysis was conducted to calculate the hourly operating cost of airships against each individual aircraft platform.

Using the output of this analysis, planners can study the possibility of replacing aging platforms with airships by comparing them to one or more particular platforms. To make this comparison, we took the total operating cost of each particular platform. We determined the operating cost of airships against each platform by taking the lowest operating cost of each platform and dividing it by the total number of operating hours airships need for a particular mission. The result of this summation is the same as we previously calculated, but these calculations provide the total costs of just one platform rather than the costs of the three aircraft platforms combined, which is the result we explained in prior paragraphs. These equations are explained and delineated further in Chapters VI and VII, in the Scenario 1 and 2 analysis.

b. Platform Savings

The airship hourly operating costs calculated in the replacement operating costs section are the maximum threshold that an airship's hourly cost needs to be below. Anything beyond the maximum threshold will make that particular airship more costly than the aircraft it is being compared against. With this in mind, we calculated what cost savings could be achieved by lowering the hourly operating costs of the airship below the threshold for each particular platform. We estimated the cost savings by reducing the maximum threshold dollar amount by $100 at a time, up to total of $1,000. The total overall costs of a mission were calculated in the same manner as described for the one-to-one comparison and the break-even analysis; however, the hourly operating costs were lowered up to the total of $1,000 to observe the overall cost savings of a particular mission.

c. Variable Short Tons with Constant Mission Duration Time

Throughout this analysis, we focused on maintaining 2,500 short tons for lift requirements, yet in real-world operations lift requirements vary from mission to mission. This section of analysis examined the effects of varying lift requirements over a fixed mission time duration of 168 and 744 hours. The goal of this section was to determine at what point the varying tonnage negatively affects the hourly operating costs of airships. In order to calculate the output of overall cost based on tonnage, the same equations were used as throughout the rest of this section; however, the tonnage was made variable while the mission duration time was a fixed constant.

4. Autonomous Airships—Manned vs. Unmanned

The goal of the manned versus unmanned section was to determine the cost savings that could be gained if airships could be designed with unmanned variants. Missions are based on 744 hours while transporting 2,500 short tons. The models output total cost savings between manned and unmanned systems.

Each variable can be changed, depending on the platform, for planning purposes. The inputs for the manned section included the total operating cost and the total manning costs that provide the total overall costs. The input for the unmanned section was only the total operating cost. The total cost change is the difference between manning cost and unmanned cost. The output is based on time and tonnage. The calculations for total operating cost, total manning cost, and total overall cost were described previously and are explained in further detail in Chapters VI and VII.

The manned versus unmanned spreadsheet compares all the airships based on their hourly operating cost, which was explained and derived in previous sections and is also presented in Chapters VI and VII.

5. Additional Airship Analysis

The goal of the additional airship analysis was to determine the overall operating and manpower hour reductions if airship developers were able to increase block speed or cargo capacity. The increase in these two variables would decrease the turnaround time (TAT) of each mission, allowing greater flexibility in the number of airships required and the types of missions airships could accomplish. The output of this model shows the reduction of total operating hours and the total manpower hours that result from increasing block speed and cargo capacity by 25%, 50%, 75%, and 100%.

Missions are based on 168 hours and the transport of 2,500 short tons. Cost savings were not analyzed in this chapter. Block speed and cargo capacity were the only characteristics examined in Chapter VIII. Hourly operating costs were derived for each of the airship platforms in Chapters VI and VII; however, the total cost savings that result from increasing block speed and cargo capacity could be understated without the valid hourly operating costs. Once the manufacturers of airships have established valid hourly operating costs, the operating and manpower hours output of this analysis can easily be calculated to determine a cost savings.

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VI. ANALYSIS FOR SCENARIO 1

A. ONE-TO-ONE COMPARISON

A one-to-one comparison was conducted for Scenario 1 (Appendix 8, Figure 43) to establish a baseline against which to analyze the characteristics of individual platforms. The purpose of the one-to-one comparison was to show the varying characteristics of each platform when time is not a critical factor. The characteristics include operating hours, turn-around time (TAT), number of sorties, and planned payload.

With these characteristics in mind, we calculated the number of days to complete a mission consisting of 2,500 short tons. A mission is defined as the total amount of time it takes to complete the delivery of the 2,500 short tons of cargo, given a certain number of sorties and a specific TAT for each platform. The ability of a platform to complete a round-trip from point of embarkation, to point debarkation, and back to the point of embarkation is called a "sortie." The equivalent of "sortie" for the MSC platforms is "trip," which has the same meaning. In this analysis, for the mission to be considered complete, all platforms must conduct a full sortie or trip. In order to calculate steady state of platforms, we recognized that a sortie or trip is twice the distance from the point of embarkation to the point of debarkation. The TAT is also used to determine the optimal number of platforms needed to complete a particular mission. The operating hours to complete a sortie or trip, the number of sorties or trips needed, and the TAT for each platform to complete the delivery of 2,500 short tons were calculated as follows.

The ratio of twice the distance (D) and the block speed (B) of the platform provides the operating hours (T_P) per sortie or trip of the platform (Equation 1). The summation of double the ground time (T_G), operating time of platforms per sortie or trip (T_P), pre-checks (for air platforms only; T_C), and double the crew rest times (for air platforms only; T_R) calculates the turn-around time (T_A) for each platform (Equation 2)**.** Later in this analysis, we change Equation 2 due to the crew rest being 12 hours rather than 24 hours since additional crews are available to augment a platform. Table 2 shows the variables associated with Equations 1 and 2.

Table 2. Variable Characteristics for Equations 1 and 2

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
D	DISTANCE	NAUTICAL MILE (NM)
B	BLOCK SPEED	KNOTS (KTS)
T_G	GROUND/ONLOAD/OFFLOAD TIME	HOUR (HR)
T_C	FLIGHT PRE-CHECK TIME	HOUR (HR)
T_R	CREW REST TIME	HOUR (HR)
T_P	OPERATING TIME PER PLATFORM	HOUR (HR)
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)

We define Equations 1 and 2 as follows:

(T_P: = Operating Time of Platforms)

$$T_P = (2 * D / B) \quad (1)$$

(T_A: = Turn-Around-Time)

$$T_A = 2 * T_G + T_P + T_C + 2 * T_R \text{ (single-platform)}$$
$$T_A = 2 * T_G + T_P + T_C + T_R \text{ (multi-platform)} \quad (2)$$

Logic parameters for each platform are used to calculate the total number of sorties or trips needed (S_{AT}) to complete a mission given a cargo movement capacity (Equation 3). If TAT (T_A) is greater than mission duration time (T_M), the total number of sorties will equal zero ($S_{AT} = 0$). If T_A is less than T_M and cargo moved (C_M) is greater than plan cargo load (C_P), S_{AT} will equal one. If C_M is less than C_P and the ratio of C_M and C_P multiplied by T_A is less than T_M, then S_{AT} will equal C_M divided by C_P, rounded up to the nearest whole number. If the opposite is true, S_{AT} will equal T_M divided by T_A, rounded down to the nearest whole number. This portion of the analysis assumes that there is only one logistical platform (I_{AT}) to conduct this mission. Table 3 shows the variables associated with Equation 3.

Table 3. Variable Characteristics for Equation 3

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AT}	TOTAL NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)
I_{AT}	TOTAL NUMBER OF PLATFORMS	PLATFORMS

Equation 3 is defined as follows:

(S_{AT}: = Maximum Number of Sorties/Trip per Platform)

IF ($T_A > T_M$)
$S_{AT} = 0$
ELSE
    IF ($C_P < C_M$)
    $S_{AT} = 1$
    ELSE
        IF ($C_M / C_P * T_A < T_M$)
            IF ($I_{AT} = 1$)
            S_{AT} = Roundup (C_M / C_P, 0)
            ELSE
            S_{AT} = Rounddown (T_M / T_A, 0) (3)

The product of the total number of platforms (I_{AT}), the total number of sorties or trips needed (S_{AT}), and operating hours per sortie or trip (T_P) calculates the total operating hours (T_O) of each platform to perform a mission (Equation 4). Again, for this single-unit analysis, we assumed that the number of platforms is equal to one ($I_{AT} = 1$). Logic functions were placed in most of the equations to determine if a platform is capable of completing the mission given the platform's TAT and time to complete the mission. Table 4 shows the variables associated with Equation 4.

Table 4. Variable Characteristics for Equation 4

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_O	TOTAL OPERATING HOURS	HOUR (HR)
T_P	OPERATING HOURS PER PLATFORM	HOUR (HR)
I_{AT}	TOTAL PLATFORMS	PLATFORMS
S_{AT}	TOTAL NUMBER OF SORTIES/TRIPS REQUIRED	SORTIES/TRIPS

Equation 4 is defined as follows:

(T_O: = Total Operating Hours) $T_O = I_{AT} * S_{AT} * T_P$ (4)

Appendix 2-4 shows the platform characteristics used in Table 5; to illustrate Equations 1–4, the characteristics of the C-130J are used as an example.

Table 5. C-130J Characteristics for 2,500 Short Tons

SYMBOLS:	VARIABLE DESCRIPTIONS:	VALUES:
D	DISTANCE	2800 nm
B	BLOCK SPEED	320 kts
C_P	PAYLOAD CAPACITY FOR PLATFORM	18 s. tons
C_M	CARGO MOVEMENT REQUIREMENT	2500 s. tons
T_G	GROUND/ONLOAD/OFFLOAD TIME	2.25 hrs
T_C	FLIGHT PRE-CHECK TIME	3 hrs
T_R	CREW REST TIME	12 hrs
I_{AT}	TOTAL PLATFORMS	1
T_P	OPERATING HOURS PER SORTIE OR TRIP	-
T_A	TAT FOR PLATFORMS	-
S_{AT}	TOTAL NUMBER OF SORTIES OR TRIPS REQUIRED	-
T_O	TOTAL OPERATING TIME	-

The operating hours (T_P) per C-130J can be calculated by using Equation 1:

$T_P = (2 * D / B) = (2 * 2800 \text{ nm}) / 320 \text{ kts} = 17.5$ hrs.

Turn-around-time (T_A) can be calculated by using Equation 2:

$T_A = 2 * T_G + T_P + T_C + 2 * T_R = (2 * 2.25 \text{ hrs}) + 17.5 \text{ hrs} + 3 \text{ hrs} + (2 * 12 \text{ hrs}) = 49.0$ hrs.

The maximum number of sorties (S_{AT}) required to be flown by a C-130J can be calculated by Equation 3:

S_{AT} = Roundup (C_M / C_P, 0) = Roundup (2,500 tons/18 tons) = 139 sorties.

Finally, the total operating time (T_O) to complete a mission is represented by Equation 4:

$T_O = I_{AT} * S_{AT} * T_P$ = 1 aircraft * 139 sorties * 17.5 hrs = 2432.5 hrs.

Table 6 shows the varying operating hours needed for each platform to complete the delivery of 2,500 tons over 2,800 and 3,800 nautical miles for airlift and sealift platforms, respectively.

Table 6. Single Platform to Complete Mission of 2,500 Short Tons with no Time Constraint

PLATFORMS	OPERATING HRS:	TURN-AROUND-TIME (Hrs):	MAXIMUM SORTIES/TRIPS:	TOTAL OPERATING HOURS (Hrs):
C-130J	17.5	49.0	139	2432.5
C-17	13.8	45.3	56	772.4
C-5M	13.5	45.0	41	551.9
LMSR	672.8	672.8	1	672.8
FSS	626.9	626.9	1	626.9
SKYCAT 220	66.7	118.3	12	800.0
H2 CLIPPER	18.4	66.8	13	239.5
AEROSCRAFT	46.7	72.5	39	1820.0
HAV 366	53.3	76.7	50	2666.7
SKYHOOK	80.0	101.7	63	5040.0
LEMV	70.0	86.7	250	17500.0

The single-unit comparison shows each platform's performance if only one unit is available to conduct a mission of 2,500 short tons. This comparison does not have a time criticality factor, thus allowing each platform an unlimited amount of time to conduct the mission. In this case, the performance measure of lowest total operating hours is used to determine the best suited platform to conduct this mission. We can conclude that the platforms best suited to conduct the mission of 2,500 short tons are the H2 Clipper and C-5M. The H2 Clipper airship beat out all three AMC platforms, both sealift vessels, and the other five airships. In addition, three out of six airships beat out the C-130J platform in total operating hours required to complete the mission. Based on the previous equations, it can also be deduced that as the amount of cargo moved increases, the total operating hours and the number of sorties or trips required will also increase. The relationship of the amount of cargo moved and the total operating time for all platforms can be seen in Figure 3.

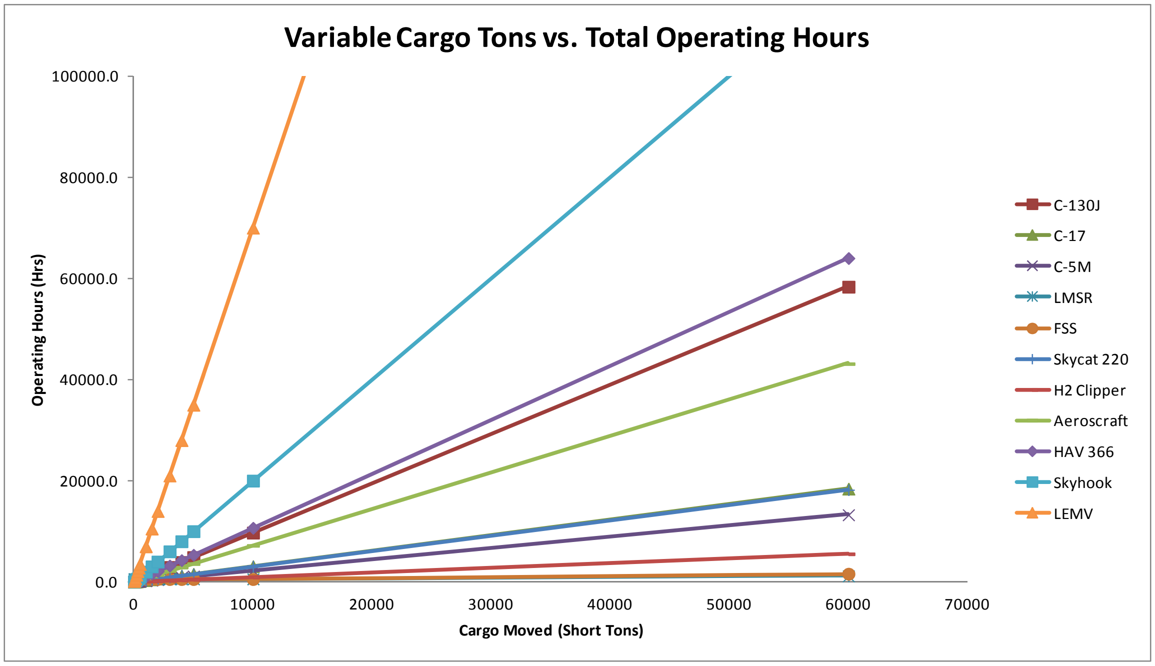

Figure 3. Cargo Tons Moved vs. Total Operating Hours—One-to-One Comparison with 2,800 Nautical Miles for Airlift and 3,800 for Sealift

As the tonnage movement requirement increases, the operating hours increase. The steepness of each platform's slope is determined by the block speed and the payload capacity of each platform. A lower block speed and smaller payload would require more sorties or trips to complete a mission. The increase in sorties or trips will increase the total operating hours required to move a certain amount of tonnage. The steeper the slope, the more sorties or trips are required to complete a mission. The LEMV airship's slope increases the fastest over a variable tonnage requirement and, therefore, is the least likely airship to be used for logistics deliveries with large tonnage requirement. On the opposite side of the spectrum, the FSS and LMSR are the preferable platforms to deliver a large tonnage requirement, as long as time is not a crucial factor.

B. BREAK-EVEN MODEL

A break-even model is used to find the maximum hourly operating costs airships can incur and be competitive with current platforms. This model calculates the minimum number of platforms required to complete a mission. The number of platforms can be determined with the time it takes to complete a mission, the total distance of a mission, and the total tonnage to be delivered. Once the number of platforms is established a minimum operating cost among current airlift platforms can be found. The minimum costs for the airlift platforms are then used as the maximum operating cost for airships. In addition to these hourly operating costs, the model provides manning costs, overall cost of missions using airships, and the cost per ton-nautical mile. Finally, the break-even model will output the total cost savings gained from using autonomous airships rather than manned variants.

1. Operational Efficiency

The first section of the break-even model outlines the operational efficiency of the platforms analyzed. The term "operational efficiency" refers to the total number of platforms required, trips or sorties that each platform must conduct, and the crews required to provide a steady state or constant flow of platforms to complete a given mission. The driving factors for the operational efficiency model are the total distance to complete the mission and the total tonnage that must be moved.

With the new time restraint, or "mission duration" (T_M), to conduct a mission, more than one platform will be required to complete a mission if the total tonnage that must be moved is greater than a platform's planned payload capacity. Unlike the one-to-one comparison analysis where only one platform was used, here we must calculate the total number of platforms (I_{AT}) required to complete a mission within a certain mission duration time (Equation 5). A logical function is used to determine whether or not a platform could perform the 2,500 short ton mission in a given time span. If the TAT (T_A) is greater than the mission duration time (T_M), the platform in question would not be selected and would be given an output of zero ($I_{AT} = 0$). If T_A is less than T_M, the number of platforms (I_{AT}) needed to complete a mission would be calculated by rounding up the ratio of cargo moved (C_M) divided by the product of planned payload (C_P) and the total number of sorties or trips required (S_{AT}). A partial platform cannot be used in order to complete a mission and, therefore, the output is rounded up to the nearest whole number.

Table 7 shows the variables associated in Equation 5 with the transportation of 2,500 short tons.

Table 7. Variable Characteristics for Equation 5

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AT}	TOTAL NUMBER OF SORTIES/TRIPS REQUIRED	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)
I_{AT}	TOTAL NUMBER OF PLATFORMS REQUIRED	PLATFORMS

We used the following equation:

(I_{AT}: = Total Number of Platforms Required)
IF ($T_A > T_M$)
$I_{AT} = 0$
ELSE
I_{AT} = Roundup (C_M / (C_P * S_{AT}), 0) (5)

Not all platforms will conduct the maximum number of sorties/trips due to the amount of tonnage required to be moved. Instead, a certain number of platforms (I_{AF}) will conduct the maximum sorties/trips (S_{AF}) while the remaining platforms will conduct the remaining sorties/trips. In order to derive the number of platforms (I_{AF}) needed to conduct the maximum number of sorties required (S_{AF}), a logic statement compares the product of maximum number of sorties or trips required (S_{AT}), total platforms required (I_{AT}), and planned payload (C_P) against cargo moved (C_M). If the product of these three variables is less than C_M, the I_{AF} is equal to $I_{AT} – 1$. If not, the I_{AF} is equal to the I_{AT} (Equation 6). To determine the maximum number of sorties/trips (S_{AF}), we used the same logic statement to compare the product of S_{AT}, I_{AT}, and C_P against C_M. If the product of these three variables is greater than C_M, then S_{AF} is equal to $S_{AT} – 1$, or else S_{AF} will equal S_{AT} (Equation 7). Table 8 shows the variables associated with Equations 6 and 7.

Table 8. Variable Characteristics for Equations 6 and 7

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AT}	TOTAL NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
S_{AF}	MAXIMUM NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)
I_{AT}	TOTAL NUMBER OF PLATFORMS	PLATFORMS
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	PLATFORMS

Equations 6 and 7 determine the number of platforms required to complete the maximum number of sorties for a given mission:

(I_{AF}: = Number of Platforms to Conduct Maximum Sorties/Trips)

IF ($T_A > T_M$)
$I_{AF} = 0$
ELSE
    IF($S_{AT}*I_{AT}*C_P > C_M$)
        IF($S_{AT}*I_{AT}*C_P - C_M > C_P$)
        $I_{AF} = I_{AT}-1$
        ELSE
        $I_{AF} = I_{AT}$
    ELSE
    $I_{AF} = I_{AT}$ (6)

(S_{AF}: = Maximum Number of Sorties/Trips)

IF ($I_{AF} * S_{AT} * C_P < C_M$)
$S_{AF} = S_{AT} - 1$
ELSE
$S_{AF} = S_{AT}$ (7)

The total number of aircraft required will not always need to conduct the maximum number of sorties for a given mission. To ensure the number of total sorties is not inflated, the limited number of sorties (S_{AP}) and the number of platforms that only complete a limited number of sorties (I_{AP}) must be calculated. If turn-around time (T_A) is greater than mission duration time (T_M), then S_{AP} is equal to zero. Otherwise, if I_{AF} is less than I_{AT}, S_{AP} is equal to the difference of C_M and the product of S_{AF}, I_{AF}, and C_P divided by C_P rounded up to the nearest whole number (Equation 8). For I_{AP}, if T_A is greater than T_M, I_{AP} is equal to zero. If I_{AF} is less than I_{AT}, I_{AP} is equal to the difference between C_M

minus the product of S_{AF}, $I_{AF,}$ and C_P divided by the product of C_P and S_{AP} (Equation 9). Table 9 shows the variables associated with Equations 8 and 9**.**

Table 9. Variables Characteristics of Equations 8 and 9

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AF}	MAXIMUM NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
S_{AP}	LIMITED NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	PLATFORMS
I_{AT}	TOTAL NUMBER OF PLATFORMS	PLATFORMS
I_{AP}	NUMBER OF PLATFORMS COMPLETING LIMITED SORTIES/TRIPS	PLATFORMS

Equation 8 determines the number of platforms that complete only a limited number of sorties:

(S_{AP}: = Limited Amount of Sorties/Trips)
IF ($T_A > T_M$)
$S_{AP} = 0$
ELSE
    IF ($I_{AF} < I_{AT}$)
    S_{AP} = Roundup ((C_M – [S_{AF} * I_{AF} * C_P]) / C_P, 0)
    ELSE
    $S_{AP} = 0$ (8)

(I_{AP}: = Number of Platforms Only Completing Limited Sorties/Trips)
IF ($T_A > T_M$)
$I_{AP} = 0$
ELSE
    IF ($I_{AF} < I_{AT}$)
    $I_{AP} = I_{AT} - I_{AF}$
    ELSE
    $I_{AP} = 0$ (9)

Given the number of platforms required to complete a mission, manpower in the form of crews will be required to supply a steady state of platforms. The number of crews (W) is equal to the product of the total number of platforms (I_{AT}) multiplied by 2 (Equation 10).

Equation 10 was used to determine the number of crews (W) required:

(W: = Number of Crews for Platforms) $W = I_{AT} \times 2$ (10)

Table 10 shows the platform characteristics, provided in detail in Appendix 2-4, of the C-130J. C-130J will be used to illustrate the use of Equations 5–10.

Table 10. C-130J Characteristics for 2,500 Short Tons

SYMBOLS:	VARIABLE DESCRIPTIONS:	VALUES:
C_P	PAYLOAD CAPACITY FOR PLATFORM	18 s. tons
C_M	CARGO MOVEMENT REQUIREMENT	2500 s. tons
T_A	TURN-AROUND TIME PER PLATFORM	49 hrs
T_M	MISSION DURATION TIME	168 hrs

Before using Equations 5 through 9, we must re-calculate the maximum number of sorties or trips required (S_{AT}) for the C-130J due to multiple platforms being involved (Equation 3). with time now a critical factor, Equation 3 uses the mission duration time (T_M) divided by the TAT (T_A), rounded down to determine the maximum number of sorties or trips required (S_{AT}). with Equation 3, we can calculate S_{AT}:

S_{AT} = Rounddown(T_M / T_A, 0) = Rounddown (168 hrs / 49 hrs) = 3 sorties.

The total number of C-130J platforms (I_{AT}) required to complete the mission can be derived by using Equation 5:

I_{AT} = Roundup (C_M / (C_P * S_{AT}))

= Roundup (2,500 tons / (18 tons * 3 sorties)) = 47 platforms needed.

The number of C-130J platforms needed to conduct the maximum number of sorties/trips (I_{AF}) is determined by S_{AT}. Because the product of S_{AT}, I_{AT}, and C_P minus C_M is less than C_P, Equation 6 becomes the following:

$I_{AF} = I_{AT} - 1$ = 47 platforms – 1 = 46 platforms.

The majority of the C-130J platforms will perform the maximum number of sorties/trips (S_{AF}); therefore, we use Equation 7: $S_{AF} = S_{AT}$ = 3 sorties.

Because I_{AF} is less than I_{AT}, we can calculate the limited number of sorties (S_{AP}) that platforms are required to conduct to complete a mission. Equation 8 is used to calculate the limited sorties required:

S_{AP} = Roundup ((C_M – [S_{AF} * I_{AF} * C_P])/ C_P, 0) = Roundup ((2500 – [3 sorties * 46 platforms * 18 tons]) / 18 tons) = 1 sortie.

We can calculate the number of platforms (I_{AP}) to conduct this single sortie. Using Equation 9, we can calculate the number of platforms needed:

$I_{AP} = I_{AT} - I_{AF}$ = 47 platforms – 46 platforms = 1 platform required.

Finally, to run the 47 C-130J platforms, crews (W) must be assigned to augment these platforms. Equation 10 states the following: $W = I_{AT} * 2$ = 47 platforms * 2 = 94 crews.

Tables 11 and 12 both show the total number of platforms, maximum sorties/trips, limited sorties/trips, platforms to conduct limited sorties/trips, and platform crews to complete a mission of 2,500 short tons based on mission duration times of 168 and 744 hours, respectively. In order to effectively compare platforms, mission duration is increased to show the value of sealift platforms when time is not a critical factor.

Table 11. Platform Characteristics—2,500 Short Tons with a 168-Hour Mission Duration Time

PLATFORMS	TOTAL TRIPS/SORTIES:	TOTAL PLATFORMS REQ:	NO. OF CREWS:	MAX TRIPS/SORTIES PER PLATFORM:	NO. OF PLATFORMS TO COMPLETE MAX TRIPS/SORTIES:	NO. OF REMAINING TRIPS/SORTIES:	NO. OF PLATFORMS REMAINING TRIPS/SORTIES:	TOTAL OPERATING HOURS:
C-130J	3	47	94	3	46	1	1	2432.5
C-17	3	19	38	3	18	2	1	772.4
C-5M	3	14	28	3	13	2	1	551.9
SKYCAT 220	1	12	24	1	12	0	0	800.0
H2 CLIPPER	2	7	14	2	6	1	1	239.5
AEROSCRAFT	2	20	40	2	19	1	1	1820.0
HAV 366	2	25	50	2	25	0	0	2666.7
SKYHOOK	1	63	126	1	63	0	0	5040.0
LEMV	1	250	500	1	250	0	0	17500.0

Table 11 shows the output of each platform when mission duration totals 168 hours. As it is expected, the LMSR and FSS platforms cannot complete this mission within the mission duration time due to their TATs being greater than the required 168 hours. with both sealift platforms unavailable, the reminder of this analysis focuses on the remaining platforms.

The important performance measures for this section of the analysis are the lowest total operating hours, lowest number of aircraft, the least number of sorties, and the least number of crews to complete the mission of 2,500 short tons within 168 hours. Not all aircraft will need to conduct the maximum number of sorties. For example, the C-130J requires 46 of the 47 aircraft to conduct a maximum of three sorties. The additional aircraft is required to complete one sortie in order to minimize the number of sorties required to deliver 2,500 short tons. This logic is applied to the rest of the platforms in the analysis.

From the analysis, we can see the airships favor comparably with the aircraft. Two of the six airships required fewer platforms than all three aircraft. In addition, two of six airships required fewer crews than the aircraft, and four of the six airships were comparable with the aircraft in the number of crews required. Finally, all six airships required fewer sorties to complete a mission than all of the aircraft in this analysis.

The H2 Clipper airship outperformed all platforms for this particular mission, while the LEMV was considered the outlier when adhering to these performance standards. The H2 Clipper's performance for this particular mission is due to its relatively large payload capacity of 200 short tons and its block speed of over 300 knots. The airships compare favorably in this section of the analysis, but it is important to remember the characteristics used for all the airships are best estimates provided by their respective companies. The airships' true potential cannot be fully realized until airships have been fully built and tested to those characteristics; however, our model is robust in that a practitioner can input the true parameters and it will calculate the true characteristics of the airship.

Table 12. Platform Characteristics—2,500 Short Tons with a 744-Hour Mission Duration Time

PLATFORMS	TOTAL TRIPS/SORTIES:	TOTAL PLATFORMS REQ:	NO. OF CREWS:	MAX TRIPS/SORTIES PER PLATFORM:	NO. OF PLATFORMS TO COMPLETE MAX TRIPS/SORTIES:	NO. OF REMAINING TRIPS/SORTIES:	NO. OF PLATFORMS REMAINING TRIPS/SORTIES:	TOTAL OPERATING HOURS:
C-130J	15	10	20	15	9	4	1	2432.5
C-17	16	4	8	16	3	8	1	772.4
C-5M	16	3	6	16	2	9	1	551.9
LMSR	1	1	1	1	1	0	0	672.8
FSS	1	1	1	1	1	0	0	626.9
SKYCAT 220	6	2	4	6	2	0	0	800.0
H2 CLIPPER	11	2	4	11	1	2	1	239.5
AEROSCRAFT	10	4	8	10	3	9	1	1820.0
HAV 366	9	6	12	9	5	5	1	2666.7
SKYHOOK	7	9	18	7	9	0	0	5040.0
LEMV	8	32	64	8	31	2	1	17500.0

Table 12 shows the output of each platform when mission duration totals 744 hours. Unlike with the previous mission duration time of 168 hours, the LMSR and FSS platforms are now available to complete the 2,500 short ton mission within the given mission duration time. The C-5M and H2 Clipper both outperform the aircraft, sealift, and other airships in these performance measures. In addition, as the mission duration time increases, the number of air platforms decreases and the number of sorties increases. The increased number of sorties counteracts the decreased number of air platforms required to complete the mission, but the total operating hours remain the same. An increase of mission duration time will not affect the total operating time to complete a mission, but it will dictate the number of sorties and platforms required when tonnage remains the same. The total cost of procurement of air platforms versus the overall maintenance cost of conducting more sorties will need to be addressed in future research.

2. Hourly Operating Costs for Airships

The hourly operating costs of current platforms are firmly established; however, due to the absence of completed airships, the hourly operating costs of airships were derived from current airlift platforms. The total operating cost (N_O) is calculated by the calculating the product of total operating hours of the platform (T_O) and the average hourly operating cost of the platform ($H_{P;}$ Equation 11**)**. The total operating hours and the total operating cost remain the same despite the varying mission duration time. As mission duration time changes, the number of sorties and platforms changes to equal the same total operating hours. A “push-and-pull” effect occurs between the number of sorties and platforms required to complete a mission with a changing mission duration time. The total operating time will always remain unchanged until the total tonnage requirement changes. Table 13 defines the variable characteristics for Equation 11 and includes the C-130J input characteristics.

Table 13. Variable Characteristics for Equation 11, Including C-130J Input Parameters

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J PARAMETERS:
N_O	TOTAL OPERATING COSTS	HOUR (HR)	-
T_O	TOTAL OPERATING HOURS	HOUR (HR)	2432.5 hrs
H_P	HOURLY OPERATING COSTS FOR PLATFORM	DOLLAR/HOUR	$5,945.00/hr

Equation 11 is defined as follows:

(N_O: = Total Operating Costs) $N_O = T_O * H_P$ (11)

The C-130J's total operating costs (N_O) can be calculated from the total operating hours (T_O) and the hourly operating costs of the C-130J as follows:

$N_O = T_O * H_P$ = (2432.5 hrs) * ($5,945.00/hr) = $14,461,212.50.

When rounding is involved, a rounding error may exist where calculated costs differ slightly from actual costs.

Tables 14 and 15 show the operating costs for all platforms, with the exception of airships, for mission duration times of 168 and 744 hours.

Table 14. Total Operating Costs for AMC/MSC Platforms—2,500 Short Tons and a 168-Hour Mission Duration Time

MISSION HOURS:	C-130J OP COSTS($):	C-17 OP COSTS($):	C-5M OP COSTS($):	LMSR OP COST ($):	FSS OP COST ($):
168	$ 14,461,212.50	$ 10,938,151.72	$ 19,657,292.31	N/A	N/A

Table 14 shows that the C-17 air platform has the lowest operating cost of the platforms that can deliver 2,500 tons within a 168-hour mission duration time. The C-17 has the second lowest operating hours amongst the three aircraft (Table 12) yet its costs are twice as low as the C-5M. This difference in hourly operating costs makes the C-17 the least costly aircraft in this situation. The LMSR and FSS platforms are not available to complete this mission within the specified mission duration time due to these platforms' turn-around times.

Table 15. Total Operating Costs for AMC/MSC Platforms—2,500 Short Tons and a 744-Hour Mission Duration Time

MISSION HOURS:	C-130J OP COSTS($):	C-17 OP COSTS($):	C-5M OP COSTS($):	LMSR OP COST ($):	FSS OP COST ($):
744	$ 14,461,212.50	$ 10,938,151.72	$ 19,657,292.31	$ 124,253.33	$ 809,907.70

Table 15 shows the same scenario, but with a mission duration time of 744 hours. This extension in mission duration time allows the LMSR and FSS to complete the mission with only a 2,500 short ton cargo requirement. Both the LMSR and FSS have lower operating costs than the C-17 and the other two aircraft. The lower operating costs can be attributed to the use of only one ship and one trip for each to complete the 2,500 short ton mission, therefore, reducing the total operating hours required to complete the mission. The aircraft platforms have the advantage over the ship platforms when mission duration times range from 48–626.9 hours, because the FSS is able to compete the mission. When mission duration time is extended beyond 672.8 hours, the LMSR has the lowest operating costs amongst all the platforms.

The total hourly operating cost ($H_{P\text{-}AIRSHIP}$) of airships is equal to the ratio of the total operating cost ($N_{O\text{-}PLATFORM}$) of a platform and the total operating time ($T_{O\text{-}AIRSHIP}$) for an airship (Equation 12). We derived the hourly operating costs of airships ($H_{P\text{-}AIRSHIP}$) by utilizing the total operating costs derived the air platforms in Tables 14 and 15**.** Because Table 14 excludes the ship platforms due to mission duration times, we will use the information provided in Table 15 when ship platforms are included. Table 16 is used to define the variable description for Equation 12 and provide the input characteristics for the C-130J and the Skycat 220.

Table 16. Variable Descriptions for Equation 12 and C-130J and Skycat 220 Characteristics—2,500 Short Tons with a 744-Hour Mission Duration Time

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J PARAMETERS	SKYCAT 220 PARAMETERS
$H_{P\text{-}AIRSHIP}$	HOURLY OPERATING COSTS FOR AIRSHIP	DOLLAR/HOUR	-	-
$N_{O\text{-}AIRCRAFT}$	TOTAL OPERATING COSTS FOR AIRCRAFT	DOLLAR	$14,461,212.50	-
$T_{O\text{-}AIRSHIP}$	TOTAL OPERATING HOURS FOR AIRSHIP	HOUR	-	800 hrs

Equation 12 is defined as follows:

($H_{P\text{-}AIRSHIP}$: = Hourly Operating Cost of Airships)

$$H_{P\text{-}AIRSHIP} = N_{O\text{-}AIRCRAFT} / T_{O\text{-}AIRSHIP} \quad (12)$$

For example, to calculate the break-even hourly cost between the C-130J aircraft and Skycat 220, we used the total operating cost of the C-130J ($N_{O\text{-}C\text{-}130J}$) to transport 2,500 short tons (see Table 15**)** and the total operating hours ($T_{O\text{-}SKYCAT\ 220}$) for the Skycat 220 to transport the same amount of cargo:

$H_{P\text{-}SKYCAT\ 220} = N_{O\text{-}C\text{-}130J} / T_{O\text{-}SKYCAT\ 220}$ = \$14,461,212.50 / 800 hrs = \$18,076.52/hr.

Using Equation 12, Table 17 shows the break-even hourly operating costs between each platform and each airship for the cargo movement requirement of 2500 short tons:

Table 17. Break-Even Hourly Costs Between Each AMC/MSC Platform and Airships

MISSION DURATION: 744 HRS **CARGO MOVEMENT:** 2500 SHORT TONS	**C-130J OP COSTS($):**	**C-17 OP COSTS($):**	**C-5M OP COSTS($):**	**LMSR OP COST ($):**	**FSS OP COST ($):**
SKYCAT 220	$ 18,076.52	$ 13,672.69	$ 24,571.62	$ 155.32	$ 1,012.38
H2 CLIPPER	$ 60,387.48	$ 45,675.80	$ 82,085.40	$ 518.86	$ 3,382.03
AEROSCRAFT	$ 7,945.72	$ 6,009.97	$ 10,800.71	$ 68.27	$ 445.00
HAV 366	$ 5,422.95	$ 4,101.81	$ 7,371.48	$ 46.59	$ 303.72
SKYHOOK	$ 2,869.29	$ 2,170.27	$ 3,900.26	$ 24.65	$ 160.70
LEMV	$ 826.36	$ 625.04	$ 1,123.27	$ 7.10	$ 46.28

To determine the minimum overall hourly operating costs for each airship to use in the rest of this analysis, we decided to choose the lowest hourly operating cost among the three air platforms versus the sealift platforms. Airships' characteristics closely resemble that of an aircraft and, therefore, would actually better portray hourly operating costs for the rest of the analysis. Choosing the lowest hourly operating costs from the three aircraft allows us to estimate the cost that an airship can operate at to meet the total operating cost of all three aircraft. These costs represent the maximum hourly threshold for airship hourly operating costs in order for them to be competitive with current aircraft.

To determine the minimum overall hourly operating costs, we extracted the lowest hourly operating cost amongst all three aircraft. Based on the data in Table 17, the C-17 had the lowest total operating cost for the transportation of 2,500 short tons. Table

18 summarizes the hourly operating cost and total operating costs (Equation 11) of each airship, based off the C-17 total operating costs. These are the costs that will be used for the rest of the analysis.

Table 18. Hourly Operating Costs for Each Airship—2,500 Short Tons

AIRSHIPS	HOURLY OP COST BASELINE:	TOTAL OP COSTS:
SKYCAT 220	$ 13,672.69	$ 10,938,151.72
H2 CLIPPER	$ 45,675.80	$ 10,938,151.72
AEROSCRAFT	$ 4,101.81	$ 10,938,151.72
HAV 366	$ 4,101.81	$ 10,938,151.72
SKYHOOK	$ 2,170.27	$ 10,938,151.72
LEMV	$ 625.04	$ 10,938,151.72

The total operational costs for each airship, as calculated in Table 18, are the same as the C-17's total operating costs. The break-even hourly operating costs for each airship were calculated by dividing the total operating hours of each airship into the C-17's total operating costs. In order to calculate the total operating cost of each airship, total operating hours must be multiplied again with the break-even hourly operating costs, therefore, cancelling out the total operating hours and giving the total operating cost of the C-17. Further analysis will show that all the airships will have the same total operating costs, but a later section analyzes the change in total operating costs based on a reduction in hourly operating costs for each airship.

Table 18 does not necessarily represent the hourly operating costs of an airship. Instead, it gives an hourly operating cost threshold at which anything greater than this cost will exclude an airship as a cost-effective alternative to other heavy-lift platforms. A larger baseline, therefore, represents an attractive alternative. Said another way, the H2 Clipper can have an hourly operating cost up to $45,675.80 and still be a competitive option compared to all heavy-lift platforms. A larger baseline provides a less restrictive range in which airships have to improve or meet the baseline. A lower baseline provides a more restrictive situation where an airship can improve hourly operating costs from the baseline. Therefore, since the H2 Clipper and Skycat 220 have the highest hourly operating cost baselines, both have the advantage to seek improvements on their hourly operating costs compared to the other airships.

For certain mission durations, some platforms could not meet the required TAT; therefore, the output of hourly operating costs did not exist. The minimum hourly operating costs was chosen from the range of values where a special function was implemented in Excel to disregard all hourly operating costs that were not applicable. As mentioned previously, MSC break-even operating costs were excluded from assigning an hourly cost because airship characteristics closely resemble that of aircraft.

Table 17 shows the break-even hourly operating costs for an airship to compete against MSC platforms. The LMSR and FSS platforms' hourly operating cost ranges from $7.10 to $3,382.03. Sealift platforms will always have the lowest overall hourly operating cost because they require fewer platforms and trips to complete a mission cargo load requirement of 2,500 short tons. In addition to minimum platform and trips, an MSC ship will not depart a port unless it is at or near its maximum plan payload, which allows the total cost of a mission to be spread across the total tonnage it is carrying.

In this analysis, we calculated the total operating cost and manpower cost for moving 2,500 short tons with an MSC ship by taking the ratio of the total tonnage required to be moved and the total plan payload capacity, and then multiplying this ratio by the actual total operating costs of moving the maximum payload capacity. In a similar fashion, we calculated manpower cost to move the required tonnage by taking the ratio of total tonnage required to be moved by the total planned payload, and then multiplying this ratio by the total manpower cost of moving the maximum payload capacity.

There will always be a trade-off between mission duration time and what platform is chosen to complete a particular mission. When time critical missions are necessary, MSC ships are usually excluded from the options. Although airships share the operating characteristics of aircraft, airships can obtain an hourly operating cost that can make them a viable alternative to MSC ships. Later in the analysis, we discuss airship manufacturers' options for improving these ships' operating characteristics so they can possibly become a viable alternative to MSC ships.

3. Manning and Overall Costs

In addition to total operating costs, manning costs were also factored into the overall cost of a mission. Each platform is manned either by a crew of officers and enlisted staff or civilians. Before calculating the total manning costs, the total manpower hours must be calculated. The total manpower hours (T_T) is calculated by multiplying the total number of platforms performing the maximum sorties (I_{AF}), the maximum sorties (S_{AF}), and the TAT (T_A) of the platform. This value is then added to the product of the number of aircraft conducting limited sorties (I_{AP}), the number of limited sorties (S_{AP}), and the TAT (T_A) of the platform (Equation 13). Table 19 provides the variables for Equation 13 and the input characteristics for the C-130J.

Table 19. Variable Descriptions for Equation 13 with C-130J Characteristics—2,500 Short Tons and a 744-Hour Mission Duration Time

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J CHARACTERISTICS:
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	PLATFORMS	9 platforms
S_{AF}	MAXIMUM NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS	15 sorties
I_{AP}	NUMBER OF PLATFORMS COMPLETING LIMITED SORTIES/TRIPS	PLATFORMS	1 platform
S_{AP}	LIMITED NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS	4 sorties
T_A	TURN-AROUND TIME FOR PLATFORM	HOURS (HR)	49 hrs
T_T	TOTAL MANPOWER HOURS/TOTAL TIME TO COMPLETE MISSION	HOURS (HR)	-

Equation 13 is calculated as follows:

(T_T: =Total Manpower Hours Costs for Air Platforms)

$$T_T = I_{AF} * S_{AF} * T_A + I_{AP} * S_{AP} * T_A \quad (13)$$

For example, to calculate the total manpower hours (T_T) for the C-130J, we use the information as calculated in previous tables and shown in Table 19:

$$T_T = I_{AF} * S_{AF} * T_A + I_{AP} * S_{AP} * T_A$$

= 9 platforms * 15 sorties * 49 hrs + 1 platform * 4 sorties * 49 hrs = 6,811 hours.

Table 20 depicts the total manpower hours required to operate each air and sealift platform based on 2,500 short tons and a 744-hour mission duration time. Total manpower hours are dependent on the number of short tons required to be moved. As tonnage required to move increases, total manpower hours will also increase. As long as tonnage required to be moved remains constant, mission duration time will not affect total manpower hours.

Table 20. Total Manpower Hours per Platform—2,500 Short Tons with a 744-Hour Mission Duration Time

PLATFORMS	TOTAL MANPOWER HOURS:
C-130J	6811.0
C-17	2536.4
C-5M	1843.4
LMSR	672.8
FSS	626.9
SKYCAT 220	1420.0
H2 CLIPPER	867.8
AEROSCRAFT	2827.5
HAV 366	3833.3
SKYHOOK	6405.0
LEMV	21666.7

The total manning cost (N_M) for air platforms is equal to the product of total time to complete a mission (T_T) and the summation product of total manning of officers (M_O) and enlisted personnel (M_E) multiplied by the hourly wage of officers (H_O) and enlisted personnel (H_E; Equation 14). The total manning cost (N_M) for sealift platforms is equal to the product of total time to complete a mission (T_T) by the product of total manning of civilian personnel (M_V) by the hourly wage of civilian personnel (H_V; Equation 15). Table 21 is used to define the variables in Equations 14 and 15:

Table 21. Variable Descriptions for Equations 14 and 15

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
H_E	HOURLY ENLISTED WAGES	DOLLARS
H_O	HOURLY OFFICER WAGES	DOLLARS
H_V	HOURLY CIVILIAN WAGES	DOLLARS
M_E	MANNING FOR ENLISTED	PERSONNEL
M_O	MANNING FOR OFFICERS	PERSONNEL
M_V	MANNING FOR CIVILIANS	PERSONNEL
N_M	TOTAL MANNING COSTS	DOLLARS
T_T	TOTAL MANPOWER HOURS/TOTAL TIME TO COMPLETE MISSION	HOURS (HR)

Equations 14 and 15 are defined as follows:

(N_M: =Total Manpower Costs for Air Platforms)
$N_M = T_T * (H_O * M_O + H_E * M_E)$ (14)

(N_M : = Total Manpower Costs for Sealift Platforms)
$N_M = T_T * (M_V * H_V)$ (15)

The final destination in Scenario 1 is not the final point of debarkation for sealift platforms. In order for equal comparison, trucking costs have been included in the overall costs for sealift platforms. Trucking costs from Karachi, Pakistan, to Bagram, Afghanistan, are based on freight rates provided by OQab Freight & Logistics Afghanistan Ltd. (2007). If the sealift platform is unable to deliver its cargo to the final point of debarkation due to the TAT being larger than mission duration time, the total trucking cost (N_T) is zero. If the TAT is less than the mission duration time, the total trucking cost is equal to the ratio of total cargo moved and 30 tons, which is then multiplied by the trucking cost (H_T) of $4,100 (Equation 16). The total cargo moved divided by 30 tons is rounded up to the nearest whole number in order to determine the number of trucks needed to complete the final leg to the point of debarkation. Table 22 provides variable descriptions for Equation 16 and provides the input parameters for the LMSR platform.

Table 22. Variable Descriptions for Equation 16

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	LMSR CHARACTERISTICS:
N_T	TOTAL TRUCKING COSTS	DOLLARS	-
H_T	COST PER 30 TONS OF FREIGHT TRANSPORTED	DOLLARS PER 30 TONS	$4,100
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS	2500 short tons
T_A	TURN-AROUND TIME	HOURS	672.8 hrs
T_M	MISSION DURATION TIME	HOURS	744 hrs

Equation 16 is calculated as follows:

(N_T: = Total Trucking Costs):
IF ($T_A > T_M$)
$N_T = 0$
ELSE
$N_T = \text{Roundup}(C_M / 30, 0) * H_T$ (16)

For example, to calculate the total trucking costs of the LMSR from Karachi, Pakistan, to Bagram, Afghanistan, we use the variables defined in Table 22 and use them in Equation 16 as follows: N_T = Roundup (C_M / 30, 0) * H_T

= Roundup (2,500 short tons / 30 short tons) * $4,100 = $344,400.

The overall cost for air platforms given a particular mission (N_A) is equal to the summation of the total operating cost (N_O) and total manning costs ($N_{M;}$ Equation 17). The overall cost for sealift platforms given a particular mission is equal to the summation of the total operating costs (N_O), total manning costs (N_M), and the total trucking costs (N_T; Equation 18). Total trucking costs are only calculated for sealifts platform in Scenario 1.

Table 23 provides the variable descriptions for Equations 17 and 18.

Table 23. Variable Descriptions for Equations 17 and 18

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
N_T	TOTAL TRUCKING COSTS	DOLLARS
N_A	OVERALL COSTS FOR AIR/SEALIFT PLATFORMS	DOLLARS
N_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS
N_O	TURN-AROUND TIME	HOURS

Equations 17 and 18 are calculated as follows:

(N_A: = Overall Costs for Air Platforms): $N_A = N_O + N_M$ (17)

(N_A: = Overall Costs for Sealift Platforms): $N_A = N_O + N_M + N_T$ (18)

For example, the total operating cost, total manning cost, and the overall costs can be calculated for the C-130J based on characteristics defined in Table 24.

Table 24. C-130J Characteristics—2,500 Short Tons with a 744-Hour Mission Duration Time

SYMBOLS:	VARIABLE DESCRIPTIONS:	C-130J:
H_E	HOURLY ENLISTED WAGES	$10.80/hr
H_O	HOURLY OFFICER WAGES	$16.27/hr
M_E	MANNING FOR ENLISTED	2 enlisted (E-6)
M_O	MANNING FOR OFFICERS	2 officers (O-3)
N_O	TOTAL OPERATING COSTS	$14,461,212.50
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	9 platforms
S_{AF}	MAXIMUM NUMBER OF SORTIES/TRIPS	15 sorties
I_{AP}	NUMBER OF PLATFORMS COMPLETING LIMITED SORTIES/TRIPS	1 platform
S_{AP}	LIMITED NUMBER OF SORTIES/TRIPS	4 sorties
T_T	TOTAL MANPOWER HOURS/TOTAL TIME TO COMPLETE MISSION	6,811 hours
N_A	TOTAL OVERALL COSTS	-
N_M	TOTAL MANNING COSTS	-

To calculate total manning costs (N_M) for C-130J to move 2,500 short tons within a 744-hour mission duration time, we used Equation 14:

$N_M = T_T * (H_O * M_O + H_E * M_E)$

$= 6,811 * (2 \text{ officers} * \$16.27/\text{hr} + 2 \text{ enlisted} * \$10.80/\text{hr}) = \$368,801.46$.

Finally, using the total operating costs (see Table 14), we can calculate the overall costs based on Equation 17:

$N_A = N_O + N_M = \$14,461,212.50 + \$368,801.46 = \$14,830,013.96$.

Table 25 shows the various manning and overall costs for the various platforms for a given mission duration of 168 hours. To determine the most suitable platform to perform this particular mission, a performance measure of lowest total overall cost was used to compare the platforms. Two of the respective airships have lower total overall costs than all three aircraft platforms. All six of the airships were more cost effective than the C-5 and the C-130J. Due to mission duration time, MSC ships are unable to complete the mission within the designated mission duration time. If the various companies make the hourly operating cost of airships lower than the baseline, the total overall cost will only decrease further. Later analysis will show the price difference of lower hourly operating costs.

Table 25. Total Overall Cost for Each Platform—2,500 Tons with a 168-Hour Mission Duration Time

PLATFORMS	TOTAL OP COST:	TOTAL MANNING COST:	TOTAL OVERALL COST:
C-130J	$ 14,461,212.50	$ 368,801.46	$ 14,830,013.96
C-17	$ 10,938,151.72	$ 137,341.52	$ 11,075,493.25
C-5M	$ 19,657,292.31	$ 159,560.43	$ 19,816,852.74
LMSR	N/A	N/A	N/A
FSS	N/A	N/A	N/A
SKYCAT 220	$ 10,938,151.72	$ 76,890.04	$ 11,015,041.77
H2 CLIPPER	$ 10,938,151.72	$ 46,989.94	$ 10,985,141.67
AEROSCRAFT	$ 10,938,151.72	$ 153,103.23	$ 11,091,254.96
HAV 366	$ 10,938,151.72	$ 207,567.01	$ 11,145,718.74
SKYHOOK	$ 10,938,151.72	$ 346,817.41	$ 11,284,969.13
LEMV	$ 10,938,151.72	$ 1,173,204.86	$ 12,111,356.59

Table 26 includes the total trucking costs along with the total operating costs, total manning costs, and the total overall cost for all platforms for a given 744-hour mission duration time. Extending the mission duration time to 744 hours allows MSC ships to be utilized as an option. Exclusively for the MSC ships, the total shipping cost to move 2,500 short tons from Karachi, Pakistan, to Bagram, Afghanistan, was included in Table 26. Using the performance measure for the previous mission duration time, the best platform to conduct this mission with the given parameters is the LMSR.

Table 26. Total Overall Cost for Each Platform—2,500 Tons with a 744-Hour Mission Duration Time

PLATFORMS	TOTAL TRUCKING COSTS:	TOTAL OP COST:	TOTAL MANNING COST:	TOTAL OVERALL COST:
C-130J	N/A	$ 14,461,212.50	$ 368,801.46	$ 14,830,013.96
C-17	N/A	$ 10,938,151.72	$ 137,341.52	$ 11,075,493.25
C-5M	N/A	$ 19,657,292.31	$ 159,560.43	$ 19,816,852.74
LMSR	$ 341,666.67	$ 124,253.33	$ 25,514.24	$ 491,434.24
FSS	$ 341,666.67	$ 809,907.70	$ 72,979.58	$ 1,224,553.95
SKYCAT 220	N/A	$ 10,938,151.72	$ 76,890.04	$ 11,015,041.77
H2 CLIPPER	N/A	$ 10,938,151.72	$ 46,989.94	$ 10,985,141.67
AEROSCRAFT	N/A	$ 10,938,151.72	$ 153,103.23	$ 11,091,254.96
HAV 366	N/A	$ 10,938,151.72	$ 207,567.01	$ 11,145,718.74
SKYHOOK	N/A	$ 10,938,151.72	$ 346,817.41	$ 11,284,969.13
LEMV	N/A	$ 10,938,151.72	$ 1,173,204.86	$ 12,111,356.59

In both Table 25 and Table 26, it can be observed that total overall costs remain constant for all platforms over the mission duration times with the exception of the MSC platforms, due to their unavailability at the lower mission duration times. Although the total operating cost for each airship is equal to the total operating cost of the C-17 platform, total manpower costs will determine the difference in total overall costs. Manpower costs will continue to increase as total cargo moved increases and can account for the subtle differences in total overall costs and cost per short ton-nautical mile, as we discuss in the next section.

4. Cost Per Ton-Nautical Mile

To ensure that sealift and airlift costs were analyzed on an equal basis after calculating the total overall costs of a particular mission, we derived a cost per ton-nautical mile for each platform. This allows planners to realize the cost efficiency of sealift over any other platform when time is not a critical factor. Cost per ton-nautical mile (N_C) is equal to the ratio of total overall costs (N_A) over amount of cargo moved (C_M), multiplied by the total distance (2 * D) traveled for a particular mission (Equation 19).

Table 27 defines the variables required in Equation 19 and the C-130J input characteristics.

Table 27. Variable Descriptions for Equation 19 with C-130J Characteristics—2,500 Short Tons and a 168-Hour Mission Duration Time

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J CHARACTERISTICS:
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS	2500 short tons
D	DISTANCE	NAUTICAL MILES	2800 nm
N_A	TOTAL OVERALL COSTS	DOLLARS	$14,830,013.96
N_C	COST PER TON-NAUTICAL MILE	DOLLARS/TON-NAUTICAL MILE	-

Equation 19 is defined as follows:

(N_C: = Cost Per Ton-NM): $N_C = N_A / (C_M * 2 * D)$ (19)

For example to calculate the C-130J's cost per ton-nautical mile, we use the C-130J characteristics shown in Table 27 Using Equation 19, we calculate the cost per ton-nautical mile as follows:

$N_C = N_A / (C_M * 2 * D)$ = $14,830,013.96 / (2,500 short tons * 2 * 2800 nm)

= $1.06 per short ton-nautical mile.

Tables 28 and 29 show each platform's cost per ton-nm with mission duration times of 168 hours and 744 hours, respectively.

Table 28. Cost/Ton-NM for Each Platform—2,500 Short Tons with a 168-Hour Mission Duration Time

PLATFORMS	COST/TON-NAUTICAL MILE:
C-130J	$ 1.06
C-17	$ 0.79
C-5M	$ 1.42
LMSR	N/A
FSS	N/A
SKYCAT 220	$ 0.79
H2 CLIPPER	$ 0.78
AEROSCRAFT	$ 0.79
HAV 366	$ 0.80
SKYHOOK	$ 0.81
LEMV	$ 0.87

Table 29. Cost/Ton-NM for Each Platform—2,500 Short Tons with a 744- Hour Mission Duration Time

PLATFORMS	COST/TON-NAUTICAL MILE:
C-130J	$ 1.06
C-17	$ 0.79
C-5M	$ 1.42
LMSR	$ 0.03
FSS	$ 0.08
SKYCAT 220	$ 0.79
H2 CLIPPER	$ 0.78
AEROSCRAFT	$ 0.79
HAV 366	$ 0.80
SKYHOOK	$ 0.81
LEMV	$ 0.87

Based on the TAT times in Table 6**,** the AMC platforms have the upper hand in delivering the 2,500 short tons for the first 45–67 hours. Both the sealift and airship platforms cannot make a round trip within that mission duration time. When the mission duration time is 67 hours, the H2 Clipper is the only airship available to complete the mission, but has the lowest cost per ton-nautical mile compared against the aircraft platforms. As the mission duration time increases to 168 hours, as depicted in Table 28, all six airships become available and have a lower cost per ton-nautical mile than the C-130J and C-5M. Two of the six airships have the same cost per ton-nautical mile as the C-17, while three of the six airships have a slightly greater cost per ton-nautical mile: $0.80, $0.81, and $0.87. Airships seem to dominate in reducing cost per ton-nautical mile until mission duration increases to 744 hours, as depicted in Table 29. At this point, both FSS and LMSR ships become available to complete the mission. The cost per ton-nautical of the FSS and LMSR is much lower than the cost of any air platforms, including airships. If time does not become a major factor, the MSC ships will always have a lower cost in general.

C. HOURLY OPERATING COST SAVINGS

The hourly operating cost for each airship was calculated in order to determine if airships could be a viable alternative to all heavy-lift aircraft. A one-size-fits-all hourly operating cost was used in our analysis in order to compare airships to all platforms. However, based on the cost of procurement and life cycle costs of current platforms, airships could provide a cheaper form of heavy-lift transportation when compared against each individual platform. The following analysis shows the hourly operating cost required to compete cost effectively against the other platforms.

1. Replacement Operating Costs

In planning for the future, the DoD and USTRANSCOM will need to address the issue of aging platforms. As the current heavy-lift platforms age, maintenance and modernization costs will increase. In turn, these costs will cause the hourly operating costs of these platforms to continually rise. This section of the analysis compares the costs of a mission given a specified tonnage and time frame. The break-even costs used in this section are not the minimum break-even costs calculated in previous sections, but are the costs based strictly on a particular tonnage and time. This allows us to compare airships against each individual air and ship platform without subtracting the higher operating costs of all the platforms combined, as we did previously.

It may not be prudent to compare airships against all platforms at once, but, instead, to compare airships against each individual platform to analyze the validity of airships replacing these platforms. Replacing all the current forms of heavy-lift transportation is most likely not feasible; however, by studying the feasibility of replacing one or more of the individual platforms, we could discover a better option for reducing the cost of the overall mission of delivering heavy-lift logistics to theaters around the world.

The following analysis is based on a mission with 2,500 short tons and a 744-hour mission duration time. Referring back to Tables 12 and 17, we find the number of airships, sorties required, and break-even costs for airships and other platforms in order to complete a cargo movement requirement of 2,500 short tons with a 744-hour mission completion time. These tables are essential for planners who are considering the future acquisition of airships and need to evaluate the costs associated with replacing current heavy-lift platforms.

a. Platform Savings

The hourly operating cost baselines (seen in Table 18) are thresholds that airships cannot go over in order to be considered an alternative to current heavy-lift logistics. Given these guidelines, we can calculate the cost savings if airship companies were able to reduce the hourly costs in Table 18 by $100. Table 30 calculates the total operational cost savings if the break-even hourly operational costs could be reduced by $100.

Table 30. Hourly Operating Cost Reduction of $100—2,500 Short Tons with a 744-Hour Mission Duration Time

AIRSHIPS:	OLD HOURLY OP COSTS:	OLD TOTAL OP COSTS:	NEW HOURLY OP COST REDUCED BY $100:	NEW TOTAL OP COSTS:	DIFFERENCE BETWEEN TOTAL OP COSTS:
SKYCAT 220	$ 13,672.69	$ 10,938,151.72	$ 13,572.69	$ 10,858,151.72	$ 80,000.00
H2 CLIPPER	$ 45,675.80	$ 10,938,151.72	$ 45,575.80	$ 10,914,204.36	$ 23,947.37
AEROSCRAFT	$ 6,009.97	$ 10,938,151.72	$ 5,909.97	$ 10,756,151.72	$ 182,000.00
HAV 366	$ 4,101.81	$ 10,938,151.72	$ 4,001.81	$ 10,671,485.06	$ 266,666.67
SKYHOOK	$ 2,170.27	$ 10,938,151.72	$ 2,070.27	$ 10,434,151.72	$ 504,000.00
LEMV	$ 625.04	$ 10,938,151.72	$ 525.04	$ 9,188,151.72	$ 1,750,000.00

Table 30 shows that for every $100 reduction in hourly operating costs, the Skycat 220, H2 Clipper, Aeroscraft, HAV 366, Skyhook, and LEMV can provide a cost savings of approximately $80,000; $24,000; $182,000; $266,000; $504,000; and $1.75 million, respectively, from the total operating costs of $10.9 million. Further analysis shows that if hourly operating costs are reduced by $1,000, the cost savings from the current total operating costs will increase 1,000-fold, as seen in Table 31. LEMV was excluded from Table 31 due to its relatively low hourly operating costs, which cannot be reduced by $1,000.

Table 31. Hourly Operating Cost Reduction of $1,000—2,500 Short Tons with a 744-Hour Mission Duration Time

	AIRSHIP OPERATING COST SAVINGS	
AIRSHIPS:	COST SAVINGS PER $100 REDUCTION	COST SAVINGS PER $1000 REDUCTION
SKYCAT 220	$ 80,000.00	$ 800,000.00
H2 CLIPPER	$ 23,947.37	$ 239,473.68
AEROSCRAFT	$ 182,000.00	$ 1,820,000.00
HAV 366	$ 266,666.67	$ 2,666,666.67
SKYHOOK	$ 504,000.00	$ 5,040,000.00

If we compare the hourly operating cost baselines for airships to the lowest hourly operating cost for an aircraft, the Skycat 220 and H2 Clipper are the only two airships that exceed the lowest hourly operating cost of the C-130J, which is $5,945 per hour. If the companies that produce the Skycat 220 and H2 Clipper were able to reduce their hourly operating costs to $5,945 per hour, both airships could possibly save a total of $6.2 million and $9.5 million, respectively, as indicated in Table 32, from the total operating cost of $10.9 million.

Table 32. Skycat 220 and H2 Clipper Hourly Operating Cost Reduction to $5,945 and Cost Savings—2,500 Short Tons with a 744-Hour Mission Duration Time

AIRSHIPS:	OLD HOURLY OP COSTS:	OLD TOTAL OP COSTS:	NEW HOURLY OP COST REDUCED:	NEW TOTAL OP COSTS:	DIFFERENCE BETWEEN TOTAL OP COSTS:
SKYCAT 220	$ 13,672.69	$ 10,938,151.72	$ 5,945.00	$ 4,756,000.00	$ 6,182,151.72
H2 CLIPPER	$ 45,675.80	$ 10,938,151.72	$ 5,945.00	$ 1,423,671.05	$ 9,514,480.67

The implications from this analysis show that if companies invest in technologies that improve engine technology, fuel efficiency, maintenance, and various other factors, they can reduce the hourly operating costs of their products and provide a larger cost savings. This is especially true if they can reduce the cost by $100 or more. These baselines could be beneficial to the future acquisition of airships, because they allow DoD planners to determine if an airship is the right platform to perform a certain mission.

2. Variable Short Tons with Constant Mission Duration Time

Under the normal circumstances encountered by the DoD and USTRANSCOM, the amount of cargo to be transferred will be larger than 2,500 short tons. The previous sections of this analysis have shown how particular missions may have a constant amount of tonnage required over variable mission durations. If mission duration time is constant and tonnage changes, the number of operating hours required to complete a mission will increase, as well as the number of aircraft and sorties. This is depicted in Figures 4 and 5.

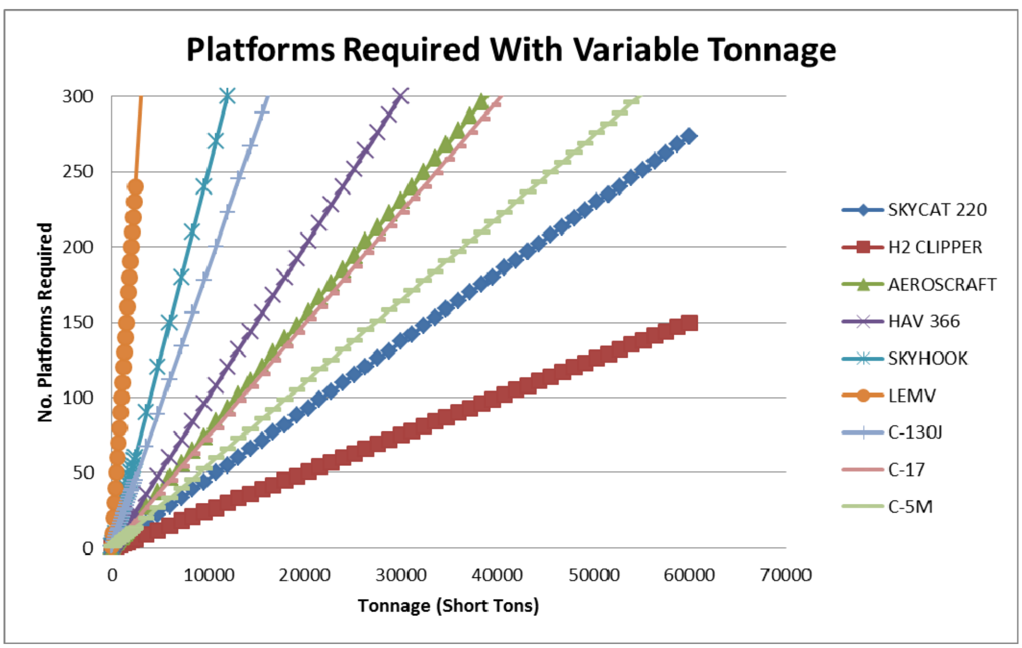

Figure 4. Number of Platforms Required with Variable Tonnage and a 168-Hour Mission Duration

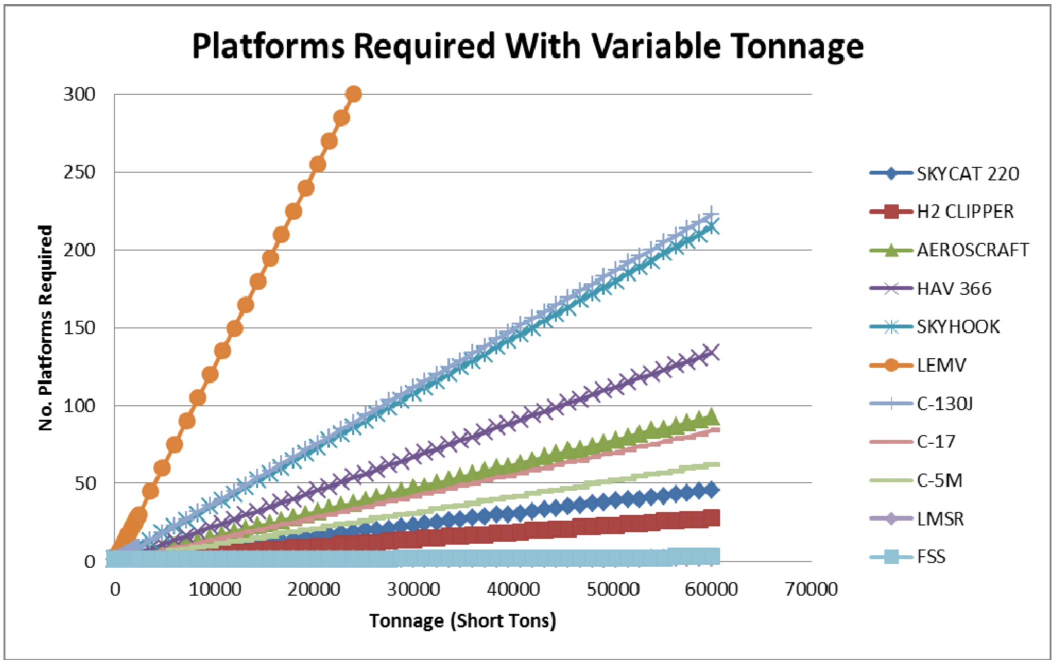

Figure 5. Number of Platforms Required with Variable Tonnage and a 744-Hour Mission Duration

Figures 4 and 5 show the number of platforms required to complete a mission whose tonnage varies from one to 60,000 short tons of material. As depicted in Figure 4, more platforms are required to complete missions with relatively short time durations. Figure 5 shows the opposite: fewer platforms are needed to complete missions with relatively long durations. Figure 5 also shows that ship platforms are available to complete missions with longer durations, but due to their large payload capacities, relatively few ship platforms will be needed to complete the missions, even when cargo tonnage increases. Although Figure 5 does not show it, the number of ship platforms required to complete these missions is one or three platforms per mission.

The effects of mission duration times can be seen in both figures; the slope of the line showing number of platforms required changes based on the variability in tonnage. with lower mission duration times, Figure 4 shows a relatively steeper slope compared to Figure 5. This sudden increase in slope can also translate into an increase in operating costs for all platforms. Based on the same event depicted in Figures 4 and 5, Figures 6 and 7 depict the impact on operating costs for mission duration times of 168 and 744 hours, respectively.

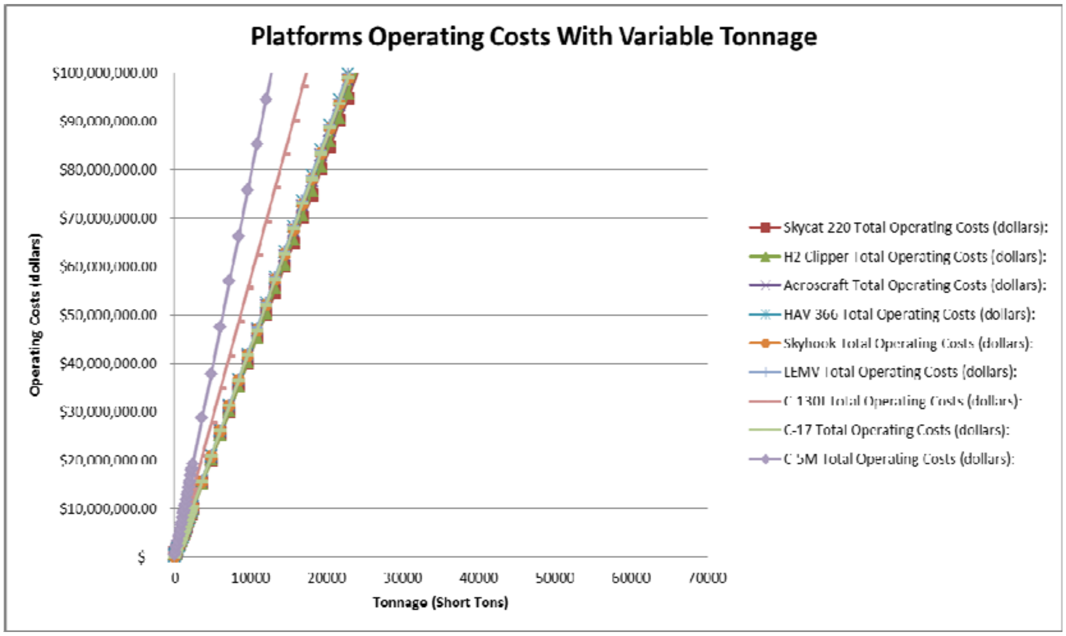

Figure 6. Platforms' Operating Costs with Variable Tonnage and a 168-Hour Mission Duration

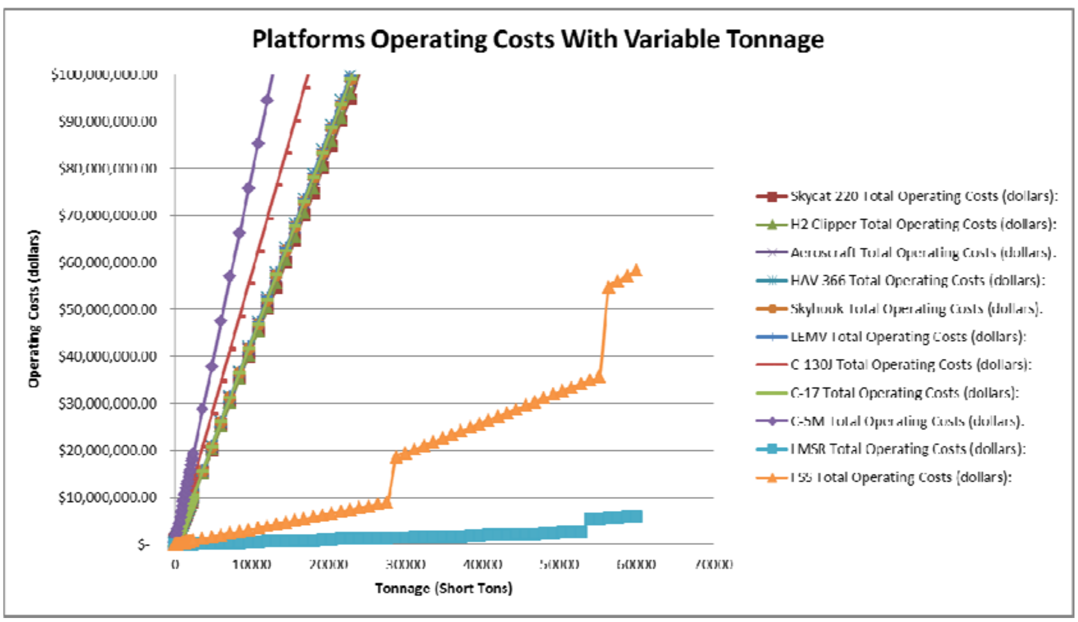

Figure 7. Platforms' Operating Costs with Variable Tonnage and a 744-Hour Mission Duration Time

From Figures 6 and 7, we can conclude that as the tonnage of cargo to be moved increases, the total operating costs will increase at the same rate, no matter what the mission duration time is. This is due to the fact that total operating hours will remain the same over a varying mission duration time, as long as that cargo required to be moved is the same. Figure 7 also shows the LMSR and FSS as options when mission duration time increases to 744 hours. The "step" in the LMSR and FSS curves is due to the added ship required to complete a mission. For example, the LMSR's planned payload capacity is 53,224.2 short tons, and once cargo required to be moved increases beyond this tonnage, another ship is needed to complete the mission. The same effect can be used to explain the FSS platform, which jumps from one to three platforms when the cargo required to be moved increases to 60,000 short tons.

D. AUTONOMOUS AIRSHIPS—MANNED VS. UNMANNED

The idea of unmanned vehicles has been source of continued debate in both politics and the military arena since the inception of unmanned drones. The benefit of unmanned vehicles stems from their ability to allow service members to remain at a safe distance from dangerous environments, while allowing them to complete the same types of missions. There are potential benefits for creating autonomous airships, including potential cost savings when it comes to heavy-lift cargo. The following analysis shows the potential total cost benefit and number of platforms necessary to complete a sample mission. In addition, the analysis shows the potential total cost benefit of autonomous airships when compared to current manned logistic platforms.

1. Manned or Unmanned Airships

Unmanned airships offer potential benefits because they both provide potential cost savings and can complete their mission in a timely and efficient manner. Unlike manned platforms, unmanned vehicles do not have to adhere to the crew rest limitations that most heavy-lift platforms have to factor into their flight plans. Table 33 shows the potential benefit of unmanned airships compared to manned airships in terms of the TAT, number of aircraft, number of crew, and number of sorties.

Table 33. Manned vs. Unmanned Airships

	MANNED AIRSHIPS				UNMANNED AIRSHIPS			
AIRSHIPS:	TAT:	MAX SORTIES PER AIRSHIP:	TOTAL NO. AIRSHIPS:	TOTAL NO. CREWS :	TAT:	MAX SORTIES PER AIRSHIP:	TOTAL NO. AIRSHIPS:	TOTAL NO. CREWS :
SKYCAT 220	118.3	6	2	4	106.3	6	2	0
H2 CLIPPER	66.8	11	2	4	54.8	13	1	0
AEROSCRAFT	72.5	10	4	8	60.5	12	4	0
HAV 366	76.7	9	6	12	64.7	11	5	0
SKYHOOK	101.7	7	9	18	89.7	8	8	0
LEMV	86.7	8	32	64	74.7	9	28	0

As Table 33 shows, the TAT of unmanned airships is 12 hours lower than that of manned aircraft due to the elimination of crew rest that pilots and crewmembers are required to take after flying for a certain number of hours. The new TAT means that airships can be used more frequently to deliver more cargo. The smaller TAT reduces the number of airships needed to maintain a steady-state delivery system, but at the same time increases the number of sorties required to complete the mission as seen in Table 33; as the total number of airships decreases, sorties increase to maintain the steady state of the aircraft. Dependent on hourly operating cost, total-operating costs will remain the same.

The biggest change from manned to unmanned airships comes from the total overall costs; this change is due to the decreased number of manpower hours needed to complete a mission. Table 34 shows the potential change to overall cost of a mission for each airship.

Table 34. Savings/Losses From Manned to Unmanned Airships—2,500 Short Tons with a 744-Hour Mission Duration

	Manned Overall Cost:	Unmanned Overall Cost:	Cost Change:
SKYCAT 220	$ 11,015,041.77	$ 10,938,151.72	$ 76,890.04
H2 CLIPPER	$ 10,985,141.67	$ 10,938,151.72	$ 46,989.94
AEROSCRAFT	$ 11,091,254.96	$ 10,938,151.72	$ 153,103.23
HAV 366	$ 11,145,718.74	$ 10,938,151.72	$ 207,567.01
SKYHOOK	$ 11,284,969.13	$ 10,938,151.72	$ 346,817.41
LEMV	$ 12,111,356.59	$ 10,938,151.72	$ 1,173,204.86

The cost change depicted in Table 34 results solely from the total manning costs that are required for manned airships. Because total operating costs will remain the same with a given tonnage, the total manning costs will make up the difference between manned and unmanned airship scenarios. All six airships show a potential benefit with unmanned variants for transporting 2,500 short tons within a 744-hour mission duration. If airships are flown at the same rate as their manned counterparts, additional cost savings will be incurred due to the total cost of manning.

Table 35 shows the potential impact that total mission costs have on the cost per ton-nautical mile for each airship. Five out of the six airships have decreased costs per ton-nautical mile, while only one airship remains the same. Overall costs and cost per ton-nautical mile are highly dependent on the mission duration and the amount of cargo to be moved. A change in either of these two may change the number of airships and sorties required to complete the mission. It is important to note that, with our model, as the number of sorties increases, the TAT decreases and number of airships available to complete a mission increases, therefore reducing the total number of airships required. Unmanned airships will not incur total manning costs and, therefore, their total overall costs will decrease.

Table 35. Cost/Ton-Nm Changes—2,500 Short Tons with a 744-Hour Duration

	Manned Cost/Ton-NM:	Unmanned Cost/Ton-NM:	Cost/Ton-NM Change:
SKYCAT 220	$ 0.79	$ 0.78	$ 0.01
H2 CLIPPER	$ 0.78	$ 0.78	$ 0.00
AEROSCRAFT	$ 0.79	$ 0.78	$ 0.01
HAV 366	$ 0.80	$ 0.78	$ 0.01
SKYHOOK	$ 0.81	$ 0.78	$ 0.02
LEMV	$ 0.87	$ 0.78	$ 0.08

2. Manned Platforms vs. Unmanned Airships

Table 35 shows that unmanned airships can offer a potential cost-saving benefit, especially when a mission happens quite frequently. Table 36 shows the total cost savings, or losses, between current heavy-lift platforms and unmanned airships.

Table 36. Total Cost Savings/Losses Between Platforms and Airships—2,500 Short Tons with a 744-Hour Mission Duration

	Manned AMC/MSC Overall Cost:	Unmanned Airships' Total Cost:	Total Cost Change:
C-130J	$ 14,830,013.96	$ 10,938,151.72	$ 3,891,862.24
C-17	$ 11,075,493.25	$ 10,938,151.72	$ 137,341.52
C-5M	$ 19,816,852.74	$ 10,938,151.72	$ 8,878,701.01
LMSR	$ 491,434.24	$ 10,938,151.72	$ (10,446,717.48)
FSS	$ 1,224,553.95	$ 10,938,151.72	$ (9,713,597.77)

Unmanned airships can provide costs savings compared to all of the heavy-lift air platforms. Table 36 shows that the greatest cost savings can be gained by using unmanned airships to replace the C-5M platform. All six airships provide a positive cost savings, ranging from $137,000 to $9 million, against the three AMC platforms. Due to the relatively small overall costs of MSC ships, unmanned airships cannot compete against them. All six airships provide a negative cost savings when compared to MSC ships.

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VII. ANALYSIS FOR SCENARIO 2

A. ONE- TO- ONE COMPARISON

We conduct a second one- to- one comparison in Scenario 2 in order to establish a baseline against which to analyze the characteristics of individual platforms. The purpose of the one-to-one comparison is the same in each scenario; however, Scenario 2 shows the varying characteristics of each platform when time is not a factor over a continuous sea route from Hawaii to Guam. The characteristics include operating hours, turn-around time (TAT), number of sorties, and planned payload. Equations 1–19 in Scenario 1 will apply to Scenario 2 to figure out the various values associated in the analysis.

Scenario inputs are based on the fact that this scenario is solely over water. The overall distance for both airlift and sealift is 3,320 nautical miles; there are no time or monetary constraints for a canal transit, and there are no associated trucking costs for delivery to the final destination for sealift. The benefit of conducting this scenario is to establish total overall costs based on the platforms alone.

With these characteristics in mind, we calculated the number of days to complete a mission consisting of 2,500 short tons. In this analysis, in order for the mission to be completed, all platforms must complete a full sortie or trip. The total distance traveled will be twice the distance from the point of embarkation to the point of debarkation in order to calculate a steady state of platforms. Again, for this single-unit analysis, we assumed that the number of platforms is one. Logic checks were placed in most of the equations to determine if a platform is capable of completing the mission given the platform's TAT and time to complete the mission. As with Scenario 1, the equations are listed to aid in the development of the scenario. With few exceptions, such as the values involving trucking costs, the equations do not change from either scenario, but the values' output will be in line with the requirements of Scenario 2.

The ratio of twice the distance (D) and the block speed (B) of the platform provides the operating hours (T_P) per sortie or trip of the platform (Equation 1). The summation of double the ground time (T_G), operating time of platforms per sortie or trip (T_P), pre-checks (for air platforms only; T_C), and double the crew rest times (for air platforms only; T_R) calculates the turn-around time (T_A) for each platform (Equation 2). Later, we will change Equation 2 due to the crew rest being 12 hours rather than 24 hours since additional crews will be available to augment a platform. Table 37 shows the variables associated with Equations 1 and 2.

Table 37. Variable Characteristics for Equations 1 and 2

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
D	DISTANCE	NAUTICAL MILE (NM)
B	BLOCK SPEED	KNOT (KTS)
T_G	GROUND/ONLOAD/OFFLOAD TIME	HOUR (HR)
T_C	FLIGHT PRE-CHECK TIME	HOUR (HR)
T_R	CREW REST TIME	HOUR (HR)
T_P	OPERATING TIME PER PLATFORM	HOUR (HR)
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)

Equations 1 and 2 are calculated as follows:

(T_P: = Operating Time of Platforms) $T_P = (2 * D / B)$ (1)

(T_A: = Turn-Around-Time) $T_A = 2 * T_G + T_P + T_C + 2 * T_R$ (single-platform)
$T_A = 2 * T_G + T_P + T_C + T_R$ (multi-platform) (2)

Logic parameters for each platform are used to calculate the total number of sorties or trips needed (S_{AT}) to complete a mission given a cargo movement capacity (Equation 3). If the TAT (T_A) is greater than the mission duration time (T_M), the total number of sorties will equal zero ($S_{AT} = 0$). If T_A is less than T_M and the cargo moved (C_M) is greater than the plan cargo load (C_P), S_{AT} will equal one. If C_M is less than C_P and the ratio of C_M and C_P multiplied by T_A is less than T_M, then S_{AT} is equal to C_M divided by C_P rounded up to the nearest whole number. If the opposite is true, S_{AT} will equal T_M divided by T_A rounded down to the nearest whole number. This portion of the analysis assumes that there is only one logistical platform (I_{AT}) to conduct this mission. Table 38 shows the variables associated with Equation 3.

Table 38. Variable Characteristics for Equation 3

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AT}	TOTAL NUMBER OF SORTIES OR TRIPS REQUIRED	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)

Equation 3 is calculated as follows:

(S_{AT}: = Maximum Amount of Sorties/Trip per platform):
IF ($T_A > T_M$)
$S_{AT} = 0$
ELSE
    IF ($C_P < C_M$)
    $S_{AT} = 1$
    ELSE
        IF ($C_M / C_P * T_A < T_M$)
            IF ($I_{AT} = 1$)
            S_{AT} = Roundup (C_M / C_P, 0)
            ELSE
            S_{AT} = Roundup (T_M / T_A, 0) (3)

The product of the total number of platforms (I_{AT}), the total number of sorties or trips needed (S_{AT}), and the operating hours per sortie or trip (T_P) calculates the total operating hours (T_O) of each platform to perform a mission (Equation 4). Again, for this single-unit analysis, we assume that the number of platforms is equal to one ($I_{AT} = 1$). Logic functions were placed in most of the equations to determine if a platform is capable of completing the mission given the platform's TAT and time available to complete the mission. Table 39 shows the variables associated with Equation 4.

Table 39. Variable Characteristics for Equation 4

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_O	TOTAL OPERATING HOURS	HOUR (HR)
T_P	OPERATING HOURS PER PLATFORM	HOUR (HR)
I_{AT}	TOTAL PLATFORMS	PLATFORMS
S_{AT}	TOTAL NUMBER OF SORTIES OR TRIPS REQUIRED	SORTIES/TRIPS

Equation 4 is calculated as follows:

(T_O: = Total Operating Hours) $T_O = I_{AT} * S_{AT} * T_P$ (4)

Appendix 2-4 shows the platform characteristics used in Table 40; to illustrate Equations 1–4, the characteristics of the C-130J are used as an example.

Table 40. C-130J Characteristics for 2,500 Short Tons

SYMBOLS:	VARIABLE DESCRIPTIONS:	VALUES:
D	DISTANCE	3320 nm
B	BLOCK SPEED	320 kts
C_P	PAYLOAD CAPACITY FOR PLATFORM	18 s. tons
C_M	CARGO MOVEMENT REQUIREMENT	2500 s. tons
T_G	GROUND/ONLOAD/OFFLOAD TIME	2.25 hrs
T_C	FLIGHT PRE-CHECK TIME	3 hrs
T_R	CREW REST TIME	12 hrs
I_{AT}	TOTAL PLATFORMS	1
T_P	OPERATING HOURS PER SORTIE OR TRIP	-
T_A	TURN-AROUND TIME FOR PLATFORMS	-
S_{AT}	TOTAL NUMBER OF SORTIES OR TRIPS REQUIRED	-

The operating hours (T_P) per C-130J can be calculated by using Equation 1:

$T_P = (2 * D / B) = (2 * 3320 \text{ nm}) / 320 \text{ kts} = 20.75$ hrs.

Turn-around time (T_A) can be calculated by using Equation 2:

$T_A = 2 * T_G + T_P + T_C + 2 * T_R = (2 * 2.25 \text{ hrs}) + 20.75 \text{ hrs} + 3 \text{ hrs} + (2 * 12 \text{ hrs}) = 52.3$ hrs.

The total number of sorties required (S_{AT}) to be flown by a C-130J can be calculated by Equation 3:

$S_{AT} = \text{Roundup}(C_M / C_P, 0) = \text{Roundup}(2{,}500 \text{ tons} / 18 \text{ tons}) = 139$ sorties.

Finally, the total operating time (T_O) to complete a mission is represented by Equation 4:

$T_O = I_{AT} * S_{AT} * T_P = 1 \text{ aircraft} * 139 \text{ sorties} * 20.75 \text{ hrs} = 2{,}884.25$ hrs

Table 41 shows the varying operating hours for each platform to complete the delivery of 2,500 tons over 3,320 nautical miles for airlift and sealift platforms.

Table 41. Single Platform to Complete Mission of 2,500 Short Tons with no Time Constraint

PLATFORMS	OPERATING HRS:	TURN-AROUND-TIME (Hrs):	MAXIMUM SORTIES/TRIPS:	TOTAL OPERATING HOURS (Hrs):
C-130J	20.8	52.3	139	2884.3
C-17	16.4	47.9	56	915.9
C-5M	16.0	47.5	41	654.4
LMSR	589.5	589.5	1	589.5
FSS	541.8	541.8	1	541.8
SKYCAT 220	79.0	130.7	12	948.6
H2 CLIPPER	21.8	70.2	13	283.9
AEROSCRAFT	55.3	81.2	39	2158.0
HAV 366	63.2	86.6	50	3161.9
SKYHOOK	94.9	116.5	63	5976.0
LEMV	83.0	99.7	250	20750.0

The single-unit comparison shows each platform's performance if only one unit is available to conduct a mission of 2,500 short tons. This comparison does not have a time criticality factor, thus allowing each platform an unlimited amount of time to conduct the mission. In this case, the performance measure of lowest total operating hours is used to determine the best suited platform to conduct this mission.

We can conclude that the platforms that are best suited to conduct the mission of 2,500 short tons are the H2 Clipper and the two sealift vessels, in that order. The H2 Clipper airship continuously has the lower operating hours compared to all three AMC platforms, both sealift vessels, and the remaining airships. In addition, three out of six airships beat out the C-130J platform in total operating hours required to complete the mission. Based on the previous equations, we can also deduce that as the amount of cargo moved increases, the total operating hours and the number of sorties or trips required will also increase. The relationship of the amount of cargo moved and total operating time for all platforms can be seen in Figure 8.

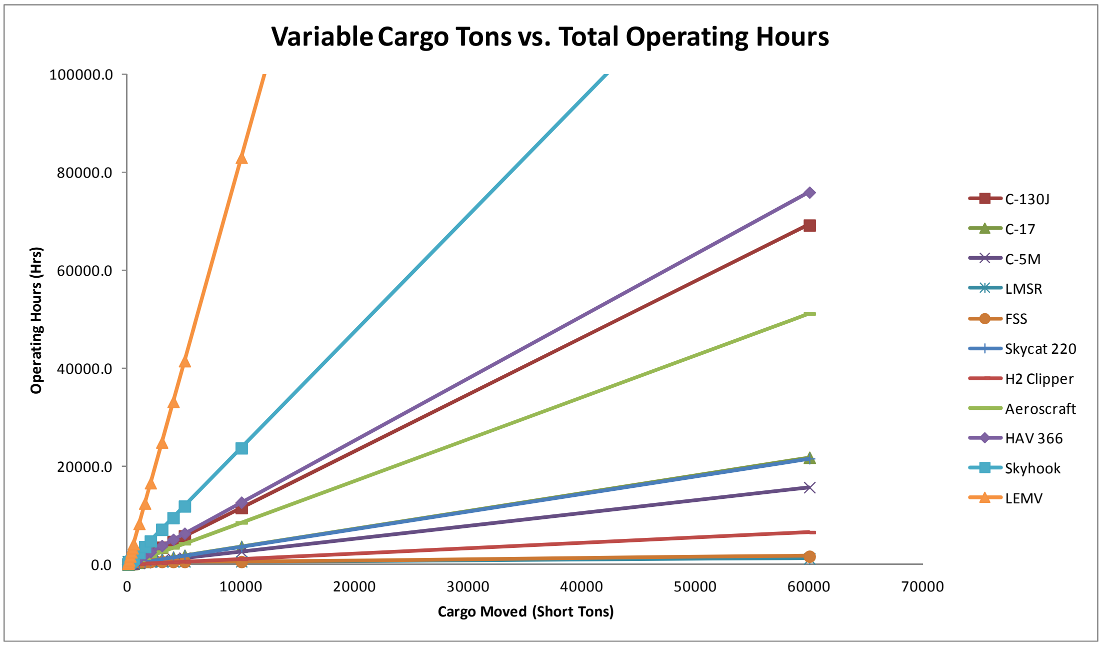

Figure 8. Cargo Tons Moved vs. Total Operating Hours—One-to-One Comparison with a Distance of 3,320 Nautical Miles and no Time Restraint

B. BREAK-EVEN MODEL

The goal of the second break-even model is the same as in the first scenario. We calculate the minimum number of platforms required to complete a mission with the new requirements listed in the previous section. The amount of time to complete a mission is based on varying the distance and the total tonnage to be delivered. The output of this model provides the number of platforms needed for a particular mission from which we can calculate the minimum hourly operating cost for each airship. In addition to the minimum hourly operating cost for each airship, the model provides manning costs, overall costs of missions using airships, and the cost per ton-nautical mile. Finally, the break-even model outputs the total cost savings gained from using autonomous airships versus manned variants.

1. Operational Efficiency

The first section of the break-even model outlines the operational efficiency of the platforms analyzed. The driving factors for the operation efficiency model are the total distance to complete the mission and the total required tonnage to be moved.

With the new time restraint or "mission duration" (T_M) to conduct a mission, more than one platform will be required to complete a mission if the total tonnage needed to be moved is greater than a platform's planned payload capacity. Unlike the one-to-one comparison analysis where only one platform was being used, we are required to calculate the total number of platforms (I_{AT}) required to a complete a mission within a certain mission duration time (Equation 5). A logical function is used to determine whether or not a platform could perform the 2,500 short ton mission in a given time span. If the TAT (T_A) is greater than the mission duration time (T_M), the platform in question would not be selected and would be given an output of zero ($I_{AT} = 0$). If T_A is less than T_M, the number of platforms needed (I_{AT}) to complete a mission would be calculated by rounding up the amount of cargo moved (C_M) divided by the product of planned payload (C_P) and the total number of sorties or trips required (S_{AT}). A partial platform cannot be used in order to complete a mission and, therefore, the output is rounded up to the nearest whole number.

Table 42 shows the variables associated with Equation 5 for the transportation of 2,500 short tons.

Table 42. Variable Characteristics for Equation 5

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AT}	TOTAL NUMBER OF SORTIES/TRIPS REQUIRED	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)
I_{AT}	TOTAL NUMBER OF PLATFORMS REQUIRED	PLATFORMS

We used the following equation:

(I_{AT}: = Total Amount Platforms Required)
IF ($T_A > T_M$)
$I_{AT} = 0$
ELSE
I_{AT} = ROUNDUP (C_M / (C_P * S_{AT}), 0) (5)

Not all platforms will conduct the maximum amount of sorties/trips due to the amount of tonnage required to be moved. Instead, a certain number of platforms (I_{AF}) will conduct the maximum sorties or trips (S_{AF}), while the remaining platforms will conduct the remaining sorties/trips. In order to derive the number of platforms (I_{AF}) needed to conduct the maximum amount of sorties (S_{AF}), a logic statement compares the product of total number of sorties (S_{AT}), total platforms required (I_{AT}), and planned payload (C_P) against (C_M). If the product of these three variables is less than C_M, the I_{AF} is equal to I_{AT} – 1. If not, the I_{AF} is equal to the I_{AT} (Equation 6). To determine the maximum number of sorties or trips required (S_{AF}), we used the same logic statement to compare the product of S_{AT}, I_{AT}, and C_P against C_M. If the product of these three variables is greater than C_M then S_{AF} is equal to S_{AT} – 1, or else S_{AF} will equal S_{AT} (Equation 7). Table 43 shows the variables associated with Equations 6 and 7.

Table 43. Variable Characteristics for Equations 6 and 7

SYMBOLS:	**VARIABLE DESCRIPTIONS:**	**UNITS:**
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AT}	TOTAL NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
S_{AF}	MAXIMUM NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)
I_{AT}	TOTAL NUMBER OF PLATFORMS	PLATFORMS
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	PLATFORMS

The following equations determine the number of platforms required to complete the maximum amount of sorties for a given mission:

(I_{AF}: = Number of Platforms to Conduct Maximum Sorties/Trips)

IF ($T_A > T_M$)
$I_{AF} = 0$
ELSE
    IF($S_{AT} * I_{AT} * C_P > C_M$)
        IF($S_{AT} * I_{AT} * C_P – C_M > C_P$)
        $I_{AF} = I_{AT} – 1$
        ELSE
        $I_{AF} = I_{AT}$
    ELSE
    $I_{AF} = I_{AT}$ (6)

(S_{AF}: = Maximum Number of Sorties/Trips)
IF ($I_{AF} * S_{AT} * C_P < C_M$)
$S_{AF} = S_{AT} – 1$
ELSE
$S_{AF} = S_{AT}$ (7)

The total number of aircraft required will not always need to conduct the maximum number of sorties for a given mission. To ensure the number of total sorties is not inflated, the limited number of sorties (S_{AP}) and the number of platforms that only complete a limited number of sorties (I_{AP}) must be calculated. If turn-around time (T_A) is greater than mission duration time (T_M), then S_{AP} is equal to zero. Otherwise, if I_{AF} is less than I_{AT}, S_{AP} is equal to the difference of C_M and the product of S_{AF}, I_{AF}, and C_P divided by C_P rounded up to the nearest whole number (Equation 8). For I_{AP}, if T_A is greater than T_M, I_{AP} is equal to zero. If I_{AF} is less than I_{AT}, I_{AP} is equal to the difference between C_M minus the product of S_{AF}, $I_{AF,}$ and C_P divided by the product of C_P and S_{AP} (Equation 9). Table 44 shows the variables associated with Equations 8 and 9.

Table 44. Variables Characteristics of Equations 8 and 9

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
T_A	TURN-AROUND TIME PER PLATFORM	HOUR (HR)
T_M	MISSION DURATION TIME	HOUR (HR)
S_{AF}	MAXIMUM NUMBER OF SORTIES OR TRIPS REQUIRED	SORTIES/TRIPS
S_{AP}	LIMITED NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS
C_P	PAYLOAD CAPACITY FOR PLATFORM	SHORT TONS (TONS)
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS (TONS)
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	PLATFORMS
I_{AT}	TOTAL NUMBER OF PLATFORMS	PLATFORMS
I_{AP}	NUMBER OF PLATFORMS COMPLETING LIMITED SORTIES/TRIPS	PLATFORMS

The following equation determines the number of platforms that only complete a limited number of sorties:

(S_{AP}: = Limited Number of Sorties/Trips)
IF ($T_A > T_M$)
$S_{AP} = 0$
ELSE
IF ($I_{AF} < I_{AT}$)
S_{AP} = Roundup (($C_M - [S_{AF} * I_{AF} * C_P]) / C_P$, 0)
ELSE
$S_{AP} = 0$ (8)

(I_{AP}: = Number of Platforms Only Completing Limited Sorties/Trips)
IF ($T_A > T_M$)
$I_{AP} = 0$
ELSE
IF ($I_{AF} < I_{AT}$)
$I_{AP} = I_{AT} - I_{AF}$
ELSE
$I_{AP} = 0$ (9)

Given the number of platforms required to complete a mission, manpower, in the form of crews, will be required to supply a steady state of platforms. The number of crews (W) is equal to the product of the total number of platforms (I_{AT}) multiplied by two (Equation 10).

The following equation was used to determine the number of crews (W) required:

(W: = Number of Crews for Platforms) $W = I_{AT} \times 2$ (10)

Table 45 shows the platform characteristics provide in more detail in Appendix 2-4 of the C-130J. The C-130J will be used as an example to demonstrate the use of Equations 5–10.

Table 45. C-130J Characteristics for 2,500 Short Tons

SYMBOLS:	VARIABLE DESCRIPTIONS:	VALUES:
C_P	PAYLOAD CAPACITY FOR PLATFORM	18 s. tons
C_M	CARGO MOVEMENT REQUIREMENT	2500 s. tons
T_A	TURN-AROUND TIME PER PLATFORM	52.3 hrs
T_M	MISSION DURATION TIME	168 hrs

Before using Equations 5–9, we must re-calculate the maximum number of sorties or trips required (S_{AT}) for the C-130J due to multiple platforms being involved (Equation 3). with time now a critical factor, Equation 3 uses the mission duration time (T_M) divided by the TAT (T_A) rounded down to determine the maximum number of sorties or trips required (S_{AT}). with Equation 3, we can calculate S_{AT}:

S_{AT} = ROUNDDOWN (T_M / T_A, 0) = ROUNDDOWN (168 hrs / 52.3 hrs) = 3 sorties.

The total number of C-130J platforms (I_{AT}) required to complete the mission can be derived by using Equation 5:

I_{AT} = ROUNDUP (C_M / (C_P * S_{AT}))

= ROUNDUP (2,500 tons / (18 tons * 3 sorties)) = 47 platforms needed.

The number of C-130J platforms needed to conduct the maximum number of sorties/trips (I_{AF}) is determined by S_{AT}. Because the product of S_{AT}, I_{AT}, and C_P minus C_M is less than C_P, Equation 6 becomes the following:

I_{AF} = I_{AT} – 1 = 47 platforms – 1 = 46 platforms.

The majority of the C-130J platforms will perform the maximum number of sorties/trips (S_{AF}); therefore, we use Equation 7: S_{AF} = S_{AT} = 3 sorties.

Because I_{AF} is less than I_{AT}, we can calculate the limited number of sorties (S_{AP}) that platforms are required to conduct to complete a mission. Equation 8 is used to calculate the limited sorties required:

S_{AP} = ROUNDUP ((C_M – [S_{AF} * I_{AF} * C_P])/ C_P, 0)

S_{AP} = ROUNDUP ((2500 – [3 sorties * 46 platforms * 18 tons]) / 18 tons) = 1 sortie.

We can calculate the number of platforms (I_{AP}) required to conduct this single sortie. Using Equation 9, we can calculate the number of platforms needed:

$I_{AP} = I_{AT} – I_{AF}$ = 47 platforms – 46 platforms = 1 platform required.

Finally, to run the 47 C-130J platforms, crews (W) must be assigned to man these platforms. Equation 10 states the following: $W = I_{AT} * 2$ = 47 platforms * 2 = 94 crews.

Tables 46 and 47 show the total number of platforms, maximum sorties/trips, limited sorties/trips, platforms to conduct limited sorties/trips, and platform crews necessary to complete a mission of 2,500 short tons based on mission duration times of 168 hours and 744 hours, respectively. In order to effectively compare platforms, mission duration is increased to show the value of sealift platforms when time is not a critical factor.

Table 46. Platform Characteristics—2,500 Short Tons with a 168-Hour Mission Duration Time

PLATFORMS	TOTAL TRIPS/SORTIES:	TOTAL PLATFORMS REQ:	NO. OF CREWS:	MAX TRIPS/SORTIES PER PLATFORM:	NO. OF PLATFORMS TO COMPLETE MAX TRIPS/SORTIES:	NO. OF REMAINING TRIPS/SORTIES:	NO. OF PLATFORMS REMAINING TRIPS/SORTIES:	TOTAL OPERATING HOURS:
C-130J	3	47	94	3	46	1	1	2884.3
C-17	3	19	38	3	18	2	1	915.9
C-5M	3	14	28	3	13	2	1	654.4
SKYCAT 220	1	12	24	1	12	0	0	948.6
H2 CLIPPER	2	7	14	2	6	1	1	283.9
AEROSCRAFT	2	20	40	2	19	1	1	2158.0
HAV 366	1	50	100	1	50	0	0	3161.9
SKYHOOK	1	63	126	1	63	0	0	5976.0
LEMV	1	250	500	1	250	0	0	20750.0

Table 46 shows the output of each platform when mission duration totals 168 hours. As it is expected, the LMSR and FSS platforms cannot complete this mission within the mission duration time due to their TATs being greater than the required 168 hours. With both sealift platforms unavailable, this portion of the analysis will focus on the non-sealift platforms.

The performance measures of importance for this section of the analysis are the lowest total operating hours, lowest number of aircraft, least number of sorties, and least number of crews to complete the mission of 2,500 short tons within 168 hours. Not all aircraft will need to conduct the maximum number of sorties. For example, the C-130J requires 46 of the 47 aircraft to conduct a maximum of three sorties. The additional aircraft is required to complete one sortie in order to minimize the number of sorties required to deliver 2,500 short tons. This logic is applied to the rest of the platforms throughout the analysis.

One of the six airships beat out all three aircraft in total operating time, while two out of the six airships required fewer platforms than the three aircraft to complete the mission. In addition, two of six airships required fewer crews than the aircraft, and three of the six airships were comparable to the number of crews that the aircraft required. Finally, all six airships required fewer sorties to complete the mission than all of the aircraft in this analysis.

The H2 Clipper airship again outperformed all platforms for this particular mission, while the LEMV was considered the outlier among all of the platforms when adhering to these performance standards. The H2 Clipper's superior performance for this particular mission is due to its relatively large payload capacity of 200 short tons and its block speed of over 300 knots. The airships compare favorably in this section of analysis, but it is important to remember the characteristics used for all the airships are best estimates provided by their respective companies. The airships' true potential cannot be fully realized until airships have been fully built and tested to those characteristics; however, our model is robust in that a practitioner can input the true parameters, and it will calculate the true characteristics of the airship.

Table 47 shows the output of each platform when mission duration totals 744 hours. Unlike with the previous mission duration time of 168 hours, the LMSR and FSS platforms are now able to complete the 2,500 short ton mission within the given mission duration time. The H2 Clipper outperforms even the LMSR and FSS now that they are available. The LMSR and FSS both outperform the aircraft and the other five airships in these performance measures, but, as Table 37 shows, as the mission duration time increases, the number of platforms required for aircraft and airships decreases, while the number sorties increases. The increased number of sorties counteracts the decreased number of air platforms required to complete the mission, but the total operating hours remain the same. An increase of mission duration time will not affect the total operating time to complete a mission, but it will dictate the number of sorties and platforms required when tonnage moved remains the same. Future research will need to analyze the total cost of procurement of air platforms versus the overall maintenance cost of conducting more sorties.

Table 47. Platform Characteristics—2,500 Short Tons with a 744-Hour Mission Duration Time

PLATFORMS	TOTAL TRIPS/SORTIES:	TOTAL PLATFORMS REQ:	NO. OF CREWS:	MAX TRIPS/SORTIES PER PLATFORM:	NO. OF PLATFORMS TO COMPLETE MAX TRIPS/SORTIES:	NO. OF REMAINING TRIPS/SORTIES:	NO. OF PLATFORMS REMAINING TRIPS/SORTIES:	TOTAL OPERATING HOURS:
C-130J	14	10	20	14	9	13	1	2884.3
C-17	15	4	8	15	3	11	1	915.9
C-5M	15	3	6	15	2	11	1	654.4
LMSR	1	1	1	1	1	0	0	589.5
FSS	1	1	1	1	1	0	0	541.8
SKYCAT 220	5	3	6	5	2	2	1	948.6
H2 CLIPPER	10	2	4	10	1	3	1	283.9
AEROSCRAFT	9	5	10	9	4	3	1	2158.0
HAV 366	8	7	14	8	6	2	1	3161.9
SKYHOOK	6	11	22	6	10	3	1	5976.0
LEMV	7	36	72	7	35	5	1	20750.0

2. Hourly Operating Costs for Airships

The total operating cost (N_O) is calculated by the product of total operating hours of the platform (T_O) and the average hourly operating cost of the platform (H_P) (Equation 11). The total operating hours and the total operating cost will remain the same despite the varying mission duration time. It can be observed that as mission duration time changes, the number of sorties and platforms changes to equal the same total operating hours. Table 48 defines the variable characteristics for Equation 11 and includes the input characteristics for the C-130J.

Table 48. Variable Characteristics for Equation 11, Including C-130J Input Parameters

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J PARAMETERS:
N_O	TOTAL OPERATING COSTS	HOUR (HR)	-
T_O	TOTAL OPERATING HOURS	HOUR (HR)	2884.25 hrs
H_P	HOURLY OPERATING COSTS FOR PLATFORM	DOLLAR/HOUR	$5,945.00/hr

We calculated Equation 11 as follows:

(No: = Total Operating Costs) $N_O = T_O * H_P$ (11)

The C-130J's total operating cost (N_O) can be calculated from the total operating hours (T_O) and hourly operating costs of the C-130J.

$N_O = T_O * H_P$ = (2884.25 hrs) * ($5,945.00/hr) = $17,146,866.25.

Tables 49 and 50 show the operating costs for all platforms, with the exception of airships, for mission duration times of 168 and 744 hours.

Table 49. Total Operating Costs for AMC/MSC Platforms—2,500 Short Tons and a 168-Hour Mission Duration Time

MISSION HOURS:	C-130J OP COSTS($):	C-17 OP COSTS($):	C-5M OP COSTS($):	LMSR OP COST ($):	FSS OP COST ($):
168	$ 17,146,866.25	$ 12,969,522.76	$ 23,307,932.31	N/A	N/A

Table 49 shows that the C-17 air platform is the platform with the lowest operating cost to deliver 2,500 short tons within a 168-hour mission duration time. The C-17 has the second lowest operating hours amongst the three aircraft, yet its costs are twice as low as the C-5M. This difference in hourly operating costs makes the C-17 the less costly aircraft in this situation. It can also be observed that the LMSR and FSS platforms are not available to complete this mission within the specified mission duration time due to the TATs of each platform.

Table 50. Table 50. Total Operating Costs for AMC/MSC Platforms—2,500 Short Tons and a 744-Hour Mission Duration Time

MISSION HOURS:	C-130J OP COSTS($):	C-17 OP COSTS($):	C-5M OP COSTS($):	LMSR OP COST ($):	FSS OP COST ($):
744	$ 17,146,866.25	$ 12,969,522.76	$ 23,307,932.31	$ 119,761.09	$ 565,275.23

Table 50 shows the same scenario, but with a mission duration time of 744 hours. This extension in mission duration time allows the LMSR and FSS to complete the mission, with only a 2,500 short ton cargo requirement. It can also be observed that both the LMSR and FSS have lower operating costs than the C-17 and the other two aircraft. The lower operating costs can be attributed to the use of only one ship and one trip for each to complete the 2,500 short ton mission, therefore, reducing the total operating hours required to complete the mission.

Based on Tables 49 and 50, we can conclude that the aircraft platforms have the advantage over the ship platforms to complete a mission with time durations up to 541.8 hours which is the time required for an FSS to finish the mission. When mission duration time is extended beyond 589.5 hours, the LMSR has the lowest operating costs amongst all the platforms.

The total hourly operating cost ($H_{P\text{-}AIRSHIP}$) of airships is equal to the ratio of the total operating cost ($N_{O\text{-}PLATFORM}$) of a platform and the total operating time ($T_{O\text{-}AIRSHIP}$) for an airship (Equation 12). We derived the hourly operating costs of airships ($H_{P\text{-}AIRSHIP}$) by utilizing the total operating costs derived for each platform in Tables 49 and 50**.** Because Table 49 excludes the ship platforms due to the short mission duration times, we will use the information provided in Table 50, which includes ship platforms. Table 51 is used to define the variable descriptions for Equation 12 and to provide the input parameters for the C-130J and the Skycat 220.

Table 51. Variable Descriptions for Equation 12, and C-130J and Skycat 220 Characteristics—2,500 Short Tons with a 744-Hour Mission Duration Time

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J PARAMETERS:	SKYCAT 220 PARAMETERS:
$H_{P\text{-}AIRSHIP}$	HOURLY OPERATING COSTS FOR AIRSHIP	DOLLAR/HOUR	-	-
$N_{O\text{-}AIRCRAFT}$	TOTAL OPERATING COSTS FOR AIRCRAFT	DOLLAR	$17,146,866.25	-
$T_{O\text{-}AIRSHIP}$	TOTAL OPERATING HOURS FOR AIRSHIP	HOUR	-	948.571 hrs

We calculated Equation 12 as follows:

($H_{P\text{-}AIRSHIP}$: = Hourly Operating Cost of Airships)

$$H_{P\text{-}AIRSHIP} = N_{O\text{-}AIRCRAFT} / T_{O\text{-}AIRSHIP} \quad (12)$$

For example, to calculate the break-even hourly cost between the C-130J aircraft and Skycat 220, we use the total operating cost ($N_{O\text{-}C\text{-}130J}$) of the C-130J to transport 2,500 short tons (shown in Table 51**)** and the total operating hours ($T_{O\text{-}SKYCAT\ 220}$) for the Skycat 220 to transport the same amount of cargo:

$$H_{P\text{-}SKYCAT\ 220} = N_{O\text{-}C\text{-}130J} / T_{O\text{-}SKYCAT\ 220} = \$17{,}146{,}866.26 / 948.571\text{ hrs} = \$18{,}076.52/\text{hr}.$$

Using Equation 12, Table 52 shows the break-even hourly operating costs between each platform and each airship for the cargo movement requirement of 2,500 short tons with a mission duration of 744 hours.

Table 52. Break-Even Hourly Costs Between Each AMC/MSC Platform and Airships—2,500 Short Tons with a 744-Hour Mission Duration Time

MISSION DURATION: 744 HRS **CARGO MOVEMENT:** 2500 SHORT TONS	C-130J OP COSTS($):	C-17 OP COSTS($):	C-5M OP COSTS($):	LMSR OP COST ($):	FSS OP COST ($):
SKYCAT 220	$ 18,076.52	$ 13,672.69	$ 24,571.62	$ 126.25	$ 595.92
H2 CLIPPER	$ 60,387.48	$ 45,675.80	$ 82,085.40	$ 421.77	$ 1,990.77
AEROSCRAFT	$ 7,945.72	$ 6,009.97	$ 10,800.71	$ 55.50	$ 261.94
HAV 366	$ 5,422.95	$ 4,101.81	$ 7,371.48	$ 37.88	$ 178.78
SKYHOOK	$ 2,869.29	$ 2,170.27	$ 3,900.26	$ 20.04	$ 94.59
LEMV	$ 826.36	$ 625.04	$ 1,123.27	$ 5.77	$ 27.24

To determine the minimum overall hourly operating costs for each airship, which we will use in the rest of this analysis for Scenario 2, we decided to choose the lowest hourly operating cost among the three air platforms versus the sealift platforms, as we did in Scenario 1.

To determine the minimum overall hourly operating costs, we extracted the lowest hourly operating cost amongst the three aircraft. Based on the data in Table 52, the C-17 had the lowest total operating cost for the transportation of 2,500 short tons. Table 53 summarizes the hourly operating cost and total operating costs (Equation 11) of each airship based on the C-17 total operating costs, results that we will use in the rest of the analysis.

Table 53. Hourly Operating Costs for Each Airship—2,500 Short Tons

AIRSHIPS	HOURLY OP COST BASELINE:	TOTAL OP COSTS:
SKYCAT 220	$ 13,672.69	$ 12,969,522.76
H2 CLIPPER	$ 45,675.80	$ 12,969,522.76
AEROSCRAFT	$ 4,101.81	$ 12,969,522.76
HAV 366	$ 4,101.81	$ 12,969,522.76
SKYHOOK	$ 2,170.27	$ 12,969,522.76
LEMV	$ 625.04	$ 12,969,522.76

The total operational costs for each airship, as calculated in Table 53, are the same as the C-17 total operating costs. The break-even hourly operating costs for each airship was calculated by dividing the total operating hours of each airship into the C-17's total operating costs which is the same calculation we used in Scenario 1. In a later section, we analyze the change of total operating costs based on a reduction in hourly operating costs for each airship.

Table 53 does not necessarily represent an airship's actual hourly operating cost. Instead, it gives an hourly operating cost threshold; anything greater than this cost will exclude an airship as a cost-effective alternative to other heavy-lift platforms. A larger baseline, therefore, represents an attractive alternative. Said another way, the H2 Clipper can have an hourly operating cost of up to $45,675.80 and still be a competitive option compared to all heavy-lift platforms. A larger baseline provides a less restrictive range in which airships can improve or meet the baseline. A lower baseline provides a more restrictive situation where an airship can improve its hourly operating costs from the baseline. Therefore, since H2 Clipper and Skycat 220 have the highest hourly operating cost baselines, both have the advantage to seek improvements on their hourly operating costs compared to the other airships.

Table 52 also shows the break-even hourly operating costs for an airship to compete against MSC platforms. The hourly operating cost ranges from $5.77 to $1,990.77 for the LMSR and the FSS platforms. Sealift platforms will always have the lowest overall hourly operating cost because they require fewer platforms and trips to complete a mission cargo load requirement of 2,500 short tons. In addition to a minimum number of platform and trips, a MSC ship will not depart a port unless it is at or near its maximum planned payload, which allows the total cost of a mission to be spread across the total tonnage it is carrying.

3. Manning and Overall Costs

The number of total manpower hours (T_T) is calculated by multiplying the total number of platforms performing the maximum sorties (I_{AF}), the maximum sorties (S_{AF}), and the TAT of the platform (T_A). This value is then added to the product of the number of aircraft conducting limited sorties (I_{AP}), the number of limited sorties (S_{AP}), and the TAT of the platform ($T_{A;}$ Equation 13). Table 54 provides the variable descriptions for Equation 13 and the input characteristics of the C-130J.

Table 54. Variable Descriptions for Equation 13 with C-130J Characteristics—2,500 Short Tons and a 744-Hour Mission Duration Time

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J CHARACTERISTICS:
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	PLATFORMS	9 platforms
S_{AF}	MAXIMUM NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS	14 sorties
I_{AP}	NUMBER OF PLATFORMS COMPLETING LIMITED SORTIES/TRIPS	PLATFORMS	1 platform
S_{AP}	LIMITED NUMBER OF SORTIES/TRIPS	SORTIES/TRIPS	13 sorties
T_A	TURN-AROUND TIME FOR PLATFORM	HOURS (HR)	52.25hrs
T_T	TOTAL MANPOWER HOURS/TOTAL TIME TO COMPLETE MISSION	HOURS (HR)	-

We calculated Equation 13 as follows:

(T_T: =Total Manpower Hours Costs for Air Platforms)

$$T_T = I_{AF} * S_{AF} * T_A + I_{AP} * S_{AP} * T_A \quad (13)$$

For example, to calculate the total manpower hours (T_T) for the C-130J, we use the information calculated in previous tables and shown in Table 54:

$T_T = I_{AF} * S_{AF} * T_A + I_{AP} * S_{AP} * T_A$

= 9 platforms * 14 sorties * 52.25 hrs + 1 platform * 13 sorties * 52.25 hrs

= 7262.75 hours.

Table 55 depicts the total manpower hours required to operate each air and sealift platform based on 2,500 short tons and a 744-hour mission duration time. Total manpower hours are dependent on the number of short tons required to be moved. As tonnage required increases, total manpower hours will also increase. As long as tonnage required to be moved remains constant, mission duration time will not affect the total manpower hours.

Table 55. Total Manpower Hours per Platform—2,500 Short Tons with a 744-Hour Mission Duration Time

PLATFORMS	TOTAL MANPOWER HOURS:
C-130J	7262.8
C-17	2679.9
C-5M	1945.9
LMSR	589.5
FSS	541.8
SKYCAT 220	1568.6
H2 CLIPPER	912.3
AEROSCRAFT	3165.5
HAV 366	4328.6
SKYHOOK	7341.0
LEMV	24916.7

The total manning cost (N_M) for air platforms is equal to the product of total time to complete a mission (T_T) and the summation product of the total manning of officers (M_O) and enlisted personnel (M_E) multiplied by the hourly wage of officers (H_O) and enlisted personnel ($H_{E;}$ Equation 14). The total manning cost (N_M) for sealift platforms is equal to the product of total time to complete a mission (T_T), the product of total manning of civilian personnel (M_V) and by the hourly wage of civilian personnel ($H_{V;}$ Equation 15).

Table 56. Variable Descriptions for Equation 14 and 15

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
H_E	HOURLY ENLISTED WAGES	DOLLARS
H_O	HOURLY OFFICER WAGES	DOLLARS
H_V	HOURLY CIVILIAN WAGES	DOLLARS
M_E	MANNING FOR ENLISTED	PERSONNEL
M_O	MANNING FOR OFFICERS	PERSONNEL
M_V	MANNING FOR CIVILIANS	PERSONNEL
N_M	TOTAL MANNING COSTS	DOLLARS
T_T	TOTAL MANPOWER HOURS/TOTAL TIME TO COMPLETE MISSION	HOURS (HR)

Equations 14 and 15 are calculated as follows:

(N_M: =Total Manpower Costs for Air Platforms)

$$N_M = T_T * (H_O * M_O + H_E * M_E) \qquad (14)$$

(N_M : = Total Manpower Costs for Sealift Platforms)

$$N_M = T_T * (M_V * H_V) \qquad (15)$$

The overall cost for both air and sealift platforms, given a particular mission (N_A), is equal to the summation of the total operating cost (N_O) and total manning costs (N_M). Total trucking costs (N_T) was not included in this scenario and only pertains to Scenario 1. Equations 17 and 18 to calculate overall costs for air and sea platforms are exactly the same in Scenario 2, but to keep continuity from Scenario 1, they are considered separate equations. The difference between Scenario 1 and Scenario 2 is that the total trucking costs (N_T) has been excluded in Equation 18. Table 57 provides the variable descriptions for Equations 17 and 18:

Table 57. Variable Descriptions for Equations 17 and 18

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:
N_A	OVERALL COSTS FOR AIR/SEALIFT PLATFORMS	DOLLARS
N_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS
N_O	TURN-AROUND TIME	HOURS

We calculated Equations 17 and 18 as follows:

(N_A: = Overall Costs for Air Platforms): $N_A = N_O + N_M$ (17)

(N_A: = Overall Costs for Sealift Platforms): $N_A = N_O + N_M$ (18)

For example, the total operating cost, total manning cost, and the overall costs can be calculated for the C-130J based on the characteristics defined by Table 58.

Table 58. C-130J Characteristics—2,500 Short Tons with a Mission Duration of 744 Hours

SYMBOLS:	VARIABLE DESCRIPTIONS:	C-130J:
H_E	HOURLY ENLISTED WAGES	$10.80/hr
H_O	HOURLY OFFICER WAGES	$16.27/hr
M_E	MANNING FOR ENLISTED	2 enlisted (E-6)
M_O	MANNING FOR OFFICERS	2 officers (O-3)
N_O	TOTAL OPERATING COSTS	$17,146,866.25
I_{AF}	NUMBER OF PLATFORMS CONDUCTING MAXIMUM SORTIES/TRIPS	9 platforms
S_{AF}	MAXIMUM NUMBER OF SORTIES/TRIPS	14 sorties
I_{AP}	NUMBER OF PLATFORMS COMPLETING LIMITED SORTIES/TRIPS	1 platform
S_{AP}	LIMITED NUMBER OF SORTIES/TRIPS	13 sorties
T_T	TOTAL MANPOWER HOURS/TOTAL TIME TO COMPLETE MISSION	7,262.75 hours
N_A	TOTAL OVERALL COSTS	-
N_M	TOTAL MANNING COSTS	-

To calculate total manning costs (NM) for C-130J to move 2,500 short tons within a 744-hour mission duration time, we used Equation 16:

$N_M = T_T * (H_O * M_O + H_E * M_E)$

$= 7{,}262.8 * (2 \text{ officers} * \$16.27/\text{hr} + 2 \text{ enlisted} * \$10.80/\text{hr}) = \$393{,}205.28$.

Finally, using the total operating costs (Table 14), we calculated the overall costs based on Equation 17:

$N_A = N_O + N_M = \$17{,}146{,}866.25 + \$393{,}205.28 = \$17{,}540{,}071.53$.

Numbers and cost outputs will vary from the examples and tables due to rounding errors. The rounding errors are negligible to the overall costs.

Table 59 shows the various manning and overall costs for the various platforms for a given mission duration of 168 hours. To determine the most suitable platform to perform this particular mission, a performance measure of lowest total overall cost is used to compare the platforms.

Table 59. Total Overall Cost for Each Platform—2,500 Short Tons with a 168-Hour Mission Duration

PLATFORMS	TOTAL OP COST:	TOTAL MANNING COST:	TOTAL OVERALL COST:
C-130J	$ 17,146,866.25	$ 393,262.78	$ 17,540,129.03
C-17	$ 12,969,522.76	$ 145,108.95	$ 13,114,631.71
C-5M	$ 23,307,932.31	$ 168,432.48	$ 23,476,364.79
LMSR	N/A	N/A	N/A
FSS	N/A	N/A	N/A
SKYCAT 220	$ 12,969,522.76	$ 84,934.88	$ 13,054,457.63
H2 CLIPPER	$ 12,969,522.76	$ 49,398.10	$ 13,018,920.86
AEROSCRAFT	$ 12,969,522.76	$ 171,405.23	$ 13,140,927.99
HAV 366	$ 12,969,522.76	$ 234,383.13	$ 13,203,905.88
SKYHOOK	$ 12,969,522.76	$ 397,499.86	$ 13,367,022.61
LEMV	$ 12,969,522.76	$ 1,349,185.59	$ 14,318,708.35

As seen in Table 59, two of the six airships beat out all three aircraft platforms. All six of the airships were more cost effective than the C-5 and the C-130J. Due to the short mission duration time, MSC ships cannot perform the mission and, therefore, are at a disadvantage compared to other air platforms. If manufacturers make the hourly operating cost of airships lower than the baseline, the total overall cost will only decrease further. Later analysis will show the price difference of lower hourly operating costs.

Table 60 shows the total operating costs, total manning costs, and the total overall cost for all platforms for a given 744-hours mission duration time. Extending the mission duration time to 744 hours allows MSC ships to be utilized as an option. Using the performance measure for the previous mission duration time, we notice that the best platform to conduct this mission with the given parameters is the LMSR.

Table 60. Total Overall Cost for Each Platform—2,500 Short Tons with a 744-Hour Mission Duration

PLATFORMS	TOTAL OP COST:	TOTAL MANNING COST:	TOTAL OVERALL COST:
C-130J	$ 17,146,866.25	$ 393,262.78	$ 17,540,129.03
C-17	$ 12,969,522.76	$ 145,108.95	$ 13,114,631.71
C-5M	$ 23,307,932.31	$ 168,432.48	$ 23,476,364.79
LMSR	$ 119,761.09	$ 22,352.91	$ 142,114.00
FSS	$ 565,275.23	$ 63,074.00	$ 628,349.23
SKYCAT 220	$ 12,969,522.76	$ 84,934.88	$ 13,054,457.63
H2 CLIPPER	$ 12,969,522.76	$ 49,398.10	$ 13,018,920.86
AEROSCRAFT	$ 12,969,522.76	$ 171,405.23	$ 13,140,927.99
HAV 366	$ 12,969,522.76	$ 234,383.13	$ 13,203,905.88
SKYHOOK	$ 12,969,522.76	$ 397,499.86	$ 13,367,022.61
LEMV	$ 12,969,522.76	$ 1,349,185.59	$ 14,318,708.35

Tables 59 and 60 show that total overall costs remain constant for all platforms over the mission duration times, with the exception of the MSC platforms due to their limited availability. Although the total operating cost for each airship is equal to the total operating cost of the C-17 platform, total manpower costs will determine the difference in total overall costs. Manpower costs will continue to increase as total cargo moved increases and can account for the subtle differences in total overall costs and cost per short ton-nautical, which we discuss in the next section.

4. Cost Per Ton-Nautical Mile

Cost per ton-nautical mile (N_C) is equal to the ratio of total overall costs (N_A) and the amount of cargo moved (C_M) multiplied by the total distance (2 * D) traveled for a particular mission (Equation 19). Table 61 defines Equation 19 and the input characteristics of the C-130J.

Table 61. Variable Description for Equation 19 with C-130J Characteristics—2,500 Short Tons and a 168Hour Mission Duration Time

SYMBOLS:	VARIABLE DESCRIPTIONS:	UNITS:	C-130J CHARACTERISTICS:
C_M	CARGO MOVEMENT REQUIREMENT	SHORT TONS	2500 short tons
D	DISTANCE	NAUTICAL MILES	3320 nm
N_A	TOTAL OVERALL COSTS	DOLLARS	$17,146,866.25
N_C	COST PER TON-NAUTICAL MILE	DOLLARS/TON-NAUTICAL MILE	-

Equation 19 is calculated as follows:

(N_C: = Cost Per Ton-NM): $N_C = N_A / (C_M * 2 * D)$ (19)

For example, to calculate the C-130J's cost per ton-nautical mile, we used the calculations in Table 61, which shows the C-130J characteristics previously presented in other tables. Using Equation 19, we calculate the cost per ton-nautical mile as follows:

$N_C = N_A / (C_M * 2 * D)$ = $17,146,866.25 / (2,500 short tons * 2 * 3,320 nm)

= $1.03 per short ton-nautical mile.

In the Excel model, the cost per ton-nautical is closer to $1.06 per short ton-nautical mile due to the rounding errors associated with this example.

Tables 62 and 63 show the cost per ton-nm for each platform, assuming mission duration times of 168 hours and 744 hours, respectively.

Table 62. Cost/Ton-NM for Each Platform—2,500 Short Tons with a 168-Hour Mission Duration Time

PLATFORMS	COST/TON-NAUTICAL MILE:
C-130J	$ 1.06
C-17	$ 0.79
C-5M	$ 1.41
LMSR	N/A
FSS	N/A
SKYCAT 220	$ 0.79
H2 CLIPPER	$ 0.78
AEROSCRAFT	$ 0.79
HAV 366	$ 0.80
SKYHOOK	$ 0.81
LEMV	$ 0.86

Table 63. Cost/Ton-NM for Each Platform—2,500 Short Tons with a 744-Hours Mission Duration Time

PLATFORMS	COST/TON-NAUTICAL MILE:
C-130J	$ 1.06
C-17	$ 0.79
C-5M	$ 1.41
LMSR	$ 0.01
FSS	$ 0.04
SKYCAT 220	$ 0.79
H2 CLIPPER	$ 0.78
AEROSCRAFT	$ 0.79
HAV 366	$ 0.80
SKYHOOK	$ 0.81
LEMV	$ 0.86

Based on the TAT times in Table 42**,** the AMC platforms have the upper hand in delivering the 2,500 tons for the first 45–70.2 hours. Neither the sealift nor the airship platforms can make a round trip within that mission duration time. When the mission duration is 70.2 hours, the H2 Clipper is the only airship available to complete the mission, but it has the lowest cost per ton-nautical mile compared with the aircraft platforms. As the mission duration time increases to 168 hours, as depicted in Table 62, all six airships become available and have a lower cost per ton-nautical mile compared to the C-130J and C-5M. Two of the six airships have the same cost per ton-nautical mile as the C-17, while three of the six airships have a slightly greater cost per ton-nautical mile of $0.80, $0.81, and $0.86. Airships seem to dominate in reducing cost per ton-nautical mile until mission duration increases to 744 hours, as depicted in Table 63**.** Both the FSS and LMSR ships become available to complete the mission at that time. The FSS and LMSR both have a cost per ton-nautical that is lower than that of air platforms, including airships. If time does not become a major factor, the MSC ships will always have a lower cost in general.

C. HOURLY OPERATING COST SAVINGS

The hourly operating cost for each airship was calculated in order to determine if airships could be a viable alternative to all heavy-lift aircraft. A one-size-fits-all hourly operating cost was used in our analysis in order to compare airships to all platforms.

However, based on the cost of procurement and life-cycle costs of current platforms, airships could provide a cheaper form of heavy-lift transportation than any other platform.

1. Replacement Operating Costs

The following analysis is based on a mission of 2,500 short tons and a 744-hour completion time. Referring back to Tables 47 and 50, we can find the number of airships, sorties required, and break-even costs between airships and other platforms for a cargo movement requirement of 2,500 short tons with a 744-hour mission completion time. These tables are essential for planners who are considering future acquisitions of airships and need to evaluate the costs savings associated with replacing current heavy-lift platforms.

a. Platform Savings

The hourly operating costs baselines (seen in Table 48) are thresholds that airships cannot go over in order to be considered an alternative to current heavy-lift logistics. Given these guidelines, we can calculate the cost savings if airship companies are able to reduce the hourly costs in Table 48 by $100. Table 64 calculates the total operational cost savings if the break-even hourly operational costs were reduced by $100.

Table 64. Hourly Operating Cost Reduction of $100—2,500 Short Tons with a 744-Hour Mission Duration Time

AIRSHIPS:	OLD HOURLY OP COSTS:	OLD TOTAL OP COSTS:	NEW HOURLY OP COST REDUCED BY $100:	NEW TOTAL OP COSTS:	DIFFERENCE BETWEEN TOTAL OP COSTS:
SKYCAT 220	$ 13,672.69	$ 12,969,522.76	$ 13,572.69	$ 12,874,665.62	$ 94,857.14
H2 CLIPPER	$ 45,675.80	$ 12,969,522.76	$ 45,575.80	$ 12,941,128.02	$ 28,394.74
AEROSCRAFT	$ 6,009.97	$ 12,969,522.76	$ 5,909.97	$ 12,753,722.76	$ 215,800.00
HAV 366	$ 4,101.81	$ 12,969,522.76	$ 4,001.81	$ 12,653,332.28	$ 316,190.48
SKYHOOK	$ 2,170.27	$ 12,969,522.76	$ 2,070.27	$ 12,371,922.76	$ 597,600.00
LEMV	$ 625.04	$ 12,969,522.76	$ 525.04	$ 10,894,522.76	$ 2,075,000.00

Table 65. Hourly Operating Cost Reduction of $1,000—2,500 Short Tons with a 744-Hour Mission Duration Time

	AIRSHIP OPERATING COST SAVINGS	
	COST SAVINGS	COST SAVINGS
AIRSHIPS:	PER $100 REDUCTION	PER $1000 REDUCTION
SKYCAT 220	$ 94,857.14	$ 948,571.43
H2 CLIPPER	$ 28,394.74	$ 283,947.37
AEROSCRAFT	$ 215,800.00	$ 2,158,000.00
HAV 366	$ 316,190.48	$ 3,161,904.76
SKYHOOK	$ 597,600.00	$ 5,976,000.00

Table 64 shows for every $100 reduction in hourly operating costs, the Skycat 220, H2 Clipper, Aeroscraft, HAV 366, Skyhook, and LEMV can provide a cost savings of approximately $94,900; $28,400; $215,800; $316,200; $597,600; and $2.1 million, respectively, from the total operating costs of $12.97 million. Further analysis shows that if hourly operating costs are reduced by up to $1,000, the cost savings from the current total operating costs will increase 1,000-fold, as seen in Table 65. The LEMV was excluded from Table 65 due to its relatively low hourly operating costs that cannot be reduced by $1,000.

If we compare the hourly operating cost baselines for airships to the lowest hourly operating cost for an aircraft, the Skycat 220 and H2 Clipper are the only two airships that are over the lowest hourly operating costs of the C-130J, which is $5,945 per hour. If the companies that produce the Skycat 220 and H2 Clipper were able to reduce their hourly costs to $5,945 per hour both airships could possibly save a total of $7.3 million and $11.3 million, respectively, as shown in Table 66, from the total operating cost of $12.97 million.

Table 66. Skycat 220 and H2 Clipper Hourly Operating Cost Reduction to $5,945 and Cost Savings—2,500 Short Tons with a 744-Hour Mission Duration Time

AIRSHIPS:	OLD HOURLY OP COSTS:	OLD TOTAL OP COSTS:	NEW HOURLY OP COST REDUCED:	NEW TOTAL OP COSTS:	DIFFERENCE BETWEEN TOTAL OP COSTS:
SKYCAT 220	$ 13,672.69	$ 12,969,522.76	$ 5,945.00	$ 5,639,257.14	$ 7,330,265.62
H2 CLIPPER	$ 45,675.80	$ 12,969,522.76	$ 5,945.00	$ 1,688,067.11	$ 11,281,455.65

The implications from this analysis show that if companies invest in technologies that improve engine technology, fuel efficiency, maintenance, and various other factors, they can reduce the hourly operating costs of their products and, therefore, can provide buyers large cost savings. This is especially true if they can reduce the cost by $100 or more. These baselines can be beneficial to the future acquisition of airships, because they allow DoD planners to determine if an airship is the right platform to perform a certain mission.

2. Variable Short Tons with Constant Mission Duration Time

Under the normal circumstances encountered by the DoD and USTRANSCOM, the amount of cargo to be transferred will be larger than the 2,500 short tons. The previous sections of this analysis have shown how particular missions may have a constant amount of tonnage required over variable mission durations. If mission duration time is constant and tonnage changes, the number of operating hours required to complete a mission will increase, as well as the number of aircraft and sorties. This is depicted in Figures 9 and 10:

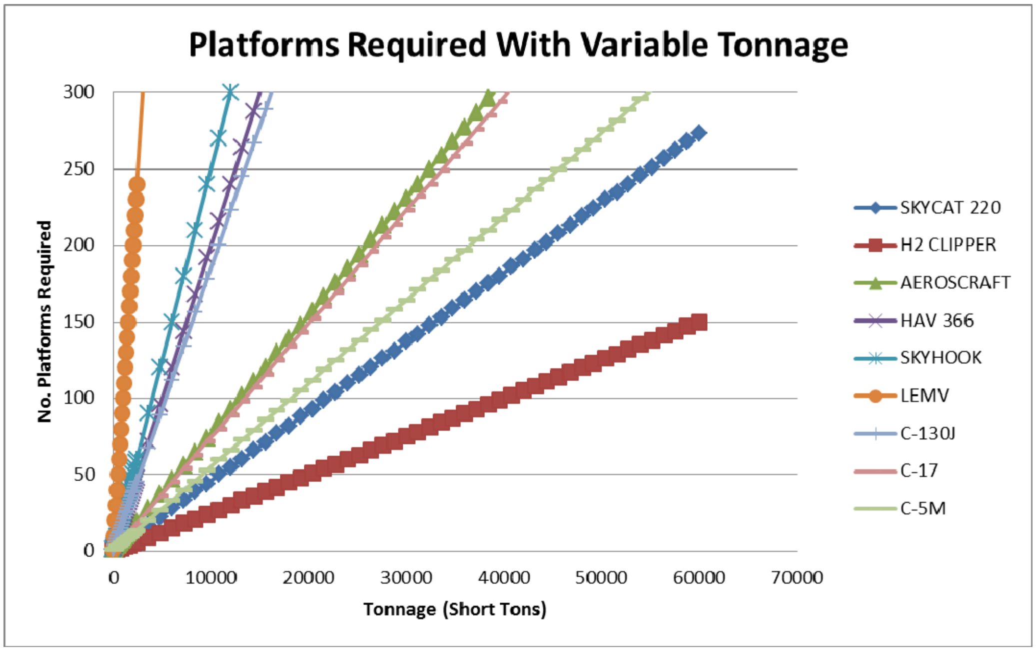

Figure 9. Platform Required with Variable Tonnage and a 168-Hour Mission Duration

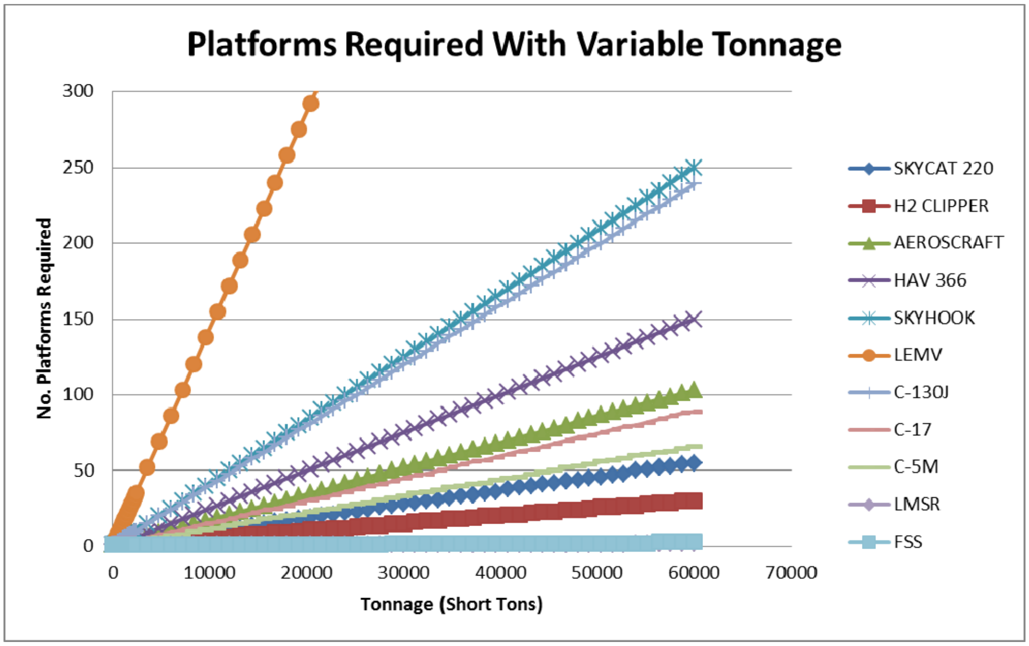

Figure 10. Platform Required with Variable Tonnage and a 744-Hour Mission Duration

Figures 9 and 10 show the number of platforms required to complete a mission whose tonnage varies from one to 60,000 short tons of material. As depicted in Figure 9, more platforms are required to complete missions that have relatively short time durations. Figure 10 shows the opposite: fewer platforms are needed for missions with relatively long time durations. As shown in Figure 10, ship platforms are available to complete missions with longer duration, but due to their large payload capacities, relatively few ship platforms will be needed to complete mission, even if the cargo tonnage to be moved increases. Although Figure 10 does not show it, the number of ship platforms required to complete each mission falls between one or three platforms.

The effects of the mission duration times can be seen in both figures where the slope of the line showing number of platforms changes based on variable tonnage. with lower mission duration times, the line in Figure 9 shows a relatively steeper slope compared to that in Figure 10. This sudden increase in slope can also translate into an increase in operating costs for all platforms. Using the same events as Figures 9 and 10, Figures 11 and 12 depict the changes in operating costs for mission duration times of 168 and 744 hours, respectively.

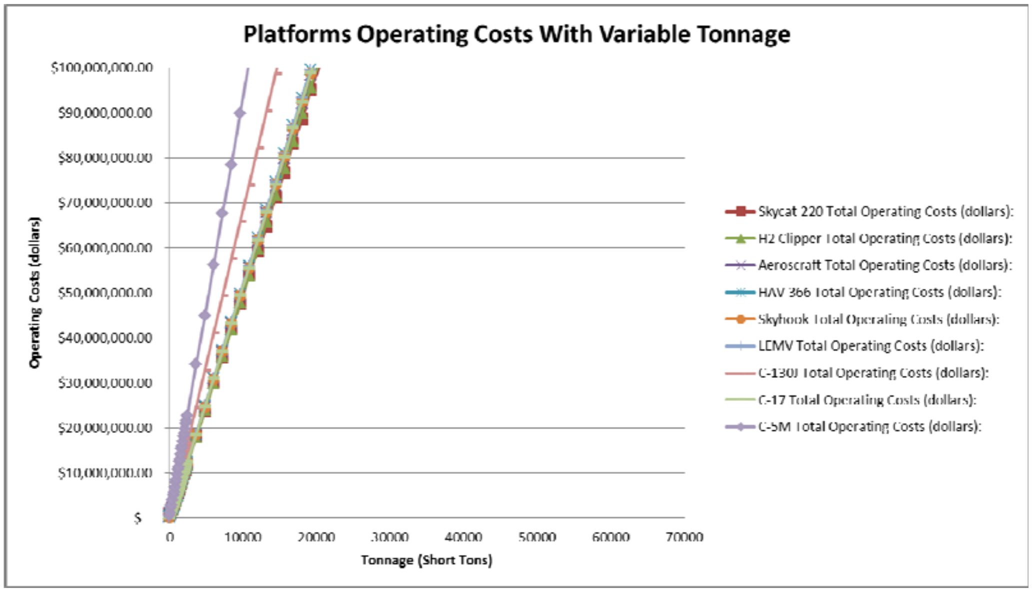

Figure 11. Platforms Operating Costs with Variable Tonnage and a 168-Hour Mission Duration

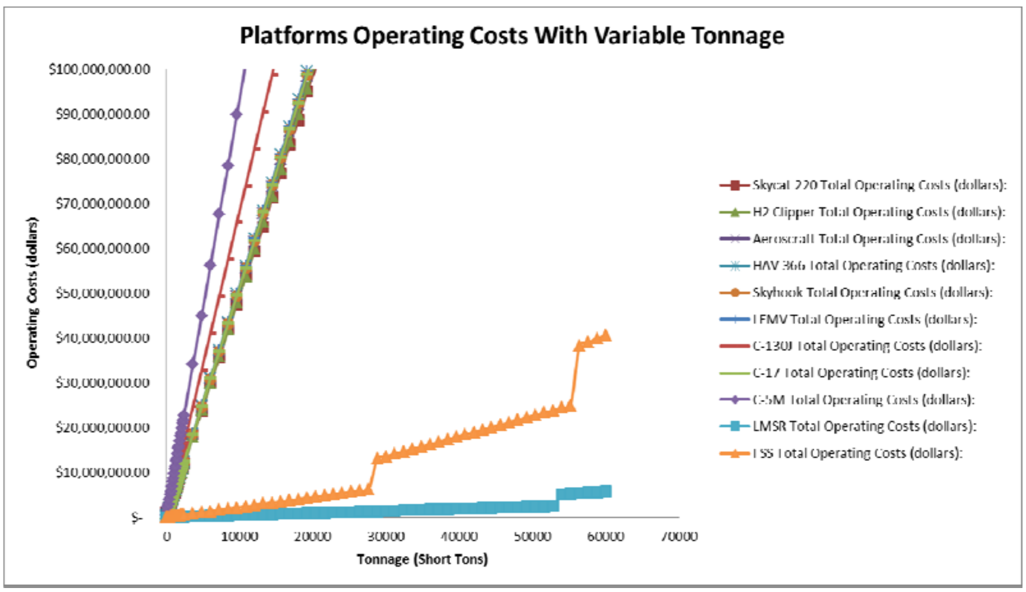

Figure 12. Platform Operating Costs with Variable Tonnage and a 744-Hour Mission Duration Time

From Figures 11 and 12, we can conclude that as the cargo required to be moved increases, the total operating costs will increase at the same rate no matter what the mission duration time is. This is due to the fact that total operating hours will remain the same over a varying mission duration time as long as the cargo required to be moved is the same. Figure 12 also shows the LMSR and FSS as options when mission duration time increases to 744 hours. The “step” in the LMSR and FSS curves is due to the added ship required to complete a mission. For example, the LMSR planned payload capacity is 53,224.2 short tons, and once the cargo required to be moved increases beyond this tonnage, another ship is needed to complete the mission. The same effect can be used to explain the FSS platform; the line jumps from one to three when the cargo required to be moved increases to 60,000 short tons.

D. AUTONOMOUS AIRSHIPS—MANNED VS. UNMANNED

The following analysis shows the potential total cost benefit, cost per ton-nautical mile benefit, and number of platforms to complete a mission. In addition, the analysis shows the potential total cost benefit of autonomous airships compared to the current manned logistics platforms.

1. Manned or Unmanned Airships

Table 67 shows the potential benefit of unmanned airships compared to manned airships in TAT, number of aircraft, number of crew, and number of sorties.

Table 67. Manned vs. Unmanned Airships

	MANNED AIRSHIPS				UNMANNED AIRSHIPS			
AIRSHIPS:	TAT:	NO. SORTIES:	NO. AIRCRAFT:	NO. CREWS :	TAT:	NO. SORTIES:	NO. AIRCRAFT:	NO. CREWS :
SKYCAT 220	130.7	5	2	6	118.7	6	2	0
H2 CLIPPER	70.2	10	1	4	58.2	13	1	0
AEROSCRAFT	81.2	9	4	10	69.2	10	4	0
HAV 366	86.6	8	6	14	74.6	9	6	0
SKYHOOK	116.5	6	10	22	104.5	7	9	0
LEMV	99.7	7	35	72	87.7	8	32	0

As Table 67 shows, the TAT of unmanned ships is 12 hours lower than for manned ships due to the elimination of the crew rest that pilots and crewmembers are required to take after flying for a certain amount of hours. The new TAT allows airships to be used more frequently to deliver more cargo. The smaller TAT reduces the number of airships needed to maintain a steady-state delivery system, but at the same time increases the number of sorties required to complete the mission, as seen in Table 67; as the total number of airships decreases, sorties increase to maintain the steady state of the aircraft. Dependent on hourly operating cost, total operating costs will remain the same.

The biggest change from manned to unmanned airships comes from the total overall costs due to the decreased number of manpower hours required to complete a mission. As seen in Table 67, as the total number of airships decreases, sorties increase to maintain the steady state of the aircraft. Table 68 shows the potential change to overall cost of a mission for each airship.

Table 68. Savings/Losses From Manned to Unmanned Airships—2,500 Short Tons with a 744-Hour Duration

	Manned Overall Cost:	Unmanned Overall Cost:	Cost Change:
SKYCAT 220	$ 13,054,457.63	$ 12,969,522.76	$ 84,934.87
H2 CLIPPER	$ 13,018,920.86	$ 12,969,522.76	$ 49,398.10
AEROSCRAFT	$ 13,140,927.99	$ 12,969,522.76	$ 171,405.23
HAV 366	$ 13,203,905.88	$ 12,969,522.76	$ 234,383.13
SKYHOOK	$ 13,367,022.61	$ 12,969,522.76	$ 397,499.86
LEMV	$ 14,318,708.35	$ 12,969,522.76	$ 1,349,185.59

The cost change shown in Table 68 results solely from the total manning costs when airships are manned. As the total operating costs will remain the same with a given tonnage, the total manning costs will make up the difference between manned and unmanned airship scenarios. All six airships show a potential benefit in using unmanned variants to transport the 2,500 short tons within a 744-hour mission duration. If airships fly at the same rate as their manned counterparts, additional cost savings will be gained because there will be no manning costs.

Table 69. Cost/Ton-Nm Changes—2,500 Short Tons with a 744-Hour Duration

	Manned Cost/Ton-NM:	Unmanned Cost/Ton-NM:	Cost/Ton-NM Change:
SKYCAT 220	$ 0.79	$ 0.78	$ 0.01
H2 CLIPPER	$ 0.78	$ 0.78	$ 0.00
AEROSCRAFT	$ 0.79	$ 0.78	$ 0.01
HAV 366	$ 0.80	$ 0.78	$ 0.01
SKYHOOK	$ 0.81	$ 0.78	$ 0.02
LEMV	$ 0.86	$ 0.78	$ 0.08

Table 69 shows the potential impact that total mission costs have on the cost per ton-nautical mile for each airship. Five out of the six airships have decreased costs per ton-nautical mile, while only one airship's costs remain the same. Overall costs and cost per ton-nautical mile are highly dependent on the mission duration and the amount of cargo to be moved. A change in either of these two may change the number of airships and sorties required to complete the mission.

It is important to note that with our model, as the number of sorties increases, the TAT decreases and number of airships available to complete a mission increases, therefore reducing the total number of airships required. with the unmanned airships, total manning costs will not be incurred and the total overall costs will decrease.

2. Manned Platforms vs. Unmanned Airships

Unmanned airships can provide a potential cost-savings benefit, especially when a mission happens quite frequently. Table 70 shows the total cost savings or losses between current heavy-lift platforms and unmanned airships.

Table 70. Total Cost Savings/Losses Between Platforms and Airships—2,500 Short Tons with a 744-Hour Mission Duration

	Manned AMC/MSC Overall Cost:	Unmanned Airships' Total Cost:	Total Cost Change:
C-130J	$ 17,540,129.03	$ 12,969,522.76	$ 4,570,606.27
C-17	$ 13,114,631.71	$ 12,969,522.76	$ 145,108.95
C-5M	$ 23,476,364.79	$ 12,969,522.76	$ 10,506,842.03
LMSR	$ 142,114.00	$ 12,969,522.76	$ (12,827,408.76)
FSS	$ 628,349.23	$ 12,969,522.76	$ (12,341,173.53)

Unmanned airships can provide costs savings compared to all of the heavy-lift air platforms. Table 70 shows that the greatest cost savings can be obtained by using unmanned airships to replace the C-5M platform. All six airships provide a positive cost savings, ranging from $145,000 to $10.5 million, against the three AMC platforms. Due to the relatively small overall cost of MSC ships, unmanned airships cannot compete against them. All six airships provide a negative cost savings when compared to MSC ships.

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VIII. ADDITIONAL AIRSHIP ANALYSIS

A. BLOCK SPEED AND PAYLOAD CAPACITY

Total operating hours and total manpower hours are the determining factors driving the overall costs of any given mission. Airships with high block speeds and relatively large payload capacities excel in keeping operating and manpower hours low. In the analysis thus far, we have assumed that an airship's block speed and payload capacity characteristics are the best case values at which they can perform a mission. Improvements in engine technology, fuel efficiency, composite material structures, and lifting systems can greatly enhance an airship's block speed and payload capacity, adding to the benefits that airships could bring to the heavy-lift logistics environment.

The following section analyzes the benefits of improving each airship's block speeds and payload capacity. It will show that changing either one or both of these characteristics greatly affects total operating hours and total manpower hours. Block speeds and payload capacities were both subjected to increases of 25%, 50%, 75%, and 100% to show the varying benefits that each airship can potentially have on the total time required to complete a mission. These outputs can function as a guide that airship companies and the DoD can use when analyzing the characteristics that are required to meet various mission demands.

1. Skycat 220

The Skycat 220, developed by World Skycat Ltd., provides a lift payload capacity of 220 short tons and a block speed of 84 knots. The Skycat 220 airship has a large payload capacity and medium block speed range. Table 71 shows 25%, 50%, 75%, and 100% increases in payload capacity and block speed in order to determine the effect of these increases on total operating hours.

Table 71. Skycat 220 Total Operating Hours with Increases in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

SKYCAT 220	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	220	275	330	385	440	TOTAL OPERATING HOURS (HRS)
84	800.0	666.7	533.3	466.7	400.0	
105	640.0	533.3	426.7	373.3	320.0	
126	533.3	444.4	355.6	311.1	266.7	
147	457.1	381.0	304.8	266.7	228.6	
168	400.0	333.3	266.7	233.3	200.0	

Table 71 shows that when payload capacity increased by 25%, from 220 short tons to 275 shorts tons, with a constant block speed of 84 knots, total operating time decreased from 800 hours to 666.7 hours. Further observation shows that for every 25% increase in payload capacity, with a constant block speed of 84 knots, total operating time decreases by a factor of 133.3 hours. When block speed is increased by 25% from 84 knots to 105 knots, with a constant payload capacity of 220 short tons, total operating hours decreased from 800 hours to 640 hours; a decrease of 160 hours compared to the original 800 hours. Further analysis shows that as block speed increases to 126, 147, and 168 knots, total operating time decreases by 266.7, 342.9, and 400 hours, respectively. Figure 13 shows that as both payload capacity and block speed increase by up to 100%, 600 hours could potentially be saved from the original 800 hours to complete the mission.

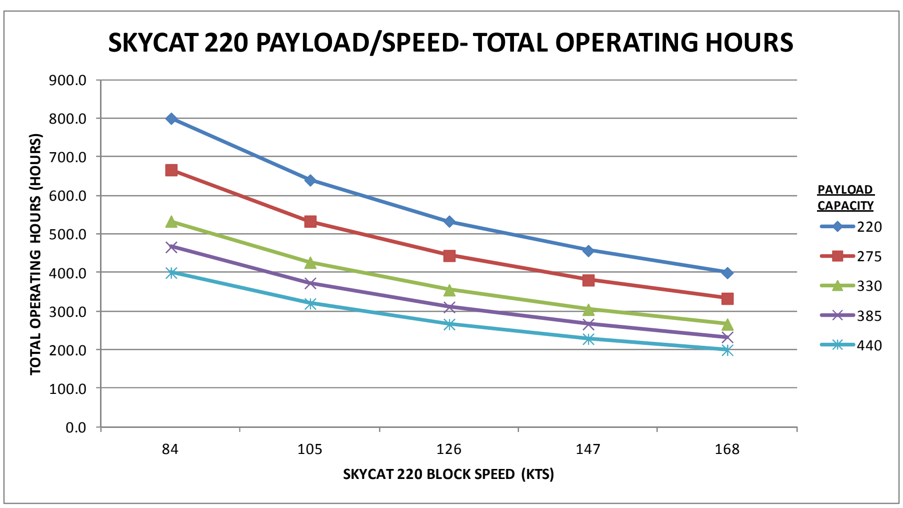

Figure 13. Skycat 220 Total Operating Hours with Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

Table 72. Skycat 220 Total Manpower Hours with Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with 168-Hour Mission Duration

SKYCAT 220	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	220	275	330	385	440	
84	1420.0	1183.3	946.7	828.3	710.0	TOTAL MANPOWER HOURS (HRS)
105	1260.0	1050.0	840.0	735.0	630.0	
126	1153.3	961.1	768.9	672.8	576.7	
147	1077.1	897.6	718.1	628.3	538.6	
168	1020.0	850.0	680.0	595.0	510.0	

Table 72 shows the potential savings in total manpower hours involved in conducting a mission of 168 hours and 2,500 short tons. When payload capacity is increased from 220 short tons to 275 shorts tons, with a constant block speed of 84 knots, the total manpower time decreased from 1,420 hours to 1,183.3 hours. This decrease in total manpower is due to the number of airships required to complete the movement of 2,500 short tons within a 168-hours mission duration time. For every 25% increase in payload capacity for the Skycat 220, total manpower time decreases by a factor of 236.7 hours. As block speed increases to 105, 126, 147, and 168 knots, total manpower time decreases by a factor of 160, 266.7, 342.9, and 400 hours, respectively. The changes in total manpower time are equivalent to the changes in total operating time because operating time factors into the TAT. The TAT is used to determine the amount of "touch time" that personnel have on each airship. Figure 14 shows that as planned payload and block speed are increased by 100%, total manpower time decreases by 50%.

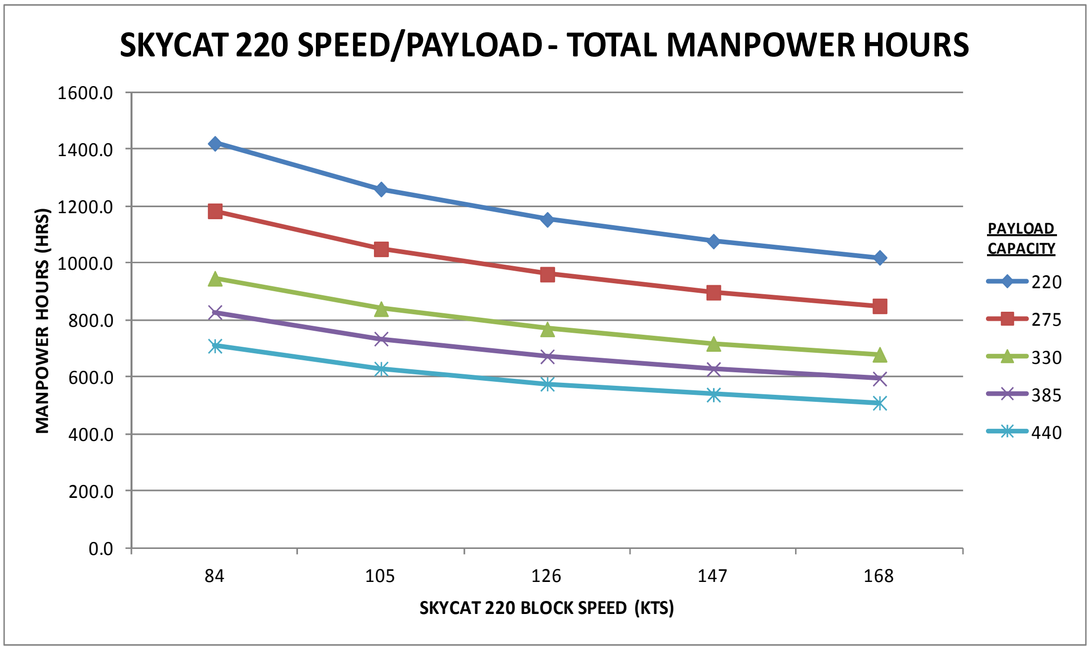

Figure 14. Skycat 220 Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

2. H2 Clipper

The H2 Clipper, developed by H2 Company, provides a lift payload capacity of 200 short tons and a block speed of 304 knots. The H2 Clipper airship has a large payload capacity and a high block-speed range. Table 73 shows a 25%, 50%, 75%, and 100% increase in payload capacity and block speed in order to determine the effect that these increases have on total operating hours.

Table 73. H2 Clipper Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

H2 CLIPPER	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	200	250	300	350	400	
304	239.5	184.2	165.8	147.4	128.9	TOTAL OPERATING HOURS (HRS)
380	191.6	147.4	132.6	117.9	103.2	
456	159.6	122.8	110.5	98.2	86.0	
532	136.8	105.3	94.7	84.2	73.7	
608	119.7	92.1	82.9	73.7	64.5	

Table 73 shows that as payload capacity increased by 25%, from 200 short tons to 250 shorts tons, with a constant block speed of 304 knots, total operating time decreased from 239.5 hours to 184.2 hours, a difference of 55.3 hours from the original total operating time of 239.5 hours. Further observation shows that as payload capacity is increased to 300, 350, and 400 short tons, total operating time decreases by a factor of 18.4 hours for each increase in cargo capacity. When block speed is increased by 25%, from 304 knots to 380 knots, with a constant payload capacity of 200 short tons, total operating hours decreased from 239.5 hours to 191.6 hours, a decrease of 47.9 hours compared to the original 239.5 hours. Further analysis shows that as block speed increases to 456, 532, and 608 knots, total operating time decreases by 79.9, 102.7, and 119.8 hours, respectively. Figure 15 shows as both payload capacity and block speed increase by up to 100%, a potential time savings of 175 hours could be achieved from the original 239.5 hours to complete the mission.

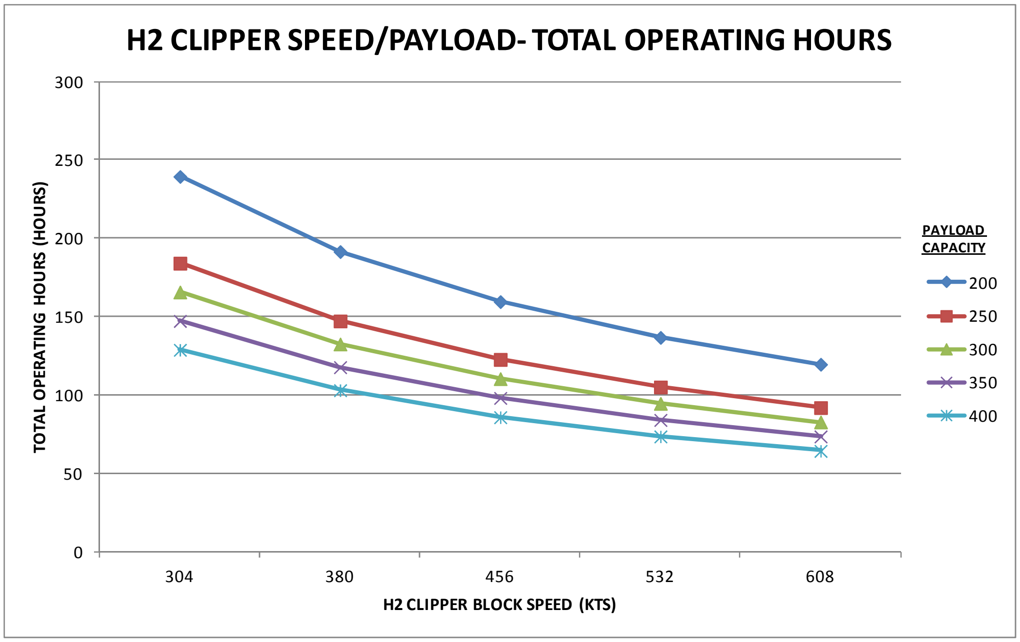

Figure 15. H2 Clipper Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

Table 74. H2 Clipper Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

H2 CLIPPER	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	200	250	300	350	400	
304	911.1	700.9	630.8	560.7	490.6	TOTAL MANPOWER HOURS (HRS)
380	863.2	664.0	597.6	531.2	464.8	
456	831.3	639.5	575.5	511.6	447.6	
532	808.5	621.9	559.7	497.5	435.4	
608	791.4	608.8	547.9	487.0	426.1	

Table 74 shows the potential savings in total manpower hours involved in conducting a mission of 168 hours and 2,500 short tons. When payload capacity is increased from 200 short tons to 250 short tons, with a constant block speed of 304 knots, the total manpower time decreased from 911.1 hours 700.9 hours. For every 25% increase in payload capacity for the H2 Clipper, total manpower time decreases by a factor of 70.1 hours. As block speed increases to 380, 456, 532, and 608 knots, total manpower time decreases by a factor of 47.9, 79.8, 102.6, and 119.7 hours, respectively. The changes in total manpower time are equivalent to the changes in total operating time due to operating time factoring into the TAT. The TAT is used to determine the amount of “touch time” that personnel have on each airship. Figure 14 shows that as planned payload and block speed are increased by up to 100%, total manpower time decreases by 485 hours from the original total manpower time of 911.1 hours.

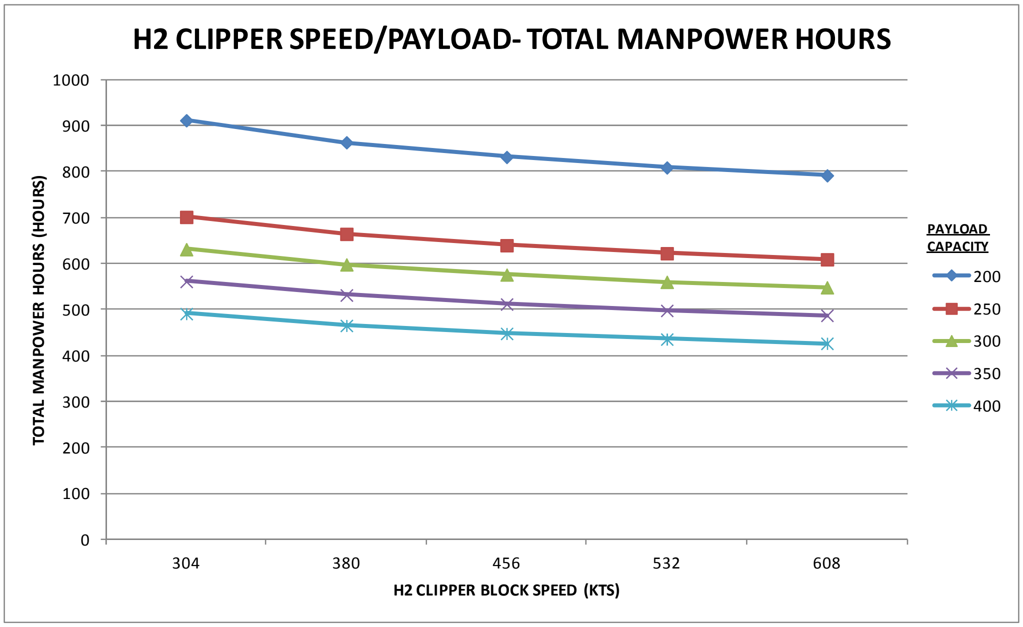

Figure 16. Skycat 220 Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

3. Aeroscraft

Aeroscraft, developed by Aeros Inc., provides a lift payload capacity of 65 short tons and a block speed of 120 knots. The Aeroscraft airship has a medium payload capacity and a medium block-speed range. Table 75 shows a 25%, 50%, 75%, and 100% increase in payload capacity and block speed in order to determine the effect that these increases have on total operating hours.

Table 75. Aeroscraft Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

AEROSCRAFT	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	65	81.25	97.5	113.75	130	
120	1820.0	1446.7	1213.3	1026.7	933.3	TOTAL OPERATING HOURS (HRS)
150	1456.0	1157.3	970.7	821.3	746.7	
180	1213.3	964.4	808.9	684.4	622.2	
210	1040.0	826.7	693.3	586.7	533.3	
240	910.0	723.3	606.7	513.3	466.7	

Table 75 shows that as payload capacity is increased by 25%, from 65 short tons to 81.25 shorts tons, with a constant block speed of 120 knots, total operating time decreased from 1,820 hours to 1,446.7 hours, a difference of 373.3 hours from the original total operating time of 1820 hours. Further observation shows that as payload capacity is increased to 97.5, 113.75, and 130 short tons, total operating time will decrease by a factor of 606.7, 793.3, and 886.7 hours, respectively, for each increase in cargo capacity. When block speed is increased by 25%, from 120 knots to 150 knots, with a constant payload capacity of 65 short tons, total operating hours decreased from 1,820 hours to 1,456 hours, a decrease of 364 hours compared to the original 1,820 hours. Further analysis shows that as block speed increases to 180, 210, and 240 knots, total operating time decreases by 606.7, 780, and 910 hours, respectively. Figure 17 shows that as both payload capacity and block speed increase by up to 100%, the potential time savings that can be achieved will be 1,353 hours from the original 1,800 hours to complete the mission.

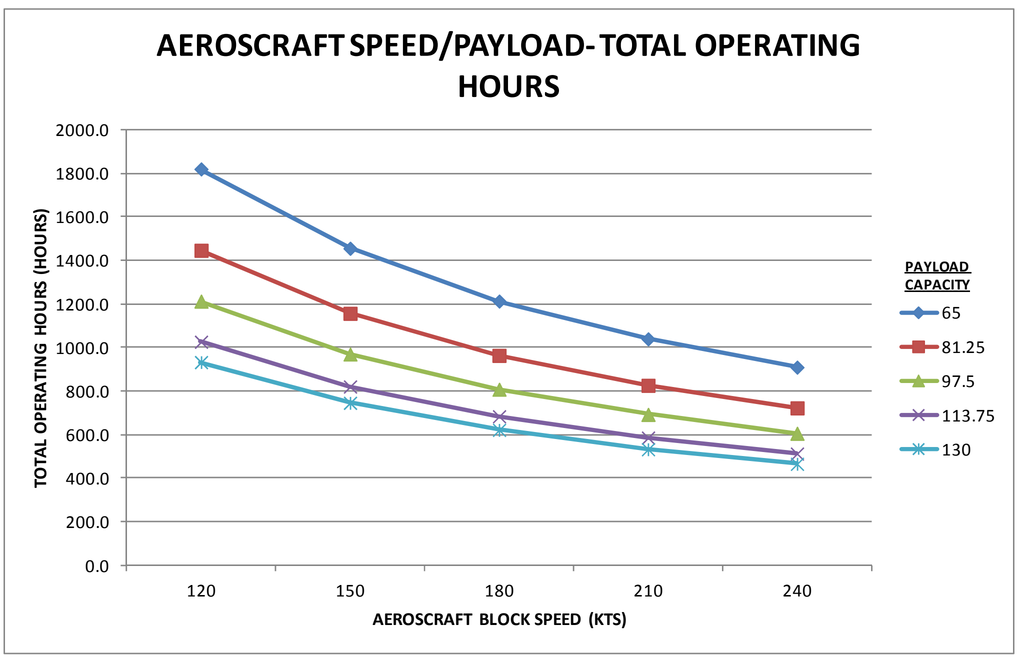

Figure 17. Aeroscraft Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

Table 76. Aeroscraft Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

AEROSCRAFT	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	65	81.25	97.5	113.75	130	
120	3835.0	3048.3	2556.7	2163.3	1966.7	TOTAL MANPOWER HOURS (HRS)
150	3471.0	2759.0	2314.0	1958.0	1780.0	
180	3228.3	2566.1	2152.2	1821.1	1655.6	
210	3055.0	2428.3	2036.7	1723.3	1566.7	
240	2925.0	2325.0	1950.0	1650.0	1500.0	

Table 76 shows the potential savings in total manpower hours involved in conducting a mission of 168 hours and 2,500 short tons. When payload capacity is increased from 65 short tons to 81.25 short tons, with a constant block speed of 120 knots, the total manpower time decreased from 3,835 hours 3,048 hours. For every 25% increase in payload capacity for the Aeroscraft, total manpower time decreases by 1,279, 1,672, and 1,869 hours, respectively. As block speed increases to 150, 180, 210, and 240 knots, total manpower time decreases by a factor of 364, 607, 780, and 910 hours, respectively. The changes in total manpower time are equivalent to the changes in total operating time due to the operating time factoring into the TAT. The TAT is used to determine the amount of "touch time" that personnel have on each airship. Figure 14 shows that as planned payload and block speed are increased by up to 100%, the total manpower time decreases by 2,335 hours from the original total manpower time of 3,835 hours.

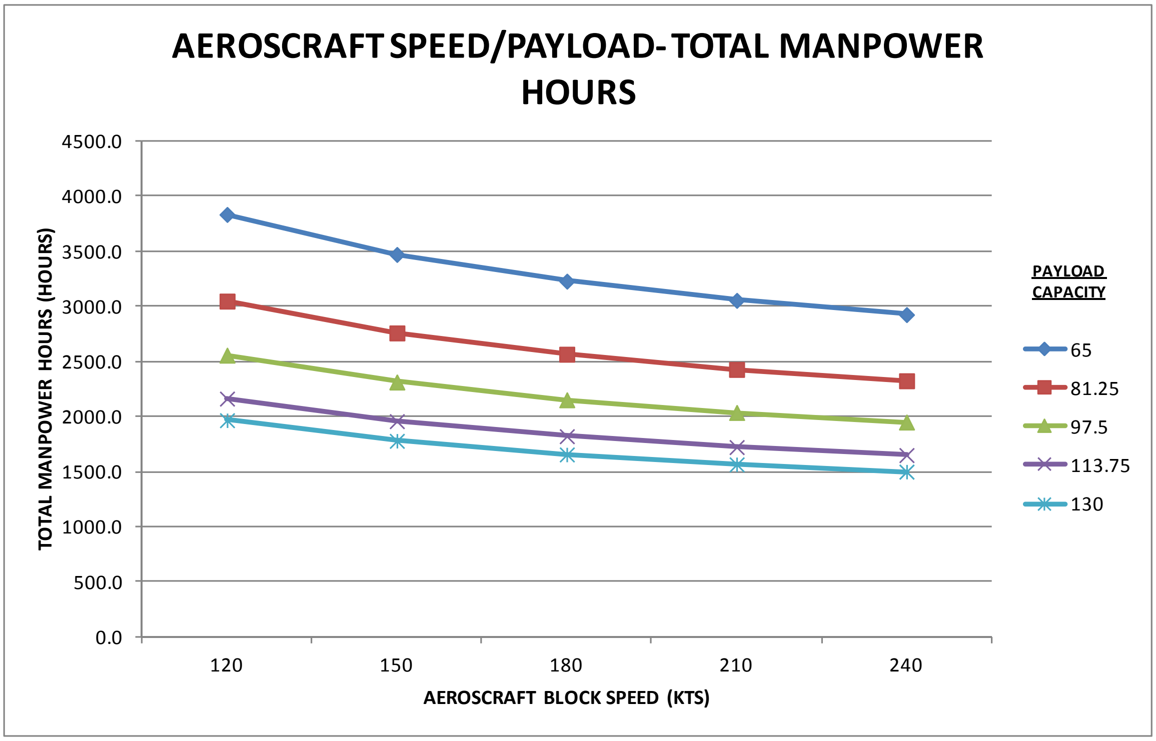

Figure 18. Aeroscraft Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

4. HAV 366

The HAV 366, developed by Discovery Air Innovation, provides a lift payload capacity of 50 short tons and a block speed of 105 knots. The Aeroscraft airship has a medium payload capacity and a medium block-speed range. Table 77 shows a 25%, 50%, 75%, and 100% increase in payload capacity and block speed in order to determine the effect that these increases have on total operating hours.

Table 77. HAV 366 Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

HAV 366	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	50	62.5	75	87.5	100	
105	2666.7	2133.3	1813.3	1546.7	1333.3	TOTAL OPERATING HOURS (HRS)
131.25	2133.3	1706.7	1450.7	1237.3	1066.7	
157.5	1777.8	1422.2	1208.9	1031.1	888.9	
183.75	1523.8	1219.0	1036.2	883.8	792.4	
210	1333.3	1066.7	906.7	773.3	693.3	

Table 77 shows that as payload capacity increased by 25%, from 50 short tons to 62.5 short tons, with a constant block speed of 105 knots, total operating time decreased from 2,666.7 hours to 2,133.3 hours, a difference of 533.4 hours from the original total operating time of 2,666.7 hours. Further observation shows that as payload capacity is increased to 75, 87.5, and 100 short tons, total operating time decreases by a factor of 853.4; 1,120; and 1,333.4 hours, respectively, for each increase in cargo capacity. When block speed is increased by 25%, from 105 knots to 131.25 knots, with a constant payload capacity of 50 short tons, total operating hours decreased from 2,666.7 hours to 2,133.3 hours, a decrease of 533.4 hours from the original 2,666.7 hours. Further analysis shows that as block speed increases to 157.5, 183.75, and 210 knots, total operating time decreases by 888.9; 1,142.9; and 1,333.3 hours, respectively. Figure 17 shows that as both payload capacity and block speed increase by up to 100%, the potential time savings that can be achieved will be 1,973.4 hours from the original 2,666.7 hours needed to complete the mission.

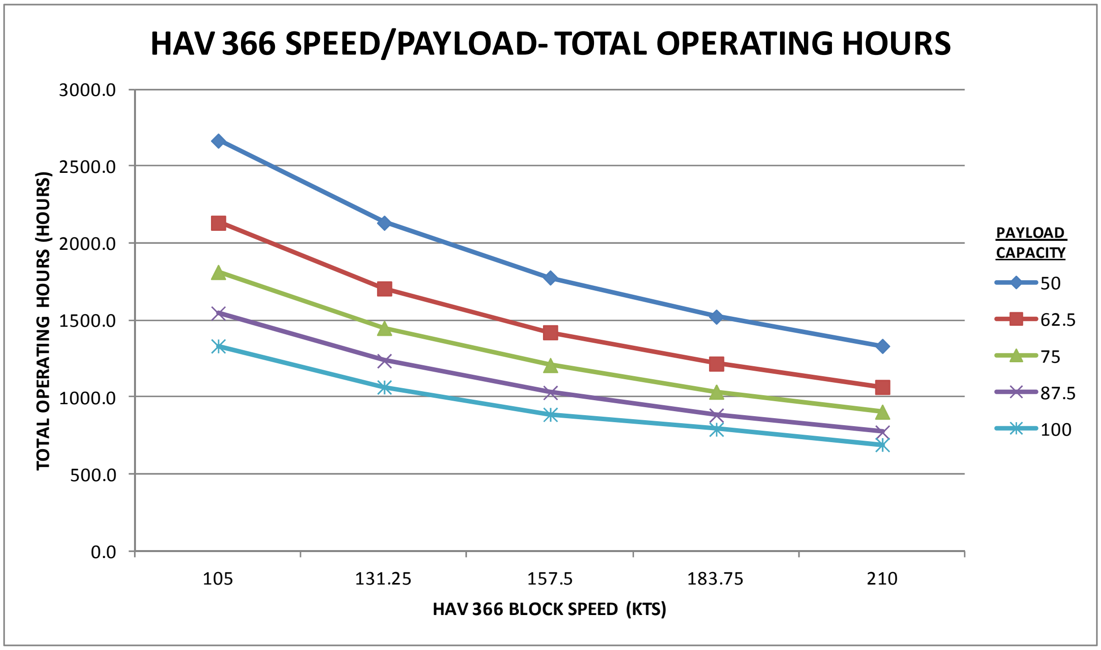

Figure 19. HAV 366 Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

Table 78. HAV 366 Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

HAV 366	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	50	62.5	75	87.5	100	
105	5250.0	4200.0	3570.0	3045.0	2625.0	TOTAL MANPOWER HOURS (HRS)
131.25	4716.7	3773.3	3207.3	2735.7	2358.3	
157.5	4361.1	3488.9	2965.6	2529.4	2180.6	
183.75	4107.1	3285.7	2792.9	2382.1	2135.7	
210	3916.7	3133.3	2663.3	2271.7	2036.7	

Table 78 shows the potential savings in total manpower hours involved in conducting a mission of 168 hours and 2,500 short tons. When payload capacity increased from 50 short tons to 62.5 short tons with a constant block speed of 105 knots, the total manpower time decreased from 5,250 hours to 4,200 hours. Further increases of payload capacity to 75, 87.5, and 100 short tons, provided a total manpower time decrease of 1,680; 2,205; and 2,625 hours, respectively. As block speed increases to 131.25, 157.5, 183.75, and 210 knots, total manpower time decreases by a factor of 533.3; 888.9; 1,142.9; and 1,333.3 hours, respectively. The changes in total manpower time are equivalent to the changes in total operating time due to operating time factoring into the TAT. The TAT is used to determine the amount of "touch time" that personnel have on each airship. Figure 20 shows that as planned payload and block speed are increased by up to 100%, total manpower time decreases by 3,213 hours from the original total manpower time of 5,250 hours.

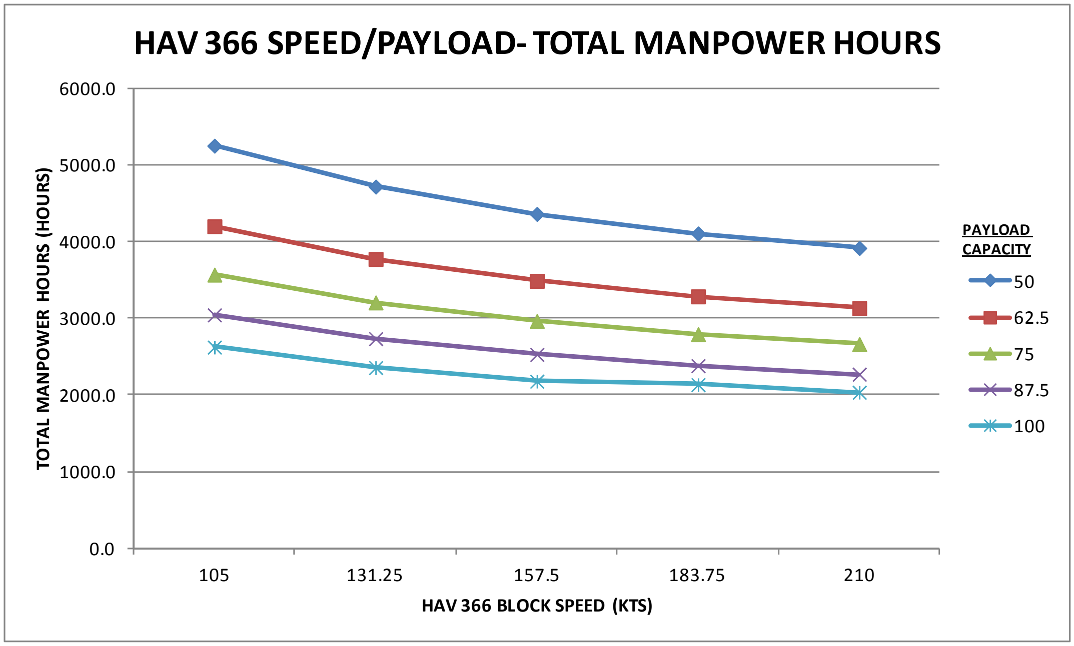

Figure 20. HAV 366 Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

5. Skyhook

Skyhook, developed by Boeing and Skyhook International, provides a lift payload capacity of 40 short tons and a block speed of 70 knots. The Skyhook airship has a low payload capacity and a medium block-speed range. Table 79 shows 25%, 50%, 75%, and 100% increases in payload capacity and block speed in order to determine the effect that these increases have on total operating hours.

Table 79. Skyhook Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

SKYHOOK	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	40	50	60	70	80	
70	5040.0	4000.0	3360.0	2880.0	2560.0	TOTAL OPERATING HOURS (HRS)
87.5	4032.0	3200.0	2688.0	2304.0	2048.0	
105	3360.0	2666.7	2240.0	1920.0	1706.7	
122.5	2880.0	2285.7	1920.0	1645.7	1462.9	
140	2520.0	2000.0	1680.0	1440.0	1280.0	

Table 79 shows that as payload capacity is increased by 25%, from 40 short tons to 50 short tons, with a constant block speed of 70 knots, total operating time decreased from 5,040 hours to 4,000 hours, a difference of 1,040 hours from the original total operating time. Further observation shows that as payload capacity is increased to 60, 70, and 80 short tons, total operating time will decrease by a factor of 1,680; 2,160; and 2,480 hours, respectively, for each increase in cargo capacity. When block speed is increased by 25%, from 70 knots to 87.5 knots, with a constant payload capacity of 40 short tons, total operating hours decreased from 5,040 hours to 4,032 hours, a difference of 1,008 hours. Further analysis shows that as block speed increases to 105, 122.5, and 140 knots, total operating time decreases by 1,680; 2,160; and 2,520 hours, respectively. Figure 21 shows that as both payload capacity and block speed increase by up to 100%, the potential time savings that can be achieved will be 3,760 hours from the original 5,040 hours needed to complete the mission.

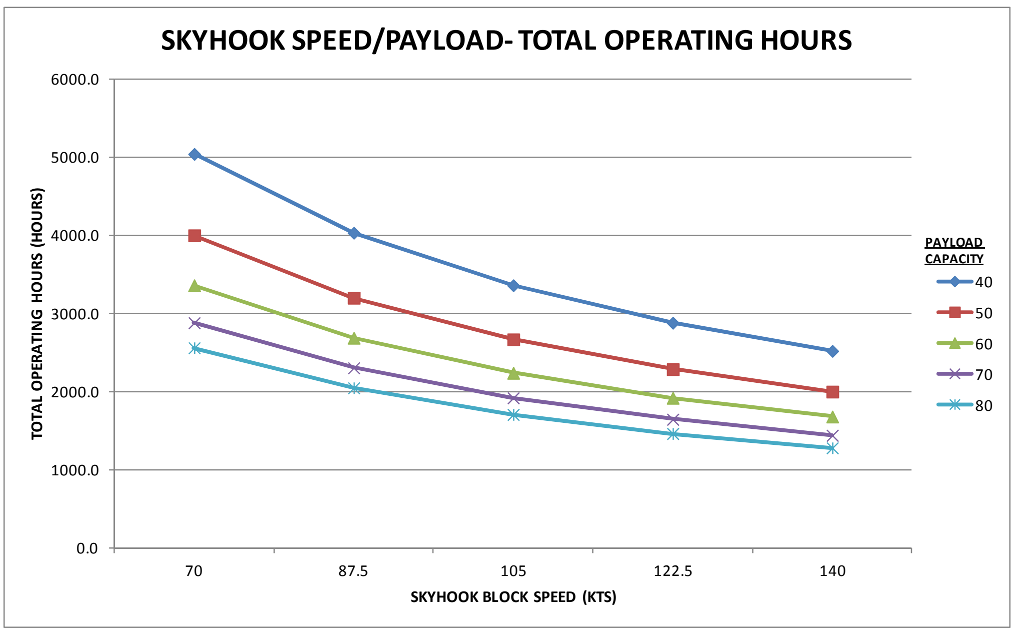

Figure 21. Skyhook Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

Table 80. Skyhook Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

SKYHOOK	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	40	50	60	70	80	
70	$ 11,387,308.69	$ 11,294,625.51	$ 11,237,589.70	$ 11,194,812.85	$ 11,166,294.95	TOTAL OVERALL COSTS (DOLLARS)
87.5	$ 11,332,727.59	$ 11,251,307.18	$ 11,201,202.30	$ 11,163,623.65	$ 11,138,571.21	
105	$ 11,296,340.19	$ 11,222,428.29	$ 11,176,944.04	$ 11,142,830.85	$ 11,120,088.72	
122.5	$ 11,270,349.19	$ 11,201,800.51	$ 11,159,616.70	$ 11,127,978.85	$ 11,106,886.95	
140	$ 11,250,855.94	$ 11,186,329.68	$ 11,146,621.20	$ 11,116,839.85	$ 11,096,985.61	

Table 80 shows the potential savings in total manpower hours involved in conducting a mission of 168 hours and 2,500 short tons. When payload capacity increased from 40 short tons to 50 short tons, with a constant block speed of 70 knots, the total manpower time decreased from 8,295 hours to 6,583 hours. For every 25% increase in payload capacity for the Skyhook, total manpower time decreases by 2,765; 3,555; and 4,082 hours, respectively. As block speed increases to 87.5, 105, 122.5, and 140 knots, total manpower time decreases by a factor of 1,008; 1,680; 2,160; and 2,520 hours, respectively. The changes in total manpower time are equivalent to the changes in total operating time due to operating time factoring into the TAT. The TAT is used to determine the amount of "touch time" that personnel have on each airship. Figure 22 shows that as planned payload and block speed are increased by up to 100%, total manpower time decreases by 5,362 hours from the original total manpower time of 8,295 hours.

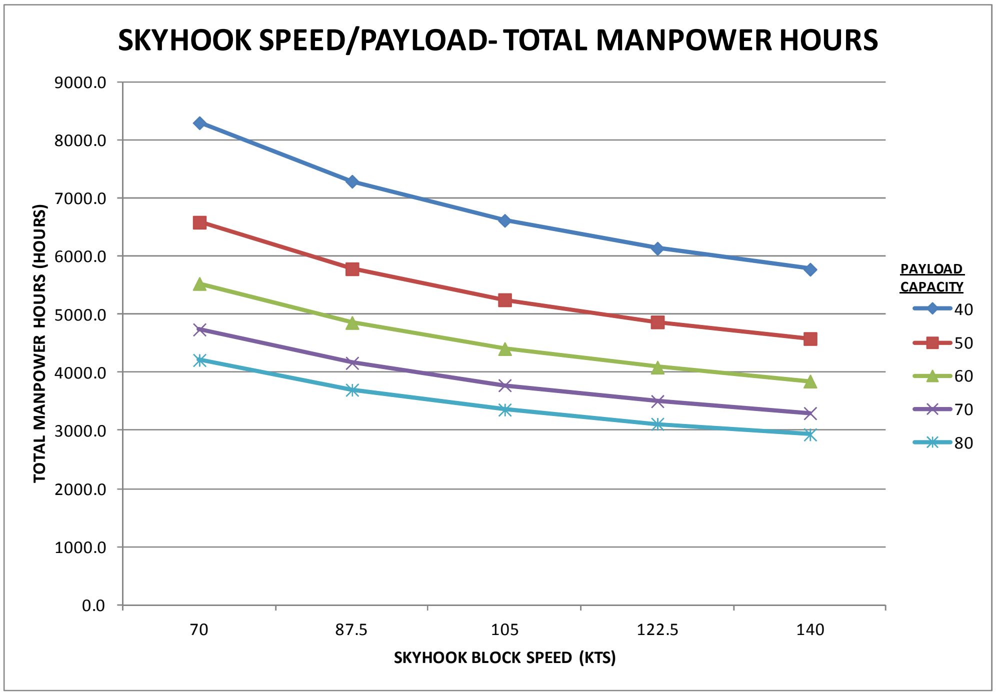

Figure 22. Skyhook 220 Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

6. LEMV

The LEMV, developed by Northrop Grumman, provides a lift payload capacity of 10 short tons and a block speed of 80 knots. The LEMV airship has a low payload capacity and a medium block-speed range. Table 81 shows 25%, 50%, 75%, and 100% increases in payload capacity and block speed in order to determine the effect that these increases have on total operating hours.

Table 81. LEMV Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

LEMV	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	10	12.5	15	17.5	20	
80	17500.0	14000.0	11690.0	10010.0	8750.0	TOTAL OPERATING HOURS (HRS)
100	14000.0	11200.0	9352.0	8008.0	7000.0	
120	11666.7	9333.3	7793.3	6673.3	5833.3	
140	10000.0	8000.0	6680.0	5720.0	5000.0	
160	8750.0	7000.0	5845.0	5005.0	4375.0	

Table 81 shows that as payload capacity is increased by 25%, from 10 short tons to 12.5 short tons, with a constant block speed of 80 knots, total operating time decreased from 17,500 hours to 14,000 hours, a difference of 3,500 hours from the original total operating time. Further observation shows that as payload capacity is increased to 15, 17.5, and 20 short tons, total operating time will decrease by a factor of 5,810; 7,490; and 8,750 hours, respectively, for each increase in cargo capacity. When block speed increased by 25%, from 80 knots to 100 knots, with a constant payload capacity of 10 short tons, total operating hours decreased with the same magnitude as the increase in payload capacity. Figure 23 shows that as both payload capacity and block speed increase by up to 100%, the potential time savings that can be achieved will be 13,125 hours from the original 17,500 hours needed to complete the mission.

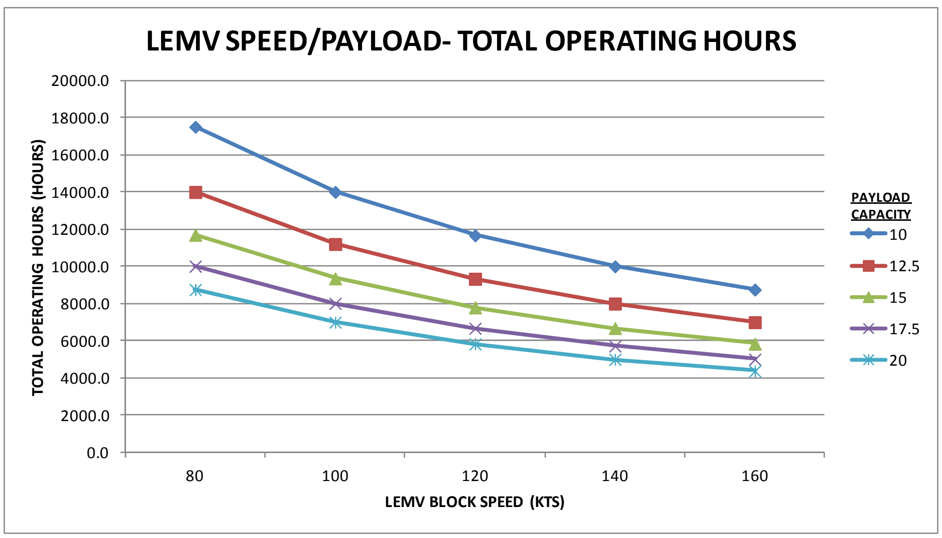

Figure 23. LEMV Total Operating Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

Table 82. LEMV Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

LEMV	PAYLOAD CAPACITY (S. TONS)					
BLOCK SPEED (KTS):	10	12.5	15	17.5	20	
80	30416.7	24333.3	20318.3	17398.3	15208.3	TOTAL MANPOWER HOURS (HRS)
100	26916.7	21533.3	17980.3	15396.3	13458.3	
120	24583.3	19666.7	16421.7	14061.7	12291.7	
140	22916.7	18333.3	15308.3	13108.3	11458.3	
160	21666.7	17333.3	14473.3	12393.3	10833.3	

Table 82 shows the potential savings in total manpower hours involved in conducting a mission of 168 hours and 2,500 short tons. When payload capacity increased from 10 short tons to 12.5 short tons, with a constant block speed of 80 knots, the total manpower time decreased from 30,416 hours to 24,333 hours. For every 25% increase in payload capacity for the LEMV, total manpower time decreases by 10,098; 13,018; and 15,208 hours, respectively. As block speed increases to 100, 120, 140, and 160 knots, total manpower time decreases by a factor of ,3500; 5,833; 7,500; and 8,750 hours, respectively. The changes in total manpower time are equivalent to the changes in total operating time due to operating time factoring into the TAT. The TAT is used to determine the amount of "touch time" that personnel have on each airship. Figure 24 shows that as planned payload and block speed are increased by up to 100%, total manpower time decreases by 19,583 hours from the original total manpower time of 30,416 hours.

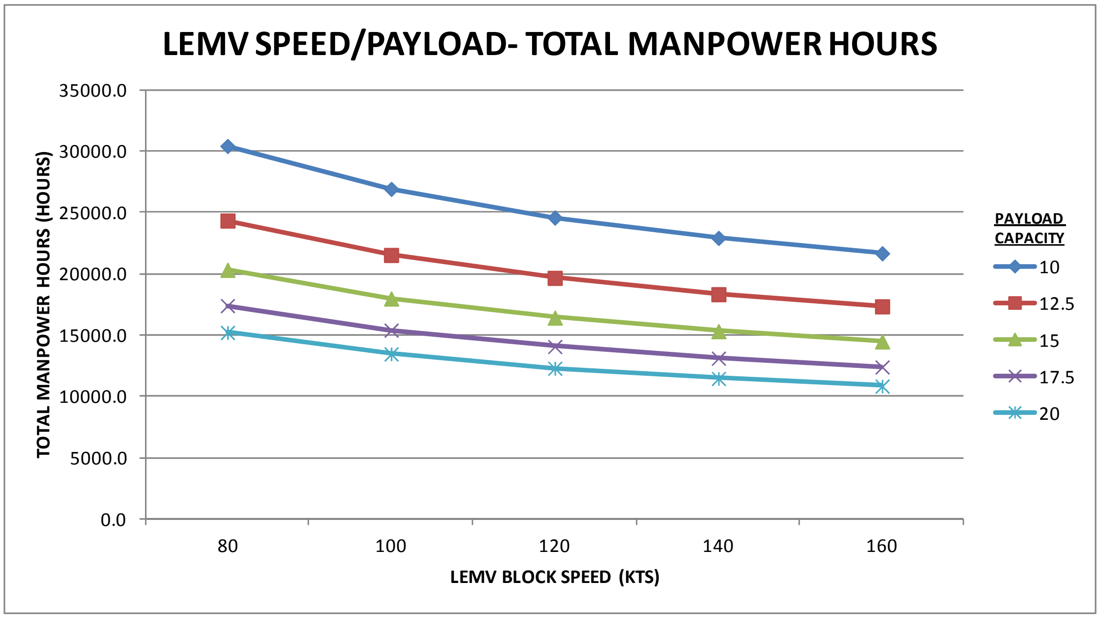

Figure 24. LEMV Total Manpower Hours with an Increase in Payload Capacity and Block Speed of 25%, 50%, 75%, and 100%—2,500 Short Tons with a 168-Hour Mission Duration

The performance measures were not based on cost effectiveness, but on the total operating and manpower hours required to complete a mission. If the break-even hourly operating costs that we calculated in Chapters VI and VII were applied to this analysis, the total operating costs would have been the same, even with improvements in block speed and planned payload capacity, which would understate the actual cost savings that airships could provide. The tables provided a good range of values for both planned payload and block speed that can indicate the number of improvements airships can achieve before hitting a point of diminishing returns. Airship manufacturers can strive to work at this point in order to improve the efficiencies of their airships.

The improvement in planned payload and block speed may also increase the hourly operating costs associated with each airship. If hourly operating costs are to increase, the hourly operating cost baseline determined in Chapters VI and VII can be used by airship companies to determine the scope of the cost to improve planned payload and block speeds. Improvements in airship characteristics could continue as long as the total overall costs remain below the total overall costs of the C-17 for a particular mission and that airship design itself does not change. The USTRANSCOM could benefit from this by cutting costs in logistics transportation while at the same time delivering cargo in a fast and efficient manner.

IX. CONCLUSION

A. RESULTS

1. Findings

The findings of this analysis conclude that airships, based on the hourly operating costs established throughout this project, could provide a viable alternative for USTRANSCOM's airlift and sealift capabilities. This analysis has shown the viability of airships in a heavy-lift environment and their ability to transport cargo cost effectively in a given time period. This is especially true with transportation of up to 2,500 short tons and when time is a critical factor.

The results of the operational cost and operational efficiency study show airships to be a viable mid-cost alternative. Simply stated, airships provide lower operational costs than aircraft but cannot compete cost wise with sealift platforms. This statement assumes that the time span needed for a given mission is great enough to allow sealift to become an option for transportation. with the given scenarios, airships are the best solution to deliver 2,500 short tons with a distance of up to 3,320 nautical miles and with time constraints of approximately 72–600 hours. For time constraints between 48–72 hours, aircraft have a distinct advantage due to their speed. Likewise, anything above 600 hours allows sealift to be the best suited platform for the given missions.

In addition to examining overall operating costs of airships, this project examined the cost effectiveness of unmanned versus manned variants of airships. The results of our calculations are dependent on the total distance traveled and the amount of cargo to be transported for a given mission. Unmanned variants of airships could be extremely cost efficient when distance and the amount of cargo increase. In our model, as crew rest times are removed from the equations, the turn-around time decreases, freeing up more airships to conduct an increased number of sorties. The cost effectiveness of unmanned versus manned variants of airships is the total cost of manning as total operating costs remain the same. The ability of airships to complete more sorties, even at the same cost as other air platforms, shows the promise of using unmanned variants of airships as a viable heavy-lift platform.

2. Way Ahead

There is a great opportunity for the USTRANSCOM to produce cost-effective savings by integrating airships into their current heavy-lift transportation systems. For this to become a reality, the USTRANSOM will need to conduct further studies into current airship technology, but based on our findings, we believe airships to be a viable alternative to the current forms of heavy-lift transportation. As stated in our findings, airships cannot replace all other forms of heavy-lift transportation, but can offer cost savings for USTRANSCOM's mission. In addition, airships could become viable replacements for the other heavy-lift platforms, but currently there are too many unknown variables with airships to recommend this action.

As a way ahead, we recommend that research be conducted on what types of airships will be best suited to meet USTRANSCOM's mission. Factors such as the use for airships, distances required, and cargo capacity must be outlined. For missions that require greater distances and heavier payload capacities, the Skycat 220 and H2 Clipper would be the airships of choice for further research. For missions that require smaller intra-theater distances with less payload capacity, the HAV-366 and Skyhook would likely be the airships requiring further research. For re-supplying forward operating bases or regional transits, smaller platforms, such as the LEMV, fit this mission description better than some of the larger airships. All of these airships could conceivably reduce transportation costs in the varying missions described previously.

The USTRANSCOM could also realize cost savings by analyzing the use of airships in tandem with current heavy-lift platforms. Examining the inter-modal mix of airlift, airship, and sealift transportation could provide additional cost savings based on the number of platforms required, the amount of cargo that needs to be transported, and the total time required to transport that cargo. From our findings, we believe airships could best fit in with today's heavy-lift platforms on mission requirements between 72 hours and 600 hours with smaller amounts of cargo that need to be transported.

B. FOLLOW-ON RECOMMENDATIONS

The following paragraphs outline follow-on recommendations for research that will need to be accomplished before airships can be considered a viable alternative to the current heavy-lift platforms that the USTRANSCOM utilizes to complete its mission. Although we have strived to be as thorough as possible, we made many assumptions in order to complete this analysis. This was due in part to the lack of information regarding airships since these platforms have only had limited research conducted into their feasibility.

The first recommendation for further study would include gathering the complete operating costs of airships. The operating costs throughout this analysis were derived from current heavy-lift aircraft. We concluded that this was the best estimate due to the fact that most airship platforms are in design or the information we sought was proprietary to the corporations producing the airships. Once airship design and production have matured, further studies will need to collect data estimating the hourly operating costs of airships. The collection of data with regards to airships' true block speeds, cargo capacity, TAT, ground times, and other variables will then determine the operating cost of airships, and can be used to determine whether they, in fact, can be considered a viable alternative to the current heavy-lift platforms.

Another factor that must be included along with the operational capabilities of airships is their lift mechanism designs. The decision to use hydrogen and helium could have lasting cost and availability implications for airships' further use. As discussed earlier in this analysis, helium is a finite resource that does not have a high production capability. Hydrogen, on the other hand, is abundantly available, but can be highly unstable without the proper safety considerations. Cost and safety considerations will need to be examined further to determine which form of lifting mechanism will best be suited for a military application within varying operating environments.

This analysis did not consider the overall acquisition costs of airships. If airships can be considered a viable alternative to current heavy-lift platforms, an acquisition cost study will need to be conducted. Items such as research and development, technology development, materiel solutions, engineering and manufacturing development, and production and deployment will all need to be considered to establish an overall cost of bringing airships to an operationally capable status. In addition, it could behoove the DoD to consider acquiring off-the-shelf airships. Many corporations are designing airships for commercial use as well as for potential military use. This would reduce the time and costs associated with bringing these platforms into an operational status through the current acquisitions process.

Another important consideration with the cost of procurement of airships is the life cycle costs associated with these platforms. The current fleet of heavy-lift platforms has established life cycle costs, maintenance costs, and time frames associated with each platform. As was noted in the analysis, some of these platforms are reaching their designated life cycle span; however, for airships to be considered a viable alternative to these platforms, their life cycle costs will need to be examined. The various levels of maintenance, including depot, intermediate, and organizational costs, must be examined to determine whether it is cost effective to replace the platforms with airships or if the current platforms should be modernized.

Finally, a study that examines the infrastructure required for airships will need to be conducted. This analysis assumed that airships could use the current infrastructure that is already in place. The need for larger maintenance facilities, staging areas, and additional ground and maintenance manpower could have additional cost implications to the airship program.

APPENDIX 1

Acronym:	**Description:**
AMC	Air Mobility Command
AN/USD	Army/Navy Special/Combination Surveillance Equipment
CBO	Congressional Budget Office
CIA	Central Intelligence Agency
CRAF	Civil Reserve Air Fleet
DAMIR	Defense Acquisition Management Information Retrieval
DARPA	Defense Advanced Research Projects Agency
DELAG	Deutsche Luftschiffahrts Aktien Gesellschaft
DoD	Department of Defense
EO/IR	Electro optical/infra-red
FSS	Fast Sealift Ship
FY	Fiscal Year
GPS	Global positioning system
HAV	Hybrid air vehicle
HEIT	High explosive incendiary tracer rounds
ISR	Intelligence, surveillance, and Reconnaissance
LEMV	Long Endurance Multi-Intelligence Vehicle
LMSR	Large, Medium Speed Roll-on/Roll-off
MMcf	Million cubic feet
NASA	National Aeronautics and Space Administration
RDT&E	Research, development, test, and evaluation
RO/RO	Roll-on/Roll-off
RRF	Ready Reserve Force
SAM	Surface-to-air missiles
SAR	Synthetic aperture radar
SD	Surveillance Drone
SDDCTEA	Surface Deployment and Distribution Command Transportation Engineering Agency
STOL	Short takeoff and landing
TAT	Turn-around time
U.S.	United States
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles
UCLA	University of California Los Angeles
USA	United States Army
USAF	United States Air Force
USN	United States Navy
USTRANSCOM	United States Transportation Command
VTOL	Vertical takeoff and landing
WWI	World War I
WWII	World War II

Symbol:	**Description:**	**Units:**
B	Block Speed	Knots (Kts)
C_M	Cargo movement requirement	Short Tons (S. tons)
C_P	Payload capacity for platform	Short Tons (S. tons)
D	Distance	Nautical Mile (NM)
H_E	Hourly enlisted wages	Dollar/hour ($/hr)
H_O	Hourly office wages	Dollar/hour ($/hr)
H_P	Hourly operating costs for platforms	Dollar/hour ($/hr)
$H_{P\text{-}AIRSHIP}$	Hourly operating costs for airships	Dollar/hour ($/hr)
H_T	Cost per 30 tons of freight transported	Dollar/30 s. tons
H_V	Hourly civilian wages	Dollar/hour ($/hr)
I_{AF}	Number of platforms conducting maximum sorties/trips	Air/sea platform
I_{AP}	Number of platforms completing limited sorties/trips	Air/sea platform
I_{AT}	Total number of platforms	Air/sea platform
M_E	Manning for enlisted	Personnel
M_O	Manning for officer	Personnel
M_V	Manning for civilians	Personnel
N_A	Overall costs for air/sealift platforms	Dollars ($)
N_C	Cost per ton-nautical mile	Dollars ($)
N_M	Total manning costs	Dollars ($)
N_O	Total operating costs	Dollars ($)
$N_{O\text{-}AIRCRAFT}$	Total operating costs for aircraft	Dollars ($)
N_T	Total trucking costs	Dollars ($)
S_{AF}	Maximum number of sorties/trips	Sorties/trips
S_{AP}	Limited number of sorties/trips	Sorties/trips
S_{AT}	Total number of sorties/trips	Sorties/trips
T_A	Turn-around-time per platform	Hours (hrs)
T_C	Flight pre-check time	Hours (hrs)
T_G	Ground/Unload/Offload Time	Hours (hrs)
T_M	Mission duration time	Hours (hrs)
T_O	Total operating hours	Hours (hrs)
$T_{O\text{-}AIRSHIP}$	Total operating hours for airships	Hours (hrs)
T_P	Operating hours per platform	Hours (hrs)
T_P	Operating time per platform	Hours (hrs)
T_R	Crew Rest time	Hours (hrs)
T_T	Total manpower hours/Total time to complete mission	Hours (hrs)

APPENDIX 2

Table 83. Model Characteristics for AMC Platforms

	AMC Assets		
	C-130J	C-17	C-5M
MANNING			
Personnel/Manning (Officers)	2	2	2
Personnel/Manning (Enlisted)	2	2	5
Personnel/Manning (Civilian)	N/A	N/A	N/A
Average Hourly Wage (Officers- O3 Pay)	$16.27	$16.27	$16.27
Average Hourly Wage (Enlisted- E5 Pay)	$9.19	$9.19	$9.19
Average Hourly Wage (Civilians)	N/A	N/A	N/A
CHARACTERISTICS			
Ground Times (Aircraft)(Hours)	2.25	3.25	4.25
Loading (Ships)(Hours) (Average)	N/A	N/A	N/A
Unloading Times (Ships)(Hours)(Average)	N/A	N/A	N/A
Pre-Check Time (Aircraft)(Average Hours)	3	3	3
Crew Rest Time (One Stop)(Average Hours)	12	12	12
Planned Cargo Payload	18	45	61
Block Speed (kts)	320	406	416
Speed	320	406	416
Range (nm)	3000	3000	3000
Altitude (ft)	36,000	36,000	36,000
SCENARIO			
Intertheater/Intratheater Distances (Nm)	2800	2800	2800
Total Cargo for Scenario (short tons)	2500	2500	2500

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APPENDIX 3

Table 84. Model Characteristics for MSC Platforms

	MSC Assets	
	LMSR	FSS
MANNING		
Personnel/Manning (Officers)	N/A	N/A
Personnel/Manning (Enlisted)	N/A	N/A
Personnel/Manning (Civilian)	30	42
Average Hourly Wage (Officers- O3 Pay)	N/A	N/A
Average Hourly Wage (Enlisted- E5 Pay)	N/A	N/A
Average Hourly Wage (Civilians)	$26.91	$30.63
CHARACTERISTICS		
Ground Times (Aircraft)(Hours)	N/A	N/A
Loading (Ships)(Hours) (Average)	72	72
Unloading Times (Ships)(Hours)(Average)	48	48
Pre-Check Time (Aircraft)(Average Hours)	N/A	N/A
Crew Rest Time (One Stop)(Average Hours)	N/A	N/A
Planned Cargo Payload	53224.2	27630.9
Block Speed (kts)	24	33
Speed	19	30
Range (nm)	12000	13373
Altitude (ft)	N/A	N/A
SCENARIO		
Intertheater/Intratheater Distances (Nm)		
Total Cargo for Scenario (short tons)	2500	2500

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APPENDIX 4

Table 85. Model Characteristics for Airship Platforms

	Airships					
	SKYCAT 220	H2 CLIPPER	AEROSCRAFT	HAV 366	SKYHOOK	LEMV
MANNING						
Personnel/Manning (Officers)	2	2	2	2	2	2
Personnel/Manning (Enlisted)	2	2	2	2	2	2
Personnel/Manning (Civilian)	N/A	N/A	N/A	N/A	N/A	N/A
Average Hourly Wage (Officers- O3 Pay)	$16.27	$16.27	$16.27	$16.27	$16.27	$16.27
Average Hourly Wage (Enlisted- E5 Pay)	$9.19	$9.19	$9.19	$9.19	$9.19	$9.19
Average Hourly Wage (Civilians)	N/A	N/A	N/A	N/A	N/A	N/A
CHARACTERISTICS						
Ground Times (Aircraft)(Hours)	18.33	16.67	5.42	4.17	3.33	0.83
Loading (Ships)(Hours) (Average)	N/A	N/A	N/A	N/A	N/A	N/A
Unloading Times (Ships)(Hours)(Average)	N/A	N/A	N/A	N/A	N/A	N/A
Pre-Check Time (Aircraft)(Average Hours)	3	3	3	3	3	3
Crew Rest Time (One Stop)(Average Hours)	12	12	12	12	12	12
Planned Cargo Payload	220	200	65	50	40	10
Block Speed (kts)	84	304	120	105	70	80
Speed	84	304	120	105	70	80
Range (nm)	3240	3045	3100	3000	1750	2000
Altitude (ft)	10000	75000	12000	9000	6000	22000
SCENARIO						
Intertheater/Intratheater Distances (Nm)	2800	2800	2800	2800	2800	2800
Total Cargo for Scenario (short tons)	2500	2500	2500	2500	2500	2500

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APPENDIX 5

Aircraft Planning Data

Aircraft Type	Pallet Positions	Cargo (Stons)		Passengers[4,6]		Standard NEO Passengers
		ACL[2]	Planning[3]	ACL	Planning	
C-130	6	17	12	90	80	92/74[5]
C-130J	8	22	18	145	128	128
C-17	18	65	45	101	90	101
C-5	36	89	61	73	51	73

Figure 25. Notional Cargo Capacity

Type	Mach	500nm	1000nm	1500nm	2000nm	2500nm	3000nm	3500nm	4000nm	4500nm	5000nm	5500nm	6000nm
C-130	0.49	242	266	272	273	272	271	-	-	-	-	-	-
C-130J	0.59	286	294	301	308	314	320	-	-	-	-	-	-
C-17	0.76	335	384	400	405	406	406	409	412	-	-	-	-
C-5	0.77	341	393	410	415	416	416	420	422	424	426	428	429

Figure 26. Notional Block Speeds

Aircraft Type	Passenger and Cargo Operations Wartime Planning Times (hrs + min)			
	Onload	Enroute Refuel only	Offload	Expedited[1]
C-130	2+15	1+30	2+15	0+45
C-17	3+15	2+15	3+15	1+45
C-5	4+15	3+15	4+15	2+00

Figure 27. Notional Ground Times

Air Force Aircraft	DoD O&M
C-130J	$5,945
C-17A	$14,161
C-5M	$35,616

Figure 28. AMC Hourly Operating Cost

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APPENDIX 6

Sealift Planning Data

Ship Type	Average Gross Cargo Space (SQFT)	Average Usable Cargo Space (SQFT) [1]	Average TEU Capacity (Weather Deck)[2]	Average TEU Capacity (Below Deck)[2]	Average TEU Capacity (All Container Sockets) [2]
LMSR - All	373,815	280,361	128	209	337
-LMSR- Conversion	311,959	233,969	63	216	279
-LMSR - New Construction	390,310	292,733	146	207	353
Fast Sealift Ship	202,627	151,970	174	46	220

Figure 29. Notional Cargo Capacity

Ship Type	Load Times (in hours)	Unload Times (in hours)
Barge Carrier (LASH)	232 - 264	232 - 264
Barge Carrier (SEABEE)	79 - 92	79 - 92
Breakbulk	72 - 96	72 - 96
Self-Sustaining Containership (Average Capacity: 1,763 TEUs)	12 - 24	12 - 24
Non-Self-Sustaining Containership (Average Capacity: 2,718 TEUs)	12 - 24	12 - 24
Fast Sealift Ship (FSS)	48 - 72	24 - 36
Large Medium Speed RORO (LMSR)	48 - 72	24 - 48
Maritime Prepositioning Ship (MPS)	72 -122	60 - 100
Roll-on Roll-off (RORO)	24 - 48	24 - 48
Auxiliary Crane Ship (T-ACS)	24 - 48	24 - 48

Figure 30. Notional Loading Times

	LMSR	FSS
Hourly Operating Cost	$7,834.83	$10,417.22
Block Speed (Knots)	19	33

Figure 31. Hourly Operating Cost and Notional Block Speed

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APPENDIX 7

Figure 32. C-130J Super Hercules (USAF)

Figure 33. C-17 Globemaster III (USAF)

Figure 34. C-5M Galaxy (USAF)

Figure 35. Large, Medium Speed Roll-On/Roll-off (MSC)

Figure 36. Fast Sealift Ships (MSC)

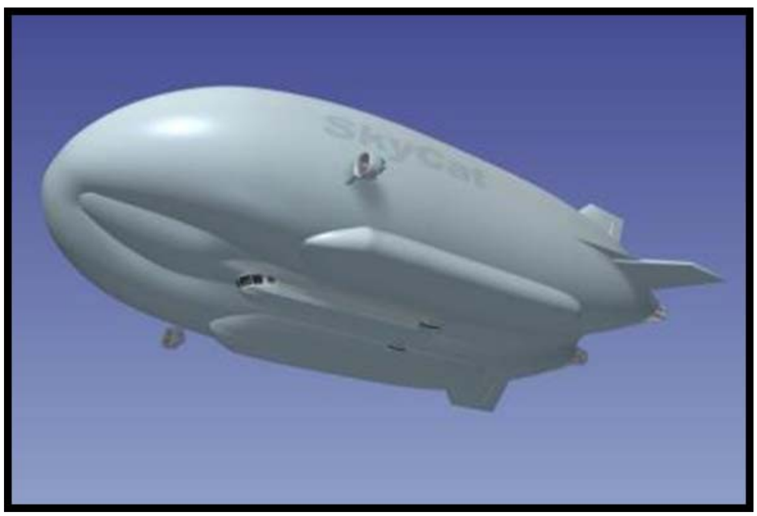

Figure 37. Skycat 220 (World Skycat Ltd.)

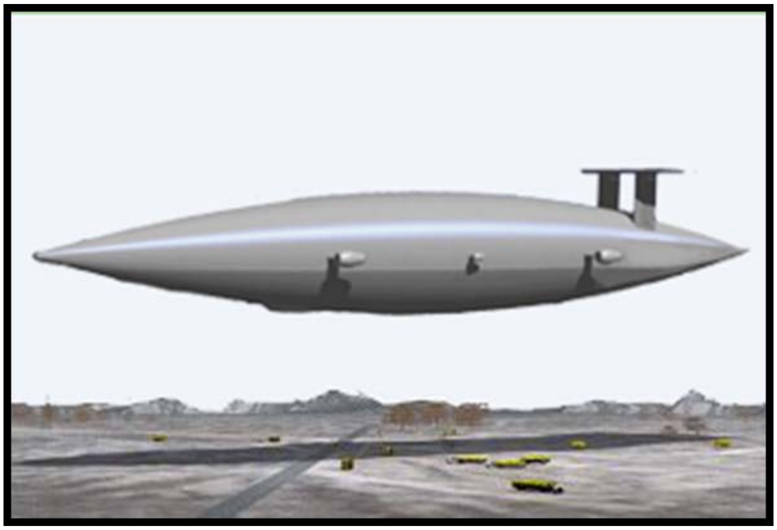

Figure 38. H2 Clipper (H2 Clipper)

Figure 39. Aeroscraft (Aeros)

Figure 40. Hybrid Air Vehicle 366 (Discovery Air Innovations)

Figure 41. Skyhook (Boeing/Skyhook International)

Figure 42. Long Endurance Multi-Intelligence Vehicle (Northrop Grumman)

APPENDIX 8

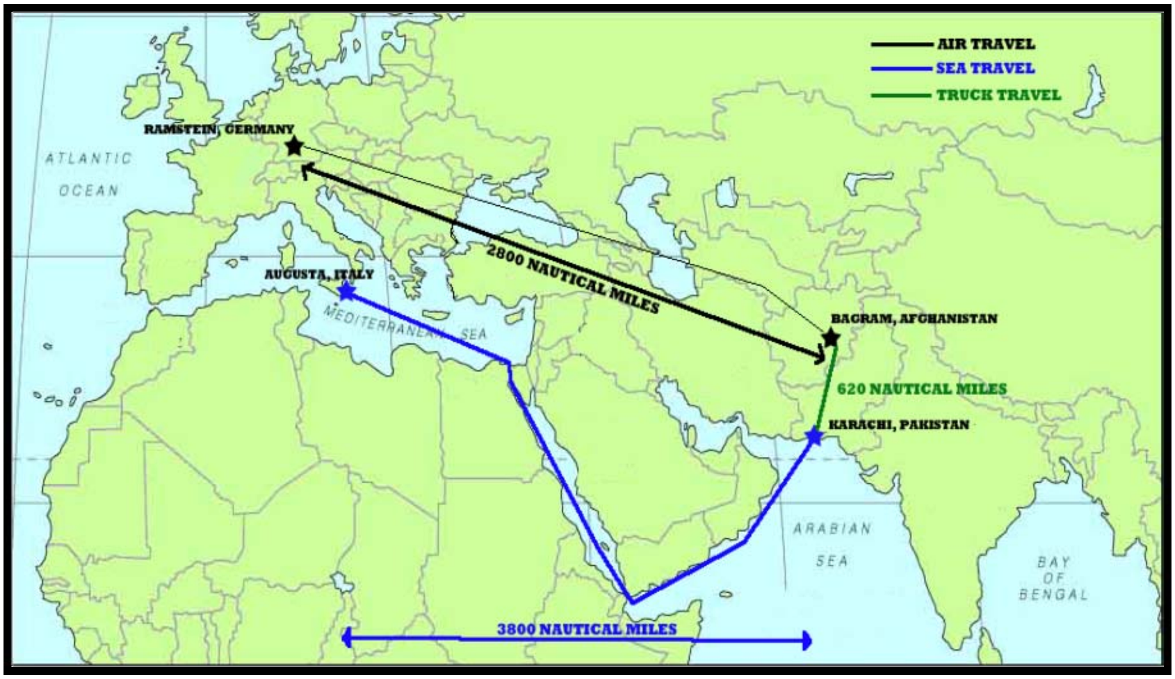

Figure 43. Scenario 1

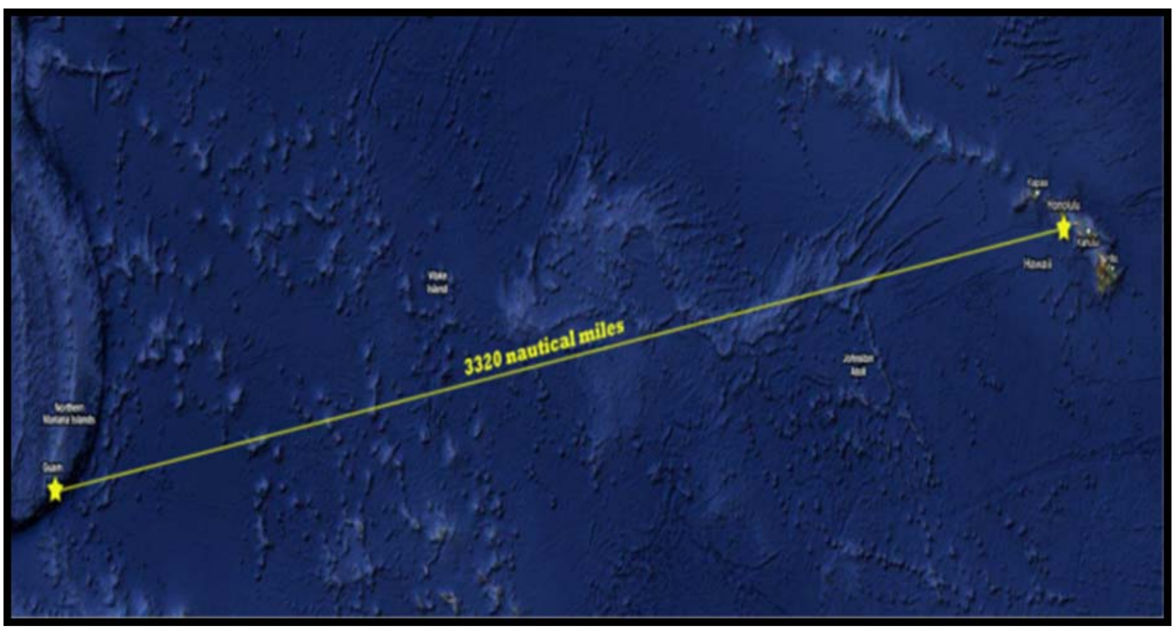

Figure 44. Scenario 2

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