



**463L PALLET COMPATIBILITY IMPLICATIONS FOR WARFIGHTING
CAPACITY IN THE CIVIL RESERVE AIR FLEET**

GRADUATE RESEARCH PAPER

John M. Habbestad, Major, USAF

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**DEPARTMENT OF THE AIR FORCE
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Major, USAF

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Abstract

The Department of Defense (DOD) uses the 463L pallet nearly exclusively in the movement of war and peacetime palletized cargo. Since its introduction in the 1960s, the pallet has been used on DOD aircraft and civilian charter cargo aircraft to move defense materials. Unfortunately, the Boeing 777, the current freighter of choice by many air carriers, is unable to accommodate the 463L pallet in a traditional configuration. AMC is very concerned with the limitations that newer CRAF aircraft purchases such as the Boeing 777 create and their ability to provide the necessary wartime support when needed. This research uses a formula to determine if 463L incompatibility within the CRAF will affect a wartime mobility capacity requirement and if so, what the extent of those impacts are.

This research focuses on an analysis of the 463L pallet and its compatibility with CRAF aircraft. It uses this quantitative information to maximize pallet loading on aircraft without modification. This analysis takes into account pallet dimensions and aircraft cargo floor limitations and flexibility. Additionally, it uses SMEs within the mobility community and the AMC CRAF office to identify these interoperability issues.

Acknowledgments

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John M. Habbestad

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463L PALLET COMPATIBILITY IMPLICATIONS FOR WARFIGHTING CAPACITY IN THE CIVIL RESERVE AIR FLEET

I. Introduction

Background and General Issue

Air Mobility Command (AMC), under the direction of the United States Transportation Command (USTRANSCOM) is charged with the responsibility of flying mobility equipment and airmen throughout the globe. These movements are primarily carried out with organic AMC aircraft with support from contracted commercial carriers. However, during conflict, requirements increase significantly and AMC must utilize their commercial contracted partners more heavily. These carriers supplement capacity to ensure the warfighter has what they need when they need it. This commercial program is called the Civil Reserve Air Fleet, or CRAF. Developed in 1951, the CRAF is activated only by request from the Commander, USTRANSCOM, with approval from the Secretary of Defense (SecDef) (GAO, 2013). The CRAF is comprised of many major and regional US airlines that during conflict, when requested, must provide mission capable support within a short period of time from notification. This unique responsibility is rewarded by offering CRAF carriers incentives during times of peace. These incentives include peacetime travel contracts for government travel and monetary incentives in fleet redevelopment and modernization (United States Transportation Command, 2014).

One of the unintended consequences of the fleet modernization incentives was the development, production and purchasing of aircraft not compatible to carry the Department

of Defense (DOD) pallet of choice, the 463L (Hondel, 2015). Unfortunately, aircraft manufactures and airlines, during the last few decades have been less influenced by the needs of the DOD and the compatibility of cargo handling systems for the 463L pallet are not a primary concern in the development and procurement of new products. This is attributed to the reduction in commercial business requests by the DOD, causing airlines to base most of their decisions in fleet recapitalization on commercial basis' versus DOD requirements.

As a result, the 463L is now incompatible with several new aircraft being developed and purchased. Specifically, the Boeing 777, the current freighter of choice by many carriers, is unable to accommodate the 463L pallet in a traditional configuration without modification (Hondel, 2015). AMC is very concerned with the limitations of newer CRAF aircraft purchases and their ability to provide the necessary support when needed. This research uses a formula based on current mobility planning information and CRAF activation requirements to create a model to determine if there is an impact on the potential employment of Boeing 777s in the CRAF cargo fleet.

Research Objectives/Questions/Hypotheses

The goal of this research is to determine if there is an impact to warfighting capacity with the employment of the Boeing 777. This research answers the following questions through quantitative analysis and subject matter expert (SME) consultations relating to this pallet issue:

1. What is the 463L capacity on the Boeing 777?

2. What aircraft provide the majority of CRAF cargo capability and what is their expected retirement timeline?
3. How many Boeing 777s would it take to fulfill the retirement capabilities of older CRAF aircraft and what are the courses of action (COA) associated with its introduction?
4. What are important limitations associated with the employment of the Boeing 777 and other CRAF aircraft used to transport the 463L and what impact will this have on further dependence on CRAF airlift?

The hypothesis is that the Boeing 777, in its current capacity, would be greatly inefficient in moving 463L pallets. Additionally, the 777, if modified, could fulfill the required capacity shortfalls in ageing CRAF airframes. Finally, there may be an issue with further acquisition of aircraft with lower hold pallet height limitations and pallet contouring, such as the Boeing 777, as they replace less restrictive aircraft such as the Boeing 747.

Research Focus

This research focuses on an analysis of the 463L pallet and its compatibility specifically with the Boeing 777. This research uses quantitative information to maximize pallet loading on aircraft without modification and with a modification. This analysis takes into account pallet dimensions and aircraft cargo floor limitations and flexibility. To accomplish this, consultation with SMEs within the mobility community is accomplished to confirm assumptions on pallet compatibility and mobility planning factors. This research analyzes the distribution of long-range cargo CRAF capabilities

and requirements among the various fleet types to determine the impact of the retirement and replacement of older CRAF aircraft.

Assumptions/Limitations

In order to set a standardized baseline for quantitative calculations on historical mobility data the following assumptions are made:

Assumption 1: Pallet requirements during FY2011 thru FY2014 are a close predictor of near-future demand within AMC.

Assumption 2: The data itself provided for the missions selected is accurate. Any inaccuracies can be assumed to be minimal and not have a significant impact on the outcome.

Assumption 3: The predictions made on the payload ranges provided in public industry documents for both the 747-100 and 777 freighters are correct.

Assumption 4: The predictions offered in multiple industry sources on the future of air freight fleet replacements and current aircraft age are accurate.

Implications

The intent of this project is to provide insights on the current pallet movement requirements and what impact a non-463L compatible aircraft has on the planned wartime capacity of the future. This is not intended to apply costs associated with future aircraft or pallet modifications, but instead outline what the current loads are, what is currently providing the airlift for those loads, and identifying the impacts of applying the Boeing 777 or other non-compatible aircraft against those missions.

Ultimately, it is the responsibility of the mobility community to provide the requirements of the Combatant Commanders and fulfill the proper mix of organic and CRAF aircraft as outlined in the current and future Mobility Capabilities Requirements Studies.

II. Literature Review

Chapter Overview

There is currently no thorough analysis on the effects on mobility cargo requirements due to 463L pallet compatibility issues on aircraft such as the Boeing 777 (Hondel, 2015). There are many factors that have led to the current situation that the Department of Defense is facing. The 463L pallet, designed decades ago, was not a design requirement for the Boeing 777 freighter. An understanding of what and how the CRAF works is important; especially to develop a plan to ensure that aircraft are as compatible and capable as possible to fulfill their supporting war and peacetime missions. Understanding what the Mobility Capabilities and Requirements Study requires will provide the “so what” on why the 463L pallet compatibility issue is so important.

By the end of this literature review, the reader should have sufficient background on the Boeing 777, its pallet accommodations and the DOD’s 463L pallet. Additionally, the reader should understand the role of the CRAF and the current health of the commercial air freight market and how it could affect the CRAF.

Introduction of the Boeing 777 Freighter

Since the 2009 introduction of the Boeing 777 freighter, sales and interest in its capabilities and efficiencies have been well documented (Boeing, 2016). However, due to the large initial investment costs for the new aircraft, its sales were initially limited. As the capabilities of the aircraft’s ability to deliver a payload of 224,900 pounds nearly

5,000 nautical miles were observed, sales began to increase. Demand for the freighter is strong with 160 total orders and over 120 aircraft delivered.

The capabilities and efficiencies of the new freighter exceed the capabilities of the MD-11 and Boeing 747-400, the freighters that make up the majority of CRAF airlift capacity (Boeing, 2016; United States Department of Transportation, 2016). If the DOD could rely solely on organic airlift to accomplish its wartime mission, there would be no issue. Unfortunately, according to the Mobility Capabilities & Requirements Study 2016, the CRAF will be counted on to provide critical support of people and cargo (GAO, 2013). Due to this reliance on our civil partners, a thorough understanding of the history and role of the 463L pallet is necessary.

463L Pallet and the Commercial Comparison

The 463L pallet, developed throughout the 1950s was officially adopted for use in the 1960s (Galloway, 1997). The pallet was designed to be a multi-role device used to carry bulk and some rolling stock items that were not containerized. The construction itself is a balsa wood core surrounded by an aluminum shell (Galloway, 1997). The dimensions are 88" X 108" X 2.25". It is surrounded by 22 d-rings used to secure cargo nets and straps (Galloway, 1997). The empty weight is 290 pounds and its carrying capacity is 10,000 pounds (Galloway, 1997).

This pallet has been reliable and cheap to manufacture and is USTRANSCOM's device of choice when moving DOD cargo. Unfortunately, standardized commercial pallets for most contracted DOD carriers such as the P6P standard pallet and MDP main deck pallet, Figures 1, 2 and 3, have exceeded the dimensions of the 463L and are not

readily compatible on AMC organic aircraft (Hondel, 2015). Additionally, the 463L is not readily compatible with commercial aircraft designed to carry these newer pallets. Due to the lack of interoperability, concern has been voiced about the increased purchases of these non-compatible aircraft.

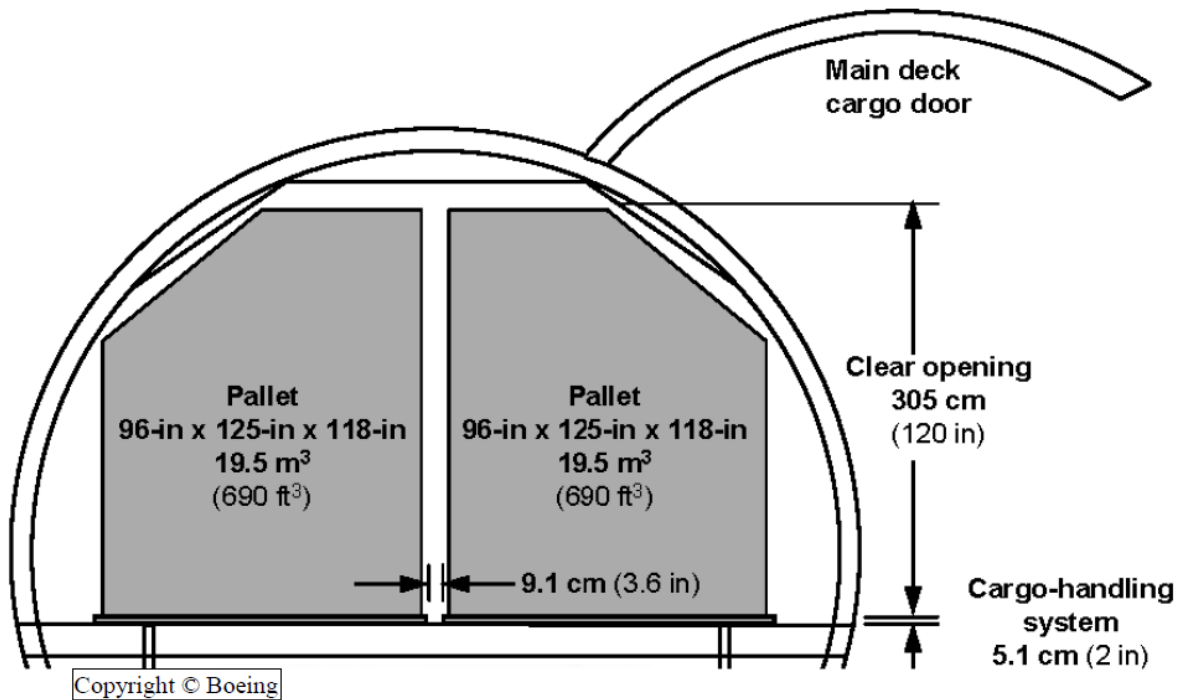


Figure 1: Boeing 777 Upper Deck Looking Aft Commercial Pallet Layout (Air Mobility Command, 2011)

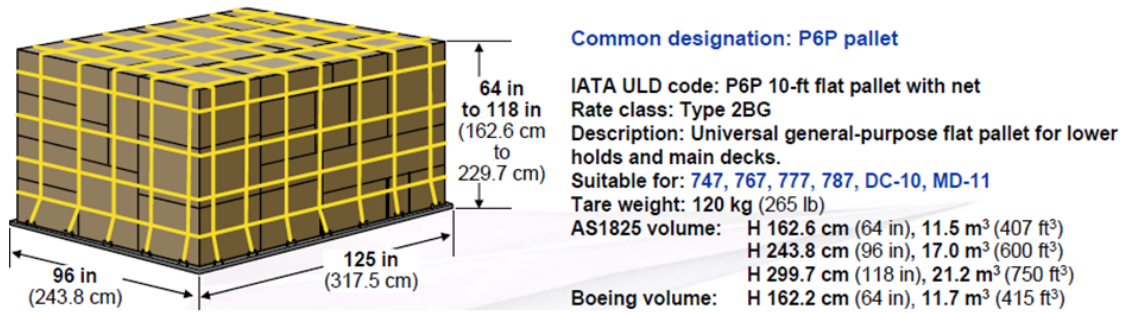


Figure 2: Standard P6P Pallet Dimensions (Boeing, 2012)

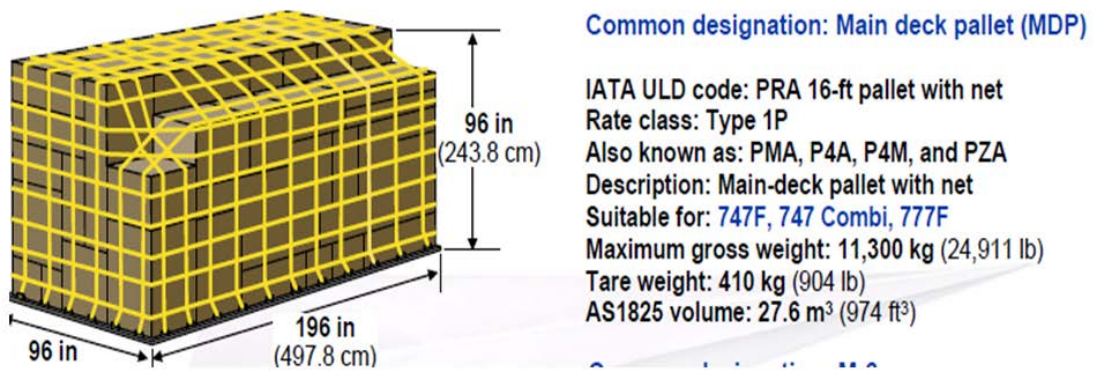


Figure 3: Main Deck Pallet (MDP) Dimensions (Boeing, 2012)

Non-compliant aircraft, such as the Boeing 777 are not completely unusable for DOD pallet movements. AMC load experts predict that the 88” X 108” bias pallet could be easily handled by the Boeing 777 with minor cargo floor modifications. Without these modifications, however, pallets would have to be manually shored and strapped, reducing the probable pallet capacity of the aircraft from 37 to 14 pallets. See Figures 4, 5 and 6. Without reconfiguring, Boeing 777s, with the use of shoring and cargo straps, could accommodate up to 14 centerline-loaded 463L pallets in the 108” width orientation on the main cargo floor (Hondel, 2015). Unfortunately, and aircraft capable of up to 37

commercial pallets would go greatly underutilized.

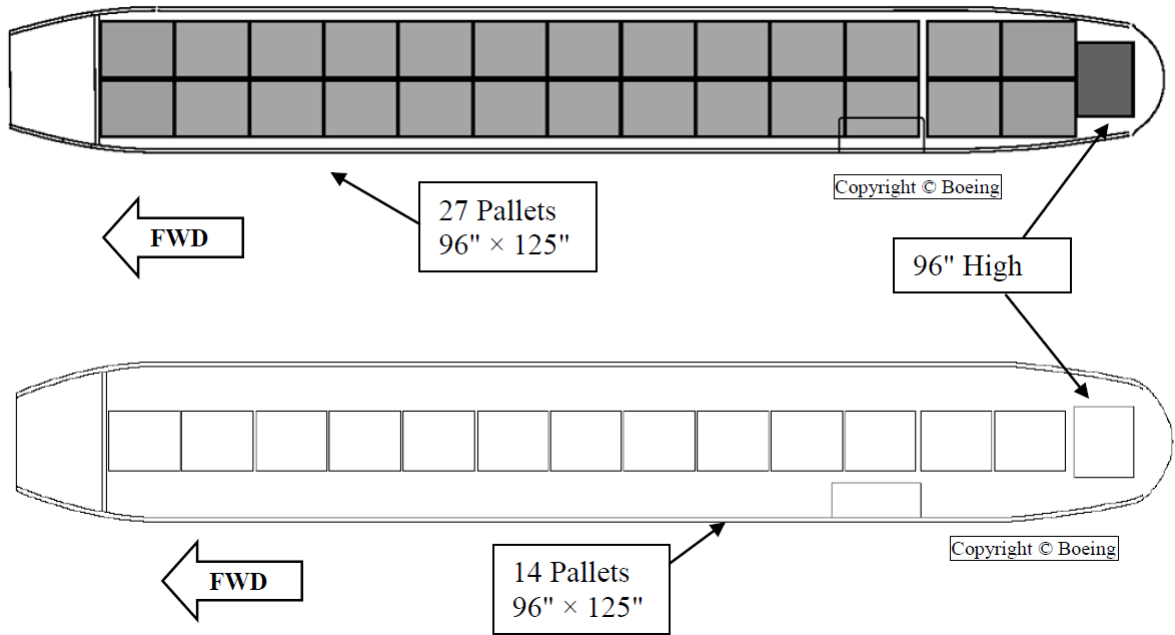


Figure 4: Boeing 777 Upper Deck Commercial/463L Pallet Layout (Air Mobility Command, 2011)

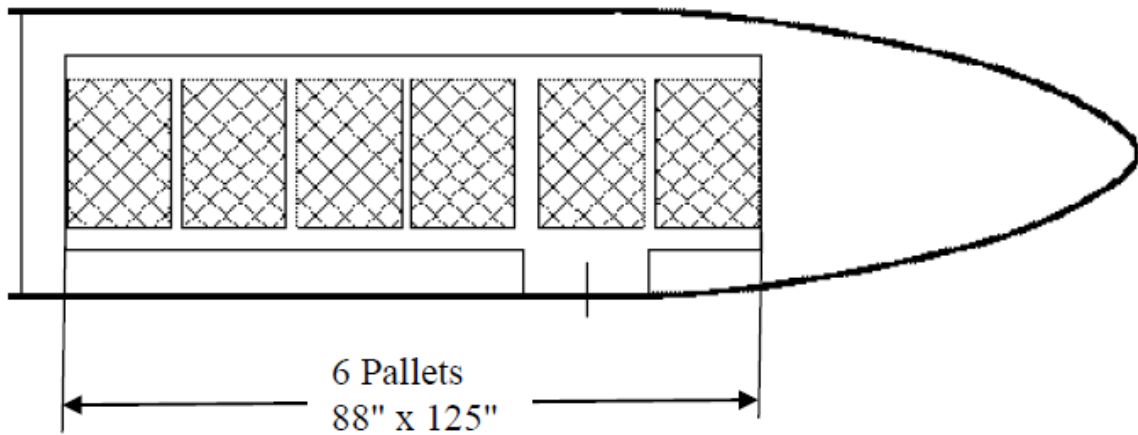


Figure 5: Boeing 777 Lower Deck Forward Compartment Commercial Pallet Layout (Air Mobility Command, 2011)

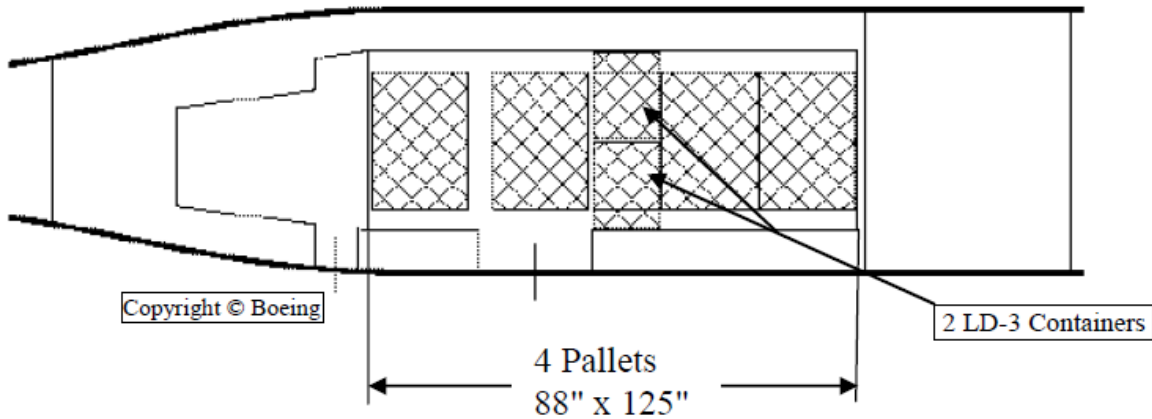


Figure 6: Boeing 777 Lower Deck Aft Compartment Pallet Configuration (Air Mobility Command, 2011)

This project aims to compare the current pallet loads on channel missions and determine what impact these non-configured aircraft will have on the number of airplanes required to accomplish the mission. Planners can take this information and apply it to wartime requirements to determine if a gap exists between capabilities and requirements.

Civil Reserve Air Fleet (CRAF) Background

“The Civil Reserve Air Fleet (CRAF) is a voluntary, contract-based agreement between DOD and U.S. commercial air carriers that augments DOD’s military airlift capability during times of war and national emergency” (GAO, 2013). The CRAF is comprised of two major divisions: International and National. These divisions are further split into international long range and international short range. The national division covers domestic events and the international division in stages is responsible for supporting events that coincide with the volume of cargo and passengers required.

There are three major activation stages associated with the CRAF (United States Transportation Command, 2014):

Stage I – covers relatively minor contingencies in a region where AMC is unable to fulfill both deployment and regular airlift requirements. This could also include Humanitarian Assistance/Disaster Response (HADR) events.

Stage II – used during a major conflict or war or to support the needs of national defense short of an official national emergency.

Stage III – a larger crisis or multi-regional conflict. National emergencies declared by the President or Congress also fall within Stage III activation.

Since the inception of the CRAF, there have been only two activations. The first activation was Stage II during Operations Desert Shield and Desert Storm in August of 1990 and January of 1991, respectively. The second activation was Stage I in support of Operation Iraqi Freedom from February through June of 2003 for passenger movements only (United States Transportation Command, 2014).

In order to incentivize carriers to provide aircraft to the CRAF, carriers that pledge assistance during activation are awarded government travel contracts during peacetime. According to Grismer (2011) participation in the CRAF is at one of the highest levels it has been with total DOD payments to CRAF members exceeding \$3.4 billion. Additionally, CRAF members are taking a larger role in their support of DOD channel missions. From fiscal year (FY) 2000 to FY 2012, contracted CRAF tonnage increased from 32 percent to 77 percent for DOD channel missions (GAO, 2013). During the same time period, missions increased from 28 to 61 percent of all DOD

channel missions. Reliance on these commercial carriers is evident and the DOD needs to ensure that they continue to be incentivized and managed properly to ensure a healthy level of their participation to ensure the warfighter's needs are met during times of activation.

The contract and point awarding system for CRAF members is robust and the scope of this research does not require a detailed review of either, therefore a limited overview is provided.

In order to participate, CRAF members must commit a minimum of 40 percent of their CRAF capable fleets to the DOD when required to activate (United States Transportation Command, 2014). Applicants must complete capability worksheets for each of their aircraft pledged to determine actual capability (United States Transportation Command, 2016). Aircraft with the same type such as the 767-300F may have different capabilities to move a fixed payload a fixed distance. This could be due to differences in upgrades, cargo floor layouts or range limitations. They are documented and used to create indexes of capability called wide-body equivalents (WBE) (United States Transportation Command, 2016).

Additionally, members are awarded points based upon the number of aircraft dedicated to particular stages of activation. Due to the increased likelihood of Stage I activation over Stages II and III, additional weight is awarded to carriers that commit aircraft to Stage I. Carriers are awarded bonus points on long range capabilities as well. The nominal requirement to carry payloads 3500 nautical miles, for war planning purposes can be exceeded and rewarded to air carriers who commit aircraft with the ability to perform in excess of this requirement.

Tables 1 and 2 outline the carriers that currently pledge support to the identified CRAF segment and the current total number of aircraft that have been allocated to the entire CRAF program. Figure 7 displays the number of long-range aircraft allocated to the CRAF by aircraft type. There is a large investment in the program and as commercial carriers begin to recapitalize their fleets, the DOD needs to be prepared to ensure that the cargo we are requiring them to handle is compatible on their platform.

Table 1: CRAF Carriers, International Segment – Long Range (Air Mobility Command, 2016)

ABX Air	Federal Express Airlines	Omni Air International
Air Transport Interantional	Hawaiian Airlines	Polar Air Cargo
American Airlines	Kalitta Air Cargo	United Airlines
Atlas Air	National Air Cargo dba National Airlines	United Parcel Service
Delta Airlines		

Table 2: CRAF Fleet Composition (United States Department of Transportation, 2016)

SEGMENT	SECTION	# AIRCRAFT
INTERNATIONAL LONG-RANGE	PASSENGER	147
	CARGO	130
INTERNATIONAL SHORT-RANGE	PASSENGER	134
	CARGO	5
NATIONAL DOMESTIC SERVICES	PASSENGER	1
	CARGO	36
TOTAL AIRCRAFT		453

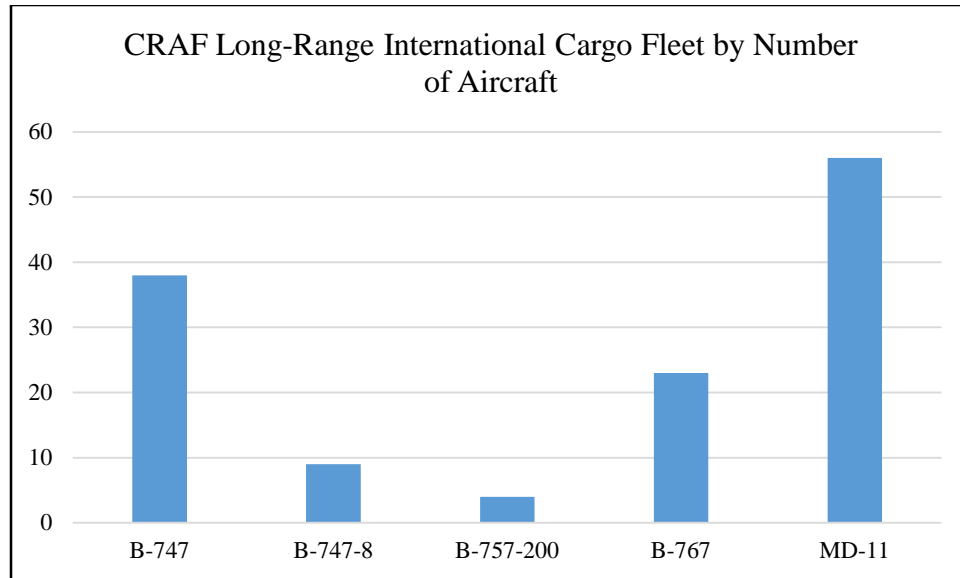


Figure 7: CRAF Long-Range International Cargo Fleet by Number of Aircraft (United States Department of Transportation, 2016)

Trends in Global Air Freight Acquisitions

Atlas Air Holdings recently acquired Southern Air for 110 million dollars (Stynes, 2016). This acquisition adds both the 737 and 777 freighter to the Atlas Air fleet. Southern Air once operated a fleet of Boeing 747-400s used in the CRAF but, after the replacement of its 747s with newer, more efficient Boeing 777s, the carrier was removed from the long-range cargo segment of the CRAF. Due to interoperability issues between the 463L pallet and the 777 freighter, the carrier no longer provides long-range cargo capacity to the CRAF. Now that Atlas Air, a large contributor to the CRAF, has acquired Southern, their fleet must be managed to support DOD activities with 463L compatible aircraft such as the 747 versus the non-compatible Boeing 777.

Federal Express (FedEx), an early investor in the Boeing 777 freighter, shares the

responsibility of managing DOD requirements with those of its commercial business. FedEx operates the country's largest fleet of Boeing 777 freighters and commits a large fleet of 463L compatible aircraft to the DOD's CRAF. FedEx is replacing ageing MD-10 and MD-11 aircraft with more fuel efficient and capable Boeing 777s and 767s (Boeing, 2016).

This trend continues globally. In fact, worldwide demand for air freight is expected to increase after a long stagnation in the global freight market (Harris, 2016). There is an expected 4.3 percent annual growth in air freight through 2035 that would increase the current global freighter fleet from 1,636 to 2821 aircraft (AJOT, 2016). This increase will require an estimated 2,400 additional freighters to replace older models and meet growth demands.

Many less fuel efficient freighters such as the 747 and MD-11 have been parked during periods of lower freight demand and higher fuel prices through 2014. As fuel prices have dropped and cargo demand has increased there is a belief that these parked freighters will become activated. However, due to large backlogs and demand for factory built freighters, many believe that the parked jets will overwhelmingly remain parked (Harris, 2016).

This means that older freighters such as the 747 and MD-11 will be replaced primarily with factory built 777 and 767 freighter and passenger to freighter conversions. Currently, these passenger to freighter conversions are primarily performed on 767s, but as 777-200 aircraft begin to age and are replaced by larger, more efficient variants, a passenger to freighter conversion program for the Boeing 777 is likely (Harris, 2016). Figures 8 and 9 show changes and orders in the widebody

freighter fleet.

Change in Widebody Freighter Fleet				
Type	2016	2015	Chg	% Chg
747-8F	63	56	7	13%
747-400ERF	37	36	1	3%
747-400F	117	113	4	4%
747-400BCF	21	21	0	0%
747-400BDSF	25	22	3	14%
747 Classic	16	18	-2	-11%
777F	119	100	19	19%
MD-11F	122	133	-11	-8%
DC/MD-10-30F	16	21	-5	-24%
DC/MD-10-10F	32	42	-10	-24%
A330-200F	33	30	3	10%
767-300F	110	98	12	12%
767-300BCF	14	13	1	8%
767-300BDSF	18	8	10	125%
767-200F	59	60	-1	-2%
A300-600F	168	165	3	2%
A300B4F	12	13	-1	-8%
A310-200/300F	13	29	-16	-55%
Total Fleet	995	978	17	1.7%

Figure 8: Change in Widebody Freighter Fleet (Harris, 2016)

Outstanding Widebody Freighter Orders March 2016					
Carrier	747-8F	777F	A330-200F	767-300F	Total
Cargolux	1				1
Cathay Pacific Airways	1				1
Etihad Airways		2	1		3
EVA Air		5			5
FedEx		16		81	97
Guggenheim Aviation Partners		6			6
Hong Kong Int'l Aviation		6			6
Korean Air	1	5			6
MNG Airlines			3		3
Nippon Cargo Airlines	2				2
Qatar Airways		8			8
Silk Way	2				2
Synergy Aerospace			1		1
TAM		2			2
Turkish Airlines			3		3
Volga-Dnepr Group	18				18
Total	25	50	8	81	164

Figure 9: Main Widebody Freighter Orders (Harris, 2016)

The negative changes in widebody fleet composition come from the MD-10s, MD-11s, classic 747s, A-300s and smaller 767s. All of these variants are currently CRAF capable. Outstanding orders for freighter aircraft are primarily comprised of 747-8s, 767s and 777s. All of these, except the 777 are capable of handling the 463L pallet with currently available cargo handling hardware.

Mobility Capabilities & Requirements Study 2016 (MCRS-16)

According to the Office of the Secretary of Defense (2010), the need for mobility support of moving our troops and bulk cargo is critical in fighting the next major land campaign. This requirement, outlined in three separate scenarios, necessitates the use of CRAF partners. It is clear that organic airlift cannot support the warfighter alone, so interoperability and understanding of how our systems interface with theirs is critical. The MCRS is responsible for establishing the requirements for operational plan cargo moved during Stages II and III of CRAF activation (United States Transportation Command, 2014). These requirements are indexed into million ton miles (MTM) that represent the requirement to move one million tons one mile. This gives CRAF managers within AMC the ability to assess and compare operational plan requirements with the management and capabilities of the CRAF (United States Transportation Command, 2014).

Summary

This research has briefly outlined the history and capabilities of the 463L pallet system. The reliance on this pallet in the global distribution network is clear. The background and importance of the CRAF has been illustrated as well. A brief

background on the current air freight industry was introduced, highlighting trends in the market. Understanding the relationship between the DOD, the CRAF and the air freight industry is crucial in making smart decisions to ensure compliance and fulfillment of the future needs of the combatant commander.

III. Methodology

Chapter Overview

This chapter discusses how this research evaluates the effects of the Boeing 777 on the WBE calculations and how the fleet might be affected by the introduction of the aircraft to the CRAF. Additionally, the expected timeline of the Boeing 777's introduction and the limitations for lower deck palletized cargo in newer CRAF aircraft is analyzed.

747 Versus 747-8

Throughout the analysis of WBE and fleet replacement predictions, the Boeing 747 and Boeing 747-8 are separated. The primary concern of this research is the ageing fleet of 747 and MD-11 aircraft being replaced with newer, non-compatible airframes. The 747-8 is a 463L compatible new production aircraft with many decades of service left, placing it in a different category than its older predecessors, the 747-200 and 747-400.

To determine the impact of the introduction of the Boeing 777 to a CRAF carrier, an estimate is made on the current capability and the total capability of the airframe. Comparisons of the 463L pallet with the commercial pallets currently used on Boeing 777 are made to predict this metric. By applying these two levels of aircraft capability to the planning calculations, million ton mile (MTM) indexes are created for the Boeing 777. MTM can be further used to create a WBE that planners can use to determine capability in the fleet. This information sheds light on the impacts of unmodified and

modified aircraft into the CRAF.

Once an index and WBE is created, an estimation is made on the number of modified and unmodified Boeing 777s required to fulfill the replacement needs for ageing aircraft that currently make up the CRAF. Additionally, pallet restrictions associated with the use of the lower deck of the aircraft are addressed.

Finally, an estimation on the timeframe required to replace existing freighters in the fleet is made based upon the current replacement schedules and forecasts in the industry.

The Wide-Body Equivalent

In order to determine the capability of a Boeing 777 in the CRAF long-range cargo fleet, an analysis of the cargo deck needs to be made. Currently, the aircraft is capable of carrying 27 commercial pallets on the main deck and a total of 10 commercial pallets on the lower forward and aft cargo holds. This is a total of 37 commercial pallet positions. These commercial P6P, or equivalent, pallets' surface dimensions are 96" X 125" and are in excess of the DOD 463L pallet dimensions of 88" X 108". It is the opinion of SMEs within AMC that the 777 could accommodate, after properly retrofitted with appropriate locks, the equivalent total number of pallets: 37 (Hondel, 2015). An unmodified aircraft today would be limited to centerline loading on the main deck only, reducing the total number of useful pallet positions to 14. Figures 1 through 6 illustrate these dimensions and assumptions.

To introduce a new aircraft to the CRAF, applicants must complete a capabilities worksheet that computes a MTM index and a WBE for each aircraft type committed to

the CRAF. See Figure 10 for an example of this tool used by AMC.

* Block Speed, Productive Payload Range, and either Standard Payload or Wartime Payload must be entered to use the Calculate button.		Calculate	Clear
Block Speed *	<input type="text" value="455.0"/>		
Productive Payload Range *	<input type="text" value="4804"/>	Nautical Miles	
Standard Payload *	<input type="text" value="122.809"/>	Short Tons	
Wartime Payload *	<input type="text" value="106.844"/>	Short Tons	
MTM	0.228		
WBE	1.337		
MV Points	13.370		
Tier MV Points	13.370	Tier 1	

Cargo Configuration

None

Freighter

Special Freighter

Convertible Freighter

Combi

Nose Loader

Figure 10: Example Boeing 747 MTM and MBE Calculator (AMC A3/A3B, 2015)

Million Ton Mile (MTM) and Wide-Body Equivalent (WBE) Equations

AMC uses the following equations to calculate an aircraft's MTM and WBE, respectively:

$$MTM_{777} = \frac{\text{Available Cargo Load} \times \text{Block Speed} \times \text{Productive Utilization Rate}}{1,000,000}$$

Equation 1: Boeing 777 Million Ton Mile (MTM) Equation (United States Transportation Command, 2016)

$$WBE_{777} = \frac{MTM_{777}}{MTM_{BASE AIRCRAFT}}$$

Equation 2: Boeing 777 Wide-Body Equivalent (WBE) Equation (United States Transportation Command, 2016)

To accomplish the same calculation for the Boeing 777, an available cargo load (ACL) needs to be calculated. To ensure accuracy and standardization with mobility

planning factors, the same method applied for the AMC base aircraft is applied to the 777. First, the average maximum total payload that the Boeing 777 can carry 3,500 nautical miles, 224,900 pounds, is divided by 2,000 pounds, the weight of one short-ton (Boeing, 2016). Next, this number is multiplied by 87 percent, the average percent of cargo actually carried on commercial aircraft during contingencies and the assumption made by AMC.

For the 777, a block speed of 464 knots was interpolated from AFPAM 10-1403 based upon a productive payload range of 5,000 nautical miles (Department of the Air Force, 2011). The productive payload range (PPR) is used for aircraft designated for the long-range section of the CRAF and represents the distance, in nautical miles, that a productive payload can be carried. Productive payload is defined as 75 percent of the maximum payload the aircraft is designed to carry. Publicly available reports designate the Boeing 777 freighter as an aircraft capable of carrying 224,900 pounds of payload the equivalent of 4,983 nautical miles. A conservative PPR of 5,000 nautical miles was used to calculate the block speed of 464.

Next, a Productive Utilization Rate (PUR) of 4.7 is used to reflect current utilization rates for all CRAF aircraft. This rate is computed by multiply the minimum daily utilization of 10 hours by the current AMC rate of productivity, .47.

To calculate WBE, the aircraft MTM is divided by the base aircraft MTM of .170469.

Validation of the WBE Equation Assumptions

To ensure the accuracy of the assumptions made for the Boeing 777, this research

applies the same assumptions to the Boeing 747-100 base aircraft to ensure that the same MTM and WBE were arrived at. To do this, the researcher takes a Boeing's range to payload chart for the 747-100 to confirm that 180,000 pounds is the maximum average total payload for the AMC planned distance of 3,500 nautical miles. This value, divided by 2,000, to compute short-tons results in 90 short-tons. 90 short-tons is multiplied by .87 for the average percent of cargo actually carried on commercial aircraft during contingencies results in 78.3 short-tons (United States Transportation Command, 2016).

78.3 short-tons is now applied to the MTM and WBE formulas provide above. Using AFPAM 10-1403, the average block speed of 465 multiplied by the PUR and ACL to obtain an MTM value of .171125 which very nearly approximates the base aircraft MTM value of .170469.

Now that the process of payload determination and speed is validated, payloads for 14 and 37 pallet position Boeing 777s are applied and MTM and WBE equivalents may be calculated. The final step in determining the differences between the two Boeing 777 capacities is the number of pallet positions available. By dividing the number of pallets on an unmodified aircraft, 14, by the number of potential pallets from a modified aircraft, 37, a reduction in capacity of over 62 percent is realized. This reduction is applied to the payload abilities of the unmodified aircraft resulting in an equivalent average maximum payload of 85,102 pounds. These values are used in the MTM and WBE formulas to determine their respective values.

Once the WBE of both the modified and unmodified Boeing 777s is calculated the number of 777s required to replace ageing fleets of MD-11 and Boeing 747 aircraft are determined.

To accomplish this, the MTM of each aircraft in the CRAF long-range cargo segment are multiplied to calculate the total WBE capability. This capability is broken down into aircraft type. Furthermore, aircraft average ages for all CRAF long-range cargo carriers are compared to determine the aircraft most susceptible to retirement and subsequent replacement by aircraft such as the 777.

Next, the number of equivalent 777s required to replace the WBE shortfall of the fleet's older aircraft are determined by dividing the WBE requirement by the WBE for both the 14 and 37 pallet 777 configurations.

Finally, a brief analysis of the lower deck pallet height limitations on the Boeing 777 and other CRAF aircraft are discussed to highlight future points of contention if further dependence on the CRAF becomes necessary. Global Air Transportation Execution System (GATES) data from fiscal years (FY) 2011 through 2014 are used to determine historical details of pallet heights to establish the feasibility of lower deck cargo loading limited to 64 inches.

Summary

This chapter has provided the methodology for the calculation on the capacity of potential 777 acquisition to the CRAF long-range cargo fleet. The explanation on how this information is used to calculate the number of 777s required to replace ageing CRAF aircraft is provided.

IV. Analysis and Results

Chapter Overview

This chapter provides the results of the MTM and WBE calculations described earlier. Additionally, application of these results to the current distribution of the long-range international widebody fleet is provided. This data, along with forecasts on the future fleet modernization within the air freight industry will answer the objectives of this research. Finally, limitations of pallet used in the lower deck of the Boeing 777 and similar aircraft are provided.

Results

MTM and WBE for 37 and 14 Pallet Boeing 777s

The MTM and WBE results for the Boeing 777 configured with 37 and 14 pallet positions are shown in by applying Equations 1 and 2:

$$MTM_{777} = \frac{98 \times 464 \times 4.7}{1,000,000} = .2137$$

Boeing 777 with 37 Pallet Positions Million Ton Mile (MTM) Equation

$$WBE_{777} = \frac{MTM_{777}}{MTM_{BASE AIRCRAFT}} = \frac{.2137}{.170469} = 1.2537$$

Boeing 777 with 37 Pallet Positions Wide-Body Equivalent (WBE) Equation

$$MTM_{777} = \frac{37 \times 464 \times 4.7}{1,000,000} = .0807$$

Boeing 777 with 14 Pallet Positions Million Ton Mile (MTM) Equation

$$WBE_{777} = \frac{MTM_{777}}{MTM_{BASE AIRCRAFT}} = \frac{.0807}{.170469} = .4736$$

Boeing 777 with 14 Pallet Positions Wide-Body Equivalent (WBE) Equation

After applying the equations, a WBE for a modified Boeing 777 with 37 pallet positions is 1.25. The WBE for an unmodified aircraft with 14 pallet positions is .4736. 1.25 represents an aircraft capability somewhere between that of an MD-11 and a Boeing 747. Based upon relative capacity, this makes sense. The WBE value of .4736 represents a capacity closely resembling that of a Boeing 767-200. The capacity restrictions on the unmodified aircraft greatly underutilize the potential capacity of the aircraft, making employment of this inefficient configuration to the CRAF very unlikely.

WBE Breakout and 777 Equivalents

Older Boeing 747s and MD-11s make up the preponderance of WBE capability in the CRAF. In fact, 79.9 percent of the total WBE committed to long-range international cargo is provided by these airframes. If the Boeing 777 were to replace these platforms outright, there would be a need for an additional 90 modified 37 pallet aircraft and an additional 238 Boeing 777s with 14 pallet positions available. Figures 11, 12 and 13 demonstrate the distribution of both WBE in the CRAF and CRAF aircraft average age.

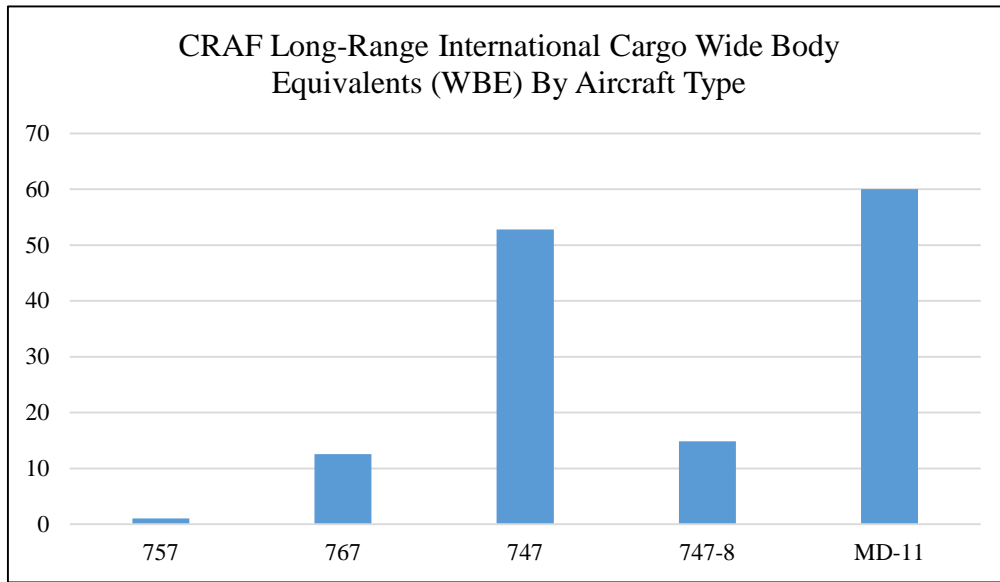


Figure 11: Distribution of WBE in CRAF (AMC A3/A3B, 2015)

CRAF Aircraft Type	Percent of Total CRAF	
	WBE	WBE
757	1.032	0.7
767	12.564	8.9
747	52.817	37.4
747-8	14.832	10.5
MD-11	59.989	42.5
Total	141.234	100.0

Note: Totals do not include the capabilities of two aircraft due to movement in CRAF allocation

Figure 12: Long-Range International Cargo Segment CRAF WBE Distribution (AMC A3/A3B, 2015)

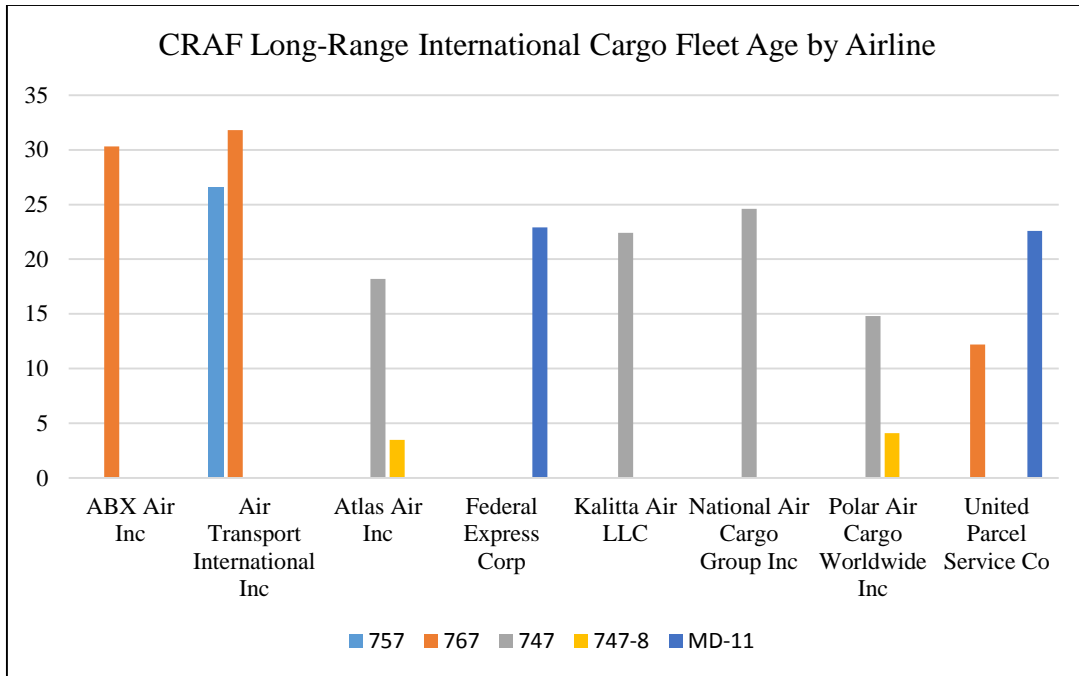


Figure 13: CRAF Long-Range International Cargo Fleet Age by Airline (Airfleets.net, 2016)

Timeline for Replacement

It is unlikely that neither the airlines providing aircraft to the CRAF nor the CRAF itself would entertain the idea of an unmodified, 14 pallet position Boeing 777 entering the fleet. However, the gap in capability between the two configurations highlight the immense differences in potential investments. More importantly, the equivalent number of 777s required to fill the WBE gap of ageing and less efficient 747s and MD-11s gives insight to the growing need for an appropriate replacement.

Order logs at Boeing demonstrate a resurgence in freighter interest. In fact, the Boeing 777, although one of the most capable and efficient freighters is being heavily out-ordered by a renewed interest in new Boeing 767 freighters. As of April 2016, there are over 186 orders for the Boeing 767-300 freighter (Boeing, 2016). 102 of these orders

belong to FedEx, the second largest provider of CRAF long-range international cargo capability. As the freighter fleets continue to age, many carriers are ordering new airframes like the Boeing 777 and 767 to replace less efficient models and to increase capacity. The MD-11 is one of the older aircraft types at FedEx and UPS, both significant providers of WBE to CRAF cargo. If the MD-11 fleet is retired, a large portion of CRAF cargo WBE capability would have to be reallocated to other airframes within the companies or re-apportioned to other CRAF carriers. FedEx's and UPS's combined MD-11 WBE account for over one third of the total WBE required for Stage III cargo requirements of the CRAF. These airframes represent the older aircraft types that could potentially be lost due to retirements in the next decade. Ultimately, when the MD-11 is retired from the CRAF fleet, this WBE capability will have to be realized either within the two carriers' other aircraft or elsewhere in the CRAF.

The timeline for replacement of MD-11s and 747s within the CRAF is an educated estimation. Based on the order books of new freighters and predictions on the gradual increase of air freight, research suggests that carriers will be replacing ageing, less fuel efficient aircraft as fuel prices begin to rise again. In the meantime, CRAF managers must apply the remaining 463L compatible airframes toward the wartime WBE requirements.

Limitations to Lower Deck Cargo

Lower deck cargo in the 777 and other aircraft such as the 767 are limited to a 64 inch pallet height. Although not an issue unique to the Boeing 777, the historical percentage of palletized cargo from FY11 through FY14 is provided in Table 3 to

demonstrate the volume and makeup of cargo that exceeds the 64 inch lower deck limitation.

Table 3: Number and Percentage of Palletized Cargo Exceeding 64 Inches (GATES, 2015)

	Total PC	PC Exceeding 64"	Percentage of Total
FY11	221633	102995	46.5
FY12	228818	110321	48.2
FY13	171367	77278	45.1
FY14	118266	56206	47.5
		FY11-FY14 Average	46.8

Before the numbers are tabulated, duplicate entries of palletized cargo during all four years are removed. Once duplicates are removed, the total AMC movements, both organic and contracted cargo, are tabulated. Table 3 demonstrates the average percentage of total palletized cargo exceeding 64 inches was 46.8, or less than half. CRAF aircraft with lower deck pallet handling all have less total capacity in their lower decks than their upper decks. If cargo is distributed evenly, then this research suggests that there should be little to no issues with the 64 inch lower deck limitation. As older 747-200 and 747-400 aircraft are retired and replaced with aircraft with large volumes of lower deck capacity, albeit with more restrictive pallet dimensions, attention should be given to the building of pallets to take full advantage of both upper and lower deck cargo capacity.

This analysis of historical palletized cargo demonstrates the ability to utilize lower deck capacity of CRAF contracted carriers during peace and wartime activities. This use of this space is important in the desire to make operations more efficient and capable.

Objectives Answered

Objective 1: What is the 463L capacity on the Boeing 777?

The WBE for a 37 pallet Boeing 777 is 1.25. The WBE for a 14 pallet Boeing 777 is .4736.

Objective 2: What aircraft provide the majority of CRAF cargo capability and what is their expected retirement timeline?

The majority of aircraft dedicated to CRAF long-range cargo are Boeing 747-200s, Boeing 747-400s and MD-11s. They are also the older of the aircraft. These aircraft provide nearly 80 percent of the total long-range cargo capability that the CRAF provides.

Objective 3: How many Boeing 777s would it take to fulfill the retirement capabilities of older CRAF aircraft and what are the COAs associated with its introduction?

To replace the gap created with the retirement of the older 747s and MD-11s alone, there would need to be 90, 37 pallet 777s or 238, 14 pallet 777s. Due to the recent orders and acquisitions of the two largest providers of WBE to long-range cargo, this research suggests that the loss of WBE from the older airframes could be partially replaced with aircraft reassignment within current CRAF carriers. However, there remains a minimum of over 50 WBE that would be lost from aging MD-11s and 747s from the CRAF's three largest CRAF contributors. This potential loss could be addressed in the short term through reassignment. There is also a likelihood that these airframes have an additional 10 years of service life remaining, but the WBE requirements need to be re-allocated before the older aircraft are removed from service.

Objective 4: What are important limitations associated with the employment of the Boeing 777 and other CRAF aircraft used to transport the 463L and what impact will this have on further dependence on CRAF airlift?

The Boeing 777, along with other CRAF airframes have a limitation of 64 inches in pallet height for lower deck cargo. CRAF aircraft with lower deck cargo capability hold less than half of their palletized cargo capacity in their lower decks. After analyzing all palletized cargo from FY11 through FY14, less than half of the cargo exceeds 64 inches. This evidence suggests that, if properly distributed, palletized cargo can be moved on the Boeing 777 and similar airframes with little impact in spite of the lower deck pallet height restrictions.

Summary

This chapter describes the use of the methodology to arrive at answers to the objectives stated at the outset of this research project. Distribution of this information for the decision makers is now necessary to provide an accurate impact of Boeing 777 introduction to the CRAF.

V. Conclusions and Recommendations

Chapter Overview

This chapter examines the conclusions and significance of the research accomplished for this project. Additionally, recommendations for future research associated with this project will be made.

Conclusions of Research

The analysis done during this research provides a quantitative capability associated with a 777 freighter. Additionally, CRAF WBE distribution is analyzed. Coupled with CRAF fleet age and future fleet replacements, a gap in WBE created by the retirement of the two largest providers of CRAF long-range cargo lift, the Boeing 747 and MD-11, is identified. This quantifiable gap was then filled with potential 777 aircraft.

According to experts at AMC, the likelihood of the introduction of a 777 to the CRAF with 14 shored and strapped pallets into the CRAF is nearly non-existent. However, the hypothetical scenario is quantified and highlights the highly efficient and capable capacity that a modified Boeing 777 could provide. The research also suggests that the likelihood of 777s replacing all WBE capability lost due to retirement of the 747 and MD-11 is unlikely. This research suggests that several of the older assets will be replaced with Boeing 767s and reassigned in the CRAF accordingly, but over a third of the CRAF's long-range cargo airframe capacity is approaching retirement age quickly and that the costs associated with fixing the issue is the next step in this research.

Finally, this research analyzed the results of all palletized cargo and provided evidence to suggest that there should be no significant issues with lower deck pallet cargo movements among CRAF carriers.

Significance of Research

This research demonstrates the capabilities of a properly modified Boeing 777. When employed as it was intended, the aircraft provides an efficient, high-capacity solution to ageing long range airplanes. This research also provides evidence to suggest that while the 777 is not compatible with the 463L, there are still other aircraft within the CRAF that can be reallocated to fulfill some of the WBE gaps. However, over a third of this capability needs to be replaced as aircraft begin to approach retirement in the next decade. The 463L compatibility issue, although currently mitigated through probable gradual retirements, still needs to be further investigated. The next step on this topic is to research options on how to potentially modify the pallet or pursue hardware installations for Boeing 777 and other non-compatible aircraft that will soon be ordered by CRAF carriers.

Recommendations for Future Research

Although there is evidence to suggest that the WBE requirements and gaps created by the retirement of older aircraft will be fulfilled, the Boeing 777 is an attractive and capable future addition to the CRAF. Detailed research on the equipment needed to either modify the 463L pallet for 777 use or modify the 777 for 463L use. Any aircraft that currently handles commercial pallets could handle a 463L pallet if either the aircraft

or the pallet are modified. Future research should include an analysis of both options to determine feasibility. This information, although proprietary, would shed light on the monetary investments required to enable AMC to take action well before the CRAF capability issue arises again. The airplane is highly capable and very efficient. Research demonstrating the costs associated with making this happen is necessary.

Summary

This chapter summarizes the findings of the research performed and has applied it to the next steps in research required to continue to address the costs associated with the addition of a 463L modified Boeing 777. Additionally, it addresses the potential research on the modification of the 463L pallet to make it compatible with the Boeing 777 or any aircraft that currently is configured for commercial pallet operations.



463L PALLET COMPATIBILITY IMPLICATIONS FOR WARFIGHTING CAPACITY IN THE CIVIL RESERVE AIR FLEET

Introduction

The Department of Defense (DOD) uses the 463L pallet nearly exclusively in the movement of war and peacetime palletized cargo. Since its introduction in the 1960s, the pallet has been used on DOD aircraft and civilian charter cargo aircraft to move defense materials.

Unfortunately, the Boeing 777, the current freighter of choice by many air carriers, is unable to accommodate the 463L pallet in a traditional configuration. AMC is very concerned with the limitations that newer CRAF aircraft purchases such as the Boeing 777 create and their ability to provide the necessary wartime support when needed. This research uses a formula to determine if 463L incompatibility within the CRAF will affect a wartime mobility capacity requirement and if so, what the extent of those impacts are.

This research focuses on an analysis of the 463L pallet and its compatibility with CRAF aircraft. It uses this quantitative information to maximize pallet loading on aircraft without modification. This analysis takes into account pallet dimensions and aircraft cargo floor limitations and flexibility. Additionally, it uses SMEs within the mobility community and the AMC CRAF office to identify these interoperability issues.

Research Focus

This research focuses on an analysis of the 463L pallet and its compatibility specifically with the Boeing 777. It takes this information to apply the equivalent number of 777s required to fulfill the capability shortfalls of the retirement of ageing wide body CRAF aircraft.

Collaboration

HQ AMC A9/A09 and AMC A3/A3B



Major John Habbestad
 Advisor: Jeffrey Weir, PhD
 Air Force Institute of Technology

Advanced Studies of Air Mobility (ENS)
 Air Force Institute of Technology

$$MTM_{777} = \frac{\text{Available Cargo Load} \times \text{Block Speed} \times \text{Productive Utilization Rate}}{1,000,000}$$

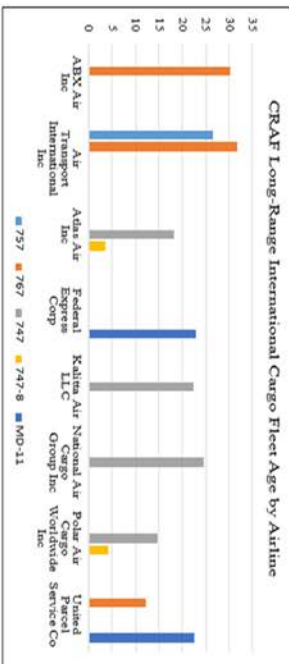
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Equation 2: Boeing 777 Wide-Body Equivalent (WBE) Equation

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747-8	14,832	10.5
MD-11	59,989	42.5
Total	141,234	100.0

Note: Totals do not include the capabilities of two aircraft due to movement in CRAF allocation



Methodology

This research uses formulas and assumptions created by AMC and publicly available data to determine the capability in wide body equivalents (WBE) for the proposed introduction of a Boeing 777 to the CRAF long-range international cargo segment. Two versions of the Boeing 777 are used. One with an unmodified aircraft, capable of only 14 centerline pallets, and a modified aircraft, capable of 37 pallets. These two capabilities are compared to the likely retirement of older CRAF aircraft and the WBE shortfall they would create. The approximate number of Boeing 777s required to fulfill the shortfall is analyzed. Additionally, a snapshot of four years of pallet data is used to determine average pallet heights to determine the impact of lower deck cargo on newly acquired aircraft. Finally, CRAF aircraft ages are compared to determine the fleet types that create the greatest impact to WBE requirements due to their likely retirements.

Summary of Research

This research identifies that that likely aircraft for retirement are the MD-11 and 747 classic (747-200 and 747-400). These two aircraft types provide the majority of the current CRAF capability in WBE. This, coupled with the possible introduction of the Boeing 777 aircraft that are currently not readily compatible with the 463L pallet, create a potential for difficulties in managing aircraft allocated to the CRAF. Currently, this research suggests that there appears to be enough 463L compatible aircraft within the CRAF to reallocate as older MD-11 and 747 aircraft are retired. However, there needs to be additional research for a long term solution such as a modification to the 463L pallet or a hardware modification to non-compatible aircraft such as the Boeing 777 to enable planners in the DOD to permanently ensure that wartime capabilities will not be impacted.

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14. ABSTRACT The Department of Defense (DOD) uses the 463L pallet nearly exclusively in the movement of war and peacetime palletized cargo. Since its introduction in the 1960s, the pallet has been used on DOD aircraft and civilian charter cargo aircraft to move defense materials. Unfortunately, the Boeing 777, the current freighter of choice by many air carriers, is unable to accommodate the 463L pallet in a traditional configuration. AMC is very concerned with the limitations that newer CRAF aircraft purchases such as the Boeing 777 create and their ability to provide the necessary wartime support when needed. This research uses a formula to determine if 463L incompatibility within the CRAF will affect a wartime mobility capacity requirement and if so, what the extent of those impacts are. This research focuses on an analysis of the 463L pallet and its compatibility with CRAF aircraft. It uses this quantitative information to maximize pallet loading on aircraft without modification. This analysis takes into account pallet dimensions and aircraft cargo floor limitations and flexibility. Additionally, it uses SMEs within the mobility community and the AMC CRAF office to identify these interoperability issues.					
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