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C-5M Super Galaxy Utilization with Joint Precision Airdrop System

Michael T. Weitz

C-5M SUPER GALAXY UTILIZATION WITH

JOINT PRECISION AIRDROP SYSTEM

THESIS

Michael T. Weitz, Major, USAF

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

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AFIT/LSCM/ENS/12-23

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Michael T. Weitz, MA

Major, USAF

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Michael T. Weitz, MA
Major, USAF

Approved:

____________//signed//___________ _21 Feb 2012__
Alan W. Johnson, Dr. (Chairman) Date

___________//signed//____________ _21 Feb 2012__
Jeffery D. Weir, Dr. (Member) Date

AFIT/LSCM/ENS/12-23

Abstract

The purpose of this research was to determine the viability of utilizing the Joint Precision Airdrop System with the C-5M Super Galaxy weapon system. Specifically, this thesis sought to research the ability of the C-5M to use the Joint Precision Airdrop System and to answer four main research questions addressing a cost benefit analysis between the C-5M Super Galaxy and the C-17 Globemaster III. The research questions were answered through a comprehensive literature review and the creation of a model that determined the cost associated with specific range versus payload mission types. The payloads used ranged from 25 short tons to 400 short tons, with mission ranges looked at between 1000 and 7000 miles. The results from the various model runs were compared to determine which airframe, C-5M or C-17, was less expensive to operate in the mission range.

This thesis is dedicated to my wife, whose inspiration, support and understanding made this endeavor possible. This thesis is also dedicated to my parents, who have supported me throughout my military career.

Acknowledgments

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C-5M SUPER GALAXY UTILIZATION WITH JOINT PRECISION AIRDROP SYSTEM

I. Introduction

Background

The C-5 Galaxy has been at the cornerstone of United States Air Force (USAF) strategic airlift for decades. Developed throughout the 1950's and 1960's, the C-5 was designed to move outsized and oversized cargo over great distances. Currently, the C-5 is the only aircraft in the Department of Defense's inventory capable of moving large and irregularly shaped cargo, such as the Army's 74-ton mobile scissors bridge (Knight, 2008).

Like most aircraft, the C-5 has undergone several upgrades throughout its operational life. The most recent iteration of the C-5 Galaxy is dubbed the C-5M Super Galaxy. The C-5M incorporates numerous updates throughout the entire airframe, with the majority of updates focusing on its avionics and engine systems. These improvements are projected to increase not only its capabilities, but its mission reliability rates as well (Knight, 2008).

The C-5M program was originally intended to upgrade all C-5A, C-5B and C-5C aircraft. As budgets have decreased and priorities have changed the decision to upgrade all C-5 airframes, has also changed. While the C-5 is projected to have an airframe life well into the year 2040, the increasing cost of the modifications and a less than stellar operational history has taken its toll on the program (Knight, 2008).

The C-5M program consisted of two major upgrade projects, discussed in further detail later in the thesis. As of 2008, the decision was made to upgrade all C-5 aircraft with the least expensive program, the Avionics Modernization Program (AMP) updates, while 52 C-5 aircraft (mainly C-5B versions) will receive the Reliability Enhancement and Re-engining Program (RERP) updates (GAO, 2008). Aircraft receiving both AMP and RERP updates will be re-designated as the C-5M Super Galaxy (GAO, 2008). Chapter II will take an in depth look at what these specific modification programs consist of and the effect they have on the C-5 airframe.

The Joint Precision Airdrop System (JPADS) was designed to allow aircraft to airdrop cargo beyond the range of many ground threats, while providing a precision airdrop capability to the combatant commander. This capability would reduce not only threats to the aircraft, but threats to the ground forces recovering the critical cargo as well.

JPADS is based upon a family of systems that can be used for cargo of various sizes and weight amounts, from 200 pounds all the way up to 10,000 pounds (Mobility Air Forces, 2009). JPADS has been successfully used in combat operations, in both Operation IRAQI FREEDOM and Operation ENDURING FREEDOM (Benney, et. al. 2009).

Combining the capability and range of the C-5M weapon system with the precision of JPADS seems like a sensible choice. This thesis will research both systems and help make a determination if C-5M JPADS airdrop is a realistic and cost effective endeavor to peruse.

Problem Statement

With the current improvements being implemented on legacy C-5s aircraft, upgrading them to C-5M, it is theorized that the C-5M will once again become a cost effective way to conduct airdrop missions. While the C-5 is a very capable aircraft, the C-17 is the primary strategic airlifter used today for the airdrop mission. With a large capacity as well as a sizeable range, it is an excellent choice for that mission. Between January 2009 and January 2012, the C-17 has a mission capability rate of 85.17%, meaning it is fairly reliable in conducting its selected missions.

With the implementation of the Super Galaxy, to include its increased capabilities, lower fuel consumption as well as its projected increased mission capability rate it is proposed that the C-5M weapon system has again become a viable option for utilization in the airdrop mission. By utilizing JPADS, aircraft can conduct precision airdrop missions, at higher altitudes, not only considerably reducing enemy threat to the aircraft but removing convoys from dangerous roads. Even with these improvements, the C-5M is an expensive aircraft to operate.

Research Questions

The goals of the research conducted for this thesis are as follows:

1. *Can the C-5M be a cost effective way to conduct airdrop missions using the Joint Precision Airdrop System?*
2. *To what extent will incorporation of an aerial refueling mission reduce the number of aircraft needed thereby reducing the cost?*
3. *How does the design limitation imposed on the C-5M and C-17 change the cost effectiveness of using one airframe versus the other?*
4. *What will incorporation of an aerial refueling mission, in conjunction with the removal of the weight associated design limitation, provide cost data in favor of the C-5M?*

Motivation

Currently, the C-17 is the only strategic airlifter that conducts airdrop missions for the Department of Defense. While the C-5 is capable of conducting airdrop missions, it is believed that the less than stellar mission-capable rates, high C-5 cost per flight hour and the growth of the C-17 fleet have led to the C-17 becoming the primary choice for this critical mission.

With the improvements to the C-5M and the projected mission-capable rates of at least 76% the C-5M is once again becoming a viable option for conducting the airdrop mission (Warner Robbins, 2011). This research will focus on the increased capabilities of the C-5M and the possibility of utilizing it in the JPADS airdrop mission.

Theory

The C-5 Galaxy was originally developed for transporting heavy and oversized cargo. Part of that transportation mission profile was conducting airdrop missions. With its massive payload capacity and almost unlimited range (using aerial refueling) the C-5 can ferry critical cargo into a warzone, airdrop it to requesting forces, then return to a safe location. With the airdrop mission in mind, the C-5 Galaxy was originally developed with the capability to airdrop individual pallets up to 50,000 pounds each (Launius & Dvorscak, 2001).

The C-5 can carry up to 36 pallets. During airdrop missions, the C-5 can use the majority of those pallet positions to carry cargo directly to the warfighter. However, there is a planning limitation imposed on C-5s, restricting them to 18 pallet positions. Mission needs will determine the amount of cargo that is carried as well as how many pallet positions are used.

Up until around 2006, C-5s were used to airdrop troops and cargo into a warzone. While the C-17 has primarily taken over the role of strategic airdrop, the C-5 was originally designed with the capability to conduct airdrop missions, and still should retain that capability. With the numerous improvements the C-5M brings to the fight, to include additional capability and reliability, the C-5 platform is once again a viable option for aerial delivery.

Research Approach

A literature review will be conducted to gain a thorough understanding of the systems involved. This research will lead to a complete understanding of the C-5M, to include its history and the upgrade program that will lead to the current configuration. JPADS will also be thoroughly researched to understand how the system works and how it interfaces with the C-5M. After thoroughly researching the systems involved, a model will be created.

In order to answer the first research question, a model will be created. This model will be developed in order to determine the difference in costs between the C-5M and the C-17, in relation to cargo loads and range. The model will be used to determine a cost associated with moving a specific amount of cargo a specific range. The model will take into account an aerial refueling mission, if needed, and add that cost into the model. The model will use current planning data for both the C-5 and the C-17 in order to help make a determination if, and at what point, the C-5M can become a more cost effective way to conduct an airdrop mission. The costs associated with the specific cargo and range will be compared between the two airframes in order to answer the first research question.

In order to exercise the model, cargo loads between 25 and 400 short tons will be used, in 25 short ton increments. In the model, a short ton is the equivalent of 2,000 pounds. The range chosen for the model will be from 1,000 to 7,000 miles in 250 mile increments. These range increments at the specific cargo loads will give a wide variety of possible mission profiles in order to determine which airframe will be more cost effective to use. This thesis will provide cost comparison tables to help make a determination if the C-5M is a viable option for airdrop missions. The model built for this research will also be used to answer the second and third research questions.

The second research question will explore the possibility of using an aerial refueling aircraft outside of the model decision. This research will focus on specifically selected cargo loads and ranges. In order to implement these changes in the model, specific settings will be changed to determine if it is more cost effective to have an aircraft receive fuel in flight, allowing it to take off with a higher cargo load.

The C-5M and C-17 are design limited to 180,000 and 110,000 pounds, respectively, of weight while conducting an airdrop mission. This design limitation is explored in more detail in chapter II. The third research question explores the possibility that the C-5M and C-17 are not limited by the design. In order to answer the third research question, the model will be used without the imposed design limitation. The costs will be compared to each other in the same mission profiles as the first research question. An answer to the third research question should further the data necessary to determine if the decision to use the C-5M in the airdrop mission should be explored further.

The final phase of this research is recommending areas for future research. Training courses and other technical information may have to be developed, at a cost.

Aircrew may need to be trained to conduct airdrop mission. These areas need to be taken into consideration when making a final decision.

Assumptions

In order to proceed with the research necessary for this thesis, numerous assumptions had to be made. These assumptions are required in order to create a model that will answer the first research goal. The C-5M mission capable rate is projected to be near the C-17 current mission capable rate. Mission capability is assumed to be equal and not figured into the model. Fuel burn rates and aircraft speed are averaged over its flight time. These averages are used in the model. This model is assumed to be used strictly for the purpose of conducting research within the bounds of this thesis. Cost per flying hour rates for the C-5M and C-17 include the cost of the fuel used for the mission, to include the fuel offloaded from the tanker, if required.

Cargo load for C-5M is based upon 18 pallet positions conducting the airdrop mission, a maximum weight of 180,000 pounds. Cargo load for the C-17 is based upon 11 pallet positions, a maximum weight of 110,000 pounds. These cargo load limitations are explored in detail in chapter III. Research question three explores the possibility of removing these restrictions.

Document Structure

Chapter II of this paper contains the literary review of the available documentation on the various systems discussed in this thesis. It provides an in-depth review of the C-5M to include the specific improvements to the C-5 platform that upgrades it to Super Galaxy status. It also includes an explanation of JPADS as well as the current utilization of JPADS. Understanding how JPADS works and is employed is vital. Chapter III outlines the methodology used in the research. Chapter III contains descriptions of the sources of data used for each stage of the research as well as the variables and their mathematical relationships used for the cost benefit analysis. Chapter IV provides details of the analysis conducted as well as the data used in the research. Chapter V summarizes the conclusions from this research. It provides current recommendations as well as recommendations for future research.

II. Literature Review

Approach

The first step in conducting this research analysis was to thoroughly study the C-5 program to include its history, development and implementation. The different models of C-5 Galaxy in use today were also researched. A complete understanding of the history, and capabilities, of the C-5 was crucial in conducting a thorough analysis. This knowledge gave insight into what mission profile the C-5 was originally designed for, as well as the capabilities the original design offered the Air Force and the Department of Defense.

Once a complete understanding of the original C-5 program was obtained, determining how the improvements developed into the C-5, over its lifespan was needed. This research included the current upgrade programs that provided the re-designation of the MDS to C-5M. The current status of the C-5M and the capabilities it brings to the warfighter was the next logical step. Understanding the improvements as well as the current usage of the C-5 was vital in being able to make a proposal as to the feasibility of utilizing the C-5M, in conjunction with the JPADS capability, to conduct critical airdrop missions.

In order to completely understand the C-5M, a grasp of the upgrade programs, to include the Avionics Modernization Program and the Reliability Enhancement and Re-engining Program was needed. In depth understanding of these two upgrade programs helped to comprehend how the reliability of the C-5 was to be improved as well as the capability increase was to be obtained. Understanding the reliability will help to make a determination as to if the C-5 could replace the C-17 in the airdrop mission, while providing the same reliable service.

The next step in research was to gain comprehensive knowledge on the employment and current use of JPADS. This was critical in understanding the problem and being able to propose a solution. JPADS is a relativity new system and as such, the Concept of Employment (CONEMP) is only two years old. The CONEMP outlines how JPADS is currently used, as well as the aircraft it is currently used with. The C-17 and C-130 are the primary aircraft used in conjunction with JPADS.

C-5 Program History

Development of the C-5 can be traced back, in concept form, to the 1950's. The original C-5 concept developed from a need to not only update the Air Force's current fleet of airlifters, but carry more weight as well as the outsized cargo the Army needed to move (Launius & Dvorscak, 2001). In 1963 the Department of Defense (DoD) released requirements for the CX-HLS experimental cargo aircraft (Launius & Dvorscak, 2001). The performance characteristics that emerged are outlined in Table 1 (Launius & Dvorscak, 2001).

Table 1. C-5 A/B Performance Characteristics

Design Weight	
Peacetime	769,000
Wartime	840,000
Max Payload	265,000
Max Fuel	51,150 gal

* (Launius & Dvorscak, 2001)

During the conception of the C-5, military leadership understood the necessity for an aircraft capable of airdropping troops and supplies. While most of the airdrop missions, at least in theory would be conducted by smaller and less expensive aircraft such as the C-130, inherent airdrop capabilities were still a requirement for the C-5 (Launius & Dvorscak, 2001). This requirement allowed the C-5 to be useful in a wider range of missions.

The original design of the C-5 took into account the aerial delivery mission. The aircraft was designed to have smooth airflow around the aircraft to aid during the airdrop mission as well as have limited airframe responses during the transition of cargo out the aft doors (Launius & Dvorscak, 2001). When airdropping heavy cargo, the aircraft response to the center of gravity shift was to be kept to a minimum allowing the pilot to keep control of the aircraft during these types of missions (Launius & Dvorscak, 2001). All C-5 aircraft have been designed from the outset to handle the airdrop mission.

The C-5 aerial delivery capability was designed to offload individual pallets weighing up to 50,000 pounds, while sequentially dropping three additional 50,000 pound pallets (Launius & Dvorscak, 2001). During the initial testing of the C-5, pallets up to 42,500 pounds were used with a sequential airdrop usage to 164,000 pounds (Launius & Dvorscak, 2001). The initial testing of the C-5 conducting airdrop missions proved the ability of the Galaxy to be useful in aerial delivery.

The initial requirements for the C-5 also took into account maintainability as well as reliability. The initial requirement was for 90% of all aircraft dispatched to reach their destination. A reliability level of 87% was to be demonstrated during the test program (Launius & Dvorscak, 2001). The aircraft was to have a minimum operational availability of 75% (Launius & Dvorscak, 2001).

Unfortunately, C-5s have had a less than stellar mission capability (MC) rating. From December 2008 through December 2011, the MC rate has been 56.73%. The Air Force describes the mission capability rating as “The percent of unit possessed aircraft/equipment that are capable of performing at least one of its assigned peacetime or wartime missions (Mission Capable = Full Mission Capable + Partial Mission Capable)” (Logistics Installations and Mission Support Enterprise, 2011). This description is stated as a business rule, retrieved from the Logistics Installations and Mission Support Enterprise (LIMS-EV).

LIMS-EV can also provide the Aircraft Availability rate for a weapon system. The Aircraft Availability rate is described as “Percentage of a fleet's Total Active Inventory (TAI) that is available (Mission Capable)” (LIMS-EV, 2011). The Aircraft Availability (AA) rate for the C-5 has been fairly low. From December 2008 through December 2011, the AA rate has been 42.14% (LIMS-EV, 2011). These less than adequate MC and AA rates helped lead to the necessity to upgrade the fleet.

In an attempt to modernize the C-5 fleet as well as improve the reliability and capability of the aircraft, the Air Force initiated two major modification programs (Knight, 2008). These modification programs would initially be conducted on all C-5’s in the active inventory. Aircraft that underwent both modification programs were to receive a new mission design series, C-5M (Warner Robbins, 2011). Unfortunately due to budget cuts and increasing costs throughout both programs, the modifications will not be accomplished on all aircraft.

C-5 Modification and Modernization programs

Two separate programs were initiated in an attempt to increase the capabilities and reliability while decreasing total ownership costs of the C-5 Galaxy, as well as improve the overall performance (Warner Robbins, 2011). The Avionics Modernization Program and the Reliability Enhancement Re-engining Program were developed to be completed on all C-5 aircraft between FY02 and FY14, and FY09 and FY15, respectively, in order to modernize the entire C-5 fleet (Warner Robbins, 2011). These programs work in conjunction with each other to increase the reliability of the C-5 allowing an expected mission capable rate of greater than 75%, considerably higher than the current rate of (as of November 2011) 62.39% (C-5 Division, 2010).

As with most programs in the DoD the costs of both modification programs increased over the years, budgets shrunk and the ability to modernize the entire C-5 fleet went away. Since the C-5 brings unique capabilities to the strategic airlift mission, a decision as to how many aircraft to upgrade had to be made.

The Avionics Modernization Program (AMP) was initiated to upgrade all C-5 aircraft with new communication systems (Knight, 2008). This program is planned for all 100 C-5s in the fleet. Scheduled to be completed in FY14, AMP ensures all C-5s are able to operate unrestricted throughout global airspace (Knight, 2008). These aircraft, though modified, retain their original Mission Design Series (MDS). Figures 1 and 2 show the difference between a legacy C-5 flight deck and an AMP modified C-5 flight deck.

Figure 1. C-5 Legacy Flight Deck

Figure 2. C-5 AMP Modified Flight Deck

The Reliability Enhancement Re-engining Program (RERP) is a modification program that requires more work than AMP. The focus of RERP is more on improving availability, reliability, and maintainability of the C-5 fleet (Knight, 2008). Funding limitation has resulted in a decision to not modify all aircraft with the RERP improvements. As of 2010, 52 C-5 aircraft will be modified with RERP.

The main focus of RERP is to upgrade the original General Electric TF-39 engines, currently installed on C-5A/B/C models to a modern and higher performing General Electric CF6 engine (Knight, 2008). This engine upgrade, along with upgrades to pylons, auxiliary power units, aircraft skin, frame, landing gear and pressurization system, is expected to increase the Mission Capable rate to at least 75%, allowing more utilization of the C-5M throughout its mission profile (Knight, 2008).

A pictorial description of the upgrades, used from the C-5 Reliability Enhancement and Re-Engining Program Acquisition Strategy, is located in figure 3. As can be seen, the RERP upgrades encompass a large portion of the aircraft. Aircraft receiving both AMP and RERP upgrades will be designated the C-5M Super Galaxy.

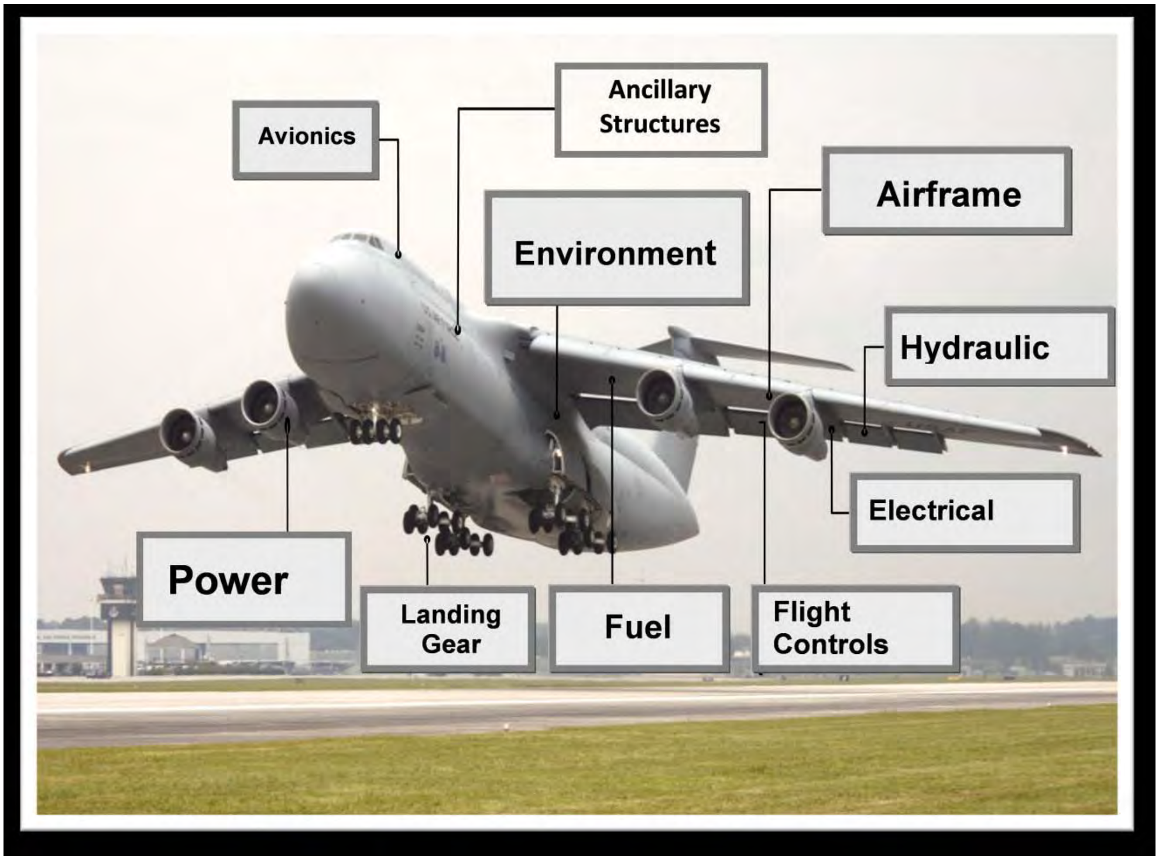


Figure 3. C-5 RERP Modification areas

C-5M Super Galaxy

The C-5M Super Galaxy incorporates both the AMP and RERP upgrades. These two upgrades work in conjunction with each other to increase not only the reliability and maintainability of the legacy C-5, but also its performance. Table 2 depicts some major differences between the legacy C-5 and C-5M.

Table 2. C-5 Legacy vs. C-5M Comparison

	C-5 A/B*	C-5M**
Length	247.8 feet	247.8 feet
T-Tail Height	65.1 feet	65.1 feet
Wing Span	222.8 feet	222.8 feet
Design Weight	840,000 lbs	840,000 lbs
Max Payload	265,000 lbs	285,000 lbs
Effective Range w/ 120,000 payload	4350	5250
Engine	TF-39	CF6
Thrust/Engine	43,000 lbs	50,580 lbs

* (Launius and Dvorscak, 2001)
** (Lockheed Martin, 2011)

C-5 Current Status

As of August 2011, the Air Force operates 100 C-5 aircraft, with 53 C-5A models, 40 C-5B models, 2 C-5C models and 5 C-5M Super Galaxy's. These aircraft operated with a combined 56.73 mission-capable rate for the period December 2008 through December 2011.

According to paragraph 1.2 of the C-5M Acquisition Strategy Review, Air Mobility Command has identified three main missions for the C-5M. Those three missions are listed below.

- Strategic airlift (delivery of outsized and oversized (O&O) cargo and passengers primarily via air-land operations)
- Aerial refueling (receiver) **–** provide extended range operations
- Emergency Aero-medical Evacuation (AE)

As can be seen, aerial delivery is not currently one of the main missions for the C-5M. While it retains the capability, it has not accomplished the mission since around 2006. With more C-5M's entering the inventory aerial delivery might become a worthwhile option once again.

JPADS Program History

The Joint Precision Airdrop System came out of a necessity to accurately and safely airdrop cargo into a warzone in order to deliver critical cargo and other goods to the warfighter. Airdrop missions have been conducted for decades however, there are two challenges that have been associated with standard airdrop missions (Mobility Air Forces, 2009).

The primary challenge that faces conventional airdrop missions is accuracy. For a conventional airdrop mission to be accurate it needs to be released from a relatively low altitude (below 3,000ft above ground level) (Mobility Air Forces, 2009). Using a large aircraft at this low of altitude has intrinsic risk such as exposure to enemy ground fire and visibility of the airdrop by enemy forces. Variations in wind speed and vector from ground level to 3,000 feet can also have an effect on the accuracy of the airdrop mission (Mobility Air Forces, 2009). These variations can throw airdropped cargo off course making the cargo dangerous to retrieve.

The second challenge to conventional airdrop missions is the recovery of cargo that has veered off course. These recoveries can be dangerous as it has the possibility of exposing friendly forces to enemy contact. One of the primary reasons to conduct an airdrop mission is to resupply ground forces limiting their exposure to enemy activity.

Cargo that did not land in its intended location still needs to be recovered, and therefore nullifies one of the primary reasons the airdrop mission was conducted in the first place.

JPADS Operations

According to section 1.4.1 System Overview of the Joint Precision Airdrop System Concept of Employment:

> "JPADS is a family of systems consisting of a Mission Planning System (MPS) laptop loaded with JPADS-MP software, multiple steerable parachute/parafoil delivery systems or conventional parachute systems, the Advanced PADS Interface Processor (DROPSONDE UHF RECEIVER/APIP) or UHF Dropsonde Receive Subsystem (UHF-DRS), a GPS Retransmit Subsystem (GPS-RTS), and Dropsondes. The JPADS steerable family has three projected weight increments: JPADS Ultra-Light, 200-700 lbs, JPADS Extra-Light (XL), up to 2200 lbs, and JPADS Light, up to 10,000 lbs weight class."

Section 1.4.1 System Overview of the Joint Precision Airdrop System Concept of Employment defines the family of JPADS. There is a JPADS capability for almost every conceivable piece of cargo that would need to be airdropped. JPADS is a very adaptable system that can be easily used on multiple airframes as well as with different sizes of cargo loads.

The Improved Container Delivery System (I-CDS) is an unguided airdrop system that uses JPADS-MP software in order to provide an accurate delivery system, without the cost associated with the JPADS AGU. The current I-CDS system is based upon the Army's conventional airdrop canopy which limits the payload to 2,200 pounds (Mobility Air Forces, 2009). I-CDS systems are currently in development that will allow payload capacities from 5,000 to 10,000 pounds. This system allows more accuracy without all the expenses of JPADS. I-CDS is a lower cost option for the Combatant Commander to provide airdrop capability.

There are multiple systems that fall under the JPADS umbrella. These systems are dependent on the type and weight of cargo being used. They are also dependent on the type of capability needed, guided or unguided. Table 3 breaks out the main types of JPADS used today (Mobility Air Forces, 2009). The multiple types of JPADS give a large variety of capability to any aircraft utilizing JPADS.

While there are multiple JPADS being used, they all constructed from and use similar components. The next few sections outline the components used by JPADS, both within the aircraft and as attached to the cargo itself.

Table 3. JPADS System Descriptions

System Name	Cargo Capacity (lbs)	Canopy System	Notes
FireFly	900-2,200	Steerable Parafoil	
Screamer	500-2,200	Steerable Parafoil w/additional chutes to slow touchdown	
Dragonfly	5,000 -10,000	Steerable Parafoil	Uses 463L pallets or similar sized platforms.
Screamer 10K	10,000	Parafoil w/additional chutes to slow touchdown	Uses 463L pallets or similar sized platforms
Improved Container Delivery System	2,200	Unguided conventional chutes	Low Cost system that uses JPADS-MP software but no AGU

* (Mobility Air Forces, 2009)

JPADS Equipment - Aircraft

Joint Precision Airdrop System consists of two main components. The primary equipment is mounted to (if necessary) and used from inside the aircraft. This mission planning equipment consists of five main components, described later. The second set of components is attached to the cargo, and varies with the size and type of cargo being used for the mission.

Joint Precision Airdrop System Mission Planning (JPADS-MP) equipment is the heart of JPADS. JPADS-MP equipment includes the software loaded onto a JPADS specific laptop, Dropsondes, a UHF dropsonde receive subsystem, GPS Retransmit Subsystem (GPS-RTS) and other Mission Specific Equipment (MSE) that might be pre-loaded onto the specific MDS (Mobility Air Forces, 2009).

The JPADS-MP laptop is preloaded with the JPADS software as well as the data required to conduct the airdrop mission. As outlined in the Joint Precision Airdrop System Concept of Employment, paragraph 1.4.4.1, the software compiles all available information and produces the items listed below (Mobility Air Forces, 2009).

A. Airdrop Release Point to include GPS Coordinates
B. Launch Acceptability Region which outlines a release envelope in which, if released, the cargo will reach its intended target.
C. I-CDS Success Footprint which graphically displays where the payload will land based on the ballistics data in the software
D. Chute Failure Footprint which graphically displays where the payload will land if a chute failure occurs

E. Guidance System Failure Footprint which graphically displays where the payload will land if the guidance system fails.

Dropsondes are small antennas that transmit GPS derived data signals to the aircraft conducting the airdrop mission (Mobility Air Forces, 2009). These antennas are deployed from the aircraft before the main airdrop takes place. These GPS antennas send data through the aircrafts lower UHF antenna, through the receive subsystem, to the JPADS-MP equipment in order to give real time wind measurements (Mobility Air Forces, 2009).

The UHF Dropsonde Receive Subsystem (UHF-DRS) receives RF signals from the deployed dropsondes through the aircrafts lower UHF antenna. The UHF-DRS sends the data to the JPADS-MP laptop in order to convert the GPS data into a wind profile for the system (Mobility Air Forces, 2009).

The final piece of JPADS equipment is the GPS retransmit subsystem (GPS-RTS). The GPS-RTS interfaces with the aircraft's GPS control unit and transmits it through temporarily mounted antennas throughout the cargo compartment to both the dropsondes as well as to the cargo itself (if required) (Mobility Air Forces, 2009).

Figure 4. JPADS-MP Equipment

The equipment used on the aircraft side of the system can also be used to determine drop points for unguided cargo, specifically the improved container delivery system, discussed later.

JPADS Equipment - Cargo

In addition to the equipment attached the aircraft JPADS also uses specific equipment attached to the cargo. This equipment might vary with the type of cargo, and mission, being conducted but the majority of JPADS use the same basic equipment set.

The primary piece of equipment attached to the cargo is the Autonomous Guidance Unit (AGU). This assembly mounts on top of the payload. The AGU houses the power pack, GPS receiver, 802.11g wireless communication suite, and hardware required for operating the steering suite, as required (Mobility Air Forces, 2009).

The GPS receiver consists of not only the receiver, but also the guidance, navigation and control software. The 802.11g wireless communication suite allows the AGU to communicate with the JPADS-MP equipment within the aircraft.

Aside from the basic equipment set, JPADS cargo can employ parafoils and other steerable chutes to ensure the cargo lands at the pre-determined location. These vary between the systems and size of cargo being used for the mission.

JPADS Equipment - Interface

As JPADS has not been used on the C-5M, there is no installation instructions published. However, a review of TO 12S1-5-4-7, the installation instructions for the C-17, gives insight on how the system interfaces with the aircraft. JPADS is intended to be a self-contained system, and as such, requires very little interface with the aircraft. JPADS Mission Support Equipment (MSE) is a temporary installed system that has been approved for use aboard Mobility Air Forces aircraft, specifically in the case of this Technical Order, C-17's (TO 12S1-5-4-7, 2010). The MSE communicates directly with the MPS.

The MSE interfaces with the aircraft through the UHF-DRS Receiver and the GPS-RTS Antenna control unit. Both of these systems need a 28 VDC power source to operate.

The UHF-DRS receives and processes data received from the dropsonde, through the aircraft UHF antenna, and sends that data to the MPS Laptop (TO 12S1-5-4-7, 2010). The UHF-DRS connects to the lower UHF antenna through a preinstalled connection panel, or directly to the aircraft's UHF receiver through the avionics compartment. Further research is required to ensure the C-5M has the correct attachment points at the aircraft UHF receiver. The UHF-DRS receiver is connected to the MPS laptop either through an Ethernet cable routed to the flight deck, or a wireless communication system.

Figure 5. JPADS UHF-DRS Equipment

Figure 6. JPADS-MP Laptop

The GPS-RTS system is also a self-contained system that requires little interface with the aircraft. The GPS-RTS does use a GPS signal from the aircraft. C-17 aircraft utilizing the GPS-RTS equipment must have modification 1853, which includes wiring and connectors, accomplished. Once accomplished, the GPS-RTS will use GPS data from the aircraft. The GPS-RTS system also uses 28 VDC from the aircraft to power the antenna control unit. The remainder of the antennas required for the system is installed along with the GPS-RTS and can be easily removed from the aircraft if necessary.

Figure 7. GPS-RTS Installed in C-17

As stated, the JPADS MSE is almost completely self-contained. Test equipment is contained within the MSE. Power is required as are two connections to the aircraft. Engineering studies beyond the scope of this thesis will have to be accomplished to ensure the C-5M provides the correct power, right information and has the right connections to the MSE.

Improved Container Delivery System

The Improved Container Delivery System (I-CDS) is a cost effective way to airdrop cargo. I-CDS uses JPADS-MP software and dropsonde data to determine the best airdrop location (Mobility Air Forces, 2009). Where I-CDS differs from JPADS is on the cargo side of the system.

I-CDS is an unguided airdrop system. While it uses JPADS-MP data to determine the best drop location, it does not use any AGU nor any steerable chutes. Utilizing I-CDS for unguided airdrops improves the error percentage 55-70% (Mobility Air Forces, 2009). I-CDS is a cost effective way to improve the accuracy of airdropped cargo, currently used on smaller cargo loads, with larger loads up to 10,000 pounds, in development.

JPADS Employment

The JPADS-MP system was first used in combat on 29 July, 2006 (Benney, et. al. 2009). This employment was used with an I-CDS system. Using JPADS-MP software in conjunction with an unguided I-CDS system allows for an airdrop that costs considerably less than a JPADS specific system, with increased accuracy over a standard airdrop. I-CDS fits nicely between a standard airdrop and a full up JPADS drop. The first combat use of a fully operational JPADS drop occurred on 31 Aug, 2006 using a Screamer JPADS package (Benney, et. al. 2009).

JPADS Acquisition Exercise

In October of 2008, the Aeronautical System Center (ASC) was directed to do an exercise to determine, from an acquisitions standpoint, if JPADS could be used on the C-5. While this was an exercise for the acquisition community, engineers from the

JPADS program office were involved. This exercise provided insight as to the feasibility of using JPADS with the C-5.

Upon completion of this exercise, it was determined that with proper planning and funding it was a low risk endeavor to incorporate JPADS into the C-5 weapon system. Due to the configuration and self-contained nature of JPADS, the strategy would leverage efforts from both the C-17 and the C-130. For the initial test, two C-5 aircraft would be required for approximately 4 weeks in order to test JPADS on the C-5. This limited amount of testing can attest to the ease as to which JPADS can be used in another airframe.

During this exercise, it was estimated that a C-5 JPADS configuration could be procured, tested, and fielded in less than 12 months (Gobeil, 2008). According to the acquisition strategy, this short timeframe was a low risk endeavor that could be obtained, with proper funding, by leveraging existing JPADS efforts. Three areas were looked at from a risk standpoint: cost, schedule and logistics. Both cost and logistics were deemed low risk due to the ability to leverage off the current program, and the limited amount of funding necessary. Schedule was deemed a moderate risk due to the uncertainty with any new contract, and the aircraft availability for testing. Overall, this exercise showed that configuring JPADS with the C-5 was a fairly low risk endeavor that could be completed within a short amount of time.

Cost Per Flying Hour Comparison

For planning purposes, SAF/FMCCC provides estimated costs per flying hour for various weapon systems in the Air Force. Air Force Instruction (AFI) 65-503 Table A4-1 provides the estimated cost per flying hour, which is a sum of multiple factors. For consistency, this thesis will use the cost per flying hour depicted in AFI 65-503 Table A4-1.

As stated above, the cost per flying hour is the sum of multiple factors. These factors are outlined in the description contained in table A4-1. They are listed below:

- General Support Division costs
- Government Purchase Card costs
- Aviation Petroleum, oil and lubrications costs
- Material Support Division costs
- Depot Maintenance Costs
- Contractor Logistics Support costs

The specific costs, for both the C-17 and C-5 are broken down in Table 4. For FY11, the cost per flying hour for the C-17 is $14,161, while the cost per flying hour for the C-5M is listed as $28,302. Table 4 is taken directly from Table A4-1, AFI 65-503. The last update to table A4-1 was in October 2011.

Table 4. Aircraft Cost Data

MDS	AVPOL (699)	GPC (619)	GSD (605)	MSD (644)	DepotMaint4-3CPFH	CLS5-2CPFH	TotalFHCosts
C-17A	$10,922	$21	$115	$323	$0	$2,780	$14,161
C-5M	$14,849	$403	$1,219	$3,181	$7,501	$1,149	$28,302

***** (AFI 65-503 A4-1, 2011)

C-17 JPADS Utilization and Aircrew Training

The C-17 and the C-130 are the principal aircraft to use the JPADS in their various missions. The C-17's mission as a strategic airlifter is the best airframe to compare to the possibility of the JPADS role within the C-5 capabilities. Currently C-17 aircrews undergo specialty training for the airdrop mission. This training is conducted by at Altus AFB. Based on similarities in their missions, the C-17 training program could be used as a baseline for the creation of the C-5M training program.

As there are no currently qualified C-5M pilots in the airdrop mission, a training class would have to be set up. C-5M aircrew would have to be qualified again to conduct airdrop missions, in addition to attending JPADS specific training. The current JPADS training is conducted in one day for pilots and engineers, and two calendar days for loadmasters. For C-5M aircrew to resume the airdrop mission, the JPADS training aspect of it could be leveraged off the C-17 efforts.

Summary

This research helped to lay the groundwork for a complete understanding of all systems in involved. A thorough understanding of the C-5M and JPADS was required in order to determine what type of information the model needed to contain as well as make a determine if the two systems were compatible. The upgrades to the C-5M should increase the reliability to equal the C-17, leading to the determination that reliability will not be figured into the model. The research showed that JPADS is a fairly self-contained system, the research showed that JPADS and the C-5M could be used together, with minor modifications to the C-5M.

The next chapter discusses why specific sources of data were used in order to conduct the research. Chapter III goes on to detail the model used for the cost comparison, and provide the data necessary to determine answers to the research questions.

III. Methodology

This chapter will focus on the sources of data used for this research as well as methodology behind the research conducted. This chapter also explains the details of the model used for the cost comparison between a C-17 and C-5M. The model uses several sources of data described in the following pages, in order to compute an estimated cost between the C-17 and C-5M in completion of a specified mission. The numbers used for the model are estimates based upon averages of the data available as well as published figures from both Air Force and outside sources.

C-5 Data Sources

In order to fully understand the research problem and the possible solution an understanding of the history of the C-5 was required. An in depth review of the C-5 history as well as the program developed during the 1960's was conducted. This review showed the initial capabilities of the C-5 and the original design specifications, particularly in the aerial delivery mission. As the C-5 has been around for decades, numerous sources of information were available on the program history and the capabilities of legacy C-5.

Information obtained from a review of the C-5 program and its history led to the current acquisition programs designed to increase reliability and performance of the legacy C-5. These programs, AMP and RERP, are used in conjunction with each other to increase the usefulness of the C-5 weapon system. Aircraft that underwent (and will undergo) both AMP and RERP modification programs will be re-designated as C-5M Super Galaxy's.

The course of the research led to an understanding of the upgrades to the C-5 via the AMP and RERP programs. The next step in the research was to gain a thorough understanding on the capabilities of the C-5M. As the C-5M is a fairly new weapon system, with only 6 in the fleet as of January 2011, information as to its reliability and maintainability is limited in duration. Since maintenance data is limited on the C-5M, the projected MC rate of 75% is assumed for the purposes of the model. Technical data used in the model is estimated based upon both the legacy system and current test data from the C-5M. For the majority of this research, the projected reliability data was used.

To fully understand the current status of the C-5M program and the capabilities various documents were obtained from the C-5 Program Office at Wright Patterson AFB. The two primary documents obtained were the Life Cycle Management Plan and the Acquisition Strategy Report which both contained in depth information on the C-5M. As the C-5M is a new configuration of an existing weapon system both documents were still in draft form awaiting coordination for final signatures. It is assumed for the purpose of this research that information contained in the draft documents will not change once they go through the final approval process.

Historical data, specifically on the C-5M program, was obtained through the use of various government documents to include Government Accountability Office Reports and Congressional Reports. These documents gave insight into the budget constraints that faced the C-5M program and the seemingly ever changing final number of aircraft that were scheduled to be upgraded.

Various other sources of data were used to gather technical information for the C-5. For example, Air Force Pamphlet (AFPAM) 10-1403 was used to obtain standard planning factors for the aircraft used in the research as well as the model, such as average fuel burn rate in pounds per hour and planning requirements for aerial refueling. Air Force Instruction (AFI) 65-503, *US Air Force Cost and Planning Factors* was used to determine the planning cost per flying hour figures for all aircraft involved in the model. Table A4-1, Logistics Cost Factors, was the primary table used to determine planning cost for the model. A copy of data used from AFI 65-503 table A4-1 is contained in table 4.

After thoroughly researching the C-5 and the C-5M, the next step in the research project was to understand the Joint Precision Airdrop System. The review of the current status of JPADS included program development history, capabilities, as well as the current employment of the system. JPADS is a fairly new system in itself and as such, documentation on it was readily available and fairly current.

JPADS Data Sources

The Joint Precision Airdrop System is a fairly new capability. The current Mobility Air Forces, Joint Precision Airdrop System Concept of Employment (CONEMP) was a main source of information for this research. The CONEMP contained a history of the program as well as the current use of JPADS in today's environment.

To fully understand how JPADS integrates into the aircraft, the installation Technical Order for the C-17 was reviewed. Technical Manual 12S1-5-4-7 documents the aircraft installation procedures for the JPADS mission support equipment for the C-17. Since JPADS is not currently used on the C-5M, the C-17 installation procedures was used as a basis for understanding the system. While specific installation procedures will differ between aircraft, the function of the equipment should be the same. This gave awareness as to how JPADS integrates into the aircraft as well as what type of support equipment and maintenance is required before the aircraft launches on its mission.

An acquisition exercise was conducted in 2008 in order to determine the feasibility of using JPADS with the C-5 weapon system. This exercise was reviewed and the information obtained from Aeronautical Systems Center conducting the exercise was used to make assumptions in this thesis. This exercise provided insight into how JPADS engineers and program office personnel interpreted how easy it would be to incorporate JPADS into another weapon system. While there were some studies that would need to be accomplished, the risk was determined to be low.

C-17 Comparison

As the two primary aircraft that employ JPADS are the C-17 and the C-130, the C-17 was chosen to be used in a comparison analysis. The C-17, while not as capable as the C-5, was the most qualified as a comparison aircraft in the scope of this analysis. Technical data for the C-17 is readily available from a multitude of sources to include both Air Force and Boeing as the prime contractor. Averages were used as necessary for the purposes of the model.

With an understanding of the C-5M capabilities, as well as JPADS current uses, an analysis was conducted. This analysis focused mainly on comparing the C-17 in the aerial delivery role, to the C-5M in the same role. A cost comparison was the type of analysis used. Estimated flying hour costs was the primary factor in conducting the analysis. As the amount of cargo loaded on an aircraft increases, their fuel capability decreases. If an aerial refueling was required for the modeled aircraft to meet its mission, it was added into the equation. Specific aircraft capabilities are key in conducting the comparison, especially as it relates to the cost.

Model Construction

The aircraft information was used to create a model in order to compare the costs associated with utilizing the C-5M versus the C-17 in various mission profiles. A model was created for both C-5M and C-17 aircraft. The representation of the C-5M model is contained in Appendix B. Appendix C contains the representation of the C-17 model. A user's guide for the construction of the specific model used is contained in Appendix I. As the model was run, it manipulated data in order for the model to make the best determination as to the cost analysis. Both Appendix B and Appendix C are snapshots in time to give an idea of what data is contained in each model. Different model imputes will create different outputs for the model.

The model was created in two main sections. First, a Nonlinear Programing (NLP) equation was created to determine the least amount of aircraft required to complete the mission. The second part of the model consists of numerous calculations necessary to determine the costs associate with each airframe type as well as other data. The model determines the cost associated with accomplishing the imputed mission type (determined by airframe). The NLP equation works in conjunction with the rest of the model to determine the least amount of aircraft required to complete the mission. The NLP equations and other calculations work in conjunction with each other to provide estimated costs and number of aircraft needed to complete a specific mission.

Microsoft Excel was used for both the NLP equation (using Excel's built in Solver) as well as the other calculations. Within Solver, the GRG Nonlinear method was used to solve the model. A separate sheet is used for to impute estimated mission range as well as estimated short tons that require movement, see Appendix D.

Information flow through the model

Figure 8 represents the flow of information within the model. The data that was initially imputed includes the range and cargo load. This information is imputed into the model. The range data is calculated within the model, based upon calculations documented later in this chapter. The range data helps determine the fuel weight. Next, the Nonlinear Programming equations, using the fuel weight and cargo weight, calculates the minimum number of aircraft required to complete the mission.

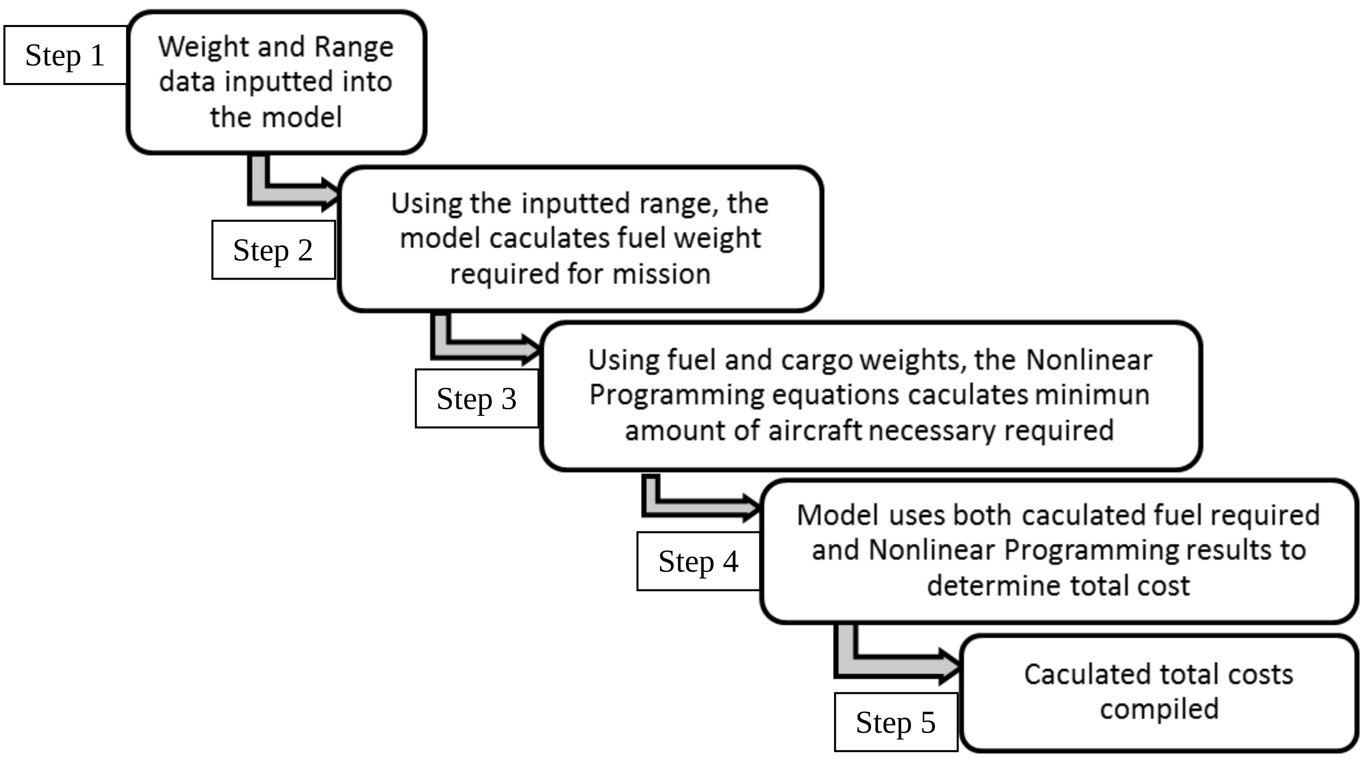


Figure 8. Information flow

Model Notation

A_i	Calculated amount of aircraft required for aircraft type *i* for *i* = (C-5M, C-17)
B_i	Actual amount of aircraft required for aircraft *i*
N_i	Cargo available weight for aircraft *i*
F_i	Pounds of fuel per mile for aircraft *i*
I_i	Takeoff Fuel Weight Needed for Mission, for aircraft *i*
J_i	Maximum fuel weight for aircraft *i*
W	Empty aircraft weight
K	Cargo limitation imposed by airlift mission
Y	Maximum takeoff weight
G	Average fuel burn rate in pounds per hour
H	Average speed
M	Maximum fuel gallons
$CPFH$	Cost per flying Hour for aircraft
S	Short Tons required to be moved, inputted by user
U	User inputted mission range retrieved from results tab
E_i	Estimated Hours of Flight Time for aircraft *i*
T_i	Total cost per aircraft for aircraft *i*
TA_i	Total aircraft costs for aircraft *i*
TR_i	Total cost per aircraft given AR (if required) for aircraft *i*
TC_i	Total cost for aircraft *i*
P_i	Total pounds of fuel needed for the mission for aircraft *i*
R_i	Aircraft range required completing assigned mission for aircraft *i*

Step One

Within the model, the researcher imputed the mission range and payload in preselected increments. Cargo moved, *S*, was selected and imputed by the researcher. A short ton is 2,000 pounds of cargo. For the purposes of this model, input is required in short tons while all calculations throughout the model are done in pounds. The researcher also inputs the mission range, *U* into the model.

Appendix D contains a graphical representation of the results tab of the model, where the researcher imputed the required data. Also included on this tab are some assumptions that the model uses. Once the researcher imputes the estimated mission range and estimated short tons, a macro is run. The "Run Aircraft Estimation" button, depicted in Appendix D, contains the macro, which is shown in detail in Appendix H. Using the macro allows the research to run through the complete model. The first step contained within the macro is resetting all calculations by setting $S/A_i = 1$. This initial feasible solution provides the Nonlinear Program algorithm a starting point to continue its calculations. The model continues through the process documented below. The results from the process will show up in the estimated number of aircraft required, and estimated total cost blocks for a quick reference as to the results the model has come up with.

Step Two – Initial calculations

Once step one is completed and the model is ran, it goes through several calculations. Those calculations are described below. The first calculation completed is the determination of aircraft range.

Aircraft range, R_i, is based upon the researcher imputed data, U, plus a 15% reserve. The 15% reserve is based upon an assumed safety factor. For example, if the user inputted a mission rage of 5,500 miles, range required by the mission aircraft would be 6,325 miles. The equation for this is documented in equation 1. As range increases, so does the amount of fuel the aircraft must carry.

$$R_i = U * 1.15 \tag{1}$$

Next, a determination of fuel weight required to support the need range. In order to determine the fuel weight needed, a calculation of pounds of fuel required per mile, F_i, is accomplished. Equation 2 depicts the calculation to determine F_i.

$$F_i = {}^{G}/_{H} \tag{2}$$

Table 5. Notation G and H

	C-5M	C-17
G	21,949*	19,484*
H	518**	515***

* (AFI 65-503 Table A13, 2011)
** (C-5, 2011)
*** (Knight, 2008)

Utilizing a figure of 42.37 (C-5M) or 37.83 (C-17) pounds of fuel required per mile, notation F_i, calculated by equation 2, the calculation for the fuel weight needed for the mission, I_i, is accomplished by multiplying F_i by the mission range, equation 3.

$$I_i = F_i * R_i \qquad (3)$$

For table 6, *H*, for the C-5M was retrieved from C-5 Galaxy specifications, from globalaircraft.org (C-5, 2011). For the C-17, *H,* was retrieved from the GAO report, *Strategic Airlift Modernization: Analysis of C-5 Modernization and C-17 Acquisition Issues* (Knight, 2008). It is assumed that the C-5M will have the same average speed as the legacy C-5. The average fuel burn rate, as well as other aviation fuel consumption factors, was retrieved from AFI 65-503, Table A13-1, *Aviation Fuel Consumption Factors* from FY11 (AFI 65-503, 2011).

Step Three - Nonlinear Programming Equation

Once the fuel weight is determined, see equation 3, the model moves onto the next step, determining the minimum amount of aircraft necessary to complete the mission with the given range and payload.

A Nonlinear Programming equation was built to run using a Microsoft Excel optimization tool, specifically the Solver function, to solve the minimization aspect of the model. The NLP equation uses data to determine the least amount of aircraft needed to complete the mission, A_i. Since the NLP equation is tied into the other calculations done by the model, the NLP equation cannot be used without the rest of the calculations the model accomplishes. The NLP equation used by Microsoft Excel's Solver is documented in equations 4 through 8. The macro used in conjunction with the model provides the NLP with a starting point of 1. This provides the NLP algorithm a point within the feasible region to begin its calculations in an attempt to determine the least amount of aircraft necessary.

Minimize: A_i (4)

Subject to:

$$S/A_i \geq 0 \quad (5)$$

$$S/A_i \leq K \quad (6)$$

$$S/A_i + I_i \leq Y - W \quad (7)$$

$A_i \geq 1$ and integer (8)

Whereas A_i equals the calculated amount of aircraft used for the mission. Equations 5 and 6 restrict the models calculation of cargo to between zero and the maximum amount of cargo an aircraft can carry, *K*. Notation *K* is a limitation imposed by the estimated capability of the aircraft within the airdrop mission, 110,000 pounds for the C-17 and 180,000 pounds for the C-5M, see table 6. This restriction is based upon 18 usable pallet positions in the airdrop mission, at a limit of 10,000 pounds each (Gobeil, 2008). Maximum cargo weight for the C-17 is limited to 110,000 pounds, based upon 11 usable pallet positions; at a maximum weight of 10,000 each position (Boeing, 2011). The assumption in this model is the cargo weight is evenly divided by the amount of aircraft. True mission needs, as well as specific cargo requirements, will determine the amount of cargo loaded on each aircraft. Equation 7 is a restriction that ensures the model restricts the aircraft load to the maximum load, *Y*. The values for *Y* are shown in table 6.

Table 6. Notation K, Y and W

	C-5M	C-17
K	180,000*	110,000*
Y	840,000**	585,000****
W	380,000***	269,000****

* (Gobeil, 2008)
** (Warner Robbins, 2011)
*** (C-5, 2011)
**** (C-17 Specifications, 2011)

Empty aircraft weight for the C-5M, *W*, was retrieved from C-5 Galaxy specifications, from globalaircraft.org (C-5, 2011). The C-5M empty weight is assumed to be the same as the C-5B. Empty aircraft weight for the C-17 was retrieved from C-17 specifications documented on globalaircraft.org (C-17 Specifications, 2011). Maximum takeoff weight, *Y*, was retrieved from the C-5M Life Cycle Management Plan (Warner Robbins, 2011) for the C-5M and C-17 specifications, from globalaircraft.org (C-17 Specifications, 2011).

Step Four – Cost Comparison

Step four builds upon the previous steps in order to calculate the cost associated with the C-5M and the C-17 in the same mission.

For the purposes of this model, a gallon of fuel weight 6.7 pounds. The maximum fuel in gallons for the C-5M, was retrieved from the Launius & Dvorscak book, *The C-5 Galaxy History Crushing setbacks, Decisive Achievements* (Launius & Dvorscak, 2001). The maximum fuel in gallons for the C-17 was retrieved from the

Defense Science Board Task Force on Mobility publication (Defense, 2005). Maximum fuel weight, J_i, was calculated by multiplying maximum fuel gallons, M, by 6.7, documented in equation 9.

$$J_i = M * 6.7 \qquad (9)$$

Table 7. Notation M

	C-5M	C-17
M	51,150*	36,567**

* (Launius and Dvorscak, 2001)

** (GAO, 2005)

Within the cost comparison, an aerial refueling is factored into the equation, if necessary. The model uses an IF/THEN statement within Microsoft Excel to make the determination if an aerial refueling is required. Equation 10 shows the equation Microsoft Excel uses to determine if an aerial refueling is required.

$$IF\ I_i \leq J_i\ then\ "No"\ else\ "AR\ Required" \qquad (10)$$

If the model determines an aerial refueling required, the model will subtract 90,000 pounds of fuel planning factor from the takeoff fuel weight needed, I_i (refer to equation 3) (AFPAM 10-1403, 2003). The IF/THEN statement is shown in equation 11.

$$IF\ I_i \leq J_i\ then\ I_i = I_i\ \ else\ I_i = I_i - 90000 \qquad (11)$$

A calculation to determine the pounds of fuel necessary for the mission is accomplished using the average fuel burn rate, in pounds per hour. The estimated hours of flight time is based upon the pounds of fuel needed for the mission, and does not include the reserve of 15% fuel. This calculation to determine the pounds of fuel needed for the mission is shown equation 12.

$$P_i = U * F_i \tag{12}$$

The estimated hours of flight time is calculated using equation 13.

$$E_i = {}^{P_i}/_{G} \tag{13}$$

Mission range is determined by equation 14, and should equal the mission range the user imputed. The mission range calculation is a check within the model to ensure proper calculations are being accomplished.

$$U = E_i * H \tag{14}$$

The actual costs are accomplished next. An estimated cost per flying hour, *CPFH*, retrieved from AFI 65-503 Table A4-1 (AFI 65-503, 2011) is used for these calculations. Total cost per aircraft, T_i, is calculated by the equation documented in equation 15.

$$T_i = CPFH * E_i \tag{15}$$

If the model determined an aerial refueling was required, refer to equation 10, it calculated the cost per aircraft for a KC-135R. A KC-135R, being the standard air refueling aircraft in the Air Force, is used for the cost comparison. The calculation for the KC-135 is based upon assuming a standard 5 hour mission for the KC-135R. The 5 hour mission planning factor was determined using data in AFPAM10-403, Table 10 (AFPAM 10-403, 2003). The cost per flying hour for a KC-135R was retrieved from AFI 65-503 Table A4-1 (AFI 65-503, 2011). Total cost for the KC-135R is determined using equation 16.

$$T_{KC135R} = CPFH * 5 \tag{16}$$

Table 8. CPFH Notation

	C-5M	C-17	KC-15R
CPFH	28,302*	14,161*	7,616*

* (AFI 65-503, 2011)

For the KC-135, number of aircraft required is based upon the number of airlift aircraft required. For example, if the model determines that 3 C-5Ms (or C-17s) are required, it will incorporate 3 KC-135R aircraft. This is based upon planning factors contained in AFPAM 10-403, Table 10 (AFPAM 10-403, 2003). Equation 18 documents this calculation.

Next, total cost per aircraft for the mission, TA_i, is calculated. The equation used in the model is documented in equation 17. Equation 18 shows the total cost per aircraft, for the mission, specifically for the KC135R, if required. Total costs given a requirement for an aerial refueling is documented in equation 19.

$$TA_i = T_i * A_i \tag{17}$$

$$TA_{KC135R} = T_{KC135R} * A_i \tag{18}$$

$$TR_i = TA_i + TA_{KC135R} \tag{19}$$

Step Five – Output

If equation 10 determined an aerial refueling was necessary, TR_i will be used for the total mission costs. If equation 10 determined that an aerial refueling was not required, TA_i, will be used for the total mission cost.

A pictorial representation of the results tab used in the model is shown as a screen capture in Appendix D. Exercise of the model consisted of short tons ranging from 25 to 400, in 25 short ton increments, with missions ranging from 1000 to 7000 miles, in 250 mile increments. Using the macro contained in Appendix H, the model was run and the results documented. The researcher ran the model by imputing the estimated mission range and estimated short tons into their respective sections in the results tab, Appendix D. The macro was then run in order to initiate the NLP equation and run the calculations.

That macro is shown in detail in Appendix H. The model then runs the calculations documented in the prior sections.

General Assumptions

In order to proceed with the creation and use of the model to predict costs associated with both airframes, a few assumptions needed to be made. These assumptions are restated from Chapter 1.

- The C-5M Mission Capable rate is projected to be near the C-17 current MC rate. Mission capability is assumed to be equal and not figured into the model.
- Fuel burn rates and aircraft speed are averaged over its flight time. These averages are used in the model
- This model is assumed to be used strictly for the purpose of conducting research within the bounds of this thesis
- Cargo load for C-5M is based upon 18 pallet positions conducting the airdrop mission, a maximum weight of 180,000 pounds
- Cargo load for the C-17 is based upon 11 pallet positions, a maximum weight of 110,000 pounds
- CPFH rates for the C-5M and C-17 include the cost of the fuel used for the mission, to include the fuel offloaded from the tanker, if required

Model Exercise

Utilizing the model constructed for the purpose of this thesis, numerous calculations were accomplished. These calculations were done to compare estimated costs of each airframe to various load and range levels. The model produced estimated and number of aircraft required in order completing the hypothetical mission. For the purposes of this thesis, the calculations were rounded to the nearest hundred dollars.

The calculations were accomplished to provide a cost comparison between the C-5M and the C-17. The data was imputed based upon a set estimation of mission range and short tons. The data was imputed in the results tab of the model. The mission range was based upon assumed mission ranges, in 250 mile increments. The estimated short tons were based in increments of 25 short tons. After each set of range and cargo data was imputed, the model was run and the results were documented. As this model is an estimation of the approximate costs associated with flying the C-5M or the C-17, the results of the model were rounded to the nearest hundred dollar increment. Appendix F contains the results of the model calculations for the basic cost comparisons. Appendix J contains the results of the model calculations for the experiment to support research question two, while Appendix L contains the results of the model runs in support of research question three and Appendix N contains the results of the model runs in support research question four.

For the purposes of running this model, estimated mission ranges varied from 1000 miles to 7000 miles. Estimated short tons ranged from 25 to 400. Line graphs that represent the data from the basic model calculations are contained in Appendix G. An analysis of specific graphs is documented in Chapter IV. Line graphs supporting research questions two, three and four are located in Appendix K, M, O respectively.

The model was run 400 times in the parameters described above. In order to compare the results, the instances where the C-17 proved a higher cost were removed and counted, the average dollar amount was document. Of the remainder of the 400 runs, in which the C-5M had a higher cost, were documented and the average difference was calculated. Appendix F summarizes the experiments 400 treatments and the response data.

Research Question Two - Aerial Refueling

After running the model with the basic data set, as described above, the model was further exercised in order to answer research question two. Using different data points, centering on the aerial refueling mission, the model was changed. To accomplish this, the data in the model was manipulated to determine if incorporating an aerial refueling mission, even if the model did not determine one was required, would in fact save money. For example, if the model determined that 3 C-5M aircraft were necessary to conduct a long range mission, it might be less expensive to use two C-5M aircraft and two KC-135R tanker aircraft. The second research question was explored to determine the possibility of a lower cost alternative to what the model determined.

In a real world event, it might be less expensive to reduce the fuel before takeoff, load more cargo on the aircraft, and then catch a tanker aircraft in flight. Doing this could allow less cargo aircraft to conduct the mission. Due to the 180,000 pound, 90 short ton limitation built into the model, exploring the second research goal only comes into play when the model determines an additional C-5M is necessary to accomplish the mission. An example of this is in the 75 Short Ton cargo load, above 6500 mile range, the model determines that an additional aircraft is necessary. The limiting factor is fuel load. The second research question explores the possibility of reducing the fuel required at takeoff, in order to allow more cargo space and limit the total overall cost.

For the purposes of this thesis, the manipulation of the model consisted of reducing J_i, when the model determines an additional C-5M was necessary due to weight restrictions imposed by the fuel requirement. Reducing J_i by 90,000 pounds forced the model to add an aerial refueling track into the results, if necessary. In sense, reducing the maximum fuel load allowed the C-5M to carry its maximum payload of 180,000 at all times, regardless of range. If fuel required for the mission range exceeded the new fuel load restriction, an aerial refueling was factored into the cost without the addition of another C-5M airframe. The results from this experiment are discussed in detail in the next chapter. Appendix J summarizes the experiments 400 treatments and the response data.

Research Question Three – Maximum Cargo Load

Research question three was explored using the same model constructed for the first two research questions. In order to answer research question three, the weight limitation restriction imposed on the aircraft was removed. As previously stated, the C-5M was restricted to 180,000 pounds, while the C-17 was restricted to 110,000 pounds in the airdrop missions. The research conducted determined that this limitation is a necessity to provide a close representation of a real world system. The third research question explores the possibility that this restriction is not imposed on the aircraft.

In order to allow the model to run without the restriction, notation K was changed to support the maximum cargo loads allowable by the aircraft. For the C-5 this was 270,000 pounds, the C-17 was 170,900. Appendix L summarizes the experiments 400 treatments and the response data. The graphs are shown in Appendix M. The results are discussed in more detail within the next chapter.

Research Question Four - Aerial Refueling with no weight limitation

Research question four explored the possibility of merging research questions two and three. This included manipulating the data points, as defined in research question two, to force an aerial refueling into the model in order to reduce the total number of cargo aircraft required. It also included changing notation *K*, as detailed in the experiment associated with research question three. This experiment should provide the best cost data in favor of the C-5M. Appendix N summarizes the experiments 400 treatments and the response data, with the graphs shown in Appendix O.

Verification and Validation

This model was built using both technical data, as well as some assumptions, it was created in an attempt to represent the true behavior of both the C-5M and the C-17. Since there are numerous factors, both controllable as well as uncontrollable, that can affect an aircraft throughout its mission; no model can create a perfect result. A best estimation of real world results was the goal. Maintenance issues, environmental concerns, actual aircraft payload, takeoff and landing altitudes and cargo size can all affect the range and payload capacity of an aircraft. Since these factors are not necessarily controllable, they are not factored into the model. Most of the costs used in this model were retrieved from Air Force planning instructions, which in themselves, are to be used for planning purposes only.

Once the model was created, the results were compared to estimated flight ranges versus payload capacities published by outside sources to include the manufactures of each aircraft and official government documentation. The basic model results were documented and compared as this model best represented a real world system. The model results were compared and determined to be close to the published figures. Again, numerous factors have an effect on an aircraft in flight. Many of these factors are not controllable.

As defined in *Discrete-Event System Simulation*, fifth edition, verification of a model is "concerned with building a model correctly" (Banks & Carson & Nelson & Nicol, 2010). In order to verify the model, the data contained within the model was compared to real world technical data in order to determine if the model was built correctly. The calculations within the model were verified individually and the results compared to real world data if available. The results from the model were reviewed to ensure it reflected what occurred in a real world situation, as well as enduring the data used by the model is the same type of data that would be used in a real world system. In addition, the results from the model were examined at the extremes to determine if it behaved predictably. The extreme results from the model were reacting as anticipated, helping to verify the model.

As defined in *Discrete-Event System Simulation*, fifth edition, validation of a model is "concerned with building the correct model" (Banks et al., 2010). As the experiment in this thesis is concerned with comparing the costs associated with two weapons systems, it was determined that, if the model produced verified results, the model itself was the correct model and assumed to be validated. These sources used to help validate the model are described below. Comparing the results from the model with published data helped to provide validation to the model. If the published range and payload data was inputted into the model, the model run, and the results did not overload the aircraft, nor leave excess cargo capacity available, it was assumed a realistic representation of the real world system. This validated the model.

Table 9 contains the C-17 comparisons of the model predictions and published technical data. The real world system technical data was retrieved from Boeing technical specification on the C-17 (Boeing, 2011).

Table 9. C-17 Model Validation

C-17

		Model Data		
Payload	Range	Payload	Range	Cargo Capacity Leftover
160000*	2420*	160,000	2,420	50,700
100300*	4000*	100,000	4,000	41,968
40000*	5610*	40,000	5,610	31,920

* (Boeing, 2011)

Range versus payload data for the C-5M is limited due to the developmental nature of the configuration. Range versus payload data for the C-17 is readily available from a multitude of sources. For the purposes of the validation, one C-5M data set estimation was used, available from Lockheed Martin (Lockheed Martin, 2011). The other two data sets are based upon legacy C-5 data. As the C-5M is set to have increased range and payload capacity, using the legacy C-5 data is a safe assumption. Table 10 contains the C-5M model validation data. As with the C-17 model validation, the model was ran with the real world technical data. The sources from the real world data are identified in the table. If the aircraft was not overloaded and had a reasonable amount of cargo capacity leftover, it was deemed to be a realistic representation of a real world mission.

Table 10. C-5 Model Validation

C-5

		Model Data		
Payload	Range	Payload	Range	Cargo Capacity Leftover
270000*	2650*	270,000	2,650	60,870
160000**	3730**	160,000	3,730	118,243
120000***	5250***	120,000	5,250	84,176

* (C-5 Factsheet, 2009)

** (Knight, 2008)

*** (Lockheed Martin, 2011)

IV. Results and Analysis

Research

This research analyzed the theoretical feasibility of using the C-5M Super Galaxy for the JPADS mission and a cost comparison between using the C-5M and the C-17 in a theoretical airdrop mission. During the course of this research, both the C-5M weapon system and JPADS were reviewed to determine if the systems could be used together. This review encompassed both programs from a historical perspective as well as a review of their current operational concepts.

In addition to the research to determine feasibility, a model was created to determine the least cost mode to conduct an airdrop mission. The model is described in detail in Chapter III. The results from the model runs are located in Appendix F, J, K and Appendix L. The below sections outline what this research found.

C-5M utilization and JPADS

By taking a look at how JPADS is used in a comparable weapon system, a determination can be made as to the feasibility of incorporating JPADS into the C-5M. Throughout this thesis, a C-17 was used as the comparison aircraft due to the similarities of their mission profiles in the strategic arena.

While a C-5M can carry more and has more range, the fleet has not been as reliable as have C-17s. This reliability can be a factor in choosing the C-5 over the C-17 as an airdrop platform. With the implementation of the C-5M, the reliability is projected to be equal to the C-17. If so, then reliability becomes less of a concern in making a decision as to use the C-5M in the airdrop mission.

The research showed that JPADS is a fairly self-contained system. While some modification to the host aircraft is necessary, the majority of JPADS is contained on equipment that can be loaded onto the aircraft in a short amount of time.

Proper engineering analysis that goes beyond the scope of this thesis will have to be conducted to make a determination if the C-5M provides the proper power, data and antenna attachments. Since these are a relativity small modification to the aircraft, if necessary, it is assumed that JPADS can interface with the C-5M.

Airlift Cost Comparison

The first research question focused on a cost comparison between two comparable platforms, the C-5 and the C-17. The C-17 was used as a comparison aircraft due to the similar nature of their missions. The first research question is below.

1. *Can the C-5M be a cost effective way to conduct airdrop missions using the Joint Precision Airdrop System?*

As discussed in Chapter III, a model was built to conduct the research necessary to answer the question. A description of the model used for the calculations is contained in Chapter III. The results from the initial model runs are contained in Appendix F, while the line graphs for the model are contained in Appendix G. All graphs were reviewed in order to determine trends within the calculations. Specific graphs were pulled out from the graphs located in Appendix G for a detailed explanation.

Breaks in the line graphs represent a shift of resources. An upward shift in the graph represents the model determining an additional aircraft is required in order to complete the mission, while a downward shift typically represents the addition of an aerial refueling mission into the model. With the addition of an aerial refueling mission, the total number of aircraft can be reduced, as individual aircraft carry less fuel and more cargo since they are receiving fuel while in flight. The model includes the estimated cost of the aerial refueling mission into the total costs.

The graphs contained in Appendix G only compare total costs of the two airframes, in relation to mission range. The next few paragraphs describe, in detail, the graphs, focusing on what the spikes, both up and down, tell the reviewer.

A pictorial description is located in figure 9. This figure represents the aircraft carrying 100 short tons of cargo. As can be seen, the C-5M line is fairly linear. An increase in required mission range causes an increase in fuel needed, relating to an increase in total costs. Two C-5Ms are required for the mission up to 7000 miles.

For the C-17 each upward movement of the line can be attributed to an additional aircraft used to fly the mission. For example, at 5000 miles, an additional C-17 is added to the model increasing the cost of accomplishing the mission. At 5750 miles, the model determines that an aerial refueling is required, which can reduce the number of aircraft required, shown in the downward movement of the line graph. This allows the C-17 to receive 90,000 pounds of fuel in flight, thus allowing it to carry more weight upon take off, resulting in only having to use two C-17s to complete the mission.

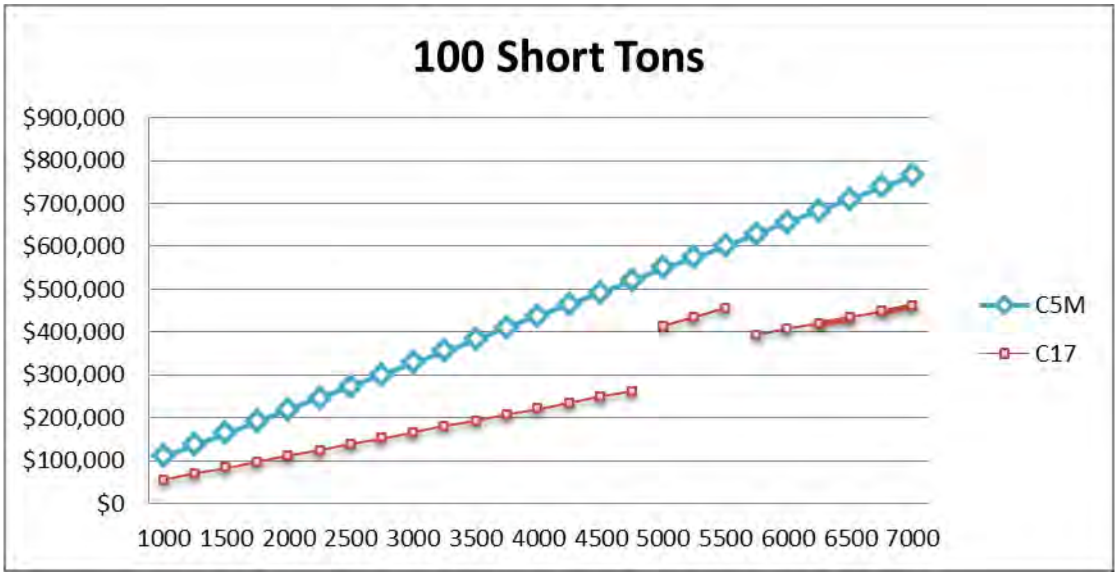


Figure 9. 100 Short Tons

Figure 10 contains a representation of the aircraft carrying 200 short tons. The model uses three C-5M aircraft up until 6500 miles, where it requires a fourth aircraft to complete the mission entered. Up until the third aircraft is inserted into the model, the cost to range ratio is fairly linear. The C-17 has a few more changes throughout the graph. At 5000 miles, a fifth C-17 was added to the model, increasing the total costs. 5500 miles shows a sixth C-17 added, however, at 5750 miles, the model determined that an aerial refueling was required, reducing the total amount of C-17 aircraft to 4.

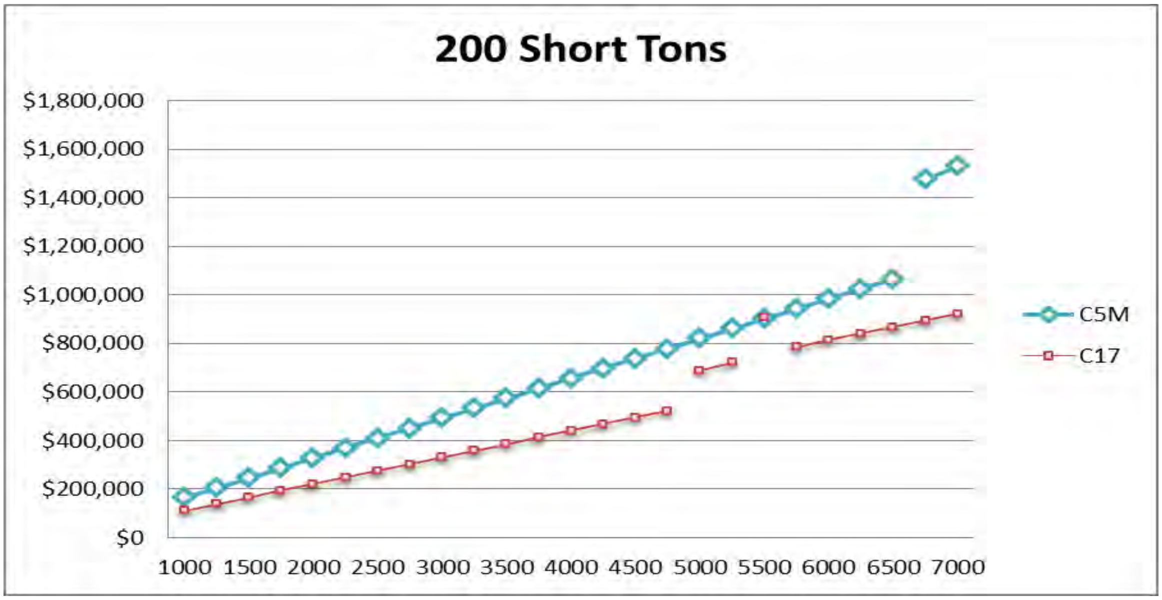


Figure 10. 200 Short Tons

Since this thesis focuses on the costs associated with using either airframe, further detail in the graphs was not required, nor desired. This research is only concerned with the estimated cost of using a C-5M versus a C-17 in a specific mission. A review of the graphs shows that in the majority of range versus cargo load costs the C-5M is more expensive to operate. Even when figuring in the additional cost of the KC-135R refueling aircraft to support the C-17 missions, the C-5M was still more expensive.

Airlift Cost Comparison – Results

A cost benefit model was created in order to answer the question. The cost benefit model is detailed in Chapter III, with the results detailed in Chapter IV. In the basic model used for the cost comparison, 71 of 400 mission profile model runs looked at showed that the C-17 was more expensive to operate. Those 71 runs had an average $25,200 higher cost associated with their respective missions. Of the 400 missions looked at, 329 of them showed the C-5M was more expensive to operate, at an average higher cost of $173,800. A bubble chart summarizing the results from the experiments supporting research question 1 is located in figure 11, with the larger bubbles representing a larger savings for their respective aircraft. Solid bubbles represent the C-5M, while empty bubbles represent the C-17.

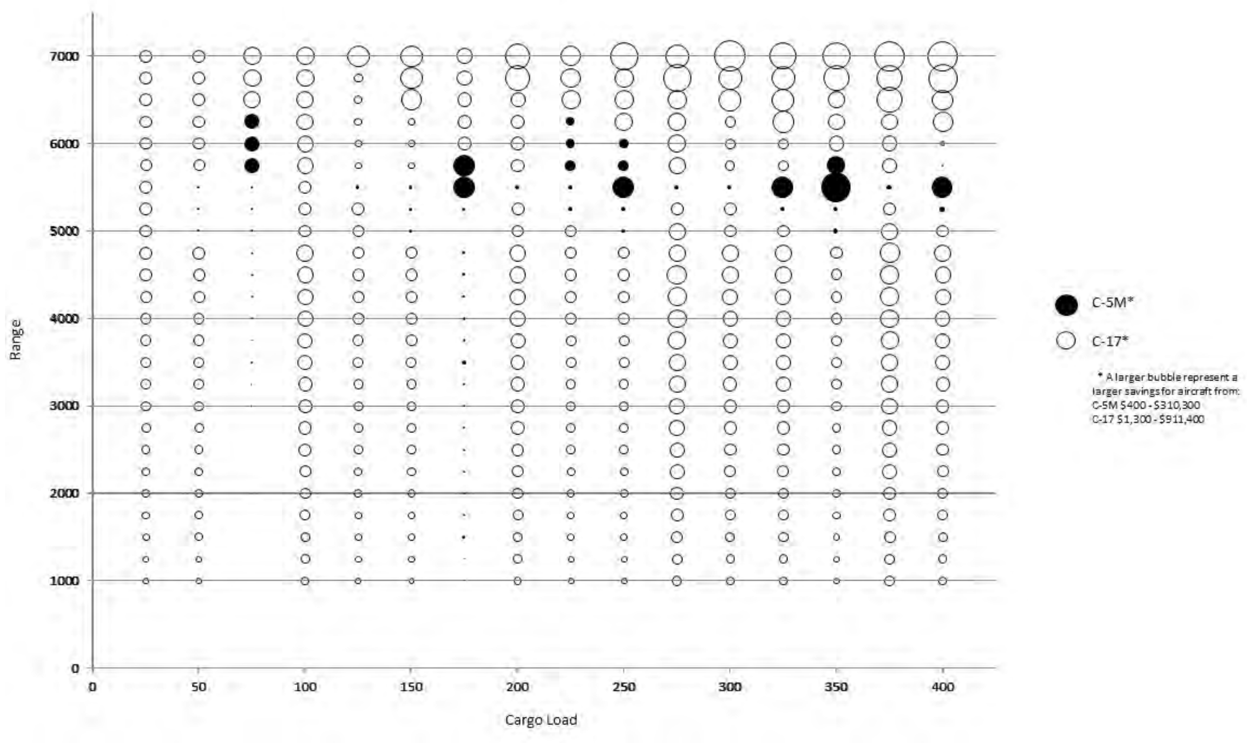


Figure 11. Research Question One Results

Within the scope of this thesis, using the cost benefit model created for this thesis and the cargo load limitation imposed by the research, the basic model does not support the cost benefit analysis in favor of the C-5M. While there are a small number of mission profiles in which the C-5M would be less expensive to operate, it is assumed the average savings would not make up the difference in cost associated with setting up a separate training program for the C-5M as well as re-training the aircrew to conduct airdrop missions in general and the assumed equipment necessary to carry out the mission.

Research Question Two – Aerial Refueling

For the second research question that was used for this research, manipulation of the model was conducted in order to determine least cost associated with specific mission profiles. Manipulation of the model allowed the researcher to determine the least cost method for moving a specific amount of short tons a specific distance. Manipulation centered on the aerial refueling costs associated with the mission. This research was accomplished to determine if it was more cost effective to use a single aircraft with an aerial refueling to move the specified amount of cargo. An explanation of this scenario is contained in Chapter III. As a review, the research question is below.

2. *To what extent will incorporation of an aerial refueling mission reduce the number of aircraft needed thereby reducing the cost?*

For example, it might be more cost effective to use a heavily loaded single C-5, with aerial refueling, than multiple, lighter loaded C-5's. This experiment only incorporated one aerial refueling, if necessary, into the mission. It did not explore the feasibility of using multiple aerial refueling missions.

In order to determine a "best case" scenario, the same cost comparison model was used, however, certain parameters were manipulated in order to determine the most cost effective way to conduct the mission. The manipulation gave an insight to a theoretical way to accomplish a mission. The model was run based upon specific cargo loads and ranges.

In choosing the cargo load, selection was based upon reviewing the graphs and determines where the model added an additional airframe due to lack of cargo space, which in turn is due to the requirement to carry the maximum amount of fuel. Due to the imposed limitation of 180,000 pounds, any cargo load over 180,000 pounds required two aircraft, and on up.

When the model determines an additional C-5M is necessary, fuel load becomes the limiting factor for the aircraft. Cargo load must be limited so the aircraft can carry enough fuel to complete the mission. Within the model, the primary way for an aircraft to get fuel is before takeoff. What this means, is that the model will provide maximum fuel to the aircraft, and if necessary, add another aircraft to the simulation.

In a real world event, it might be less expensive to reduce the fuel before takeoff, load more cargo on the aircraft, and then catch a tanker aircraft in flight. Doing this could allow less cargo aircraft to conduct the mission.

As described in chapter III, when the model determines an additional aircraft is necessary due to the inability to carry enough fuel, the model is manipulated by reducing the maximum fuel the C-5M can carry by 90,000 pounds, in essence, forcing it to receive fuel from an AR mission.

The areas explored for this phase of the research were specifically the areas in which the model determined an additional C-5M was necessary due to the fuel load requirement limiting the cargo capacity of the aircraft. The first cargo weight explored was 75 Short tons. See figure 12.

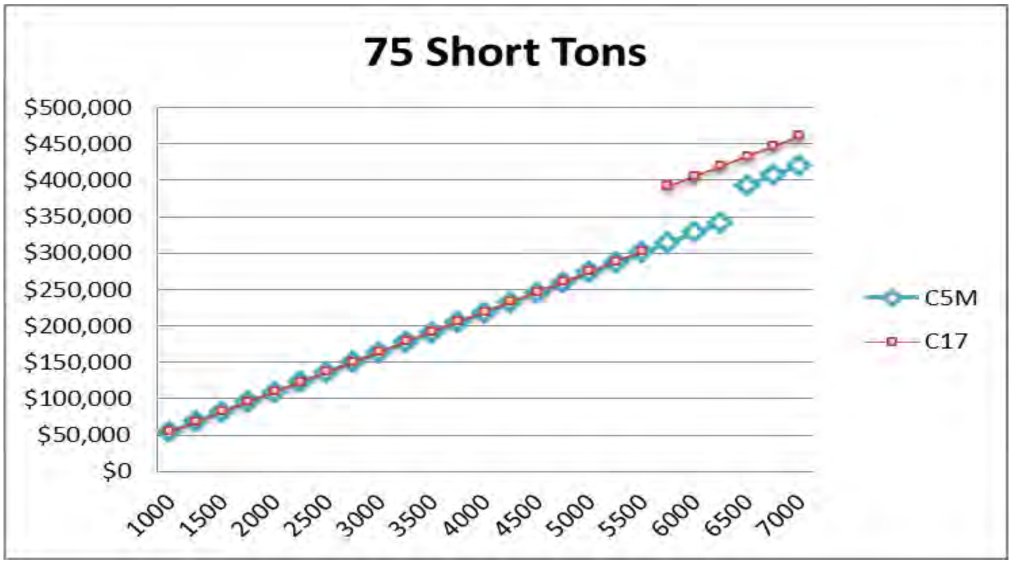


Figure 12. Aerial Refueling 75 Short tons

As figure 11 shows, it becomes more cost effective to use one C-5M aircraft, with an aerial refueling conducted in flight, than two C-17 aircraft. Figure 13 shows data for the second research question, with 150 Short Tons of cargo.

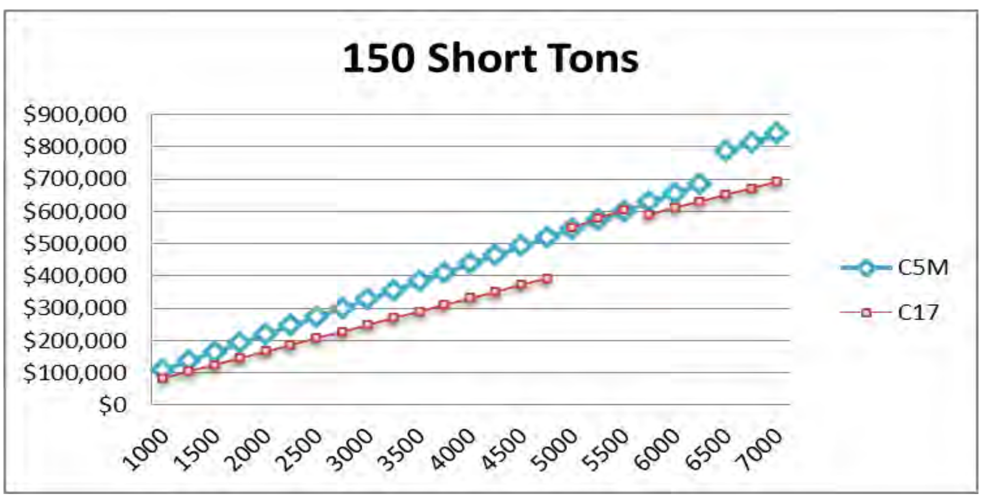


Figure 13. Aerial Refueling 150 Short Tons

The results from figure 13 suggest that the C-17 is the preferred choice, from a cost analysis. Even with the reduction of aircraft in the upper range limits, and inclusion of an AR mission, it is still more cost effective to use the C-17. It appears that at 6500 miles in almost all cases is where the fuel load becomes a limiting factor and forces the model to add another aircraft to carry the required weight. Figure 14 show the same data as figure 13, even above 6500 miles, where an aerial refueling track is added, the C-17 is still the more cost effective way to conduct the mission. The results from this experiment are located in Appendix J.

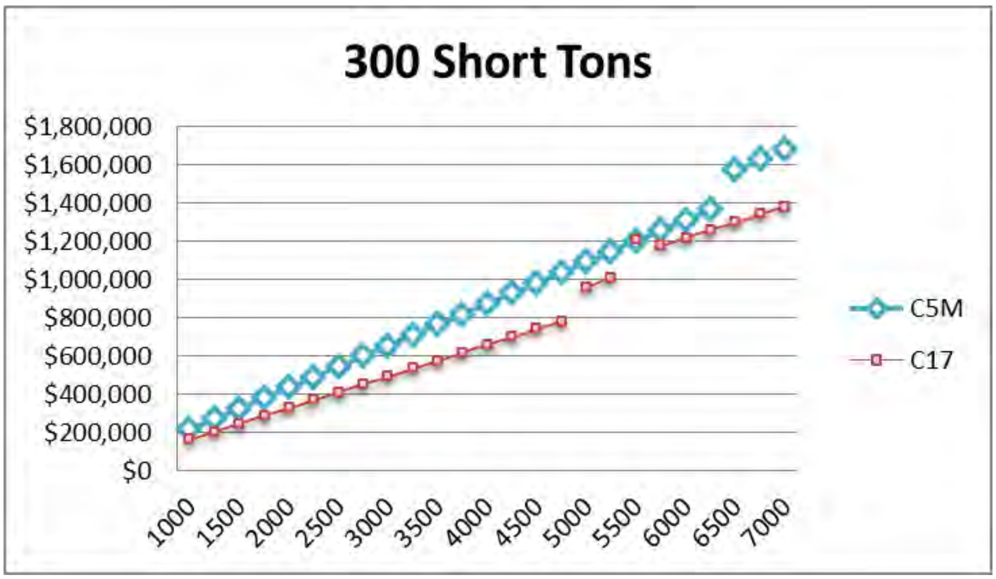


Figure 14. Aerial Refueling 300 Short Tons

Research Question Two – Aerial Refueling – Results

The results from research question two show that above 6500 miles, the fuel weight becomes the limiting factor in the cargo loads for the C-5M. However, even when adding an aerial refueling into the model, which reduces the total amount of C-5M aircraft required, there is only one complete mission set that it is more cost effective to use the C-5M versus the C-17. That is at 75 short tons. The majority of the rest of the cargo loads explored showed the majority of the time the C-17 more cost effective than the C-5M.

In the 400 mission profiles analyzed, the C-5M was less expensive to operate in 74 missions, with an average savings in favor of the C-5M of $25,800. In the 326 mission profiles explored in which the C-17 was less expensive to operate, the average savings was $167,000. Even with the inclusion of the aerial refueling costs into a scenario where the model didn't not determine one was necessary, the results are not in favor of the C-5M. With few exceptions, it is still more expensive to operate the C-5M in the airdrop mission. A bubble chart summarizing the results from the experiments supporting research question 2 is located in figure 15, with the larger bubbles representing a larger savings for their respective aircraft. Solid bubbles represent the C-5M, while empty bubbles represent the C-17.

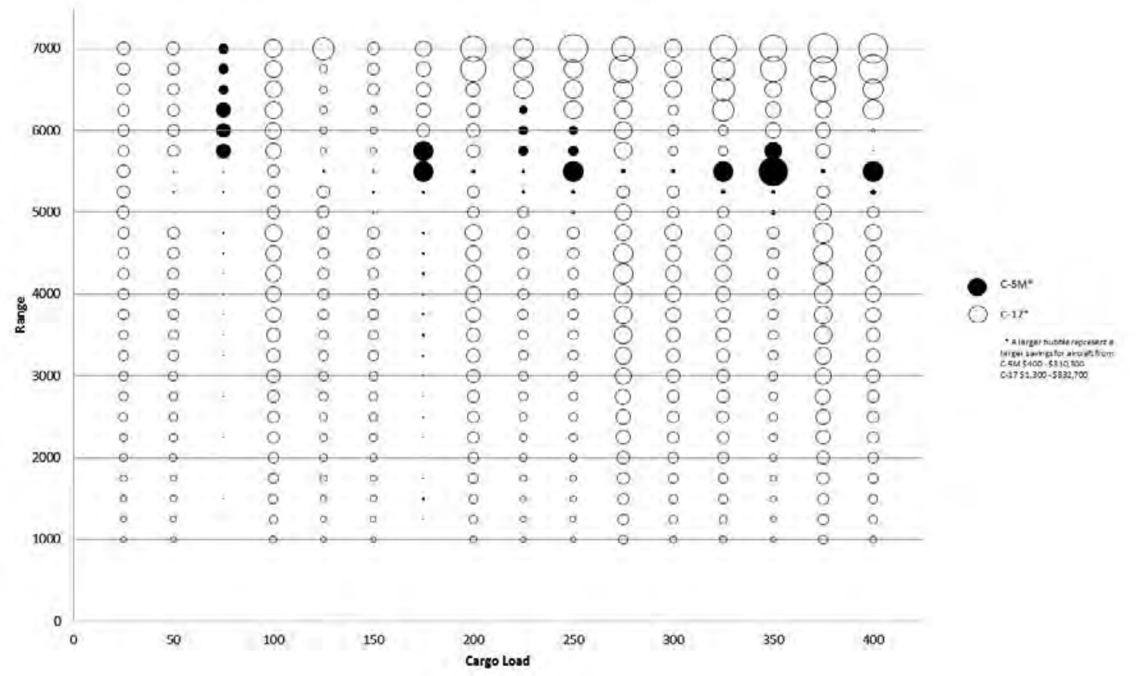


Figure 15. Research Question Two Results

Research Question Three – No cargo limitation

For the third research question the cargo weight restriction was removed. This cargo weight restriction was applied to the previous two models due to the assumed design limitation imposed on both aircraft in the airdrop mission. This design limitation was determined to be a representation of a real world system. The research conducted for this thesis supported the assumption. As a review, research question three is below.

3. *How does the design limitation imposed on the C-5M and C-17 change the cost effectiveness of using one airframe versus the other.*

For the purposes of answering this research question, the limitation was removed. The model was run given the same circumstances as in the first research question. The results from the model runs are contained in Appendix L.

In order to remove the limitation within the model, notation *K* was changed to match the full cargo capacity of the aircraft, 285,000 pounds for the C-5M and 170,900 pounds for the C-17. The graphs for the calculations were reviewed in the same manner as in the other research questions.

Research Question Three – No cargo limitation – Results

The results from the model runs conducted for research question 3 follow the trend of the other two research questions. As previously stated, the cargo restriction was removed for both aircraft. The design limitation imposed on the aircraft changes the cost effectiveness of using one airframe versus the other, however, it did not bode well for the C-5M. The removal of the design limitation also worked in favor of the C-17.

In the 400 mission profiles looked at, detailed in Chapter III, 96 of the resulted in favor of the C-5M, missions in which the C-5M was less to operate. The average difference was $38,300 less for the C-5M to conduct a specified mission, than the C-17. However, in the remainder of the 304 missions looked at, the C-17 was less expensive to operate. Within those 304 missions, it was, on average, $183,200 less to operate the C-17 compared to the same missions as the C-5M. A bubble chart summarizing the results from the experiments supporting research question 3 is located in figure 16, with the larger bubbles representing a larger savings for their respective aircraft. Solid bubbles represent the C-5M, while empty bubbles represent the C-17.

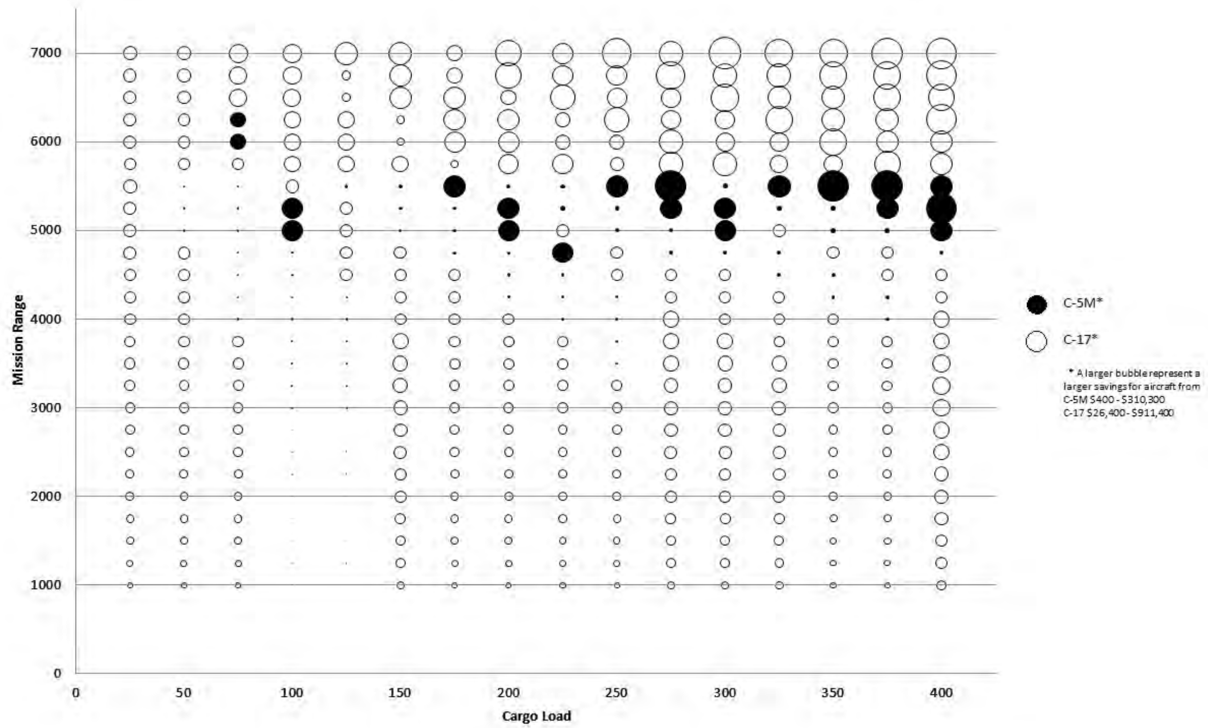


Figure 16. Research Question Three Results

Research Question Four – Aerial Refueling with no weight limitation

Research question four explored the possibility of merging experiments two and three, to provide the best case scenario in favor of the C-5M. This involved changing the parameters of the model to force an aerial refueling, as detailed in Chapter III, while removing the weight limitation, leading to the possibility of allowing both aircraft to carry their maximum cargo load. Research question four is below.

4. *What will incorporation of an aerial refueling mission, in conjunction with the removal of the weight associated design limitation, provide cost data in favor of the C-5M?*

For this research, the model was run in the same manner as the previous model runs. The model was run in 250 mile increments, beginning at 1000 and ending at 7000, with cargo loads ranging from 25 short tons to 400 short tons, in 25 short ton increments. The model run results are located in Appendix N, with the line graphs in Appendix O.

Research Question Four – Aerial Refueling with no weight limitation – Results

The results from the model runs conducted for research question 4 follow the trend of the other three research experiments. As previously stated, the cargo restriction was removed for both aircraft and an aerial refueling mission was added, if the model determined an additional aircraft was necessary, due to the decision to carry fuel over cargo. The aerial refuel mission allowed the model to reduce the total number of cargo aircraft, in some missions, while adding in the cost of an air refueling mission. While these changes helped the C-5M in various missions, they also worked in favor of the C-17.

In the 400 mission profiles looked at, detailed in Chapter III, 106 of them resulted in favor of the C-5M, missions in which the C-5M was less to operate. The average difference was $36,100 less for the C-5M to conduct a specified mission, than the C-17. However, in the remainder of the 294 missions looked at, the C-17 was less expensive to operate. Within those 294 missions, it was, on average, $100,000 less to operate the C-17 compared to the same missions as the C-5M. A bubble chart summarizing the results from the experiments supporting research question 4 is located in figure 17, with the larger bubbles representing a larger savings for their respective aircraft. Solid bubbles represent the C-5M, while empty bubbles represent the C-17.

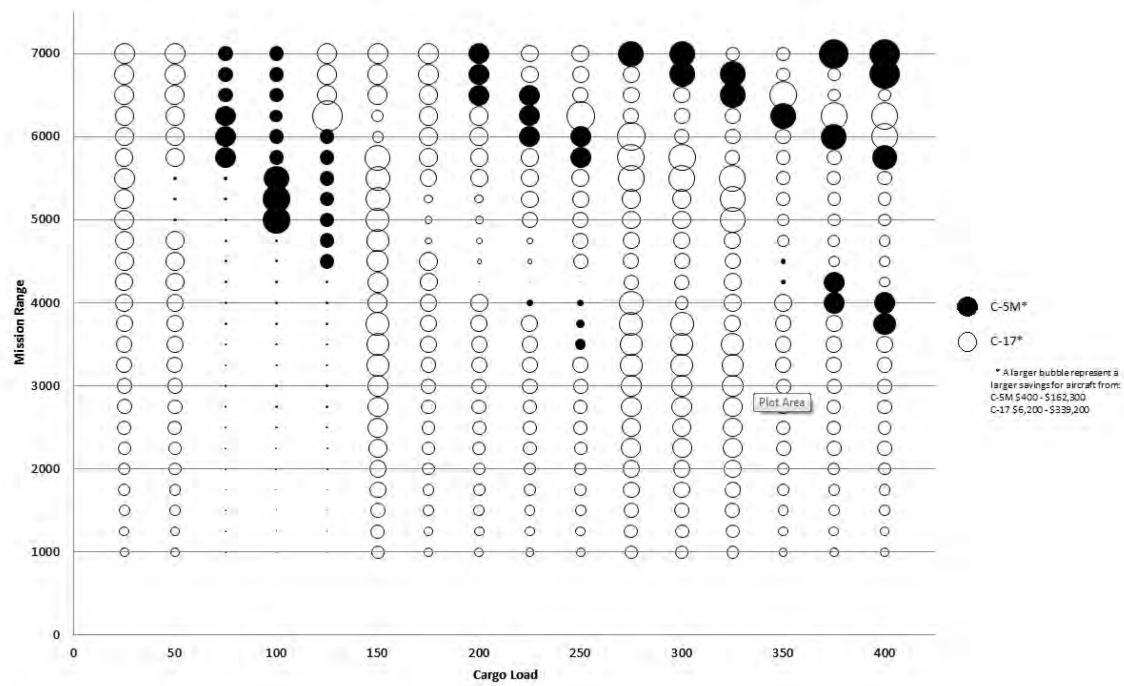


Figure 17. Research Question Four Results

Research Summary

The results from the four experiments do not support the C-5M being more cost effective than the C-17. In all four research experiments, there were only some of the mission profiles (range vs payload) in which the C-5M was cost effective. The best case scenario in favor of the C-5M was the experiment in support of the fourth research question. These limited amount of missions would not support the cost and effort necessary to set up a training program for JPADS and the C-5M, as well as the cost of the research necessary to ensure the proper operation between the two weapon systems.

The next chapter focuses on a discussion about the results. It also contains some areas to consider for future research.

Table 11. Model Results

	Missions in which C-5M less costly to operate	Average Savings for C-5M
Model Run 1	71	$25,200
Model Run 2	74	$25,800
Model Run 3	96	$38,300
Model Run 4	106	$36,100

	Missions in which C-17 less costly to operate	Average Savings for C-17
Model Run 1	329	$173,800
Model Run 2	326	$167,000
Model Run 3	304	$183,200
Model Run 4	294	$100,000

* Model Runs support their respective research questions

V. Discussion

Conclusions

This thesis provides data to make a determination as to if the C-5M is still a viable option in in the airlift role, more specifically, using JPADS in the airlift role. It also looked at a cost comparison between the C-5M and the C-17 in conducting airdrop missions. While older, the C-5 is still a very capable aircraft that has suffered from a lower than expected mission capable and aircraft availability rates. The complexity of the C-5 has resulted in high operating costs as well as low reliability. With the incorporation of the C-5M into the fleet, and the improvement that it brings, the C-5M is projected to have the same reliability rates as the C-17. This projected improvement in reliability, as well as the higher range and payload capabilities can make the C-5M a great option for resuming the airlift mission, especially when combined with JPADS.

The C-5M is more capable than the C-17 in both payload and range. While the legacy C-5 operating costs are almost double the C-17's, the C-5M brings those operating costs much closer to the C-17's. With the increased payload capability and range, the C-5 is still a critical tool in the combatant commander's toolbox.

Weight limits

One of the restrictions imposed on the first two runs of the model was an airdrop weight limit of 180,000 pounds for the C-5M and 110,000 pounds for the C-17. These imposed weight limits are based upon an estimated 18 of 36 usable pallet positions for the C-5M and 11 of 18 for the C-17, at a maximum pallet limit of 10,000 pounds. This imposed limitation was deemed to be a necessity for the model, in order to make it represent a generic real world system as closely as possible.

The imposed weight limits, especially for the C-5M, limited the usability of the airframe. With the limit, the C-5M was able to carry up to a maximum fuel load most of the time, negating the need for an AR mission. Any cargo moved over 90 short tons required the addition of a 2nd C-5M, doubling the operating costs. Since real world mission needs, and common sense, would dictate the amount of aircraft necessary for the mission, the imposed weight limit might not be a limitation for a real world mission.

The imposed weight limits on the basic model should be reviewed, and compared to a real world operation to determine how the weight limitation would affect the proposed mission. This restriction was removed from the model runs accomplished to support research questions three and four.

For example, if the mission required 185,000 pounds of cargo to be airdropped, with a mission range of 6000 miles, the basic model will determine two C-5Ms are necessary to accomplish that mission. However, true cargo size and type would affect that decision. If it can be determined that one C-5M can be used in that specific mission, it might be overall less expensive to use that one airframe, versus two C-17s with a KC-135R aircraft providing support.

In exploring the third research question, this limitation was removed from the mode. This research showed that that, while there were more mission combinations in which the C-5M was less costly to operate, there was not enough of a cost savings to make a recommendation in favor of the C-5M. Further exploration of this limitation might open the C-5M up to be less costly across more missions.

Recommendations for Further Research

The incorporation of the Joint Precision Airdrop System into the C-5M mission profile is not a black and white answer. As such, follow on research should focus on the additional cost of the logistics necessary to complete this endeavor. These additional logistics requirements can range from the cost of incorporating JPADS training for C-5 to the cost of refurbishing support equipment necessary for the C-5M to take on the mission.

The JPADS training mission should be easy to implement. With JPADS being such a self-contained system, the C-17 training can be easily leveraged on to build the C-5 JPADS training program. The costs will have to be research and incorporated into the final decision.

The C-5 aircrew training program will require more in depth research than the JPADS training. As C-5s have not been used in the airdrop mission for a number of years, it is assumed there are no current airdrop qualified C-5 pilots. All C-5 aircrew will need to be qualified to conduct the mission. While it is assumed that older training programs could be updated and used to develop a current airdrop qualification program for the C-5, there is no guarantee. The costs to qualify C-5 aircrew on the airdrop mission would have to be research and incorporated into the final decision.

As discussed in the previous section, the imposed weight limit for both aircraft needs to be reviewed, from an engineering point of view. The engineering analysis needed to determine if the imposed weight limit is a hard and fast rule, or just a suggestion goes beyond the scope of the research conducted by this thesis. Research questions three and four explore the possibility that this limitation does not exist, however, proper engineering analysis would need to be accomplished.

In addition to the logistical costs and training program costs that will need to be researched thoroughly before an in depth recommendation can be made, the engineering analysis needs to be completed and the costs need to be factored into the recommendation.

Occasionally, it might be cost effective to use multiple aerial refueling in a mission than numerous cargo aircraft supported by only one aerial refueling. A consideration for future research would be to look at that scenario and determine if a cargo aircraft, supported by multiple aerial refueling might be less expensive to operate than only support from one tanker aircraft.

This research focused on the feasibility of using the C-5M in the airdrop role, in conjunction with JPADS. While JPADS should be able to be used with the C-5M, proper engineering analysis will need to be conducted. The costs associated with implementing JPADS into the C-5M should be minimal, as should the costs associated with aircrew training. However, the model created for this research does not show a cost savings with using the C-5M versus the C-17 in the airdrop mission across most missions. The limitation of 180,000 pounds for the C-5M requires further engineering research and, if removed, could cause the C-5M to become less expensive than the C-17 in certain missions.

Appendix A: List of Acronyms

AA:	Aircraft Availability
AFB:	Air Force Base
AFI:	Air Force Instruction
AFPAM:	Air Force Pamphlet
AGU:	Autonomous Guidance Unit
AMP:	Avionics Modernization Program
AR:	Aerial Refueling
ASC:	Aeronautical Systems Center
CONEMP:	Concept of Employment
DOD:	Department of Defense
GAO:	Government Accountability Office
GPS:	Global Positioning System
GPS-RTS:	GPS Retransmit Subsystem
HQAMC:	Headquarters Air Mobility Command
I-CADS:	Improved – Container Delivery System
JPADS:	Joint Precision Airdrop System
JPADS-MP:	Joint Precision Airdrop System – Mission Planning
LP:	Linear Programing
MC:	Mission Capability
MDS:	Mission Design Series
MPS:	Mission Planning Software
MSE:	Mission Support Equipment
RERP:	Reliability Enhancement and Re-engining Program
RF:	Radio Frequency
ST:	Subject To
TO:	Technical Order
UHF:	Ultra High Frequency
UHF-DRS:	UHF Dropsonde Receive Subsystem
USAF:	United States Air Force
VDC:	Volts Direct Current

Appendix B: C-5M Spreadsheet

Misson Range	3250	3737.5	Range * 1.15 for 15% reserve
Cargo moved (short tons)	200	400000	

		C-5M	KC135R		
Section 1	Max Fuel Gal	51,150			
	Max Fuel Weight	342,705			
	Max Takeoff Weight	840,000			
	Speed	518			
	Empty Aircraft Weight	380,000			
Section 2	Caculated Cargo Weight Per Aircraft	180,000			
	True Cargo Weight Per Aircraft	133,333			
	Total Cargo Weight to Move	400,000		42.37	C-5 Lbs of Fuel Per Mile
				158367.54	Total Lbs of fuel Needed per aircraft
Section 3	TO Fuel Weight Needed for Mission	158,368		AR Required?	
	Total Aircraft Weight	671,701		No	
	Cargo Avilable Weight	168,299			
Section 4	Average Fuel Burn Rate lbs/hr	21,949		137710.91	Lbs of fuel requried for mission
	Hours of flight time	6.27			
Section 5	Average Speed	518			
	Range	3250.00			
Section 6	CPFH	$28,302.00	$7,616.00		
	Total Cost per Aircraft	$177,570.46	$38,080.00		
Section 7	# aircraft Caculated	2.2222			
	# of Aircraft required	3.00	3.00		
Section 8	Total Aircraft Costs	$532,711.39	$114,240.00		
	Total Costs given AR	$646,951.39			

Total Cost	***$532,711.39***

Appendix C: C-17 Spreadsheet

Misson Range	5500	6325	Range * 1.15 for 15% reserve			
Cargo moved (short tons)	350	700000				
		C-17				
Section 1	Max Fuel Gal	35,546				
	Max Fuel Weight	238,158				
	Max Takeoff Weight	585,000				
	Speed	515				
	Empty Aircraft Weight	282,500			543,747	
Section 2	Caculated Cargo Weight Per Aircraft	110,000			209779.6117	Lbs of Fuel needed for mission
	True Cargo Weight Per Aircraft	100,000				
	Total Cargo Weight to Move	700,000				
Section 3	TO Fuel Weight Needed for Mission	151,247				
	Total Aircraft Weight	533,747	REQUIRES AR	Yes		
	Cargo Avilable Weight	51,253	151,247			
					38.14	C-17 Lbs of Fuel Per Mile
Section 4	Average Fuel Burn Rate lbs/hr	19,643			241,246.55	Lbs of Fuel Needed Per Aircraft
	Hours of flight time	10.68				
Section 5	Speed	515				
	Range	5500.00				
			KC135R		KC-135R	$7,616.00
Section 6	CPFH	$14,161.00	$7,616.00		Fuel Price	$3.03
	Estimated Total Cost per Aircraft	$151,233.98	$38,080.00			
					KC-135R Range	1500 miles w/150,000 lbs transfer fuel
Section 7	# aircraft Caculated	6.3636				
	# of Aircraft required	**7.00**	**7.00**			
Section 8	Total Aircraft Costs	$1,058,637.86	$266,560.00			
	Total Costs given AR	$1,325,197.86				
	Total Cost	***$1,325,197.86***				

Appendix D: Results Tab

The Run Aircraft Estimation button runs the macro contained in Appendix H, which initiates the model.

User Input		
	Estimated Mission Range	5500
	Estimated Short Tons	350

Run Aircraft Estimation

	C-5	C-17
Estimated Number of Aircraft Required	4	7
Estimated Total cost	$1,202,015.44	$1,325,197.86
Is an AR Required?		Yes

User Input estimated Mission Range (Round Trip) and Estimated Short Tons
Click on "Run Aircraft Estimation"
Gives Estimated amount of aircraft and estimated cost* to utilize aircraft

Assumptions:
- All figures are estimates for planning purposes only. Actual rates and figures varies acording to mission profile, AC model, configuration, altitude, airspeed and a multitude of other factors.
- Aircraft can utilize max weight avilable
- If an aircraft requires AR it will depart with required mission fuel minus 90,000 lbs. It will recive 90,000 lbs fuel in flight to continue its mission.
- Estimated Cost of KC-135R support is added to Estimated Total Cost if required.

*Cost based upon published Oct 2011 CPFH

Appendix E: Air Force Planning Factors

Aircraft Type	Fuel Burn Rate lbs/hr	Aircraft Type	Fuel Burn Rate lbs/hr	Aircraft Type	Fuel Burn Rate lbs/hr
C-9	6,661	B-707	13,916	F-117	9,197
C-130	5,109	B-747	26,800	F-22A	13,154
C-141	13,768	B-767	10,552	F-15C	10,822
C-17	19,643	DC-8	13,916	F-15E	12,669
C-5	23,132	DC-10	20,616	F-18	5,829
KC-10	17,830	L-1011	17,219	F-16	5,854
KC-135R	10,718	MD-11	17,511	A/OA-10	4,160

NOTE: Fuel burn rates extracted from AFPAM 23-221, Fuels Logistics Planning, 1 May 98 and AFI 65-503, US Air Force Cost and Planning Factors, September 02 (converted to lbs/hr using 6.7 lbs/gal conversion rate). Fuel burn rates are for planning purposes only. Actual rate varies according to mission profile, AC model, configuration, altitude, airspeed etc.

Aircraft	Takeoff Gross Weight (lbs)	Takeoff Fuel Load (lbs)	Max Offload Available (lbs)			
			Mission Radius			
			500nm	1000nm	1500nm	2500nm
KC-135E	300,500	160,000	101,200	78,600	55,800	10,500
KC-135R/T	322,500	180,000	122,200	99,400	76,400	30,700
KC-10	587,000	327,000	233,500	195,200	156,000	78,700

NOTES:

1. This table was extracted from MCM 3-1, Vol II, Tactical Employment KC-135/KC-10, 10 May 95.
2. Based on Sea level, standard day, 10,000-ft dry runway.
3. Offload data based on 1-hour orbit.
4. Cargo carried will reduce fuel load on a 1:1 basis.
5. All KC-10 and a limited number of KC-135 aircraft are refuelable, providing increased range, off-load, and loiter capabilities.

Receiver# / Aircraft Type				Distance (nm)		
	1000	2000	3000	4000	5000	6000
2 F-117[4]	1	2	3	3	4	4
3 F-18	0	1	2	3	5	6
6 F-15C	0	2	3	5	6	9
6 F-15E	1	2	5	6	7	8
6 F-22A	1	2	5	6	7	8
6 F-16	0	1	2	3	5	7
6 A/OA-10	0	1	3	4	-	-
3 EA-6B	0	1	2	3	4	4
3 F-14	0	1	2	3	4	5
1 C-141[5]	-	-	-	1	1	2
1 C-17[5]	-	-	-	1	1	2
1 C-5[5]	-	-	-	0	1	2

NOTES:

1. Due to the multitude of Air Refueling variables, this table reflects an "order of magnitude" only.
2. Table assumes multiple tanker launch bases would be used for AR distances greater than 3000nm.
3. Fighter/tanker ratio can be limited by boom cycle time.
4. The F-117 is currently limited to a ratio of only 2 F-117's per tanker.
5. For the airlift aircraft, assume average payloads, maximum takeoff gross weight, optimum located air refueling tracks and divert bases, and a minimum tanker off-load capability of 90,000 lbs.

Appendix F: Model Calculations

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$54,900
2250	$112,900	$61,900
2500	$136,600	$68,700
2750	$151,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$128,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$137,500
5250	$286,800	$144,400
5500	$300,500	$151,200
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

25 Short Tons

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$55,000
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$150,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

50 Short Tons

	C5M	C17
1000	$54,600	$55,000
1250	$68,300	$68,700
1500	$82,000	$82,500
1750	$95,600	$96,200
2000	$109,300	$110,000
2250	$122,900	$123,700
2500	$136,600	$137,500
2750	$150,300	$151,200
3000	$163,900	$165,000
3250	$177,600	$178,700
3500	$191,200	$192,500
3750	$204,900	$206,200
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$245,900	$247,500
4750	$259,500	$261,200
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$392,400
6000	$327,800	$406,100
6250	$341,500	$419,900
6500	$710,300	$433,600
6750	$737,600	$447,400
7000	$764,900	$461,100

75 Short Tons

	C5M	C17
1000	$109,300	$55,000
1250	$136,600	$68,700
1500	$163,900	$82,500
1750	$191,200	$96,200
2000	$218,500	$110,000
2250	$245,900	$123,700
2500	$273,200	$137,500
2750	$300,500	$151,200
3000	$327,800	$165,000
3250	$355,100	$178,700
3500	$382,500	$192,500
3750	$409,800	$206,200
4000	$437,100	$220,000
4250	$464,400	$233,700
4500	$491,700	$247,500
4750	$519,100	$261,200
5000	$549,400	$412,500
5250	$573,700	$433,100
5500	$601,000	$453,700
5750	$628,300	$392,400
6000	$655,600	$406,100
6250	$683,000	$419,900
6500	$710,300	$564,400
6750	$737,600	$578,200
7000	$764,900	$461,100

100 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$350,600
4500	$491,700	$371,200
4750	$519,100	$391,800
5000	$549,400	$412,500
5250	$573,700	$433,100
5500	$601,000	$604,900
5750	$628,300	$588,600
6000	$655,600	$609,200
6250	$683,000	$629,800
6500	$710,300	$650,400
6750	$737,600	$671,100
7000	$1,147,400	$691,700

125 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$350,600
4500	$491,700	$371,200
4750	$519,100	$391,800
5000	$549,400	$549,900
5250	$573,700	$577,400
5500	$601,000	$604,900
5750	$628,300	$588,600
6000	$655,600	$609,200
6250	$683,000	$629,800
6500	$1,065,400	$650,400
6750	$1,106,400	$671,100
7000	$1,147,400	$691,700

150 Short Tons

	C5M	C17
1000	$109,300	$110,000
1250	$136,600	$137,500
1500	$163,900	$168,000
1750	$191,200	$192,500
2000	$218,500	$220,000
2250	$245,900	$247,500
2500	$273,200	$275,000
2750	$300,500	$302,500
3000	$327,800	$330,000
3250	$355,100	$357,500
3500	$382,500	$388,000
3750	$409,800	$412,500
4000	$437,100	$440,000
4250	$464,400	$467,500
4500	$491,700	$494,900
4750	$519,100	$522,400
5000	$549,400	$549,900
5250	$573,700	$577,400
5500	$601,000	$756,200
5750	$628,300	$784,800
6000	$983,500	$812,300
6250	$1,024,400	$839,700
6500	$1,065,400	$867,200
6750	$1,106,400	$894,700
7000	$1,147,400	$922,200

175 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$368,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$412,500
4000	$655,600	$440,000
4250	$696,600	$467,500
4500	$737,600	$494,900
4750	$778,600	$522,400
5000	$819,600	$687,400
5250	$860,500	$721,800
5500	$901,500	$907,400
5750	$942,500	$784,800
6000	$983,500	$812,300
6250	$1,024,400	$839,700
6500	$1,065,400	$867,200
6750	$1,475,200	$894,700
7000	$1,529,800	$922,200

200 Short Tons

	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$220,000
2250	$368,800	$309,300
2500	$409,800	$275,000
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$584,300
4500	$737,600	$618,700
4750	$778,600	$653,100
5000	$819,600	$687,400
5250	$860,500	$866,200
5500	$901,500	$907,400
5750	$942,500	$980,900
6000	$983,500	$1,015,300
6250	$1,024,400	$1,049,700
6500	$1,420,600	$1,084,100
6750	$1,475,200	$1,118,400
7000	$1,529,800	$1,152,800

225 Short Tons

	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$368,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$584,300
4500	$737,600	$618,700
4750	$778,600	$653,100
5000	$819,600	$824,900
5250	$860,500	$866,200
5500	$901,500	$1,058,600
5750	$942,500	$980,900
6000	$983,500	$1,015,300
6250	$1,365,900	$1,049,700
6500	$1,420,600	$1,084,100
6750	$1,475,200	$1,118,400
7000	$1,912,300	$1,152,800

250 Short Tons

	C5M	C17
1000	$218,500	$137,500
1250	$273,200	$171,900
1500	$327,800	$206,200
1750	$382,500	$240,600
2000	$437,100	$275,000
2250	$491,700	$309,300
2500	$546,400	$343,700
2750	$601,000	$378,100
3000	$655,600	$412,500
3250	$710,300	$446,800
3500	$764,900	$481,200
3750	$819,600	$515,600
4000	$874,200	$549,900
4250	$928,800	$584,300
4500	$983,500	$618,700
4750	$1,038,100	$783,700
5000	$1,092,700	$824,900
5250	$1,147,400	$1,010,500
5500	$1,202,000	$1,209,900
5750	$1,256,700	$980,900
6000	$1,311,300	$1,015,300
6250	$1,365,900	$1,049,700
6500	$1,420,600	$1,084,100
6750	$1,844,000	$1,118,400
7000	$1,912,300	$1,383,400

275 Short Tons

	C5M	C17
1000	$218,500	$165,000
1250	$273,200	$206,200
1500	$327,800	$247,500
1750	$382,500	$288,700
2000	$437,100	$330,000
2250	$491,700	$371,200
2500	$546,400	$412,500
2750	$601,000	$453,700
3000	$655,600	$494,900
3250	$710,300	$536,200
3500	$764,900	$577,400
3750	$819,600	$618,700
4000	$874,200	$659,900
4250	$928,800	$701,200
4500	$983,500	$742,400
4750	$1,038,100	$783,700
5000	$1,092,700	$962,400
5250	$1,147,400	$1,010,500
5500	$1,202,000	$1,209,900
5750	$1,256,700	$1,177,100
6000	$1,311,300	$1,218,400
6250	$1,365,900	$1,259,600
6500	$1,775,700	$1,300,900
6750	$1,844,000	$1,342,100
7000	$2,294,800	$1,383,400

300 Short Tons

	C5M	C17
1000	$218,500	$165,000
1250	$273,200	$206,200
1500	$327,800	$247,500
1750	$382,500	$288,700
2000	$437,100	$330,000
2250	$491,700	$371,200
2500	$546,400	$412,500
2750	$601,000	$453,700
3000	$655,600	$494,900
3250	$710,300	$536,200
3500	$764,900	$577,400
3750	$819,600	$618,700
4000	$874,200	$659,900
4250	$928,800	$701,200
4500	$983,500	$742,400
4750	$1,038,100	$783,700
5000	$1,092,700	$962,400
5250	$1,147,400	$1,154,900
5500	$1,202,000	$1,361,100
5750	$1,256,700	$1,177,100
6000	$1,311,300	$1,218,400
6250	$1,707,400	$1,259,600
6500	$1,775,700	$1,300,900
6750	$1,844,000	$1,342,100
7000	$2,294,800	$1,613,900

325 Short Tons

	C5M	C17
1000	$218,500	$192,500
1250	$273,200	$240,600
1500	$327,800	$288,700
1750	$382,500	$336,800
2000	$437,100	$385,000
2250	$491,700	$433,100
2500	$546,400	$481,200
2750	$601,000	$529,300
3000	$655,600	$577,400
3250	$710,300	$625,600
3500	$764,900	$673,700
3750	$819,600	$721,800
4000	$874,200	$769,900
4250	$928,800	$818,000
4500	$983,500	$866,200
4750	$1,038,100	$914,300
5000	$1,092,700	$1,099,900
5250	$1,147,400	$1,154,900
5500	$1,202,000	$1,512,300
5750	$1,256,700	$1,373,300
6000	$1,639,100	$1,421,400
6250	$1,707,400	$1,469,600
6500	$1,775,700	$1,517,700
6750	$2,212,800	$1,565,800
7000	$2,294,800	$1,613,900

350 Short Tons

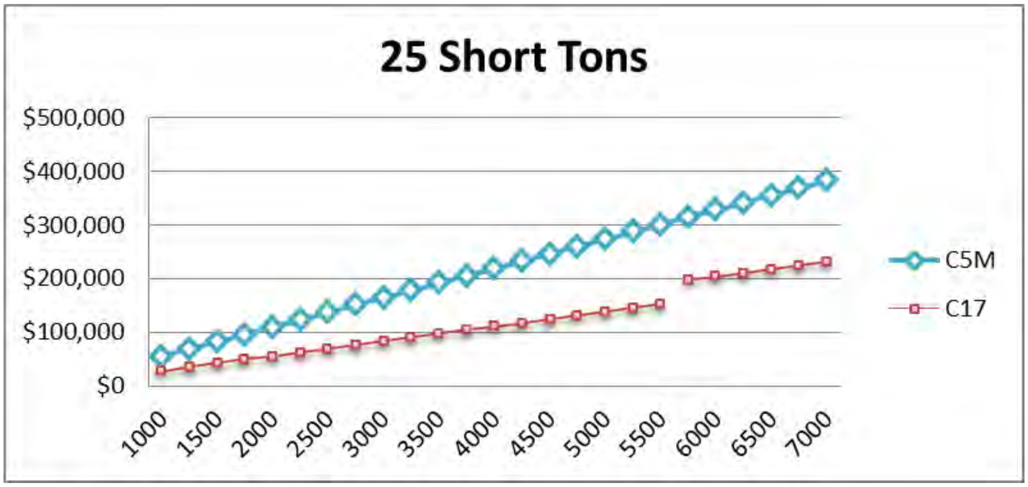
	C5M	C17
1000	$273,200	$192,500
1250	$341,500	$240,600
1500	$409,800	$288,700
1750	$478,100	$336,800
2000	$546,400	$385,000
2250	$614,700	$433,100
2500	$683,000	$481,200
2750	$751,300	$529,300
3000	$819,600	$577,400
3250	$887,900	$625,600
3500	$956,100	$673,700
3750	$1,024,400	$721,800
4000	$1,092,700	$769,900
4250	$1,161,000	$818,000
4500	$1,229,300	$866,200
4750	$1,297,600	$914,300
5000	$1,365,900	$1,099,900
5250	$1,434,200	$1,299,200
5500	$1,502,500	$1,512,300
5750	$1,570,800	$1,373,300
6000	$1,639,100	$1,421,400
6250	$1,707,400	$1,469,600
6500	$2,130,800	$1,517,700
6750	$2,212,800	$1,565,800
7000	$2,677,200	$1,844,500

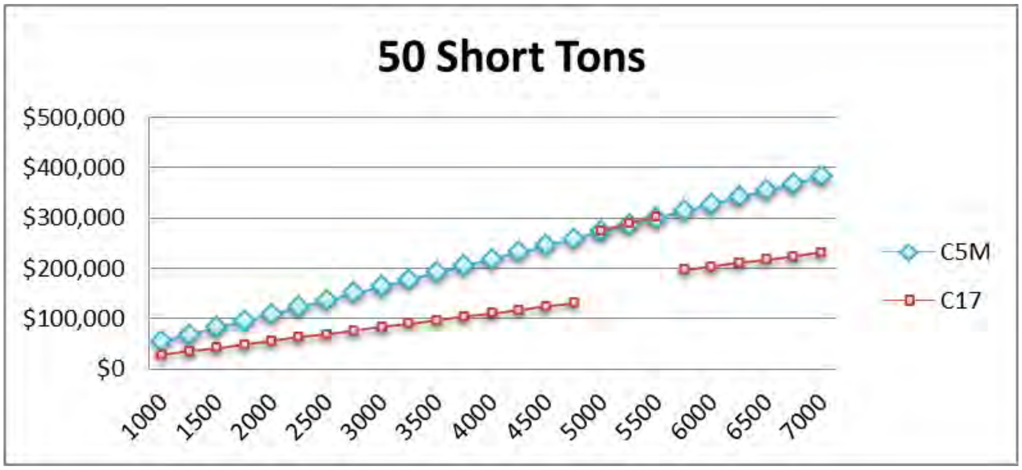
375 Short Tons

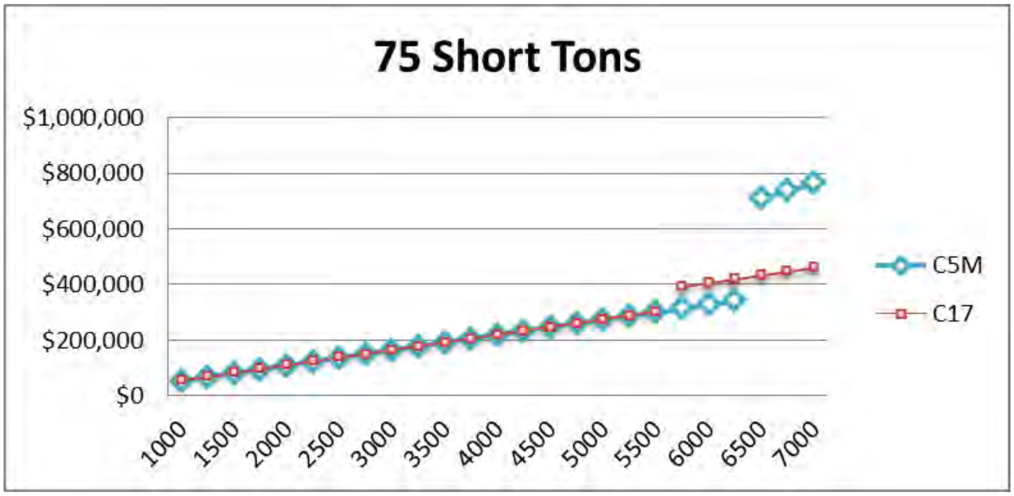
	C5M	C17
1000	$273,200	$220,000
1250	$341,500	$275,000
1500	$409,800	$330,000
1750	$478,100	$385,000
2000	$546,400	$440,000
2250	$614,700	$494,900
2500	$683,000	$549,900
2750	$751,300	$650,900
3000	$819,600	$659,900
3250	$887,900	$714,900
3500	$956,100	$769,900
3750	$1,024,400	$824,900
4000	$1,092,700	$879,900
4250	$1,161,000	$934,900
4500	$1,229,300	$989,900
4750	$1,297,600	$1,044,900
5000	$1,365,900	$1,237,400
5250	$1,434,200	$1,443,600
5500	$1,502,500	$1,663,600
5750	$1,570,800	$1,569,500
6000	$1,639,100	$1,624,500
6250	$2,048,900	$1,679,500
6500	$2,130,800	$1,734,500
6750	$2,581,600	$1,789,500
7000	$2,677,200	$1,844,500

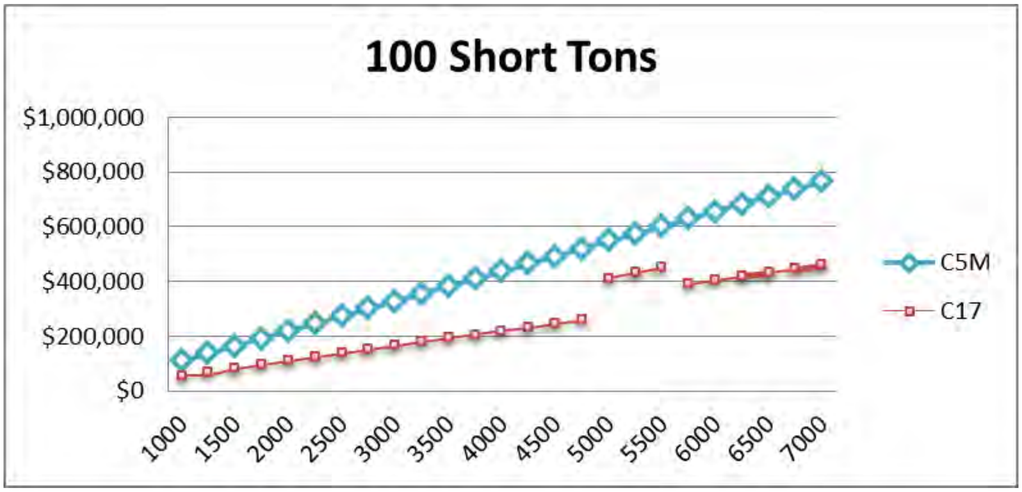
400 Short Tons

Appendix G: Line Graphs





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2500
3000
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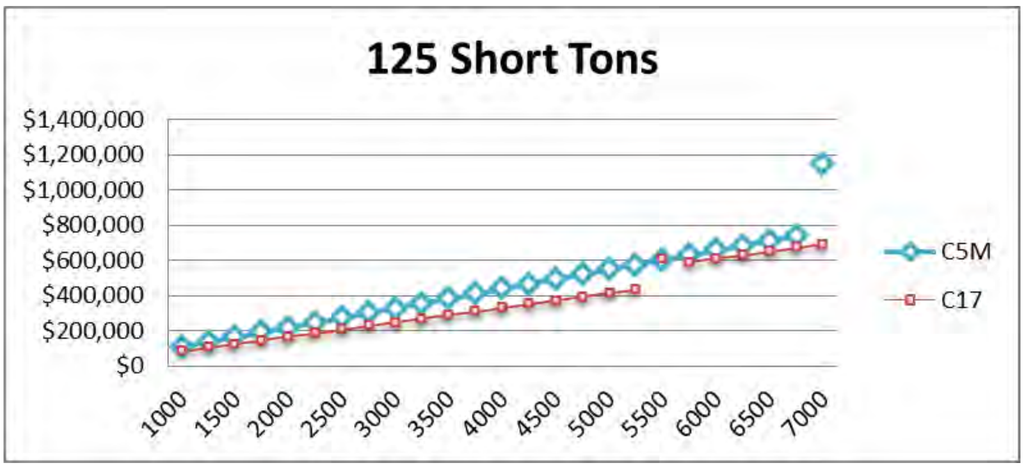
4000
4500
5000
5500
6000
6500
7000
C5M
C17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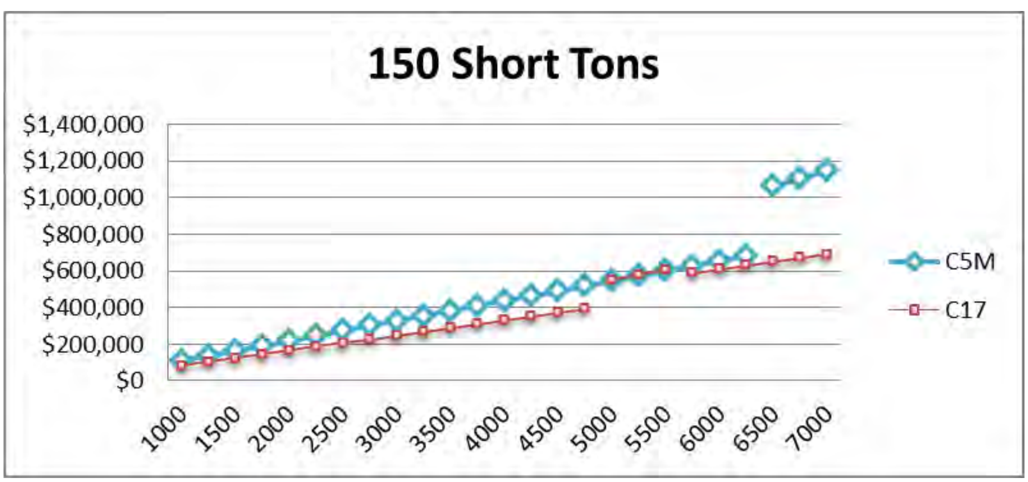
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


150 Short Tons
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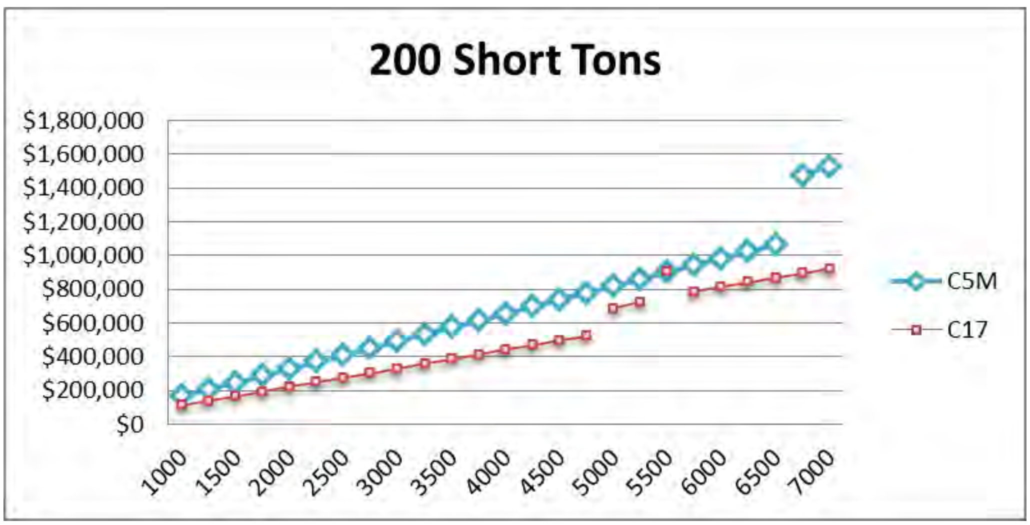
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


175 Short Tons
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17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$1,600,000
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$1,200,000
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$400,000
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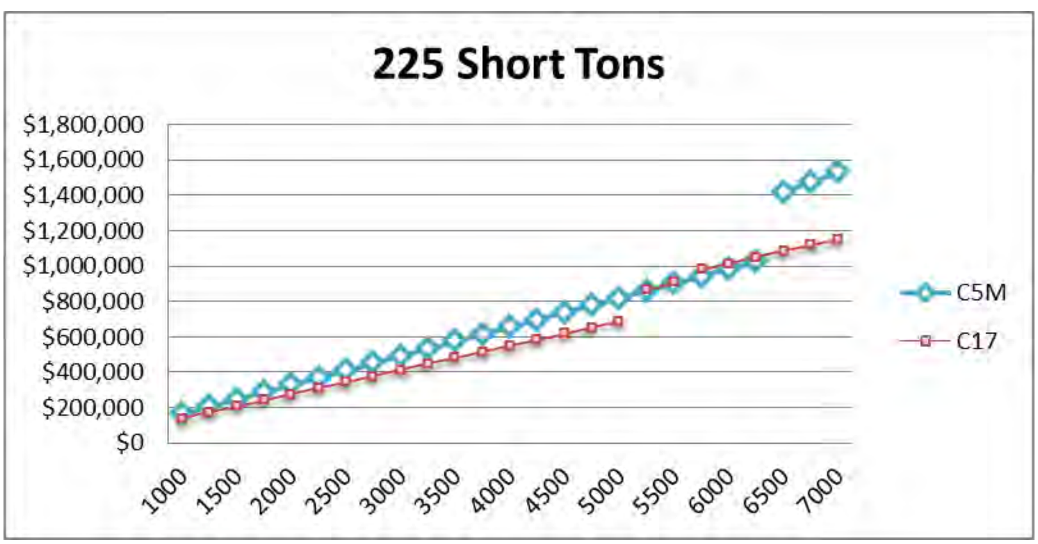
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17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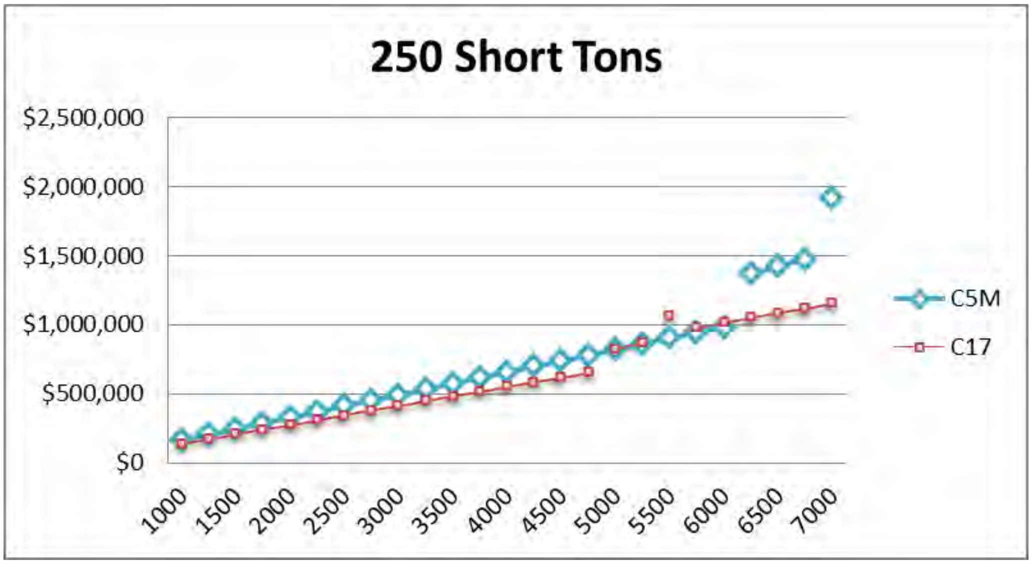
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17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$2,000,000
$1,500,000
$1,000,000
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$0
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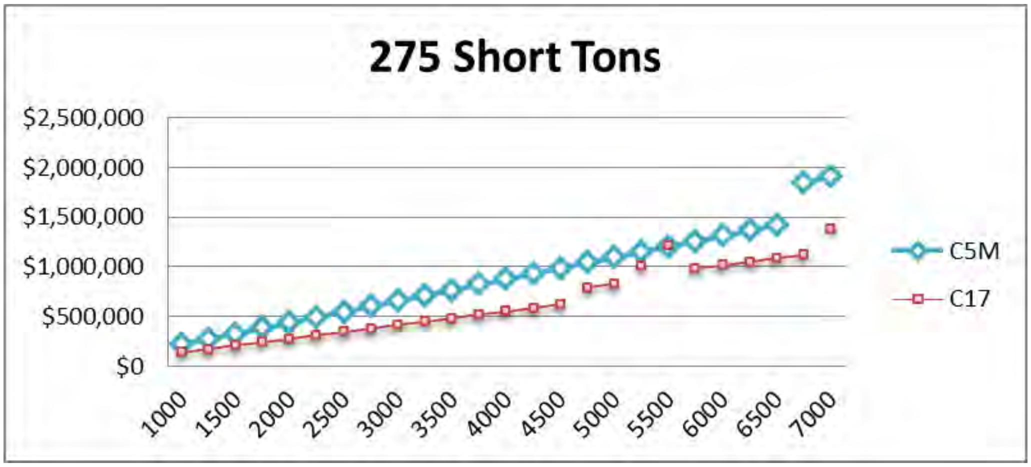
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17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$2,000,000
$1,500,000
$1,000,000
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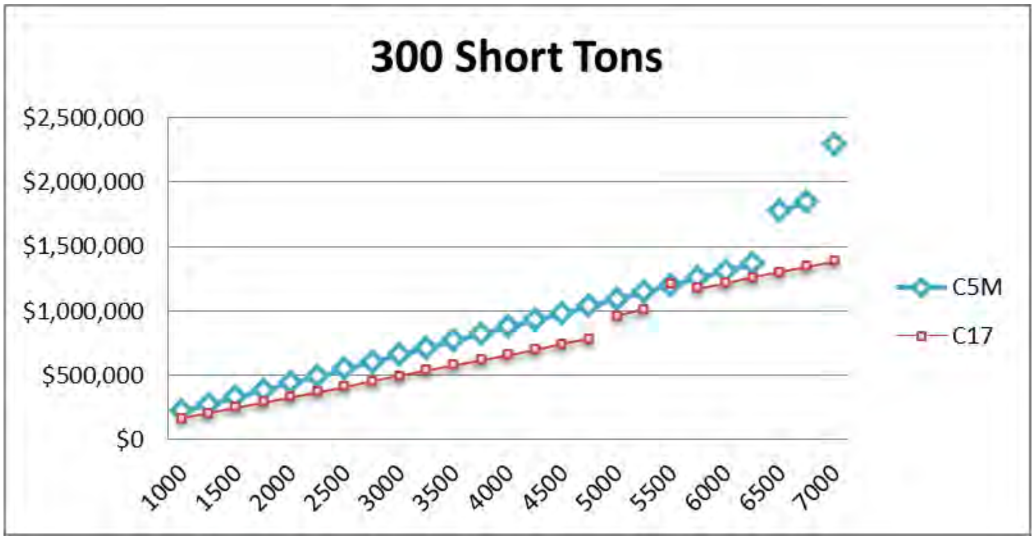
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17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$2,000,000
$1,500,000
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$0
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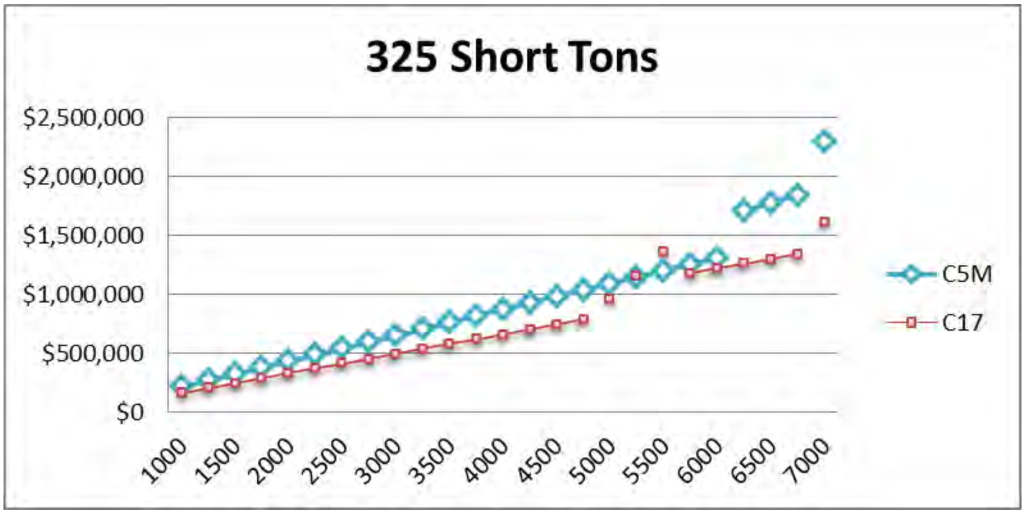
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


325 Short Tons
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$2,000,000
$1,500,000
$1,000,000
$500,000
$0
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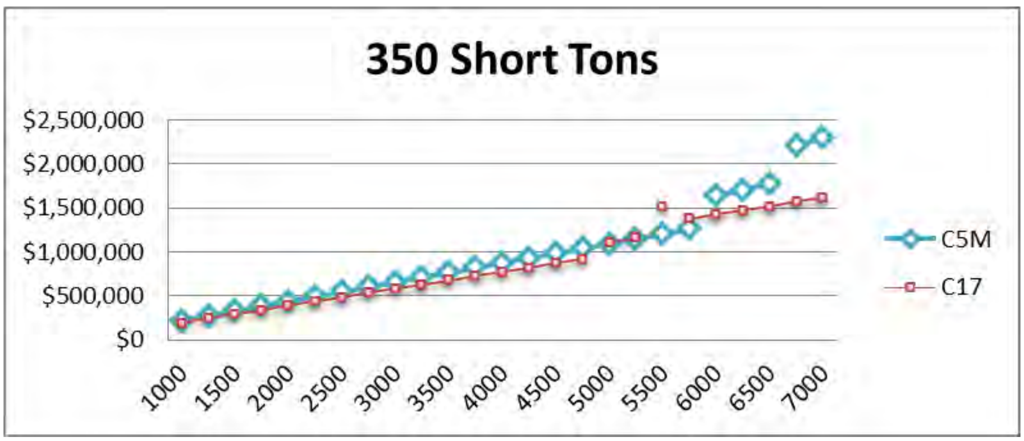
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


350 Short Tons
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2500
3000
3500
4000
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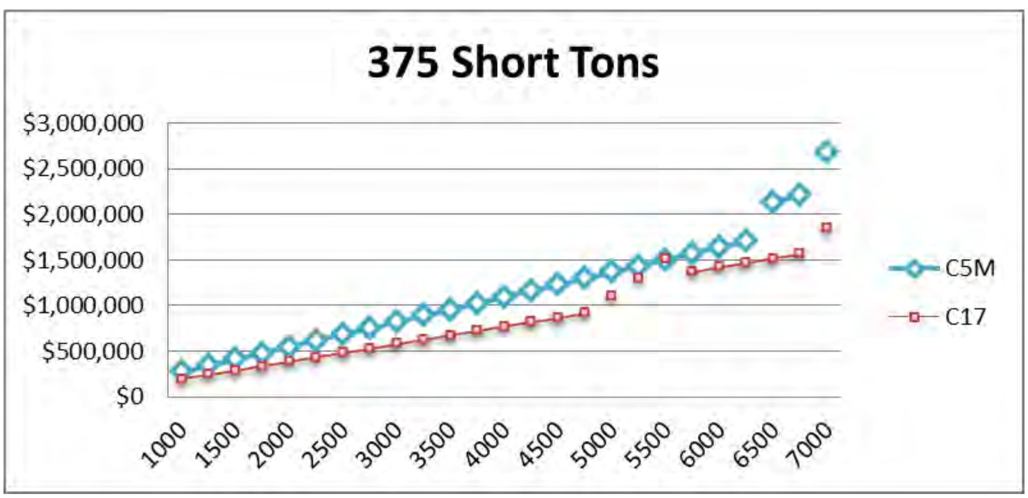
5000
5500
6000
6500
7000
C5M
C17


375 Short Tons
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2500
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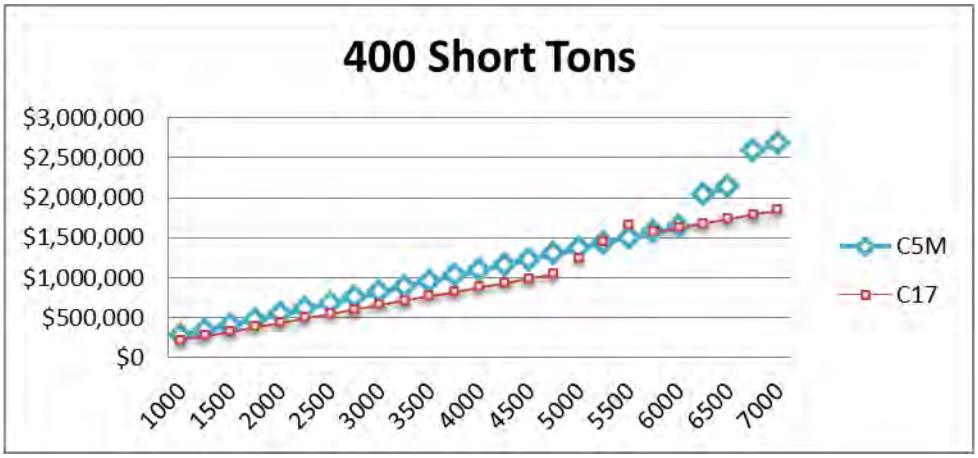
7000
C5M
C17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$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

Appendix H: Microsoft Excel Macro

```
Sub Button4_Click()

'
' Button4_Click Macro
'

'
    Sheets("C17").Select
      Range("E13").Select
    ActiveCell.FormulaR1C1 = "1"
    SolverOk Setcell:="$E$31", MaxMinVal:=2, ValueOf:=0, ByChange:="$E$13",
Engine _
        :=1, EngineDesc:="GRG Nonlinear"
    SolverOk Setcell:="$E$31", MaxMinVal:=2, ValueOf:=0, ByChange:="$E$13",
Engine _
        :=1, EngineDesc:="GRG Nonlinear"
    SolverSolve True
    Sheets("Results").Select

    Sheets("C5M").Select
     Range("E13").Select
    ActiveCell.FormulaR1C1 = "1"
    SolverOk Setcell:="$E$31", MaxMinVal:=2, ValueOf:=0, ByChange:="$E$13",
Engine _
        :=1, EngineDesc:="GRG Nonlinear"
    SolverOk Setcell:="$E$31", MaxMinVal:=2, ValueOf:=0, ByChange:="$E$13",
Engine _
        :=1, EngineDesc:="GRG Nonlinear"
    SolverSolve True
    Sheets("Results").Select

End Sub
```

Appendix I: Model Construction Users Guide

Model Construction

Due to the complicated nature of building models, and attempting to recreate the work in a thesis, this appendix reviews construction of the specific model used in this research. This section should only be used to recreate the model within Microsoft Excel. This section contains pictorial representations of the various sections used. The equations are the same as in the previous section, and will be referenced as such.

User Input

Within the model, the user inputs the mission range and payload (in short tons) into the results tab. A detailed description of the results tab is contained below. Also included on this tab are some assumptions that the model uses. Once the user inputs the estimated mission range and estimated short tons, they would click the "Run Aircraft Estimation" button. Upon clicking the "Run Aircraft Estimation" button, the model runs through the process documented in the next sections. The results from the process will show up in the estimated number of aircraft required, and estimated total cost blocks for a quick reference as to the results the model has come up with.

C-5M Model

Section 1, of the model contains technical data found in documents specific to the C-5M. The specific data is contained in table I.1. The data contained in table I.1 was retrieved from sources documented in the previous sections.

Table I.1. Section 1 from C-5M Spreadsheet

Max Fuel Gal	51,150
Max Fuel Weight	342,705
Max Takeoff Weight	840,000
Speed	518
Empty Aircraft Weight	380,000

Section 2 contains cargo data for the mission, which is retrieved from what the user inputted. Table I.2 depicts section 2. Microsoft Excel, using solver, calculates the calculated cargo weight per aircraft. The NLP model is documented in equations 4 through 8. The calculation for true cargo weight per aircraft is documented in equation I.1. A limitation imposed on this model is a maximum calculated cargo weight of 180,000 pounds for the C-5M and 110,000 pounds for the C-17. The assumption in this model is the cargo weight is evenly divided by the amount of aircraft. True mission needs, as well as specific cargo requirements, will determine the amount of cargo loaded on each aircraft. Total cargo weight to move is *U* multiplied by 2000.

$$A_i/S \qquad \text{I.1}$$

Table I.2. C-5M Spreadsheet Section 2

Calculated Cargo Weight Per Aircraft	180,000
True Cargo Weight Per Aircraft	133,333
Total Cargo Weight to Move	400,000

Section 3 has multiple functions within the model. Table I.3 depicts section 3. The takeoff fuel weight needed for the mission is calculated using equation 3.

Section 3 also makes the determination if an aerial refueling is required. The model uses an IF/THEN statement within Microsoft Excel to make the determination if an aerial refueling is required. Equation 10 shows the formula Microsoft Excel uses to determine if an aerial refueling is required.

If the model determines an aerial refueling required, the model will subtract 90,000 pounds of fuel planning factor from the takeoff fuel weight needed, I_i, (AFPAM 10-1403, 2003). The IF/THEN statement is shown in equation 11.

Total aircraft weight is calculated using the equation I.2.

$$A_i/S + W + I_i \qquad \text{I.2}$$

Table I.3. C-5M Spreadsheet Section 3

TO Fuel Weight Needed for Mission	170,550
Total Aircraft Weight	683,883
Cargo Available Weight	156,117

Section 4 contains the average fuel burn rate in pounds per hour estimated for the C-5M. See table 4. The average fuel burn rate, as well as other aviation fuel consumption factors, is retrieved from AFI 65-503, Table A13-1, *Aviation Fuel Consumption Factors* from FY11 (AFI 65-503, 2011). The estimated hours of flight time is based upon the pounds of fuel needed for the mission, and does not include the reserve of 15% fuel. The estimated hours of flight time is calculated using equation 13.

Table I.4. C-5M Spreadsheet Section 4

Average Fuel Burn Rate lbs/hr	21,949
Hours of flight time	6.76

Section 5 contains average speed, H_i, retrieved from the Air Force fact sheet on the C-5 Galaxy (C-5 Factsheet, 2009). Table I.5 shows what information is contained in section 5. It is assumed that the C-5M will have the same average speed as the legacy C-5. This section also contains the mission range. Mission range is determined by equation 19, and should equal the mission range the user imputed.

Table I.5. C-5M Spreadsheet Section 5

Average Speed	518
Range	3500.00

Section 6 uses the estimated cost per flying hour, *CPFH*, retrieved from AFI 65-503 Table A4-1 (AFI 65-503, 2011). See table I.6 for a representation of section 6. The estimated cost per flying hour for both the C-5, as well as the KC-135R (if required) was retrieved from AFI 65-503 (AFI 65-503, 2011). Total cost per aircraft is calculated by the equation documented in equation 15.

Table I.6. C-5M Spreadsheet Section 6

		KC135R
CPFH	$28,302.00	$7,616.00
Total Cost per Aircraft	$191,229.73	$38,080.00

If the model determines an AR is required, refer to equation 10, it will calculate the cost per aircraft for a KC-135R. A KC-135R, being the standard air refueling aircraft in the Air Force, is used for the cost comparison. The calculation for the KC-135 is based upon assuming a standard 5 hour mission for the KC-135R. The 5 hour mission planning factor was determined using data in AFPAM10-403, Table 10 (AFPAM 10-403, 2003). The cost per flying hour for a KC-135R was retrieved from AFI 65-503 Table A4-1 (AFI 65-503, 2011). Total cost for the KC-135R is determined using equation 16.

Section 7 contains the results from the NLP model. The NLP model, in conjunction with equation 7, determines A_i. As stated above, the NLP model minimizes A_i. It is assumed that aircraft will be employed in only one mission profile. The model takes the calculated number of aircraft and rounds up to the next integer. Actual mission requirements, load planning and common sense will be required to determine the true number of aircraft required for the mission.

Table I.7. C-5M Spreadsheet Section 7

# aircraft calculated	2.2222	KC-135
# of Aircraft required	3.00	3.00

For the KC-135, number of aircraft required is based upon the number of airlift aircraft required. For example, if the model determines that 3 C-5Ms are required, it will incorporate 3 KC-135R aircraft. This is based upon planning factors contained in AFPAM 10-403, Table 10 (AFPAM 10-403, 2003).

Section 8 contains the final costs as determined by the model. A representation of section 8 is located in table I.8. All aircraft use the same formula, in different cells, to determine TA_i, see equation 17. The specific formula for the KC135R is contained in equation 18. Total costs given a requirement for an aerial refueling is documented in equation 19.

The total cost, TC_i, is determined by the Total Aircraft Costs, TA_i, or the Total Costs given aerial refueling, TR_i. If the equation 10 determined an aerial refueling was necessary, TR_i will be copied and transferred to the results tab. If equation 10 determined that an AR was not required, TA_i, is copied and transferred to the results tab of the model.

Table I.8. C-5M Spreadsheet Section 8

Total Aircraft Costs	$887,852.32	$190,400.00
Total Costs given AR	$1,078,252.32	

Total Cost	***$887,852.32***

C-17 Model

The C-17 model uses the same calculations documented in detailed explanation of the model. The technical data for the C-17 model has been updated to C-17 specific information. Section 1 information is located in table I.9.

Table I.9. Section 1 from C-17 Spreadsheet

Max Fuel Gal	36,567
Max Fuel Weight	245,000
Max Takeoff Weight	585,000
Speed	515
Empty Aircraft Weight	269,000

Maximum cargo weight for the C-17 is limited to 110,000 pounds, based upon 11 usable pallet positions; at a maximum weight of 10,000 each position (Boeing, 2011). As with the C-5M model, *CPFH* and average fuel burn rate, *G*, were retrieved from AFI 65-503, Tables A4-1 and A13-1 respectively.

Appendix J: Aerial Refueling model run results

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$54,900
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$151,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$137,500
5250	$286,800	$144,400
5500	$300,500	$151,200
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

25 Short Tons

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$55,000
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$150,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

50 Short Tons

	C5M	C17
1000	$54,600	$55,000
1250	$68,300	$68,700
1500	$82,000	$82,500
1750	$95,600	$96,200
2000	$109,300	$110,000
2250	$122,900	$123,700
2500	$136,600	$137,500
2750	$150,300	$151,200
3000	$163,900	$165,000
3250	$177,600	$178,700
3500	$191,200	$192,500
3750	$204,900	$206,200
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$245,900	$247,500
4750	$259,500	$261,200
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$392,400
6000	$327,800	$406,100
6250	$341,500	$419,900
6500	$393,200	$433,600
6750	$406,900	$447,400
7000	$420,500	$461,100

75 Short Tons

	C5M	C17
1000	$109,300	$55,000
1250	$136,600	$68,700
1500	$163,900	$82,500
1750	$191,200	$96,200
2000	$218,500	$110,000
2250	$245,900	$123,700
2500	$273,200	$137,500
2750	$300,500	$151,200
3000	$327,800	$165,000
3250	$355,100	$178,700
3500	$382,500	$192,500
3750	$409,800	$206,200
4000	$437,100	$220,000
4250	$464,400	$233,700
4500	$491,700	$247,500
4750	$519,100	$261,200
5000	$549,400	$412,500
5250	$573,700	$433,100
5500	$601,000	$453,700
5750	$628,300	$392,400
6000	$655,600	$406,100
6250	$683,000	$419,900
6500	$710,300	$433,600
6750	$737,600	$447,400
7000	$764,900	$461,100

100 Short Tons

125 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$350,600
4500	$491,700	$371,200
4750	$519,100	$391,800
5000	$546,400	$412,500
5250	$573,700	$433,100
5500	$601,000	$604,900
5750	$628,300	$588,600
6000	$655,600	$609,200
6250	$683,000	$629,800
6500	$710,300	$650,400
6750	$737,600	$671,100
7000	$1,147,400	$691,700

150 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$350,600
4500	$491,700	$371,200
4750	$519,100	$391,800
5000	$546,400	$549,900
5250	$573,700	$577,400
5500	$601,000	$604,900
5750	$628,300	$588,600
6000	$655,600	$609,200
6250	$683,000	$629,800
6500	$786,400	$650,400
6750	$813,800	$671,100
7000	$841,100	$691,700

175 Short Tons

	C5M	C17
1000	$109,300	$110,000
1250	$136,600	$137,500
1500	$163,900	$168,000
1750	$191,200	$192,500
2000	$218,500	$220,000
2250	$245,900	$247,500
2500	$273,200	$275,000
2750	$300,500	$302,500
3000	$327,800	$330,000
3250	$355,100	$357,500
3500	$382,500	$388,000
3750	$409,800	$412,500
4000	$437,100	$440,000
4250	$464,400	$467,500
4500	$491,700	$494,900
4750	$519,100	$522,400
5000	$549,400	$549,900
5250	$573,700	$577,400
5500	$601,000	$756,200
5750	$628,300	$784,800
6000	$983,500	$812,300
6250	$1,024,400	$839,700
6500	$1,065,400	$867,200
6750	$1,106,400	$894,700
7000	$1,147,400	$922,200

200 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$368,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$412,500
4000	$655,600	$440,000
4250	$696,600	$467,500
4500	$737,600	$494,900
4750	$778,600	$522,400
5000	$819,600	$687,400
5250	$860,500	$721,800
5500	$901,500	$907,400
5750	$942,500	$784,800
6000	$983,500	$812,300
6250	$1,024,400	$839,700
6500	$1,065,400	$867,200
6750	$1,475,200	$894,700
7000	$1,529,800	$922,200

	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$368,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$584,300
4500	$737,600	$618,700
4750	$778,600	$653,100
5000	$819,600	$687,400
5250	$860,500	$866,200
5500	$901,500	$907,400
5750	$942,500	$980,900
6000	$983,500	$1,015,300
6250	$1,024,400	$1,049,700
6500	$1,420,600	$1,084,100
6750	$1,475,200	$1,118,400
7000	$1,529,800	$1,152,800

225 Short Tons

	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$368,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$584,300
4500	$737,600	$618,700
4750	$778,600	$653,100
5000	$819,600	$824,900
5250	$860,500	$866,200
5500	$901,500	$1,058,600
5750	$942,500	$980,900
6000	$983,500	$1,015,300
6250	$1,365,900	$1,049,700
6500	$1,420,600	$1,084,100
6750	$1,475,200	$1,118,400
7000	$1,912,300	$1,152,800

250 Short Tons

	C5M	C17
1000	$218,500	$137,500
1250	$273,200	$171,900
1500	$327,800	$206,200
1750	$382,500	$240,600
2000	$437,100	$275,000
2250	$491,700	$309,300
2500	$546,400	$343,700
2750	$601,000	$378,100
3000	$655,600	$412,500
3250	$710,300	$446,800
3500	$764,900	$481,200
3750	$819,600	$515,600
4000	$874,200	$549,900
4250	$928,800	$584,300
4500	$983,500	$618,700
4750	$1,038,100	$783,700
5000	$1,092,700	$824,900
5250	$1,147,400	$1,010,500
5500	$1,202,000	$1,209,900
5750	$1,256,700	$980,900
6000	$1,311,300	$1,015,300
6250	$1,365,900	$1,049,700
6500	$1,420,600	$1,084,100
6750	$1,844,000	$1,118,400
7000	$1,912,300	$1,383,400

275 Short Tons

	C5M	C17
1000	$218,500	$165,000
1250	$273,200	$206,200
1500	$327,800	$247,500
1750	$382,500	$288,700
2000	$437,100	$330,000
2250	$491,700	$371,200
2500	$546,400	$412,500
2750	$601,000	$453,700
3000	$655,600	$494,900
3250	$710,300	$536,200
3500	$764,900	$577,400
3750	$819,600	$618,700
4000	$874,200	$659,900
4250	$928,800	$701,200
4500	$983,500	$742,400
4750	$1,038,100	$783,700
5000	$1,092,700	$962,400
5250	$1,147,400	$1,010,500
5500	$1,202,000	$1,209,900
5750	$1,256,700	$1,177,100
6000	$1,311,300	$1,218,400
6250	$1,365,900	$1,259,600
6500	$1,572,800	$1,300,900
6750	$1,627,500	$1,342,100
7000	$1,682,200	$1,383,400

300 Short Tons

	C5M	C17
1000	$218,500	$165,000
1250	$273,200	$206,200
1500	$327,800	$247,500
1750	$382,500	$288,700
2000	$437,100	$330,000
2250	$491,700	$371,200
2500	$546,400	$412,500
2750	$601,000	$453,700
3000	$655,600	$494,900
3250	$710,300	$536,200
3500	$764,900	$577,400
3750	$819,600	$618,700
4000	$874,200	$659,900
4250	$928,800	$701,200
4500	$983,500	$742,400
4750	$1,038,100	$783,700
5000	$1,092,700	$962,400
5250	$1,147,400	$1,154,900
5500	$1,202,000	$1,361,100
5750	$1,256,700	$1,177,100
6000	$1,311,300	$1,218,400
6250	$1,707,400	$1,259,600
6500	$1,775,700	$1,300,900
6750	$1,844,000	$1,342,100
7000	$2,294,800	$1,613,900

325 Short Tons

	C5M	C17
1000	$218,500	$192,500
1250	$273,200	$240,600
1500	$327,800	$288,700
1750	$382,500	$336,800
2000	$437,100	$385,000
2250	$491,700	$433,100
2500	$546,400	$481,200
2750	$601,000	$529,300
3000	$655,600	$577,400
3250	$710,300	$625,600
3500	$764,900	$673,700
3750	$819,600	$721,800
4000	$874,200	$769,900
4250	$928,800	$818,000
4500	$983,500	$866,200
4750	$1,038,100	$914,300
5000	$1,092,700	$1,099,900
5250	$1,147,400	$1,154,900
5500	$1,202,000	$1,512,300
5750	$1,256,700	$1,373,300
6000	$1,639,100	$1,421,400
6250	$1,707,400	$1,469,600
6500	$1,775,700	$1,517,700
6750	$2,212,800	$1,565,800
7000	$2,294,800	$1,613,900

350 Short Tons

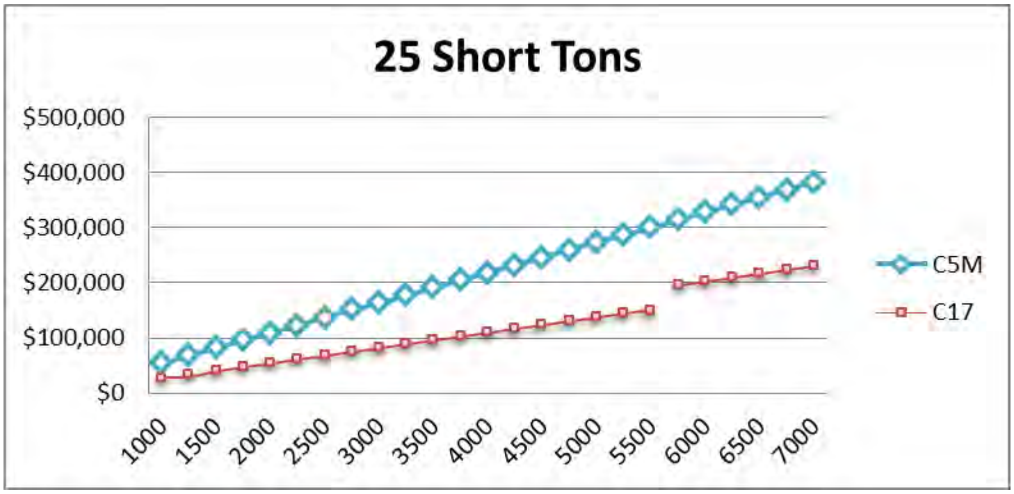
	C5M	C17
1000	$273,200	$192,500
1250	$341,500	$240,600
1500	$409,800	$288,700
1750	$478,100	$336,800
2000	$546,400	$385,000
2250	$614,700	$433,100
2500	$683,000	$481,200
2750	$751,300	$529,300
3000	$819,600	$577,400
3250	$887,900	$625,600
3500	$956,100	$673,700
3750	$1,024,400	$721,800
4000	$1,092,700	$769,900
4250	$1,161,000	$818,000
4500	$1,229,300	$866,200
4750	$1,297,600	$914,300
5000	$1,365,900	$1,099,900
5250	$1,434,200	$1,299,200
5500	$1,502,500	$1,512,300
5750	$1,570,800	$1,373,300
6000	$1,639,100	$1,421,400
6250	$1,707,400	$1,469,600
6500	$2,130,800	$1,517,700
6750	$2,212,800	$1,565,800
7000	$2,677,200	$1,844,500

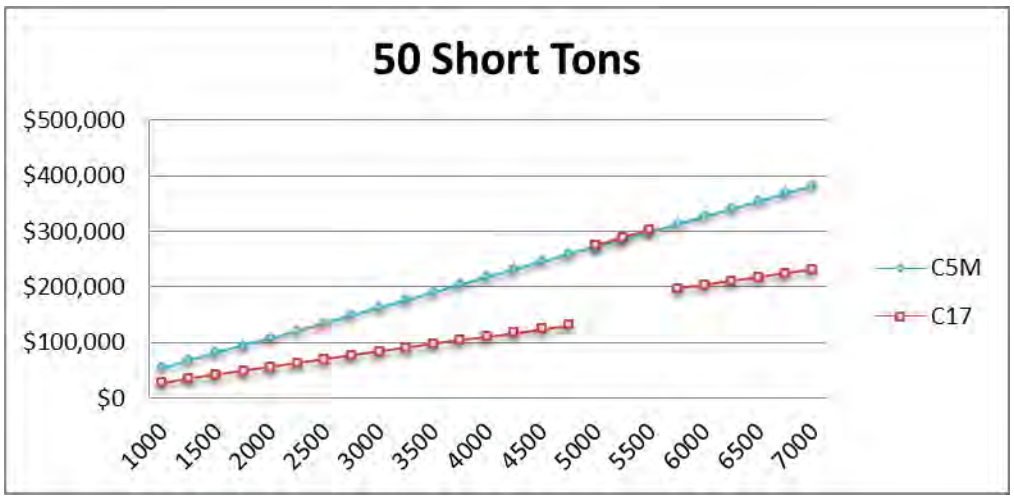
375 Short Tons

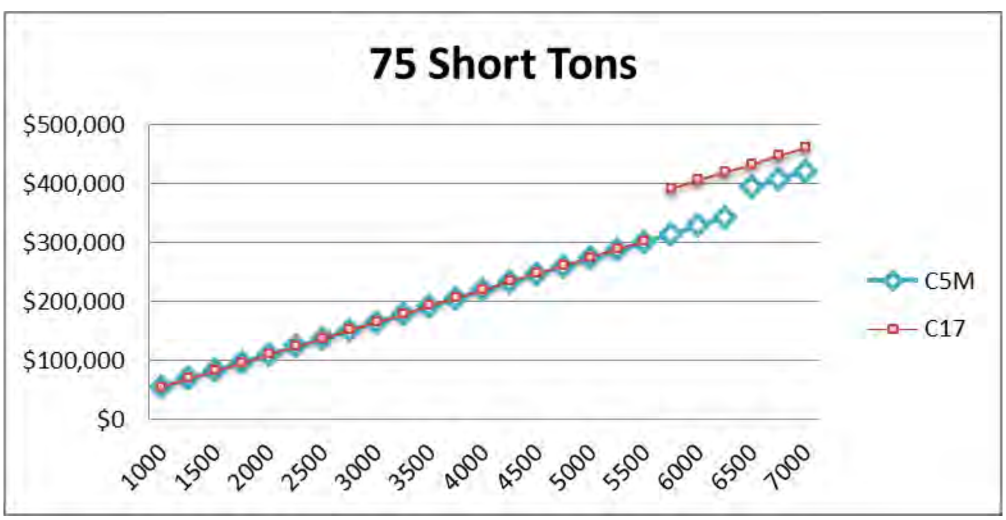
	C5M	C17
1000	$273,200	$220,000
1250	$341,500	$275,000
1500	$409,800	$330,000
1750	$478,100	$385,000
2000	$546,400	$440,000
2250	$614,700	$494,900
2500	$683,000	$549,900
2750	$751,300	$604,900
3000	$819,600	$659,900
3250	$887,900	$714,900
3500	$956,100	$769,900
3750	$1,024,400	$824,900
4000	$1,092,700	$879,900
4250	$1,161,000	$934,900
4500	$1,229,300	$989,900
4750	$1,297,600	$1,044,900
5000	$1,365,900	$1,237,400
5250	$1,434,200	$1,443,600
5500	$1,502,500	$1,663,600
5750	$1,570,800	$1,569,500
6000	$1,639,100	$1,624,500
6250	$2,048,900	$1,679,500
6500	$2,130,800	$1,734,500
6750	$2,581,600	$1,789,500
7000	$2,677,200	$1,844,500

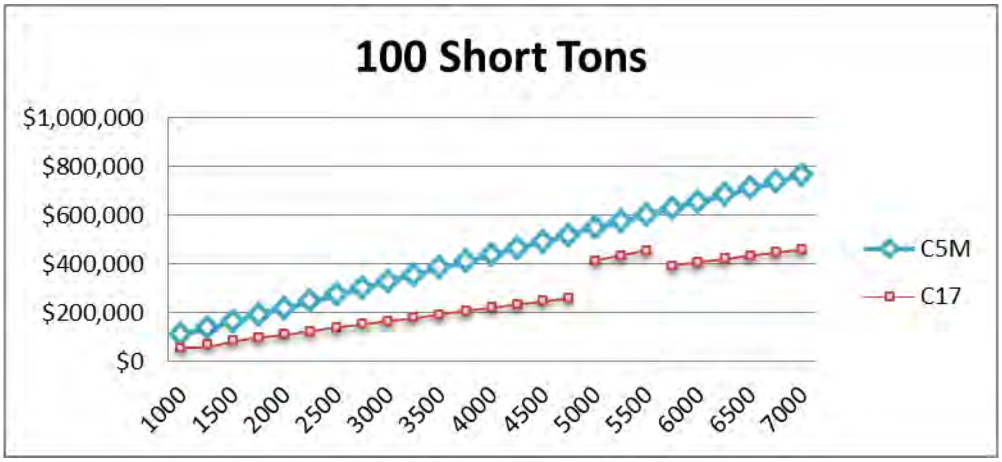
400 Short Tons

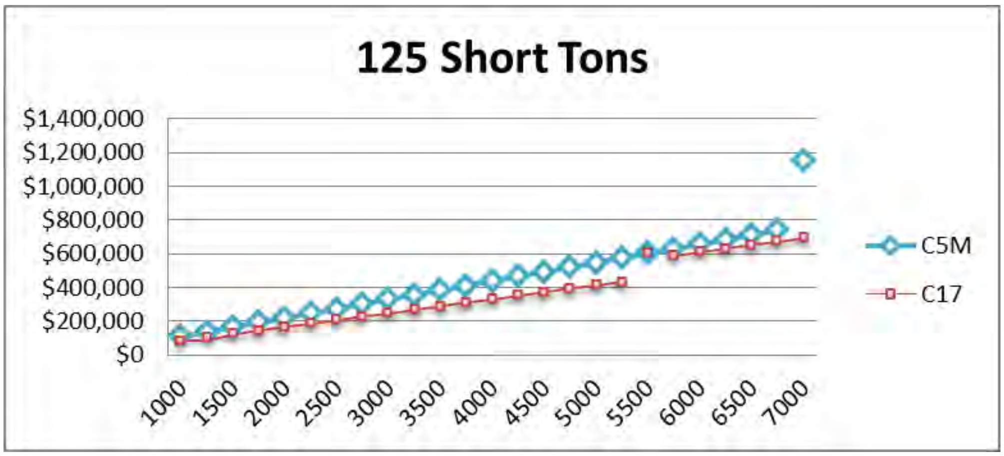
Appendix K: Aerial Refueling model run graphs

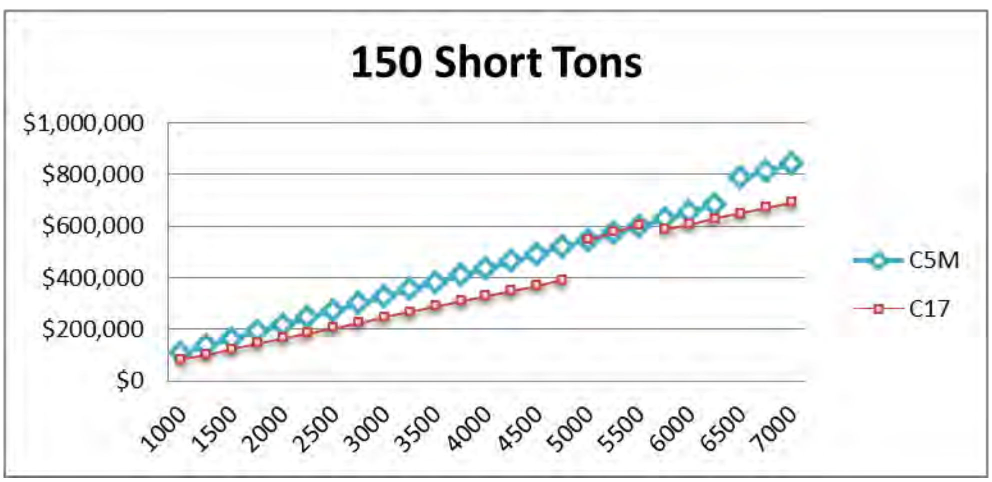


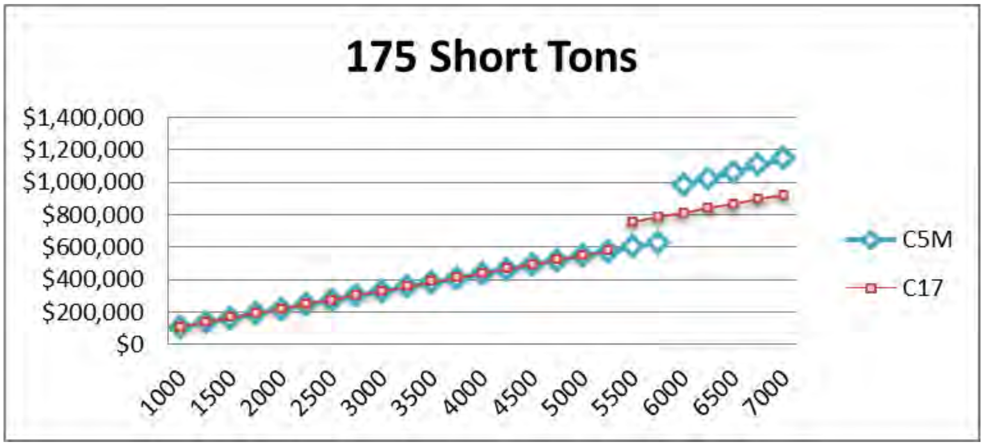


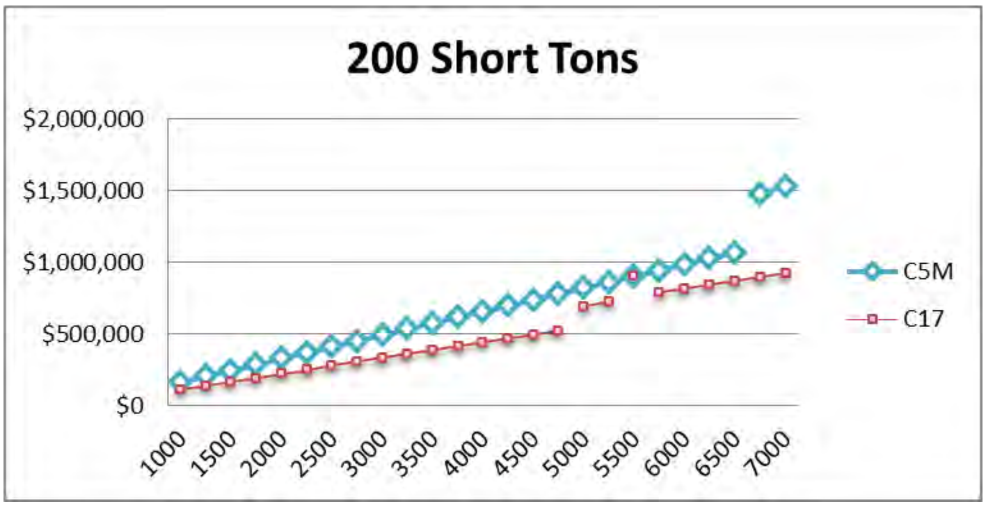


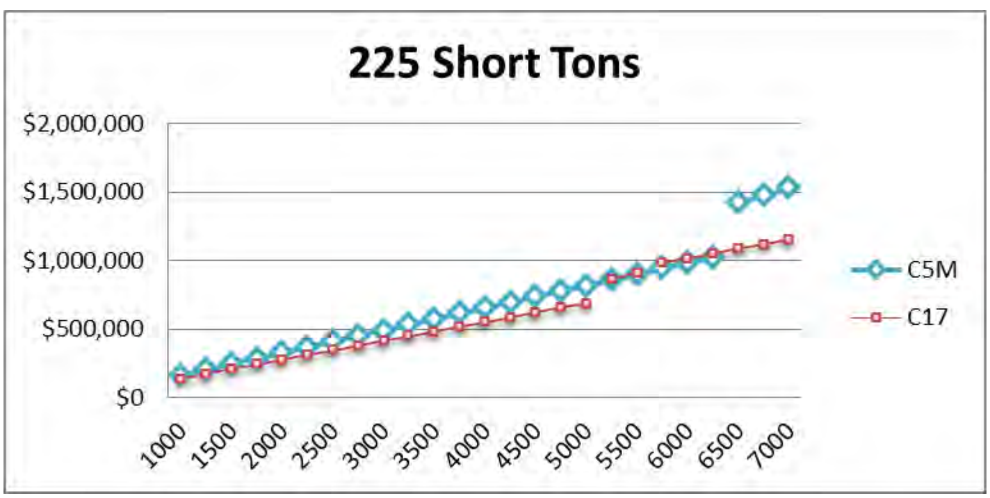

100 Short Tons
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

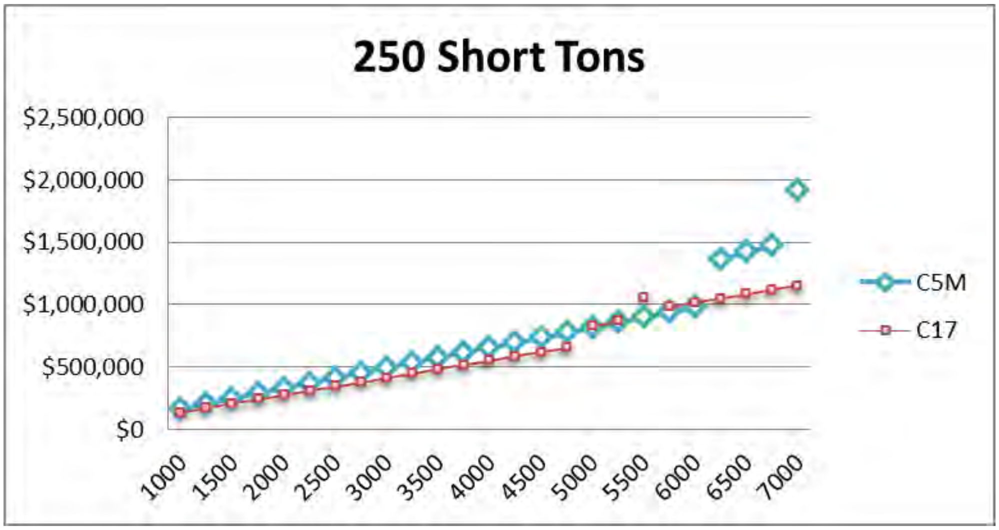

125 Short Tons
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


150 Short Tons
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

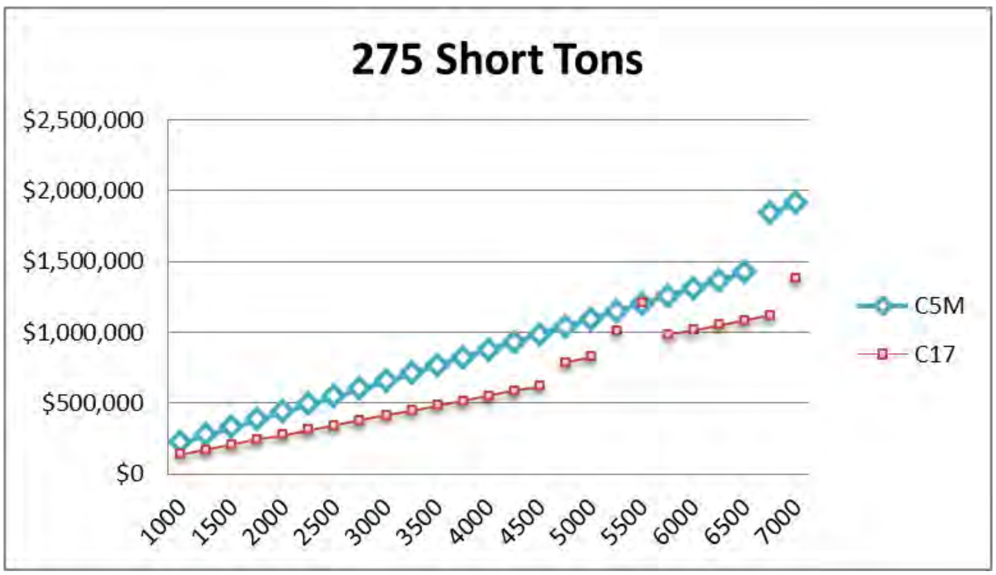

175 Short Tons
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


200 Short Tons
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

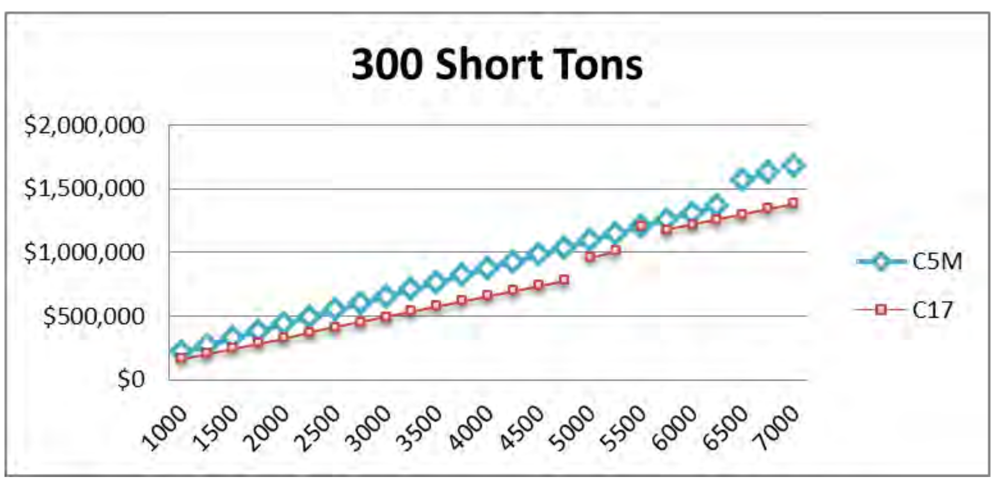

225 Short Tons
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17



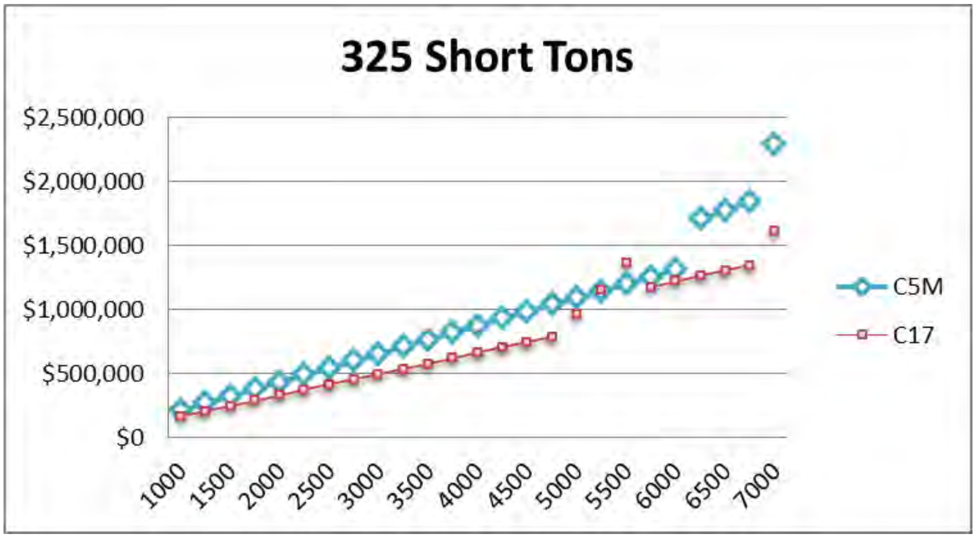
250 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

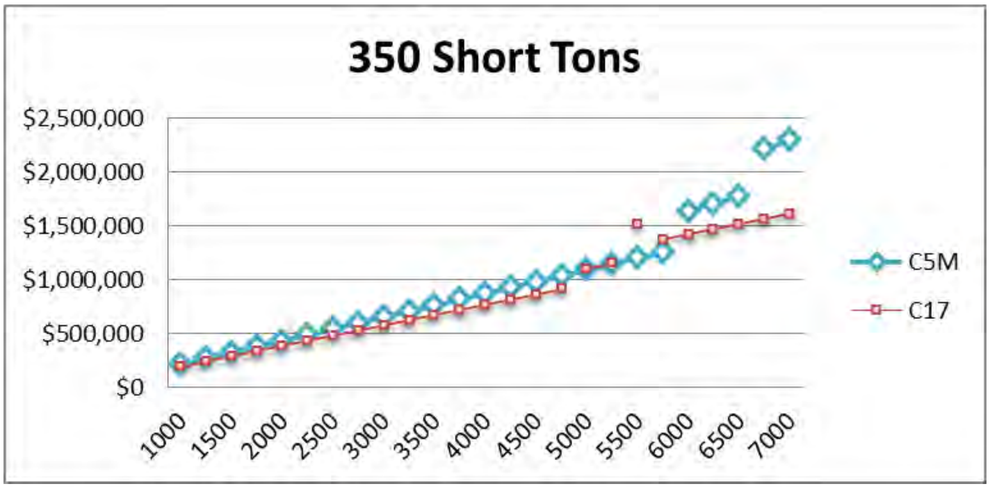


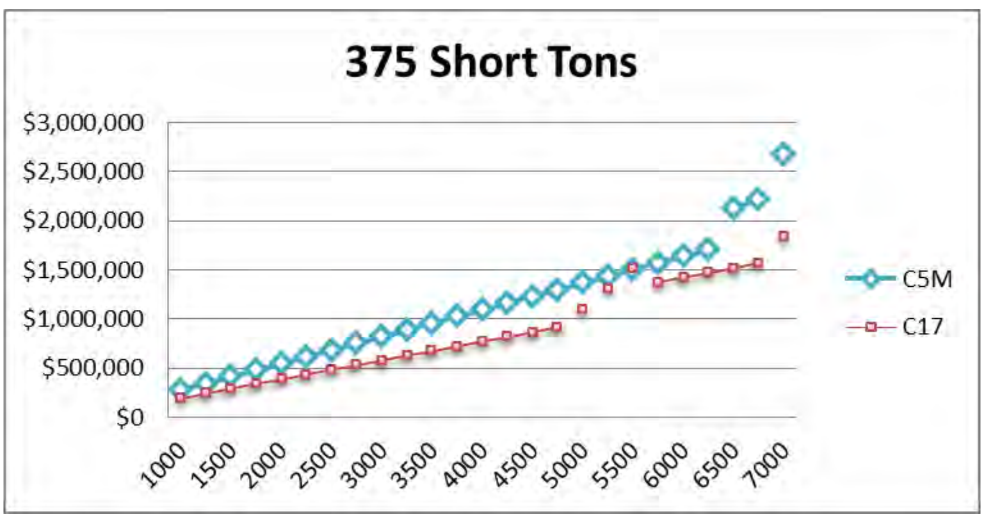
275 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

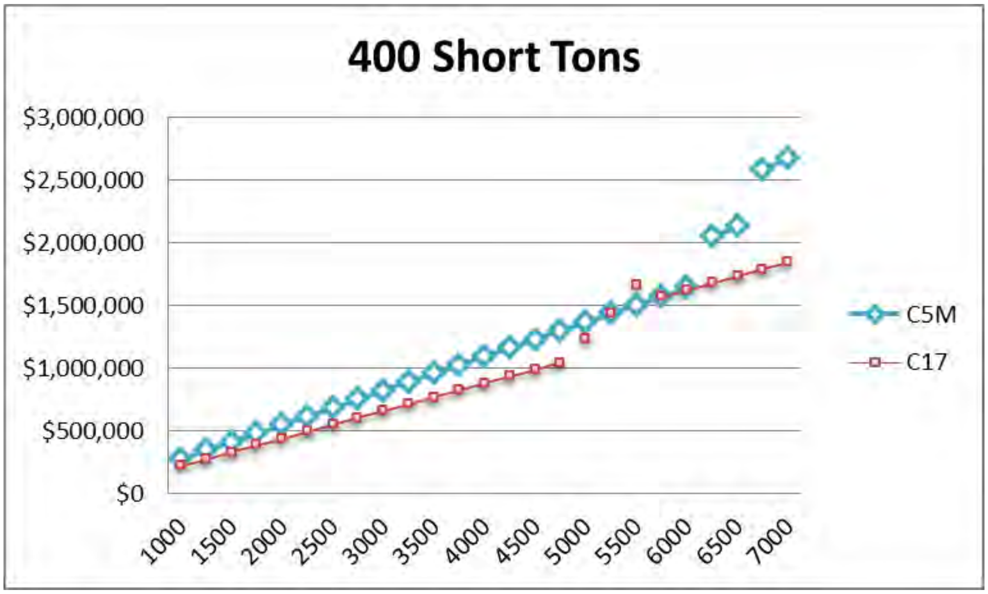


300 Short Tons
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


325 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


350 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


375 Short Tons
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


400 Short Tons
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

Appendix L: Maximum cargo load model run results

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$54,900
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$151,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$137,500
5250	$286,800	$144,400
5500	$300,500	$151,200
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

25 Short Tons

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$55,000
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$150,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

50 Short Tons

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$55,000
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$150,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$245,900	$247,500
4750	$259,500	$261,200
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$196,200
6000	$327,800	$406,100
6250	$341,500	$419,900
6500	$710,300	$433,600
6750	$737,600	$447,400
7000	$764,900	$461,100

75 Short Tons

	C5M	C17
1000	$54,600	$55,000
1250	$68,300	$68,700
1500	$82,000	$82,500
1750	$95,600	$96,200
2000	$109,300	$110,000
2250	$122,900	$123,700
2500	$136,600	$137,500
2750	$150,300	$151,200
3000	$163,900	$165,000
3250	$177,600	$178,700
3500	$191,200	$192,500
3750	$204,900	$206,200
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$245,900	$247,500
4750	$259,500	$261,200
5000	$273,200	$412,500
5250	$286,800	$433,100
5500	$601,000	$453,700
5750	$628,300	$392,400
6000	$655,600	$406,100
6250	$683,000	$419,900
6500	$710,300	$433,600
6750	$737,600	$447,400
7000	$764,900	$461,100

100 Short Tons

	C5M	C17
1000	$54,600	$55,000
1250	$68,300	$68,700
1500	$82,000	$82,500
1750	$95,600	$96,200
2000	$109,300	$110,000
2250	$122,900	$123,700
2500	$136,600	$137,500
2750	$150,300	$151,200
3000	$163,900	$165,000
3250	$177,600	$178,700
3500	$191,200	$192,500
3750	$204,900	$206,200
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$491,700	$371,200
4750	$519,100	$391,800
5000	$546,400	$412,500
5250	$573,700	$433,100
5500	$601,000	$604,900
5750	$628,300	$392,400
6000	$655,600	$406,100
6250	$683,000	$419,900
6500	$710,300	$650,400
6750	$737,600	$671,100
7000	$1,147,400	$691,700

125 Short Tons

	C5M	C17
1000	$109,300	$55,000
1250	$136,600	$68,700
1500	$163,900	$82,500
1750	$191,200	$96,200
2000	$218,500	$110,000
2250	$245,900	$123,700
2500	$273,200	$137,500
2750	$300,500	$151,200
3000	$327,800	$165,000
3250	$355,100	$178,700
3500	$382,500	$192,500
3750	$409,800	$206,200
4000	$437,100	$330,000
4250	$464,400	$350,600
4500	$491,700	$371,200
4750	$519,100	$391,800
5000	$546,400	$549,900
5250	$573,700	$577,400
5500	$601,000	$604,900
5750	$628,300	$392,400
6000	$655,600	$609,200
6250	$683,000	$629,800
6500	$1,065,400	$650,400
6750	$1,106,400	$671,100
7000	$1,147,400	$691,700

150 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,800
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$350,600
4500	$491,700	$371,200
4750	$519,100	$522,400
5000	$546,400	$549,900
5250	$573,700	$577,400
5500	$601,000	$756,200
5750	$628,300	$588,700
6000	$983,500	$609,200
6250	$1,024,400	$629,800
6500	$1,065,400	$650,400
6750	$1,106,400	$894,700
7000	$1,147,400	$922,200

175 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,800
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$467,500
4500	$491,700	$494,900
4750	$519,100	$522,400
5000	$546,400	$687,400
5250	$573,700	$721,800
5500	$901,500	$907,400
5750	$942,500	$588,600
6000	$983,500	$609,200
6250	$1,024,400	$629,800
6500	$1,065,400	$867,200
6750	$1,475,200	$894,700
7000	$1,529,800	$922,200

200 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,800
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$440,000
4250	$464,400	$467,500
4500	$491,700	$494,900
4750	$519,100	$653,100
5000	$819,600	$687,400
5250	$860,500	$866,200
5500	$901,500	$907,400
5750	$942,500	$588,600
6000	$983,500	$812,300
6250	$1,024,400	$839,700
6500	$1,420,600	$867,200
6750	$1,475,200	$1,118,400
7000	$1,529,800	$1,152,800

225 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,800
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$385,000
3750	$409,800	$412,500
4000	$437,100	$440,000
4250	$464,400	$467,500
4500	$737,600	$618,700
4750	$778,600	$653,100
5000	$819,600	$824,900
5250	$860,500	$866,200
5500	$901,500	$1,058,600
5750	$942,500	$784,800
6000	$983,500	$812,300
6250	$1,365,900	$839,700
6500	$1,420,600	$1,084,100
6750	$1,475,200	$1,118,400
7000	$1,912,300	$1,152,800

250 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$368,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$412,500
4000	$655,600	$440,000
4250	$696,600	$584,300
4500	$737,600	$618,700
4750	$778,600	$783,700
5000	$819,600	$824,900
5250	$860,500	$1,010,500
5500	$901,500	$1,209,900
5750	$1,256,700	$784,800
6000	$1,311,300	$812,300
6250	$1,365,900	$1,049,700
6500	$1,420,600	$1,084,100
6750	$1,844,000	$1,118,400
7000	$1,912,300	$1,383,400

275 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$368,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$412,500
4000	$655,600	$549,900
4250	$696,600	$584,300
4500	$737,600	$618,700
4750	$778,600	$783,700
5000	$819,600	$962,400
5250	$860,500	$1,010,500
5500	$1,202,000	$1,209,900
5750	$1,256,700	$784,800
6000	$1,311,300	$1,015,300
6250	$1,365,900	$1,049,700
6500	$1,775,700	$1,084,100
6750	$1,844,000	$1,342,100
7000	$2,294,800	$1,383,400

300 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$368,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$584,300
4500	$737,600	$742,400
4750	$778,600	$783,700
5000	$1,092,700	$962,400
5250	$1,147,400	$1,154,900
5500	$1,202,000	$1,361,100
5750	$1,256,700	$980,900
6000	$1,311,300	$1,015,300
6250	$1,707,400	$1,049,700
6500	$1,775,700	$1,300,900
6750	$1,844,000	$1,342,100
7000	$2,294,800	$1,613,900

325 Short Tons

	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$368,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$701,200
4500	$737,600	$742,400
4750	$1,038,100	$914,300
5000	$1,092,700	$1,099,900
5250	$1,147,400	$1,154,900
5500	$1,202,000	$1,512,300
5750	$1,256,700	$980,900
6000	$1,639,100	$1,015,300
6250	$1,707,400	$1,259,600
6500	$1,775,700	$1,300,900
6750	$2,212,800	$1,565,800
7000	$2,294,800	$1,613,900

350 Short Tons

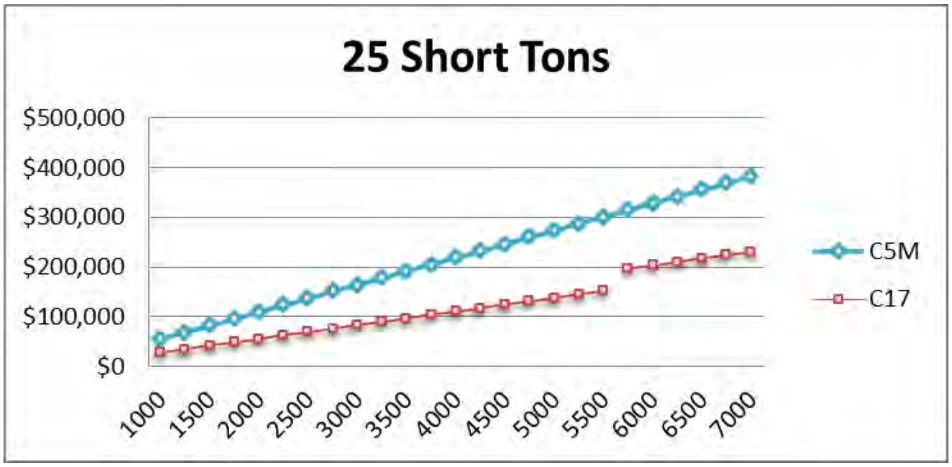
	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$368,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$659,900
4250	$696,600	$701,200
4500	$983,500	$866,200
4750	$1,038,100	$914,300
5000	$1,092,700	$1,099,900
5250	$1,147,400	$1,299,200
5500	$1,202,000	$1,512,300
5750	$1,570,800	$980,900
6000	$1,639,100	$1,218,400
6250	$1,707,400	$1,259,600
6500	$2,130,800	$1,517,700
6750	$2,212,800	$1,565,800
7000	$2,677,200	$1,844,500

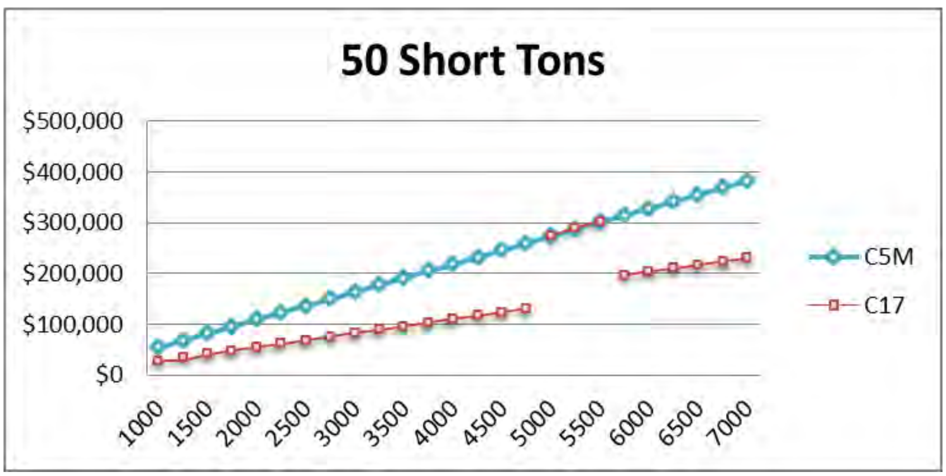
375 Short Tons

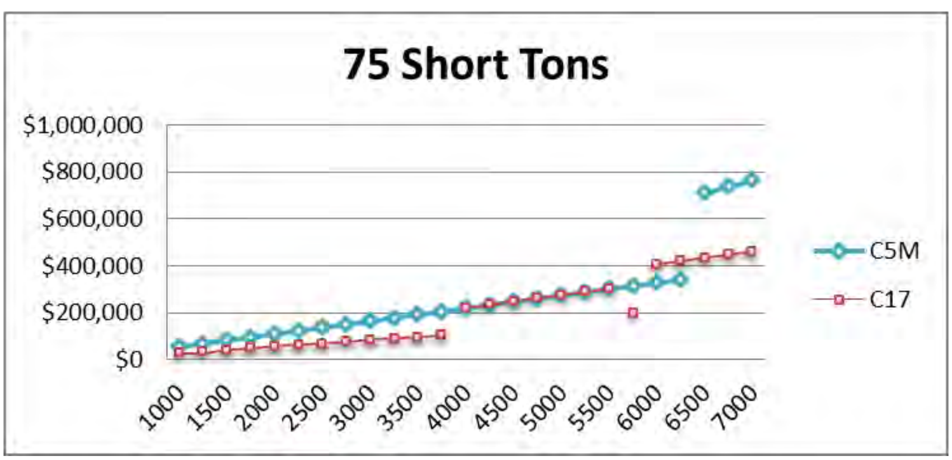
	C5M	C17
1000	$218,500	$137,500
1250	$273,200	$171,900
1500	$327,800	$206,200
1750	$382,500	$240,600
2000	$437,100	$275,000
2250	$491,700	$309,300
2500	$546,400	$343,700
2750	$601,000	$378,100
3000	$655,600	$412,500
3250	$710,300	$446,800
3500	$764,900	$481,200
3750	$819,600	$618,700
4000	$874,200	$659,900
4250	$928,800	$818,000
4500	$983,500	$866,200
4750	$1,038,100	$1,044,900
5000	$1,092,700	$1,237,400
5250	$1,147,400	$1,443,600
5500	$1,502,500	$1,663,600
5750	$1,570,800	$1,177,100
6000	$1,639,100	$1,218,400
6250	$2,048,900	$1,259,600
6500	$2,130,800	$1,517,700
6750	$2,581,600	$1,789,500
7000	$2,677,200	$1,844,500

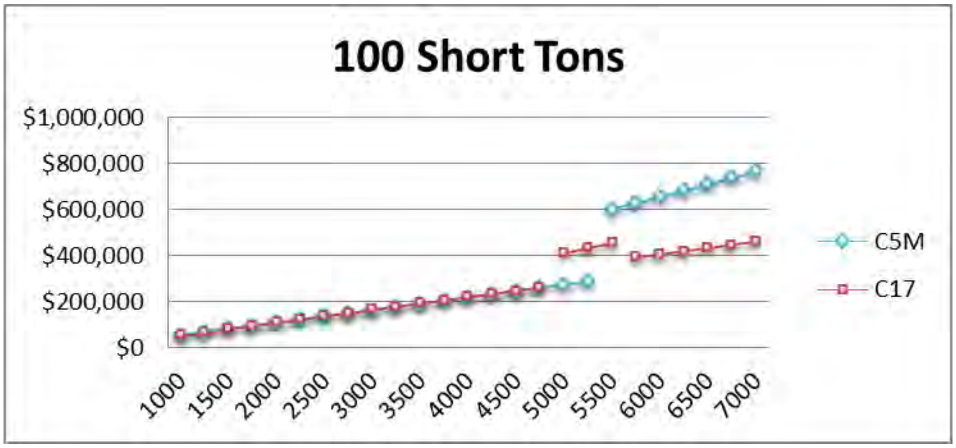
400 Short Tons

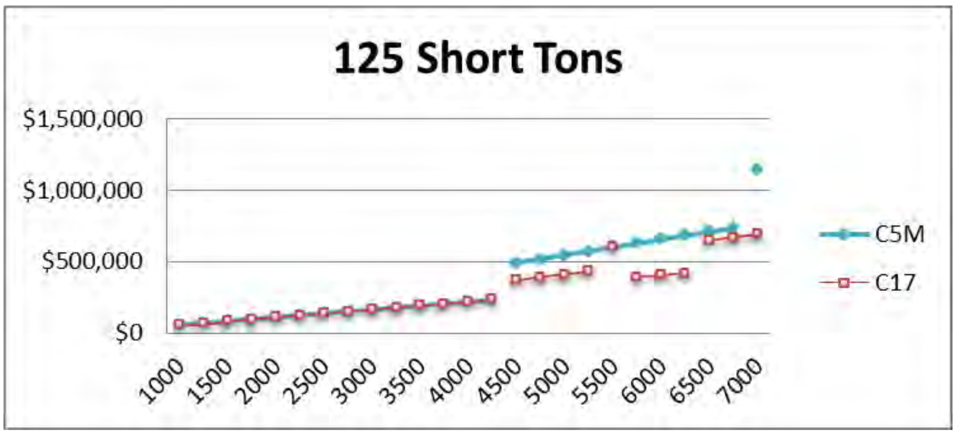
Appendix M: Maximum cargo load model graphs

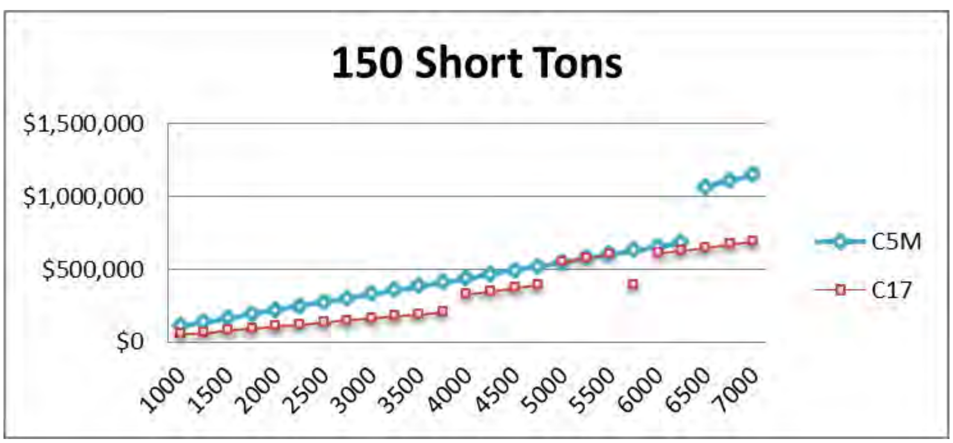







100 Short Tons
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


125 Short Tons
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


150 Short Tons
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
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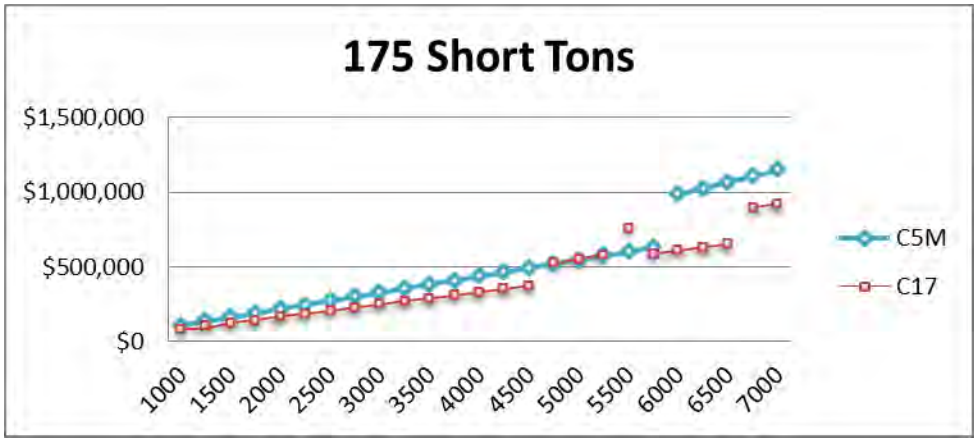
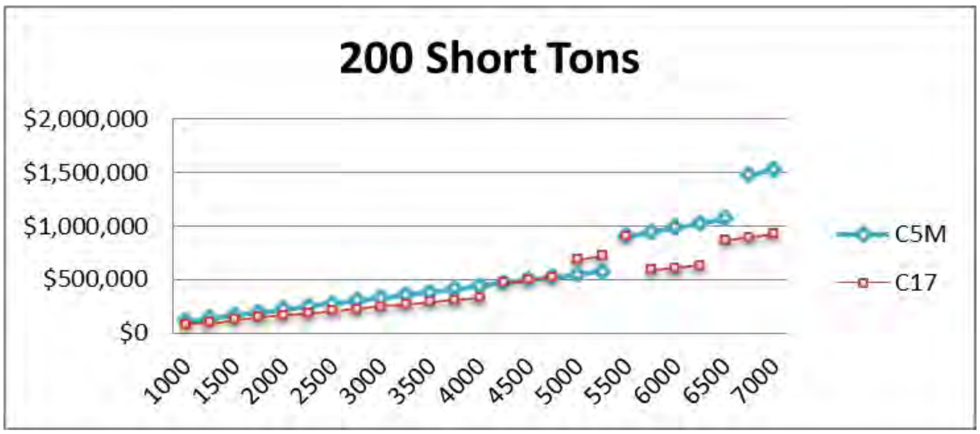
6500
7000
C5M
C17


175 Short Tons
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


200 Short Tons
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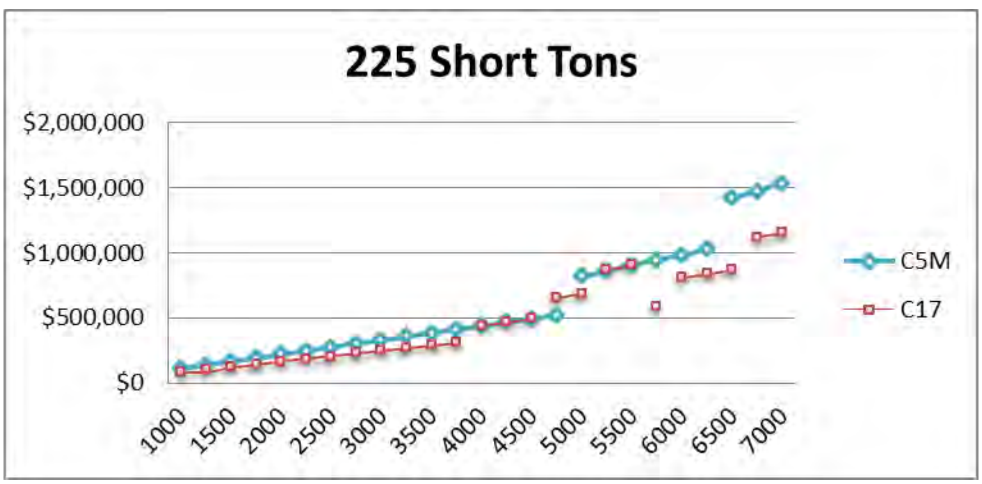
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


225 Short Tons
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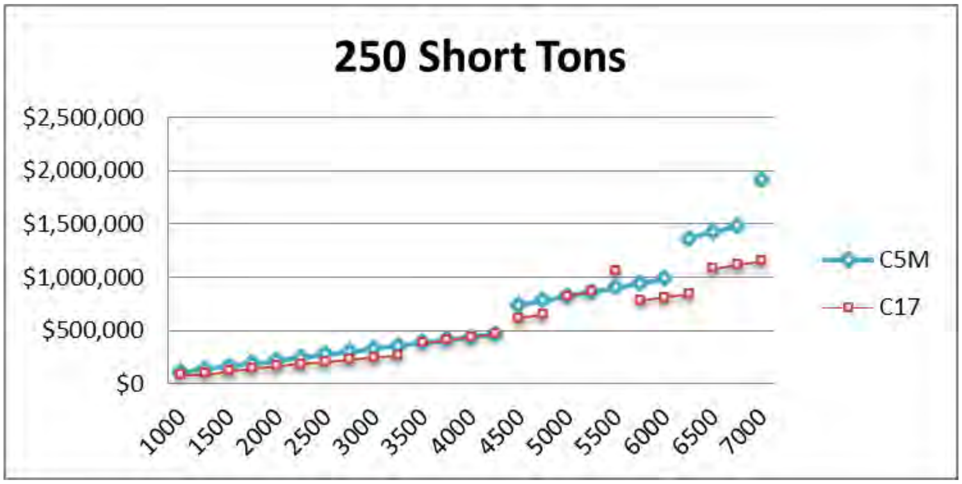
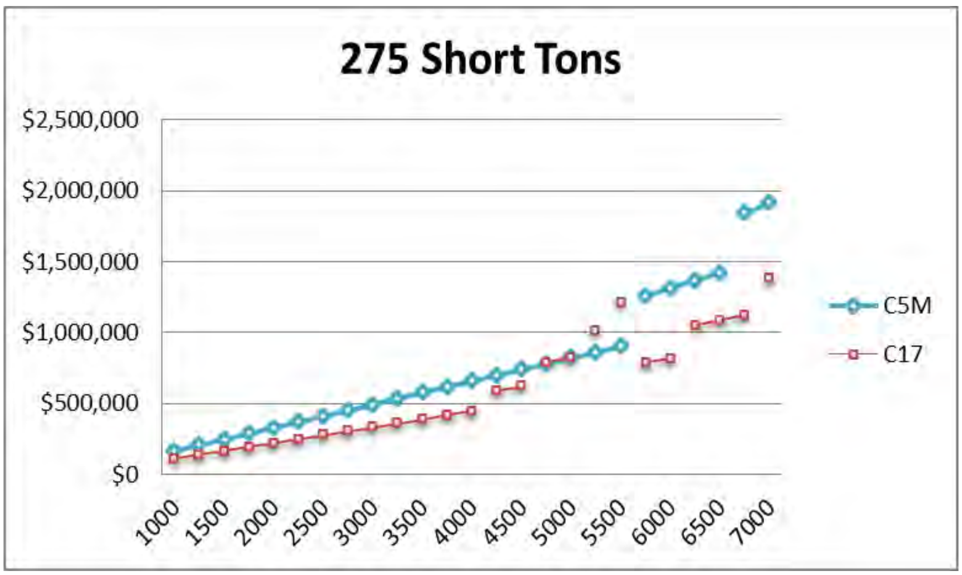
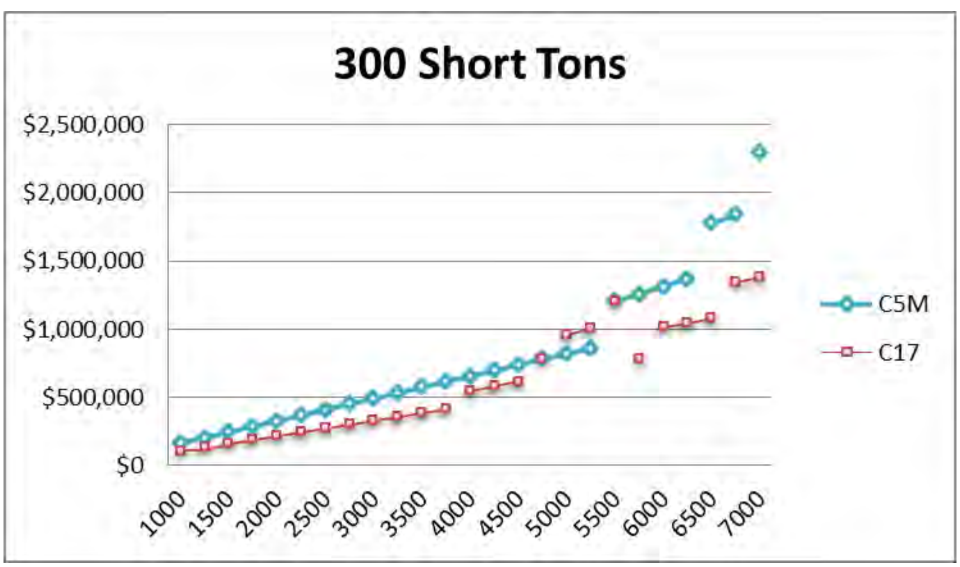
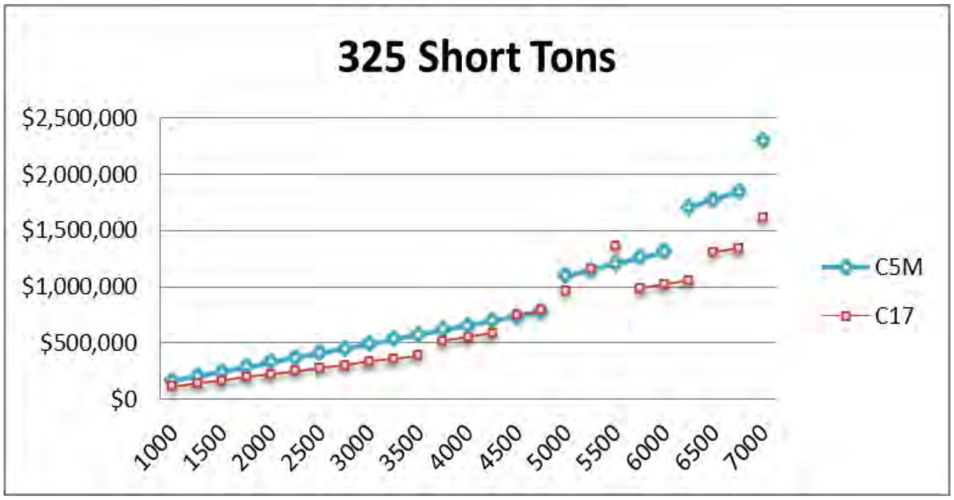
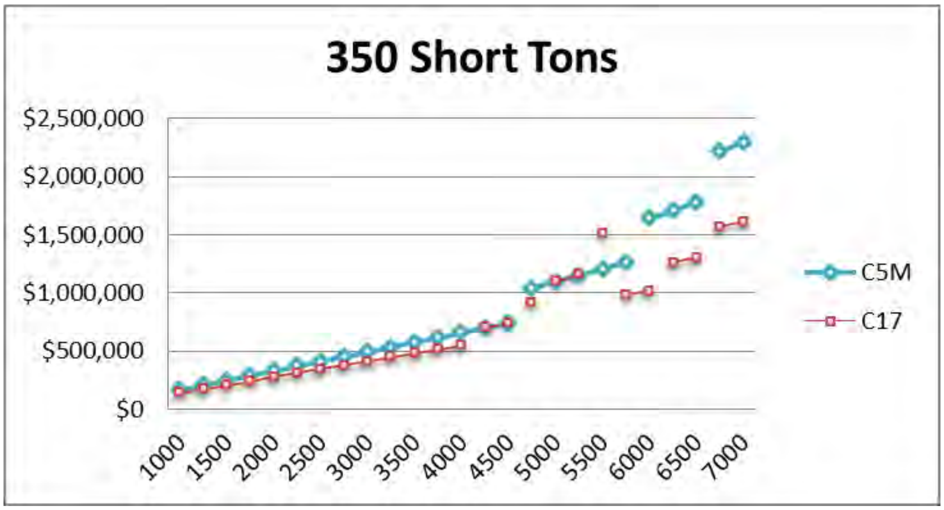
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


250 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


275 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


300 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


325 Short Tons
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


350 Short Tons
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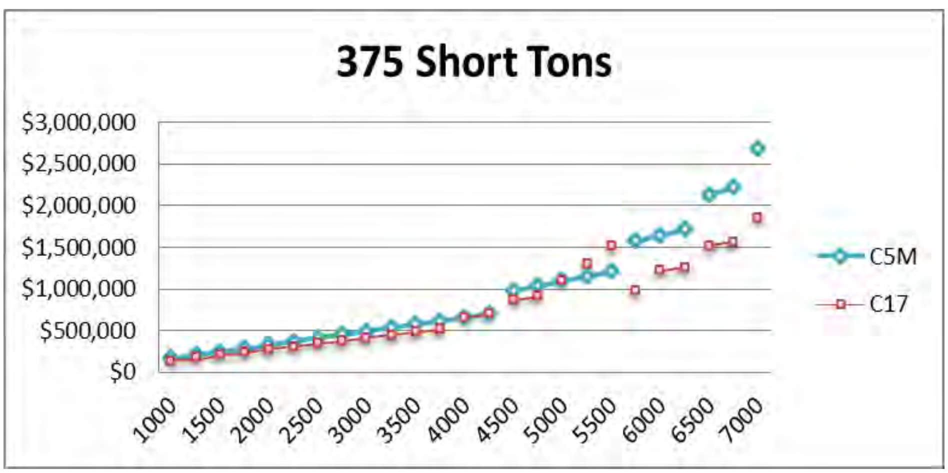
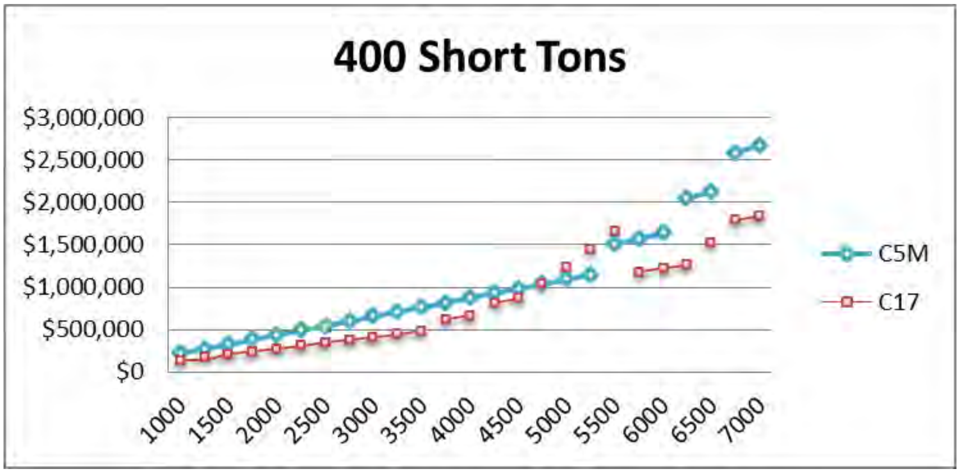
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


375 Short Tons
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


400 Short Tons
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

Appendix N: No weight restriction and aerial refueling model run results

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$54,900
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$151,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$137,500
5250	$286,800	$144,400
5500	$300,500	$151,200
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

25 Short Tons

	C5M	C17
1000	$54,600	$27,500
1250	$68,300	$34,400
1500	$82,000	$41,200
1750	$95,600	$48,100
2000	$109,300	$55,000
2250	$122,900	$61,900
2500	$136,600	$68,700
2750	$150,300	$75,600
3000	$163,900	$82,500
3250	$177,600	$89,400
3500	$191,200	$96,200
3750	$204,900	$103,100
4000	$218,500	$110,000
4250	$232,200	$116,900
4500	$245,900	$123,700
4750	$259,500	$130,600
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$196,200
6000	$327,800	$203,100
6250	$341,500	$209,900
6500	$355,100	$216,800
6750	$368,800	$223,700
7000	$382,500	$230,600

50 Short Tons

	C5M	C17
1000	$54,600	$55,000
1250	$68,300	$68,700
1500	$82,000	$82,500
1750	$95,600	$96,200
2000	$109,300	$110,000
2250	$122,900	$123,700
2500	$136,600	$137,500
2750	$150,300	$151,200
3000	$163,900	$165,000
3250	$177,600	$178,700
3500	$191,200	$192,500
3750	$204,900	$206,200
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$245,900	$247,500
4750	$259,500	$261,200
5000	$273,200	$275,000
5250	$286,800	$288,700
5500	$300,500	$302,500
5750	$314,200	$392,400
6000	$327,800	$406,100
6250	$341,500	$419,900
6500	$393,200	$433,600
6750	$406,900	$447,400
7000	$420,500	$461,100

75 Short Tons

	C5M	C17
1000	$54,600	$55,000
1250	$68,300	$68,700
1500	$82,000	$82,500
1750	$95,600	$96,200
2000	$109,300	$110,000
2250	$122,900	$123,700
2500	$136,600	$137,500
2750	$150,300	$151,200
3000	$163,900	$165,000
3250	$177,600	$178,700
3500	$191,200	$192,500
3750	$204,900	$206,200
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$245,900	$247,500
4750	$259,500	$261,200
5000	$273,200	$412,500
5250	$286,800	$433,100
5500	$338,600	$453,700
5750	$352,200	$392,400
6000	$365,900	$406,100
6250	$387,600	$419,900
6500	$393,200	$433,600
6750	$406,900	$447,400
7000	$420,500	$461,100

100 Short Tons

	C5M	C17
1000	$54,600	$55,000
1250	$68,300	$68,700
1500	$82,000	$82,500
1750	$95,600	$96,200
2000	$109,300	$110,000
2250	$122,900	$123,700
2500	$136,600	$137,500
2750	$150,300	$151,200
3000	$163,900	$165,000
3250	$177,600	$178,700
3500	$191,200	$192,500
3750	$204,900	$206,200
4000	$218,500	$220,000
4250	$232,200	$233,700
4500	$283,900	$323,600
4750	$297,600	$337,400
5000	$311,300	$351,100
5250	$324,900	$364,900
5500	$338,600	$378,600
5750	$352,200	$392,400
6000	$365,900	$406,100
6250	$759,100	$419,900
6500	$786,400	$650,400
6750	$813,800	$671,100
7000	$841,100	$691,700

125 Short Tons

	C5M	C17
1000	$109,300	$55,000
1250	$136,600	$68,700
1500	$163,900	$82,500
1750	$191,200	$96,200
2000	$218,500	$110,000
2250	$245,900	$123,700
2500	$273,200	$137,500
2750	$300,500	$151,200
3000	$327,800	$165,000
3250	$355,100	$178,700
3500	$382,500	$192,500
3750	$409,800	$206,200
4000	$437,100	$296,100
4250	$464,400	$309,900
4500	$491,700	$323,600
4750	$519,100	$337,400
5000	$546,400	$351,100
5250	$573,700	$364,900
5500	$601,000	$378,600
5750	$628,300	$392,400
6000	$655,600	$609,200
6250	$683,000	$629,800
6500	$786,400	$650,400
6750	$813,800	$671,100
7000	$841,100	$691,700

150 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$350,600
4500	$491,700	$371,200
4750	$519,100	$506,100
5000	$546,400	$526,700
5250	$573,700	$547,300
5500	$677,200	$567,900
5750	$704,500	$588,600
6000	$731,800	$609,200
6250	$759,100	$629,800
6500	$786,400	$650,400
6750	$813,800	$671,100
7000	$841,100	$691,700

175 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$330,000
4250	$464,400	$464,800
4500	$491,700	$485,500
4750	$519,100	$506,100
5000	$546,400	$526,700
5250	$573,700	$547,300
5500	$677,200	$567,900
5750	$704,500	$588,600
6000	$731,800	$609,200
6250	$759,100	$629,800
6500	$786,400	$867,200
6750	$813,800	$894,700
7000	$841,100	$922,200

200 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$288,700
3750	$409,800	$309,300
4000	$437,100	$444,200
4250	$464,400	$464,800
4500	$491,700	$485,500
4750	$519,100	$506,100
5000	$622,500	$526,700
5250	$649,800	$547,300
5500	$677,200	$567,900
5750	$704,500	$588,600
6000	$731,800	$812,300
6250	$759,100	$839,700
6500	$786,400	$867,200
6750	$1,220,600	$1,118,400
7000	$1,261,600	$1,152,800

225 Short Tons

	C5M	C17
1000	$109,300	$82,500
1250	$136,600	$103,100
1500	$163,900	$123,700
1750	$191,200	$144,400
2000	$218,500	$165,000
2250	$245,900	$185,600
2500	$273,200	$206,200
2750	$300,500	$226,900
3000	$327,800	$247,500
3250	$355,100	$268,100
3500	$382,500	$403,000
3750	$409,800	$423,600
4000	$437,100	$444,200
4250	$464,400	$464,800
4500	$567,900	$485,500
4750	$595,200	$506,100
5000	$622,500	$526,700
5250	$649,800	$547,300
5500	$677,200	$567,900
5750	$704,500	$784,800
6000	$731,800	$812,300
6250	$1,138,700	$839,700
6500	$1,179,700	$1,084,100
6750	$1,220,600	$1,118,400
7000	$1,261,600	$1,152,800

250 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$386,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$412,500
4000	$655,600	$440,000
4250	$696,600	$619,800
4500	$737,600	$647,300
4750	$778,600	$674,800
5000	$819,600	$702,300
5250	$860,500	$729,800
5500	$1,015,800	$757,300
5750	$1,056,700	$784,800
6000	$1,097,700	$812,300
6250	$1,138,700	$1,049,700
6500	$1,179,700	$1,084,100
6750	$1,220,600	$1,118,400
7000	$1,261,600	$1,383,400

275 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$386,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$412,500
4000	$655,600	$592,300
4250	$696,600	$619,800
4500	$737,600	$647,300
4750	$778,600	$674,800
5000	$819,600	$702,300
5250	$860,500	$729,800
5500	$1,015,800	$757,300
5750	$1,056,700	$784,800
6000	$1,097,700	$1,015,300
6250	$1,138,700	$1,049,700
6500	$1,179,700	$1,084,100
6750	$1,220,600	$1,342,100
7000	$1,261,600	$1,383,400

300 Short Tons

	C5M	C17
1000	$163,900	$110,000
1250	$204,900	$137,500
1500	$245,900	$165,000
1750	$286,800	$192,500
2000	$327,800	$220,000
2250	$386,800	$247,500
2500	$409,800	$275,000
2750	$450,800	$302,500
3000	$491,700	$330,000
3250	$532,700	$357,500
3500	$573,700	$385,000
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$584,300
4500	$737,600	$647,300
4750	$778,600	$674,800
5000	$933,800	$702,300
5250	$974,700	$729,800
5500	$1,015,800	$757,300
5750	$1,056,700	$980,900
6000	$1,097,700	$1,015,300
6250	$1,138,700	$1,049,700
6500	$1,179,700	$1,300,900
6750	$1,220,600	$1,342,100
7000	$1,682,200	$1,613,900

325 Short Tons

	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$386,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$549,900
4250	$696,600	$701,200
4500	$737,600	$742,400
4750	$892,800	$843,500
5000	$933,800	$877,800
5250	$974,700	$912,200
5500	$1,015,800	$946,600
5750	$1,056,700	$980,900
6000	$1,097,700	$1,015,300
6250	$1,138,700	$1,259,600
6500	$1,572,800	$1,300,900
6750	$1,627,500	$1,565,800
7000	$1,682,200	$1,613,900

350 Short Tons

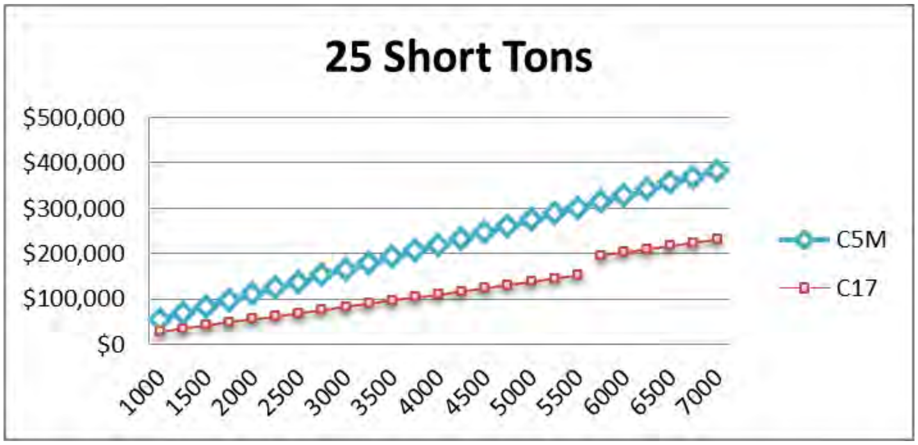
	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$386,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$515,600
4000	$655,600	$740,300
4250	$696,600	$774,700
4500	$851,800	$809,100
4750	$892,800	$843,500
5000	$933,800	$877,800
5250	$974,700	$912,200
5500	$1,015,800	$946,600
5750	$1,056,700	$980,900
6000	$1,097,700	$1,218,400
6250	$1,518,200	$1,259,600
6500	$1,572,800	$1,517,700
6750	$1,627,500	$1,565,800
7000	$1,682,200	$1,844,500

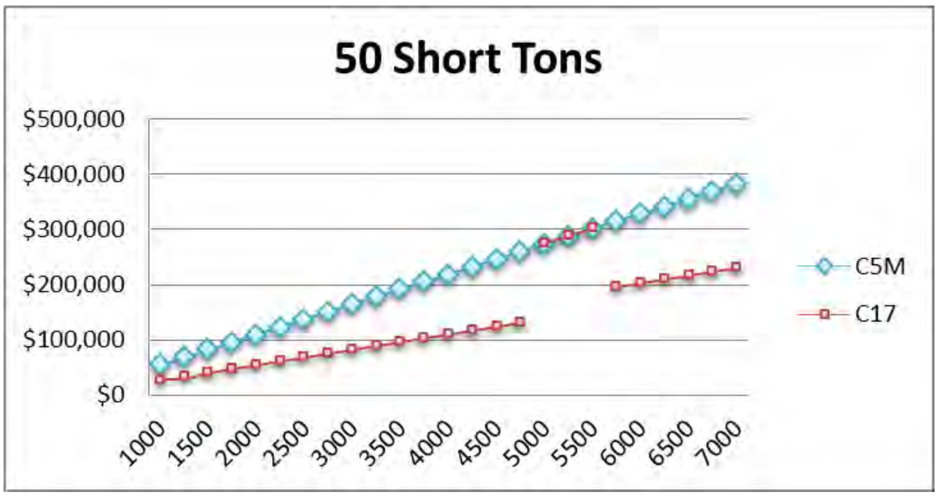
375 Short Tons

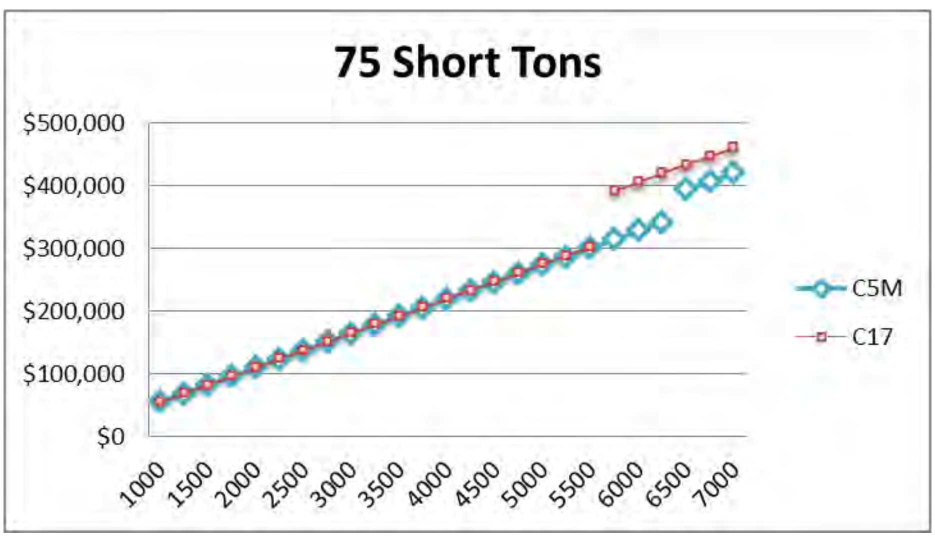
	C5M	C17
1000	$163,900	$137,500
1250	$204,900	$171,900
1500	$245,900	$206,200
1750	$286,800	$240,600
2000	$327,800	$275,000
2250	$386,800	$309,300
2500	$409,800	$343,700
2750	$450,800	$378,100
3000	$491,700	$412,500
3250	$532,700	$446,800
3500	$573,700	$481,200
3750	$614,700	$706,000
4000	$655,600	$740,300
4250	$810,900	$774,700
4500	$851,800	$809,100
4750	$892,800	$843,500
5000	$933,800	$877,800
5250	$974,700	$912,200
5500	$1,015,800	$946,600
5750	$1,056,700	$1,177,100
6000	$1,463,600	$1,218,400
6250	$1,518,200	$1,259,600
6500	$1,572,800	$1,517,700
6750	$1,627,500	$1,789,500
7000	$1,682,200	$1,844,500

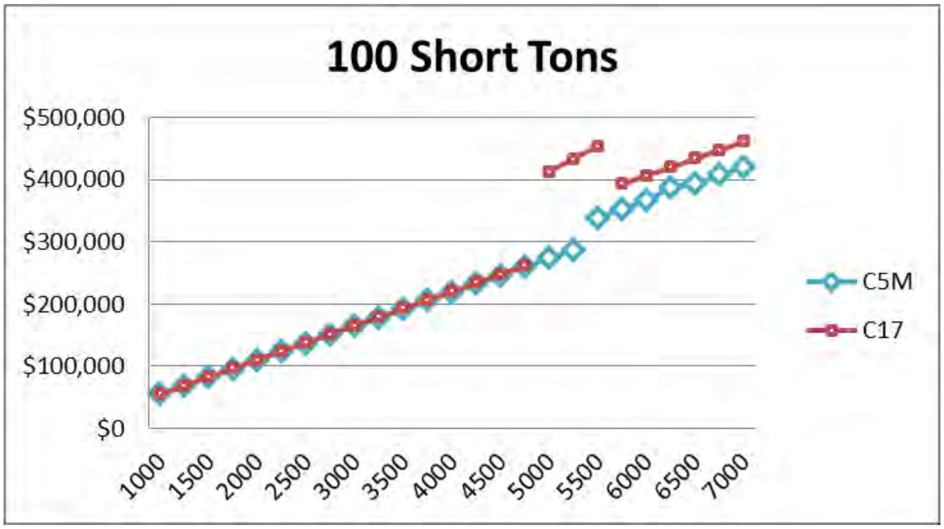
400 Short Tons

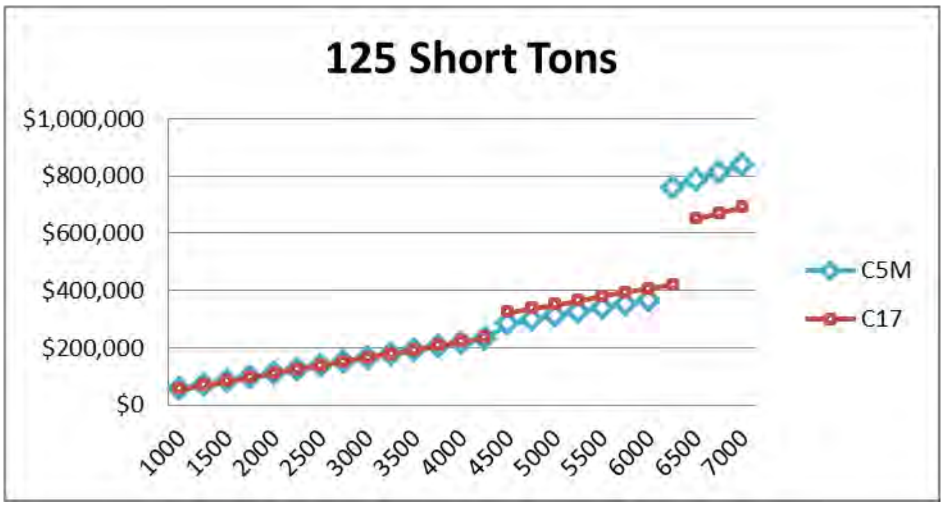
Appendix O: No weight restriction and aerial refueling model graphs

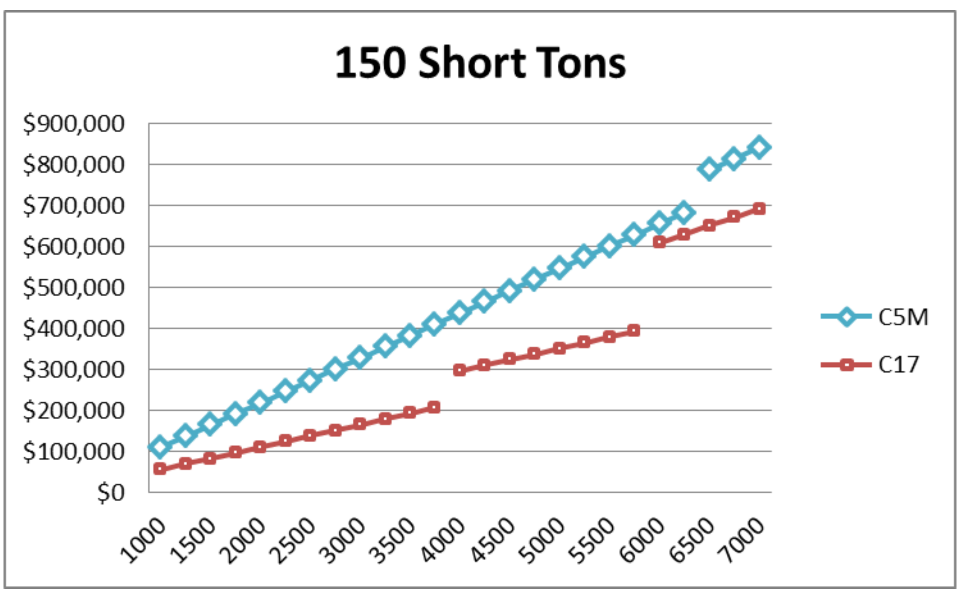


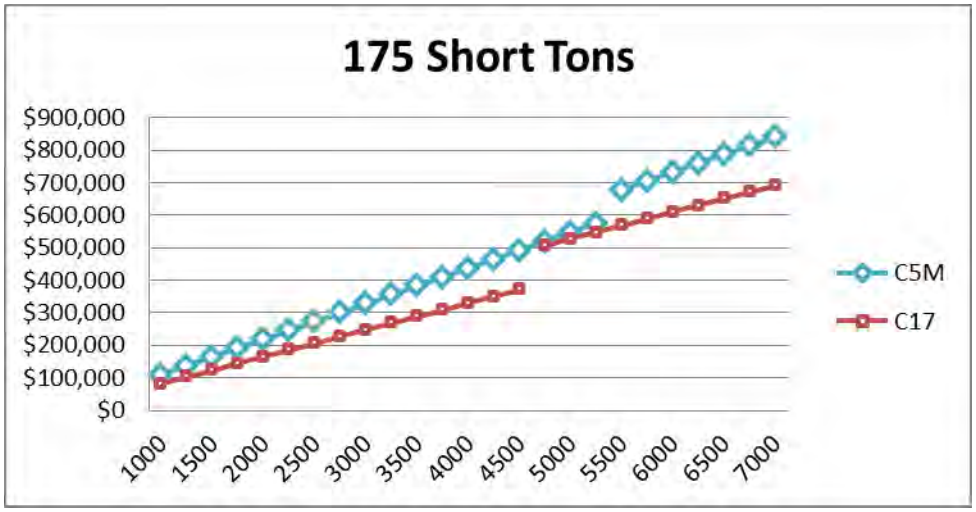


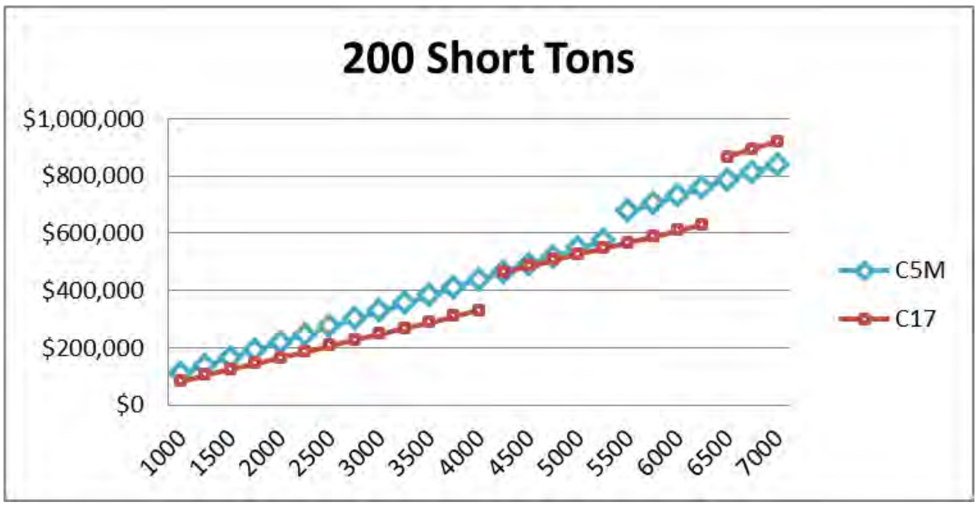


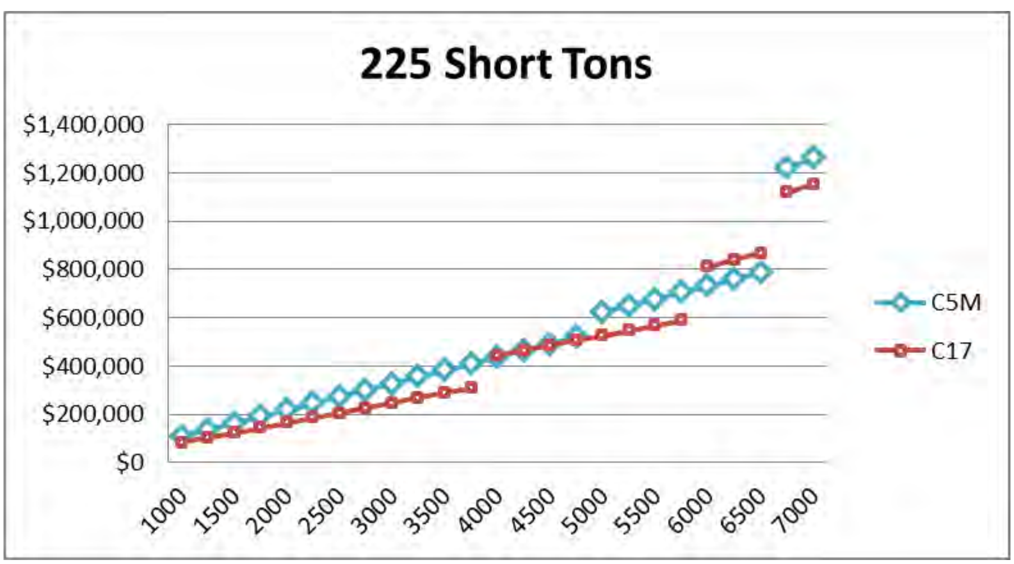

100 Short Tons
$500,000
$400,000
$300,000
$200,000
$100,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

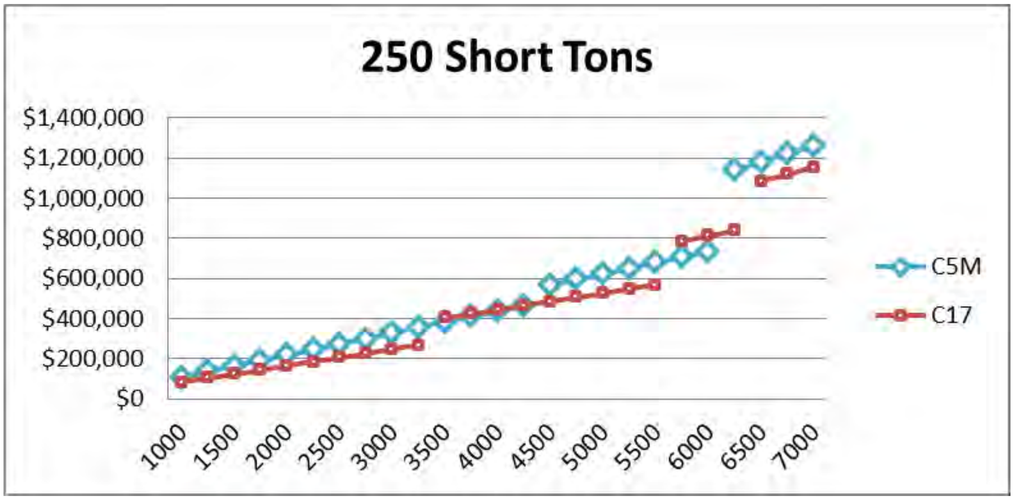

125 Short Tons
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

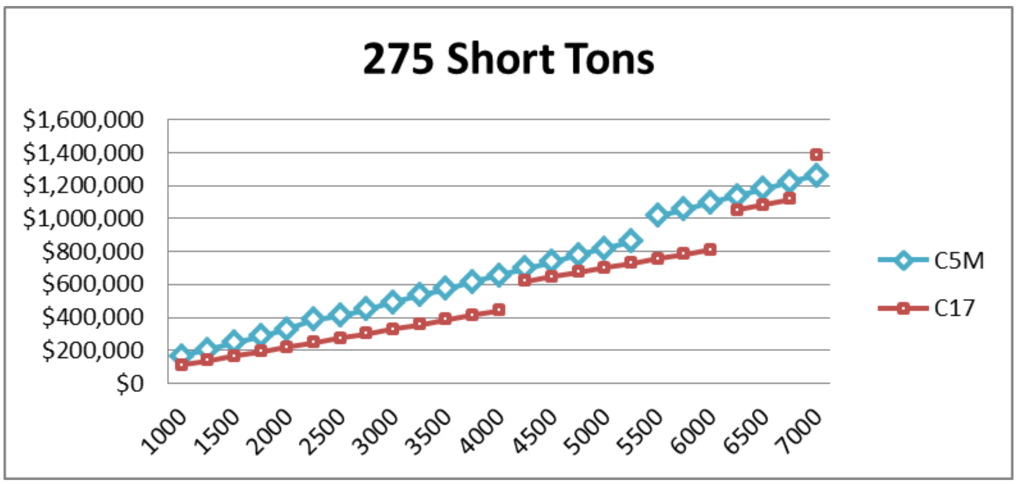

150 Short Tons
$900,000
$800,000
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17

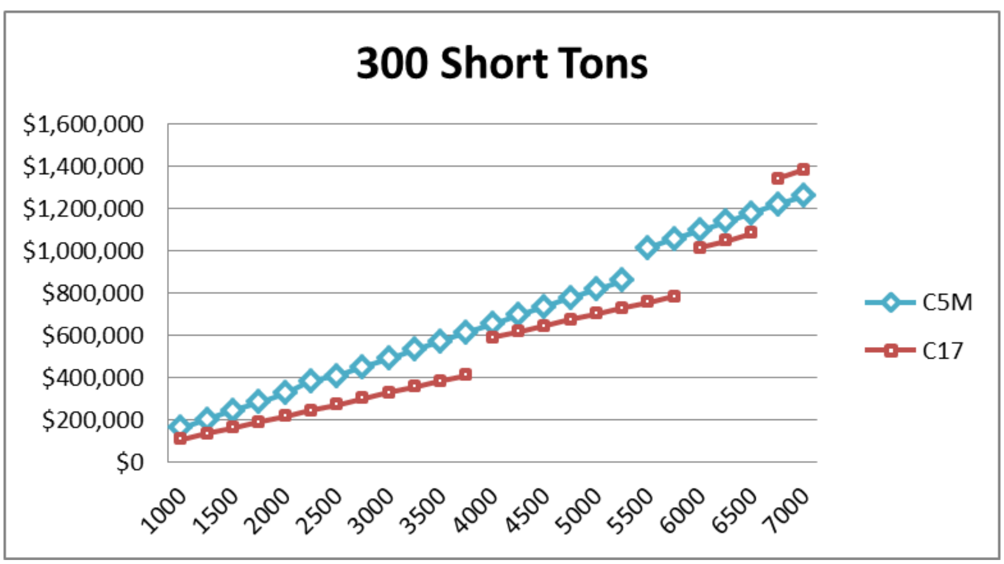

175 Short Tons
$900,000
$800,000
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


200 Short Tons
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


225 Short Tons
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


250 Short Tons
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17


275 Short Tons
$1,600,000
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
C5M
C17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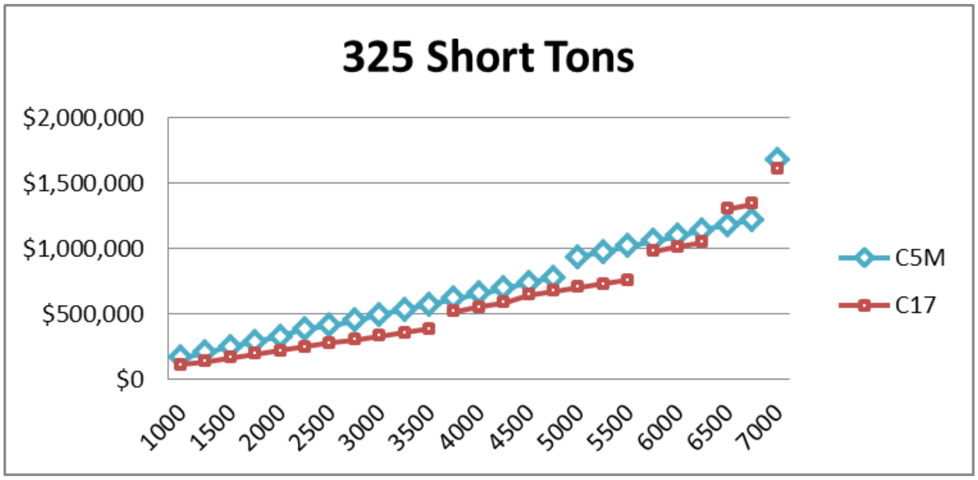
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C5M
C17


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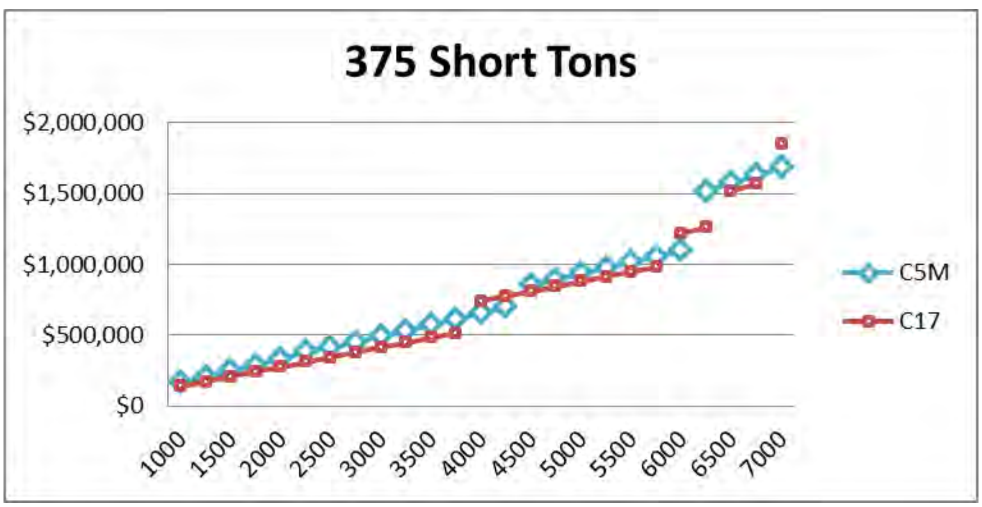
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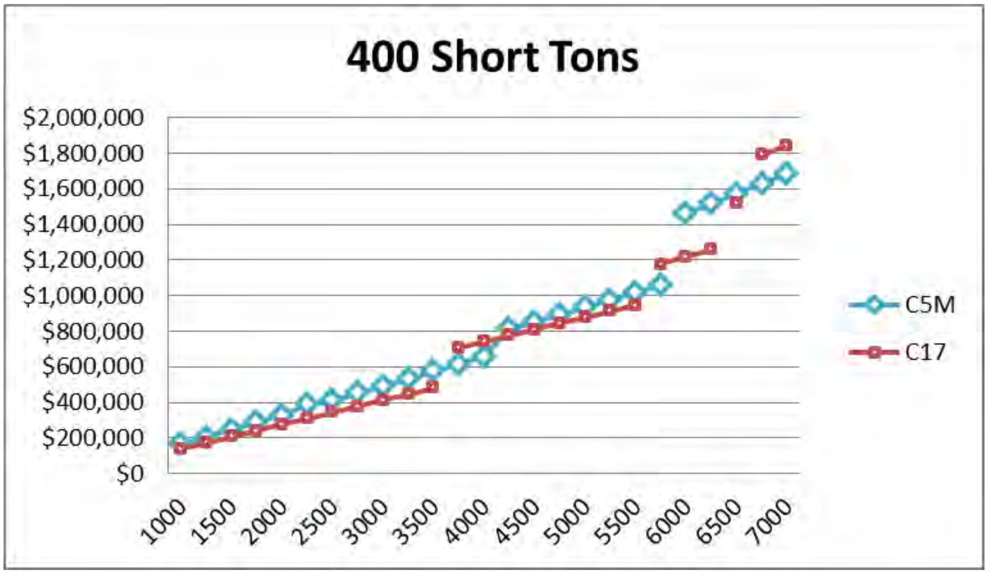
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Appendix P: Storyboard

C-5M Super Galaxy Utilization with Joint Precision Airdrop System

Major Michael T. Weitz

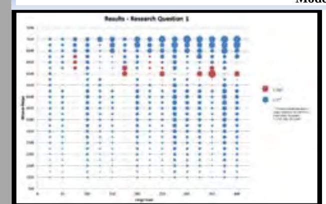
Advisor: Dr. Alan Johnson

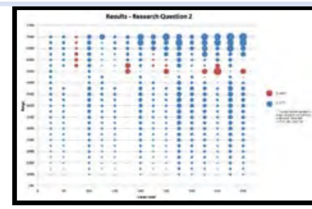
Reader: Dr. Jeffery Weir

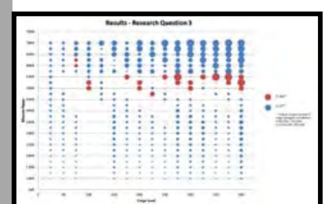
Department of Operational Sciences (ENS)

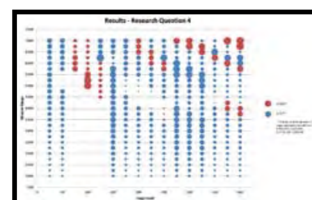
Air Force Institute of Technology

Model Results









Introduction

The purpose of this research was to determine the viability of utilizing the Joint Precision Airdrop System with the C-5M Super Galaxy weapon system. Specifically, this thesis sought research the ability of the C-5M to use the Joint Precision Airdrop System and to answer four main research questions addressing a cost benefit analysis between the C-5M Super Galaxy and the C-17 Globemaster III. The research questions were answered through a comprehensive literature review and the creation of a model that determined the cost associated with specific range versus payload mission types. The payloads used ranged from 25 short tons, to 400 short tons, with mission ranges looked at between 1000 and 7000 miles. The results from the various model runs were compared to determine which airframe, C-5M or C-17, was less expensive to operate in the mission range.

Research Questions

- *Can the C-5M be a cost effective way to conduct airdrop missions using the Joint Precision Airdrop System?*
- *To what extent will incorporation of an aerial refueling mission reduce the number of aircraft needed thereby reducing the cost?*
- *How does the design limitation imposed on the C-5M and C-17 change the cost effectiveness of using one airframe versus the other?*
- *What will incorporation of an aerial refueling mission, in conjunction with the removal of the weight associated design limitation, provide as to cost data for the C-5M?*

Model Methodology

Model Summary

	Missions in which C-5M less costly to operate	Average Savings for C-5M
Model Run 1	71	$25,200
Model Run 2	74	$25,800
Model Run 3	96	$38,300
Model Run 4	106	$36,100

	Missions in which C-17 less costly to operate	Average Savings for C-17
Model Run 1	329	$173,800
Model Run 2	326	$167,000
Model Run 3	304	$183,200
Model Run 4	294	$100,000

* Model Runs support their respective research questions

Sponsor:
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Conclusions

- *Bubble chart represent cost difference between C-5M and C-17 in their respective mission (Cargo load vs. mission range)*
  - *Larger bubble represent larger cost difference*
- *C-17 lowest cost alternative in majority of scenarios*
  - *Different in costs between C-5M and C-17 is small in numerous missions focused around 75 short ton cargo load which relates to one C-5M and two C-17 aircraft*
- *C-5M still a viable option for airlift mission using JPADS*
  - *Minimal cost difference in multiple missions means C-5M can be a worthwhile asset in aerial delivery*

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14. ABSTRACT

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