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A between-squadron analysis of cannibalization on the MV-22

Okyere-Boateng, Kwabena O.

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THESIS

A BETWEEN-SQUADRON ANALYSIS OF CANNIBALIZATION ON THE MV-22

by

Kwabena O. Okyere-Boateng

December 2015

Thesis Advisor: Kenneth Doerr
Second Reader: Donald Summers

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The Naval Aviation Maintenance Program recognizes cannibalization as a viable management tool when properly used in aviation squadrons. Squadrons consequently practice cannibalization in an attempt to reduce gaps in their logistical and maintenance support systems. This thesis analyzed cannibalizations on the MV-22 aircraft platform to examine how the practice varied between squadrons in the community, which specific components drove cannibalizations, and how the practice of cannibalization affected aircraft availability. Using descriptive and inferential statistics, cannibalization data from 2010 to 2014 for 13 selected MV-22 squadrons were analyzed under six selected categories. All MV-22 components cannibalized during that period were also analyzed to examine the top cannibalization drivers and how those components changed over time. Lastly, statistical tests were performed to uncover how cannibalizations affected aircraft availability. The analysis revealed some squadrons as better performers at cannibalization than others, and that squadrons also varied under reasons for cannibalization, maintenance hour documentation, partial mission capable cannibalizations, and cannibalizations on deployment. The statistical test also revealed that cannibalizations had little to no effect on MV-22 aircraft availability. Recommendations for maintenance data system improvements were provided along with suggested MV-22 best cannibalization practices.

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Kwabena O. Okyere-Boateng
Captain, United States Marine Corps
B.S., Embry-Riddle Aeronautical University, 2007

Submitted in partial fulfillment of the
requirements for the degree of

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December 2015

Approved by: Kenneth Doerr, Ph.D.
Thesis Advisor

Donald Summers
Second Reader

Chad Seagren
Academic Associate
Graduate School of Business and Public Policy

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ABSTRACT

The Naval Aviation Maintenance Program recognizes cannibalization as a viable management tool when properly used in aviation squadrons. Squadrons consequently practice cannibalization in an attempt to reduce gaps in their logistical and maintenance support systems. This thesis analyzed cannibalizations on the MV-22 aircraft platform to examine how the practice varied between squadrons in the community, which specific components drove cannibalizations, and how the practice of cannibalization affected aircraft availability. Using descriptive and inferential statistics, cannibalization data from 2010 to 2014 for 13 selected MV-22 squadrons were analyzed under six selected categories. All MV-22 components cannibalized during that period were also analyzed to examine the top cannibalization drivers and how those components changed over time. Lastly, statistical tests were performed to uncover how cannibalizations affected aircraft availability. The analysis revealed some squadrons as better performers at cannibalization than others, and that squadrons also varied under reasons for cannibalization, maintenance hour documentation, partial mission capable cannibalizations, and cannibalizations on deployment. The statistical test also revealed that cannibalizations had little to no effect on MV-22 aircraft availability. Recommendations for maintenance data system improvements were provided along with suggested MV-22 best cannibalization practices.

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LIST OF ACRONYMS AND ABBREVIATIONS

3M	maintenance and material management
AMSRR	aviation maintenance and supply readiness reporting
ANOVA	analysis of variance
AO	area of operation
AVCAL	aviation consolidated allowance list
AWP	awaiting parts
CDD	Central De-ice Distributor
CDU	Computer Display Unit
CM	configuration management
CNO	Chief of Naval Operations
COMNAVAIRPAC	Commander Naval Air Forces Pacific
DON	Department of Navy
EAPS	Engine Air Particulate System
EDD	estimated delivery date
FAD	force activity designator
FCC	flight control computer
FCF	functional check flight
FLTHRS	flight hours
FMC	full mission capable
FOM	facilitate other maintenance
FRS	fleet replacement squadron
GAO	General Accounting Office
I-Level	intermediate level
IR	in reporting
IRS	infra-red section
IM	item manger
LTD	long term down

MAG	Marine Aircraft Group
MALS	Marine Aviation Logistic Squadron
MAW	Marine Aircraft Wing
MC	mission capable
MCN	maintenance control number
MEDEVAC	medical evacuation
MESM	mission-essential subsystems matrix/matrices
MEU	Marine Expeditionary Unit
MFD	multi-function display
MMCO	maintenance material control officer
MMH	maintenance man hour
MTBF	mean time between failure
NAE	Naval Aviation Enterprise
NALCOMIS	naval aviation logistics command maintenance information system
NAMP	naval aviation maintenance program
NC	not carried
NIIN	national item identification number
NIS	not in stock
NMC	not mission capable
NMCS	not mission capable supply
OOR	out of reporting
OPNAVINST	Office of the Chief of Naval Operations Instruction
OPTEMPO	operational tempo
P-VALUE	probability value
PD	priority designator
PMCS	partial mission capable supply
PMI	periodic maintenance inspection
RBA	ready basic aircraft
RFI	ready for issue material

SAR	search and rescue
SDC	signal data converter
SOP	standard operating procedure
SSWG	supply system working group
TAT	turnaround time
TEEP	training exercise employment plan
T/M/S	type/model/series
TYCOM	type commander
UND	urgency of need designator
UNS	unified numbering system
UPA	units per assembly
VFG	variable frequency generator
VMM	marine medium tiltrotor squadron
VMMT	marine medium tiltrotor training squadron
WUC	work unit code

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LIST OF DEFINITIONS

Fleet replacement squadron	An aircraft platform's flight training designated squadron
Full mission capable	A status assigned to an aircraft that is capable of performing all of its assigned missions
Functional check flight	A test flight required to check the correct functionality of specific replaced components or specific maintenance performed
In reporting	An aircraft not undergoing major repair or modification
Infra-red section	The engine's exhaust section of the V-22 aircraft
Long term down	Aircraft that have not flown in 60 days or more
Naval aviation logistics command maintenance information system	A real-time maintenance information system used for tracking aircraft maintenance actions
Naval aviation maintenance program	Naval aviation guidelines that addresses maintenance policies, procedures, and responsibilities for the conduct of all levels of maintenance throughout naval aviation
Not carried	A supply status code assigned to part requisitions that have no allowance requirement in the local supply warehouse
Not in stock	A supply status code assigned to part requisitions that have an allowance but are stocked out
Operational tempo	The rate of a unit's mission or military action
Out of reporting	An aircraft undergoing major depot repair or modification
Partial mission capable supply	A status code for an aircraft that can only perform part of its assigned mission due to an outstanding requisition
Priority designator	An assigned code that relates the mission of the requisition or to their urgency of need designator

Ready basic aircraft	An aircraft that is operable and committable to an operational flight
Ready for issue material	A part or item that is functionally reliable and meets applicable performance specifications
Urgency of need designator	A letter code assigned to indicate a unit's relative urgency of need compared to other activities
Work unit code	A code that identifies an aircraft system, subsystem or major end item being worked on

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I. INTRODUCTION

A. PURPOSE

Cannibalization is the removal of a working or functional component from one aircraft for installation in another non-flyable aircraft. The purpose of this thesis is to analyze the practice of cannibalization in the MV-22 community and evaluate how practices vary between the different MV-22 squadrons, all of which are governed by the same Naval Aviation Maintenance Program (NAMP). This research will explore how cannibalization in the community has trended over time and between squadrons to evaluate significant changes that have taken place in the community since standing up the MV-22 program. Performing a between-squadron analysis of cannibalization will also identify the drivers of cannibalization in the community and reveal how those drivers vary over time. This between-squadron analysis will reveal if the practice of cannibalization actually contributes to overall aircraft availability. This analysis will identify the associated costs of cannibalization to the squadrons in terms of maintenance man-hours exhausted to remove and install components, and in terms of how it increases the unit's not mission capable maintenance (NMCM) time. This research will give an insight into how the practice and problem of cannibalization can be expected to trend as new squadrons continue to transition to the MV-22 platform. The comparative analysis will provide maintenance officers with informed decisions to better manage their available resources as well as provide recommendations on their alternatives to manage cannibalization.

B. BACKGROUND

This section briefly describes cannibalization as a general term and introduces the squadrons and support activities in the MV-22 community.

1. Cannibalization

The purpose of cannibalization is to return non-flyable aircraft to flying status. Maintenance managers use this practice to consolidate parts across multiple non-flyable aircraft in an effort to make more flyable aircraft in the process. This practice is intended to minimize the effect that a constrained supply system might have on an aircraft maintenance department's overall readiness.

The practice of cannibalization differs across and within all the branches of service. The definition of cannibalization, reasons for cannibalizing, and the impacts of cannibalization all differ and are not standardized across squadrons. Policies governing the practice, views, and overall management and perception of cannibalization vary widely. Within specific aircraft platforms, the practice also differs in types of components cannibalized, frequency, and the different drivers of cannibalization in the platform community (General Accounting Office, 2001).

The MV-22 community is one of several that practices cannibalization. As one of the newest aircraft platforms in the Department of Defense (DOD) inventory, this platform competes among the most-frequently cannibalized aircraft platforms in the Navy. In 2014, total count of cannibalized parts on this platform was 1,727, ranking it the second most cannibalized aircraft in the Marine Corps aircraft inventory after the CH-53 platform (Naval Air Systems Command 6.8.2.1 data analyst, personal communication, June 5, 2015).

2. MV-22 Aircraft Squadrons and Support Activities

The Marine Corps MV-22 aircraft community continues to grow around this new platform. The community is made up of 16 Marine Medium Tiltrotor (VMM) squadrons and one Marine Medium Tiltrotor Training (VMMT) fleet replacement squadron (FRS). The FRS is the only Marine Corps and Air Force V-22 training unit. It provides aircrew and pilot training to personnel in both services. These 17 squadrons are spread throughout the four Marine Aircraft Wings (MAW).

The 1st MAW squadrons include VMMs 262 and 265, which are based in Okinawa, Japan. The 2nd MAW squadrons include VMMs 162, 261, 263, 264, 266, 365, and VMMT 204, all of which are based at the Marine Corps Air Station (MCAS) New River, NC. The 3rd MAW squadrons include VMMs 161, 163, 165, 166, 268, and 363, which are based in MCAS Miramar, CA. VMM-764 is a reserve squadron for the 4th

MAW and is also based in MCAS Miramar, CA. Two non-operational squadrons, Marine Test and Operational Evaluation Squadron 22 and Marine Helicopter Squadron One, also have MV-22 aircraft in their aircraft inventory (USMC, 2015).

Each aircraft location is supported by a Marine Aviation Logistics Squadron (MALS). MALS 36, 26, 16, and 41 supports the 1st, 2nd, 3rd, and 4th MAW squadrons respectively with supply logistics and Intermediate Level (I-Level) maintenance support capability. MALS 26 is a V-22-specific supporting MALS, while MALS 16, 36, and 41 remain composite MALS, providing support for all aircraft platforms in their Marine Aircraft Groups (MAG). With MALS 26 being the V-22's first and only V-22 unique-supporting MALS, resident expertise of some I-Level capabilities resides in this MALS, which is able to provide support to the other MALS when required. Additionally, each of the aircraft locations has an Osprey Support Center staffed with Bell Boeing and Rolls Royce fleet support representatives (FSR). These FSRs provide engineering and technical support on aircraft and associated support equipment as required.

C. RESEARCH QUESTIONS

The thesis focuses on the following research questions:

> **Primary Question:** How do cannibalization practices vary across squadrons?
>
> **Secondary Questions:** What are the drivers of cannibalization in the MV-22 community, and how much does that vary across time and between squadrons? How does cannibalization affect availability and how much does that vary across time and between squadrons?

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II. LITERATURE REVIEW

The literature review focuses on cannibalization as a general term and how this term is used in the context of the military, specifically the naval aviation community. Special consideration was paid to the MV-22 aircraft platform and community to explain how the practice and policies surrounding cannibalization applies across the naval aviation aircraft fleet. The review gathered existing literature on four areas of cannibalization to provide the reader with a broad understanding of reasons for and impacts of cannibalization, specifically potential problems and issues.

Literature was accessed and obtained through the Naval Postgraduate School Dudley Knox Library to include research publications, directives, and existing cannibalization and cannibalization related information.

A. CANNIBALIZATION

Different branches of the military have and create unique definitions of cannibalization. The Army regulation 750-1 defines cannibalization as the “authorized removal of components from materiel designated for disposal” (Department of the Army, 2013, p. 45). The Navy’s OPNAVINST 4440.19 defines cannibalization as “the removal of serviceable material or components from installed equipment for installation in other equipment to restore the latter to an operational condition” (Department of the Navy, 2012, p. 1). The Air Force’s AFI 21-101 defines cannibalization as “the authorized removal of a specific assembly, subassembly, or part from one weapon system, system, support system, or equipment end item for installation on another end item to satisfy an existing supply requisition and to meet priority mission requirements with an obligation to replace the removed item” (Department of the Air Force, 2011, p. 242).

The cannibalization process can be applied to equipment of all sizes; this ranges from small components, with removable sub-assemblies, to larger equipment such as automotive, aircraft, and vessels. In *Cannibalization Policies for a Set of Parallel Machines*, Ormon and Cassady (2004) state: “Cannibalization actions are used in many high-tech manufacturing environments due to the high cost of spare parts and the need for short maintenance turnarounds" (p. 540).

Cannibalization, in the context of naval aviation, assumes the same process of physically removing one component from an aircraft and installing it in another aircraft, with the objective of creating an additional mission-capable aircraft. As explained by Danny Kowalski (2000), aircraft squadrons practice this form of maintenance in an effort to ensure a maximum number of aircraft remain or stay in a mission capable state. This allows squadrons to have enough available aircraft to support their daily sortie requirements.

B. CANNIBALIZATION POLICY

The NAMP, Commander Naval Air Forces Instruction (COMNAVAIROFRINST) 4790.2B sets cannibalization policy for naval aviation squadrons. The NAMP recognizes cannibalization as a viable short-term solution for operational squadrons to overcome maintenance or logistical failures. Chapter 5.1.1.11.1 states that "Cannibalization, with few exceptions, is a manifestation of a gap in logistics or maintenance support systems" (Department of the Navy, 2013, p. 5-23). Squadron commanders at the operational level are given this authority to use cannibalizations in moderation. This helps them manage their available assets in an effort to minimize the impact of a supply system constraint on the aircraft unit's primary mission: flying.

The NAMP provides specific guidance to commanders, aircraft maintenance officers, and maintenance material control officers (MMCO) on the proper use of cannibalization. Aviation ground officers and maintenance officers receive classroom instruction on cannibalization during their NAMP indoctrination course of their military occupational specialty school before they assume duties in their operational squadrons.

The NAMP recognizes the importance of properly managing cannibalizations at the operational level. It stresses the elimination of unnecessary cannibalization as a direct responsibility of logistics and maintenance operations. In this light, Chapter 5.1.1.11.12 states: "Under no circumstance shall cannibalization be performed to create a pool of Ready for Issue (RFI) parts for general use to support flight operations or detachments"

(Department of the Navy, 2013, p. 5-23). This verbiage restricts cannibalization of naval aviation aircraft parts and components only for returning a not mission capable (NMC) aircraft to flight status.

Chapter 5.1.1.11.12 of the NAMP provides aviation squadron commanders with specific cannibalization guidance:

> To pursue courses of action to manage cannibalization properly within their areas of purview.
>
> Assess the effectiveness of their cannibalization policy by using outcome measurements, such as supply material availability, A-799 (malfunction could not be duplicated) rate, I-level TAT, point of entry effectiveness, supply response time, cannibalizations per 100 flight hours, and maintenance man-hours per cannibalization.
>
> Cannibalization on ejection seat systems shall be minimized due to the inherent potential to impact safety.
>
> Cannibalization from Awaiting Parts (AWP) assets is a recognized tool for reducing the total number of AWP equipment, but must be carefully managed and documented.
>
> Monitor and report cannibalization actions between squadron aircraft per Type Wing/Air Wing instructions. (Department of the Navy, 2013, p. 5-23)

The NAMP gives only squadron commanders cannibalization authority over aircraft under their cognizance. This allows any unit commander the latitude to moderately move specific aircraft parts and components within his or her own unit-assigned aircraft without a need for higher approval, unless specifically dictated in the NAMP guidance (Department of the Navy, 2013).

Type Wing/Air Wing commanders retain the sole authority for inter-squadron cannibalizations as detailed in the NAMP (Department of the Navy, 2013). This policy requires unit commanders seeking to cannibalize parts from another unit's aircraft to submit a written justification to their respective wing commander for approval prior to proceeding with the cannibalization action. Requirements for the written request typically include the supply systems stock posture for the part or component required, the status of the outstanding requisition in the supply system, and the anticipated effect of the cannibalization on the operational readiness of both the supplying and receiving squadrons. Once the wing commander is convinced through the justification that the cannibalization action is warranted, a naval message addressing all parties involved is drafted and released directing the cannibalization action (Department of the Navy, 2013). The intent of the naval message is to formally address the cannibalization action through the aircraft Type Model Series (T/M/S) hierarchy to allow proper tracking of the component being cannibalized and the replacement requisition in the supply system. This also affords the specific T/M/S logisticians and reliability groups to address broader issues of supply and component reliability that might have led to the cannibalization action.

T/M/S Type Commanders (TYCOM) retain the sole authority for approving cannibalization requests between Air Wings or Marine Aircraft Groups (MAG), and from any aircraft that has been NMC for more than 120 days. Cannibalization requests of this type are generated by naval message from the squadron level through the MAG or Wing to the TYCOM for approval. Once approved, the TYCOM directs the cannibalization action through naval message with related instructions to the supporting supply support activities on how to handle the transfer of the component (Department of the Navy, 2013). Operational, test, and training activities request cannibalization approval from separate authorities at the T/M/S level. These activities request approval from the Commander Naval Air Forces, Commander Naval Air Systems Command, and Chief of Naval Air Training respectively for their squadrons (Department of the Navy, 2013).

Additional supplemental policies to the NAMP can also be generated by Air Wing Commanders in an effort to control cannibalization across squadrons under their cognizance. Squadron commanders are required to report any in reporting (IR) status aircraft that has remained NMC for 60 days as long term down (LTD) aircraft on the Navy's Aircraft Maintenance and Supply Readiness Report (AMRR). Aircraft undergoing periodic maintenance inspections (PMI), rework, or planner and estimator repairs are also reported as out of reporting (OOR) on the AMSRR. Wing commanders generate local wing policies to govern cannibalization from these categories of aircraft. This prevents prolonging aircraft in a LTD/OOR status due to continuous cannibalization.

The 2nd MAW LTD order directs squadron maintenance officers to submit a cannibalization request to the Wing Aviation Logistics Department prior to cannibalizing from a LTD or OOR aircraft (Commanding General, 2nd Marine Aircraft Wing, 2008). This Wing Order also directs squadron maintenance officers to "provide the chain of command a Return to Flight Status brief that includes a recovery plan that optimizes available resources and ensures that the cannibalization of aircraft components is held to a minimum" (Commanding General 2dMAW, 2008, p. 3).

C. IMPACTS OF CANNIBALIZATION

Cannibalization of aircraft parts can have significant negative impacts on a unit's aircraft assets and the maintenance personnel performing the cannibalization actions. A United States Government Accounting Office (GAO) (2001) study among the different services revealed some of the impacts of cannibalization on individual squadrons and their personnel. This GAO report on *Cannibalizations Adversely Affect Personnel and Maintenance* stated that "Cannibalizations are done to meet operational and readiness needs but they come at a high cost. Cannibalizations have increased the workload of maintenance personnel by millions of hours since fiscal year 1996" (General Accounting Office, 2001, p. 6). Jimmie S. Griffea also stated in his research on *Causes of EA6B cannibalizations* that "cannibalizations double the work of maintenance personnel, due to switching parts with other aircraft" (1998, p. 49). When a decision is made at the unit level to cannibalize a part, maintenance personnel are obligated to exhaust twice the amount of maintenance man hours (MMH) that would have been required to return the original aircraft back to mission capable status. An example scenario to illustrate this increase in workload follows:

> Aircraft 08 returns from flight with a maintenance discrepancy that requires troubleshooting. Subsequent maintenance troubleshooting reveals a faulty control box that needs to be removed and replaced. A supply system stock check reveals that control box is not in stock at the local supply warehouse. Since Aircraft 08's return to flight is critical in meeting the unit's flight schedule, a decision is made to cannibalize the control box from Aircraft 09. The total MMH required to remove and replace the control box is five hours. Maintenance personnel remove the control box from Aircraft 09 and install it on Aircraft 08, successfully returning

> Aircraft 08 to mission capable status. At the end of the process, Aircraft 08 consumed a total of five maintenance hours for the removal and replacement of the control box. Aircraft 09 separately consumed 2.5 hours during the cannibalization of the control box and is awaiting parts from supply for a new control box that would require an additional 2.5 hours for installation once received. Total additional MMHs incurred due to the cannibalization action is five hours.

Another impact of cannibalization is the extended loss of use of a major expensive asset. As the GAO study stated, “Cannibalizations takes expensive aircraft out of service, sometimes for long periods of time” (General Accounting Office, 2001, p. 2). Parts and components that are cannibalized from aircraft are of varying sizes and fluctuate in the workload required to remove them. Some aircraft parts like consumable hardware are fairly easy to remove and install, requiring minimal manpower, while others like an engine or major drive system component commands an ample workload to remove. Additionally, removing major components for cannibalization most often will require maintenance personnel to remove other components before they can gain access to the part that needs to be cannibalized, a process known as a removal to facilitate other maintenance (FOM) in naval aviation (Department of the Navy, 2013). Once all these removed to FOM components are uninstalled, they often sit on parts shelves or bins awaiting the replacement for the cannibalized part to arrive from the supply system.

Depending on the supply lead time of the cannibalized part, an aircraft can be in AWP status for days, weeks, or in some cases months due to gaps in the logistics system. The 3 June 2015 V-22 AMSRR revealed several outstanding supply documents, some of which had been on order in the supply system for months and in some cases over a year (AMSRR 2015). This can make it easier for maintenance managers to cannibalize additional parts for other aircraft if required. The ongoing process of continuously cannibalizing parts from the same aircraft resets if not properly controlled, and will keep an aircraft consistently waiting for parts, eventually turning it into a LTD aircraft.

Multiple aircraft parts on order can be very difficult to track and control. When an aircraft’s multiple outstanding supply documents are not being diligently tracked by maintenance officers, it can easily create a recipe for missing parts that can hold the aircraft in a LTD status for even longer periods. The GAO cannibalization study in 2001 revealed an aircraft that had not flown in more than 300 days due to missing 111 parts as a result of uncontrolled cannibalization. Four other aircraft were also identified that had not flown for periods ranging from 903 to 1,756 days due to uncontrolled cannibalization (General Accounting Office, 2001). Multi-million dollar LTD aircraft like these are often referred to as “hangar queens” or “wind chimes” among maintainers and often become the lowest priority on a maintenance department’s workload (General Accounting Office, 2001).

An aircraft’s complexity coupled with a maintenance department’s capacity management issues can significantly contribute to the LTD status of an aircraft. Additionally, inaccurate maintenance data inputted into the maintenance data systems creates issues of data integrity, causing supply asset visibility and tracking to be a very demanding process. The most visible consequence of all these is the hangar queen.

Although not as common in today’s naval aviation, hangar queen aircraft still exist in some aircraft platforms. In reviewing the 3 June 2015 V-22 AMSRR, two MV-22 aircraft were identified that had not flown since 2008. Both aircraft were AWP for varying repairable and consumable parts, the majority of which are V-22 major and critical components. A supply document number count revealed a combined 59 outstanding requisition document numbers, some of which are estimated to be received in 2017 (AMSRR, 2015). Figure 1 is a picture of MV-22 Bureau Number 166488, one of the two cannibalized MV-22 aircraft. This picture was captured by the researcher while he was stationed at MCAS New River.

Figure 1. Cannibalized MV-22 Aircraft Bureau Number 166488.

Due to the unrealistic and unpredictable demands that aircraft maintenance can place on maintenance personnel, a cannibalization action can be required day or night to meet operational demands. This means that personnel might be required to work additional hours until the part being cannibalized is removed and installed into the second aircraft to get it operationally ready for the flight schedule. Jacobs (2003) explained in his research on E-2C aircraft cannibalization that the idea of using cannibalization to return a NMC aircraft to mission capable status can make it very profitable for maintainers to cannibalize—even on late Fridays and weekends—even if the aircraft is not required for the next day's schedule.

As mentioned, the NAMP recognizes the many impacts of cannibalization, one of which is the negative impact on morale of maintenance personnel. Chapter 5.1.2.10.1 states "Cannibalization has a tendency to adversely impact morale and to worsen the NMCS or PMCS situation which it theoretically is intended to overcome" (Department of the Navy, 2013, p. 5-33). Maintenance personnel are salaried and do not accumulate any additional pay or incentives for working overtime. Any maintenance task that tends to take them past their normal work shift can be viewed as working without pay, reducing the morale of the maintenance personnel. This view on reduced morale was reinforced by the Naval Inspector General when he stated in a GAO report that "cannibalization is counterproductive and has a huge impact on morale" (General Accounting Office, 2001, p. 8). This reduced morale of the unit personnel over time adversely affects overall unit readiness due to decreased productivity in a maintenance department.

Cannibalization due to unavailable parts affects overall personnel retention in the DOD. A GAO survey conducted on the retention of officer and enlisted personnel in critical specialties ranked the availability of needed equipment, parts, and materials as the number one and number two reasons respectively why officers and enlisted personnel left the military service (General Accounting Office, 1999).

D. REASONS WHY SQUADRONS CANNIBALIZE

Squadrons cannibalize parts based on their individual needs. This section provides four main reasons why naval aviation squadrons practice cannibalization.

1. Supply System Shortages

DOD squadrons cannibalize parts for a variety of different reasons, the most common of which is a supply shortage of the required part. Jacobs (2000) again stated in his E-2C cannibalization research that "the first and probably most obvious reason for squadron-level cannibalization is a material shortage where the local supply system does not have a replacement asset" (p. 24). Production delays, manufacturer repair delays, component reliability, and aging aircraft airframes are just a few reasons why part shortages can arise. When a required part needed for replacement is not readily available at the local supply, maintenance managers have to make a quick decision on how to get the NMC aircraft back to a flying status.

As also revealed in the GAO-02-86 report on cannibalization, service officials also believe the main reason for cannibalizations was the shortage of spare repair parts (General Accounting Office, 2001). This often results in a decision to cannibalize the component from another aircraft and replace it once the supply system is able to yield the needed part. Depending on what part is required and the supply system's availability stock posture, these high-priority part requisitions can be on order in the supply system for days or even months for some limited aircraft parts. The April 2015 V-22 Supply System Working Group report revealed 91 supply requisition document numbers that had been on order for greater than 365 days. These document numbers accounted for a total of 231 parts ordered against 49 MV-22 airframes in operational squadrons (V-22 SSWG, 2015).

2. High Operational Tempo

The GAO explained in their study on cannibalization that high-unit operational tempo places heavy pressure on the supply system to be able to provide needed parts immediately when needed (General Accounting Office, 2001). When aircraft squadrons sporadically increase their daily operational requirements, the number of flying hours flown on aircraft increase causing a corresponding increase in the number of aircraft scheduled and unscheduled maintenance required. As Retzlaff and DeSilva (2005) stated in Achieving maximum unit mission capability, "Availability is directly dependent on the level of OPTEMPO, especially in older weapon systems. This means as OPTEMPO increases, availability will decrease as systems reach their point of required maintenance and logistical support quicker" (p. 6).

To complete aircraft scheduled and unscheduled maintenance, parts are needed. As the frequency of these maintenance requirements increases, so does the demand for its associated part requirements. These additional increases in part requirements at the squadron level create an irregular demand on a supply system and can quickly deplete in-stock items in the supply warehouse. As stated by Torres in *Supportability Requirements for the V-22 Osprey*, "When parts allowances are set and fleet requests exceed 200 percent or greater of the initial allowance, it creates a ripple effect in support" (2005, p. 27). Aviation logistics squadrons stock their posture on historical demand forecasts and sporadic increases in operational tempo among different squadrons makes it difficult to satisfy immediate part requirements and often leads to stock outs. Maintenance managers are therefore left with an only option of cannibalizing the part required.

3. High Readiness Demands

The Chief of Naval Operations (CNO) has established aircraft readiness goals for all aircraft platforms in the Naval Aviation Enterprise (NAE). Readiness goals are established in two categories; mission capable (MC) and full mission capable (FMC) rates. The NAMP publishes the overall NAE readiness goal as 73% MC and 56% FMC (Department of the Navy, 2013). Each specific aircraft T/M/S has its own assigned readiness goals as stated in the applicable T/M/S Mission Essential Subsystem Matrix (MESM).

As explained in Chapter 17 of the NAMP, "An aircraft unit's MC rate reflects the percentage of all aircraft assigned to the unit which are capable of performing at least one, but not all missions published in the MESM, while the FMC rate reflects the percentage of all aircraft assigned which are capable of performing all missions outlined in the MESM" (Department of the Navy, 2013, p. 17-19). Table 1 provides an example list of CNO readiness goals for the various operational T/M/S aircraft assigned to 2dMAW:

Table 1. Second MAW Aircraft CNO Readiness Goals.

T/M/S	**MC (%)**	**FMC (%)**	**T/M/S**	**MC (%)**	**FMC (%)**
EA6B	73	54	CH53E	70	60
KC130J	81	70	FA18A	75	58
UH1N	85	75	FA18C	75	58
UH1Y	85	75	FA18D	75	58
AH1W	85	75	AV8B	76	68
AH1Z	85	75	MV-22B	82	75

Adapted from: Commanding General, 2nd MAW. (2012 January 9). *Aircraft readiness requirements.* Cherry Point, NC: United States Marine Corps. Retrieved from http://www.2ndmaw.,arines.mil/Portals/7/WingAdjutatn/Order/WgO%203501.4E.pdf

Aircraft squadrons are required to report their specific unit's readiness daily through the Navy's AMSRR website to show their current state of aircraft readiness. This report once published by the unit becomes visible to all higher echelons up to CNO level. Aircraft maintenance managers take pride in readiness reporting since it is looked at as a measure of the effectiveness of the unit's maintenance management. Multiple aircraft that are AWP lowers a unit's MC and FMC rate and can cause them to fall below the CNO goal. As Myette (1981) stated in his research on *Cannibalization of the F-14A and S-3A aircraft*, "Squadron level maintenance managers consolidate unfilled supply requirements to as few aircraft as possible in order to maximize readiness" (p. 49). Aviation squadrons still use cannibalization to consolidate the number of aircraft that are AWP in an effort to create more flyable aircraft thereby increasing their mission capable rating. The daily readiness reporting demands keep every aircraft unit's maintenance department focused on high readiness to avoid any undue attention and scrutiny from their higher-ranked commanders.

4. Supply Response Time

Similar to aircraft squadron operations, the CNO has established acceptable standards for aviation logistics supply units for delivering aircraft parts to the aircraft squadrons. Supply units have a designated response time to issue local in-stock parts to the requisitioning unit or to provide the unit with an accurate requisition status for items that are not locally available. This includes not in stock (NIS) and not carried (NC) parts (Department of the Navy, 2013).

A requisition response time begins when the squadron unit places an order for a part on the supply system and ends when the part is delivered to the requesting unit. Response times vary based on the issue priority group of the part and the priority designator (PD) of the unit. Table 2 shows the NAMP's published supply response times for aviation supply squadrons.

Table 2. Supply Response Time for Aviation Supply Squadrons.

Issue Priority Group	Priority Designator	Processing Time
1	1–2	1 Hour
2	4–8	2 Hours
3	9–15	24 Hours

Adapted from: Department of the Navy. (2013 Jun 15). The Naval aviation maintenance program. Patuxent River, MD: Author. Retrieved from http://www.navair.navy.mil/logistics/4790/library/contents.pdf

A parts-issue priority group is based on the parts' impact on the mission capability of the aircraft. Parts that cause an aircraft to be NMC are assigned Priority 1, those that affect the FMC status of the aircraft are assigned Priority 2, and routine parts that do not impair the aircraft's ability to fly or perform any specific mission are issued a Priority 3. A unit's priority designator is determined by the force or activity designator (FAD) assigned to the unit and the urgency of need designator (UND) for the unit. (Deputy Under Secretary of Defense [L&MR], 2003).

Supply response time can be a major deciding factor for maintenance managers when it comes to cannibalizing an aircraft part. When a Priority 1 part is required from supply for a NMC aircraft to make a scheduled launch, maintenance managers have to make decisions on the total timeframe for repairs to be completed on the aircraft. If the supply response time appears to be greater than 30 minutes to receive the part, the scheduled launch has a high chance of getting aborted due to the repair delay. As Jacobs stated in his research, "A replacement component that takes more than 30 minutes to deliver is of little use to a maintenance manager for that launch" (2000, p. 26). This realization that the aircraft might not make the scheduled launch often leads to a cannibalization decision to quickly remove the part from another aircraft for quick installation to reduce the total repair time for the NMC aircraft. This allows the NMC aircraft to make the scheduled launch, and the replacement part from supply to be installed in the cannibalized aircraft at a later time. Appendix E of the NAMP directs a maintenance data system Malfunction Code of 814 to be used for documenting cannibalization actions taken as a result of a time constraint to make a scheduled launch or to complete a turnaround inspection for an aircraft (Department of the Navy, 2013).

E. SUMMARY

The NAMP acknowledges the issue of supply constraints in the naval aviation community and has established policies on the use of cannibalization as a viable technique to allow squadrons to minimize the impact of the supply constraint on their aircraft readiness. This practice enables maintenance managers to systematically orchestrate moving parts between aircrafts to manage their MC and NMC assets.

Although aviation squadrons cannibalize for a variety of reasons to include (but are not limited to) supply system shortages, supply response time, high operational tempo, and high readiness demands, the negative impacts of cannibalization can be quite adverse to the aviation squadrons and the DOD as a whole. Excessive MMHs are exhausted during cannibalization, which significantly contributes to reduced personnel morale and personnel retention in the DOD. Aircraft assets are also taken out of service for long periods of time, costing the services the loss of use of these very expensive assets.

III. METHODOLOGY

This chapter explains how the data used in the analysis was collected and analyzed to answer the research questions stated in Chapter I. The data sources section provides the sources of the data used in the thesis. The research design strategy section describes how the data to be presented in Chapter IV was organized and analyzed. The measures of cannibalization section describes how the Navy measures cannibalization in the naval aviation community. Lastly, the research scope and limitations section explains the specific aspects of the MV-22 cannibalizations that were or were not considered in this research. It also identifies the MV-22 squadrons in the community that were analyzed in this research.

A. DATA SOURCES

The data used in this research was sourced from a variety of different naval aviation maintenance data sources.

Five years of historical MV-22 aircraft cannibalization data from January 2010 to January 2015 was received from two different system analysts; the Commander Naval Air Forces Pacific (COMNAVAIRPAC) systems analyst, and the MV-22 platform systems analyst. The data was sourced from these two locations to allow the researcher to compare and contrast the two sets of data and ensure accuracy of the data being received. This data contained all cannibalization work order information for the five year period.

The VMMT-204 maintenance department provided a January 2015 combined maintenance and material management (3M) summary report for the 2dMAW VMM squadrons. This report included summary maintenance information for all squadrons that were on station and not deployed during the month of January 2015.

A consolidated matrix report of aviation maintenance and supply readiness reporting (AMSRR) and 3M data from 2013 to 2015 for all community wide MV-22 squadrons was obtained from the MV-22 Current Readiness Analyst aboard MCAS New River. This report contained all pertinent monthly AMSRR readiness information and 3M monthly maintenance summary report information for all the MAG 16 and MAG 26 VMM squadrons.

The COMNAVAIRPAC database systems analyst provided the historical MV-22 flight summary data from January 2010 to January 2015. This report contained monthly flight hour and flight sortie information for all the MV-22 squadrons.

A data set containing 2010 to 2015 historical MV-22 aircraft inventory counts and yearly count of all in reporting (IR) status aircraft in the community was sourced and received from the COMNAVAIRPAC database systems analyst.

MV-22 deployment maintenance data from 2011 to 2013 was acquired from the MV-22 database system analyst. This data contained MV-22 land-based and shipboard deployment maintenance data for seven selected squadrons that deployed during that timeframe.

B. RESEARCH DESIGN STRATEGY

This research uses an inductive approach to identify trends, patterns and differences in the practice of cannibalization between squadrons and over time. In this context, an inductive approach means there were no specific hypotheses the researcher intended to test. Instead, an analysis of the data was undertaken to better understand potential problem areas and potential avenues for improvement.

The researcher's existing knowledge and experience on the topic of aircraft cannibalization was heavily relied upon in analyzing the data and understanding the different aspects of the various maintenance work order codes, MV-22 aircraft components, and general MV-22 maintenance and flight operational concepts. This knowledge and experience stemmed from 10 years of being an aircraft mechanic and five years of experience as an MV-22 maintenance officer.

The five year historical work order data received was organized using Microsoft Excel pivot tables. This allowed for the selection of specific MV-22 squadrons and cannibalization pertinent work order information required for the analysis. The pertinent work order information retrieved included: The cannibalization reason codes; the maintenance man hours (MMH) documented, repairable and consumable information; the component part number and nomenclature information, and the equipment operational capability (EOC) codes. This information was then sorted by squadron and by time frames and used as factors to compare the different squadrons. The cannibalized component data was also sorted into yearly frequency distributions to identify the top frequently cannibalized components across the community.

A between-squadron comparison of cannibalization rates, as measured by the Navy, was also conducted. Using this rate and the total number of cannibalizations as performance metrics, the researcher was able to identify which squadrons performed better at cannibalization.in relation to their number of flight hours flown over a given period. This also enabled the researcher to identify if any relationship existed between cannibalizations and the number of flight hours flown.

A total of seven squadrons were selected for cannibalization by deployment analysis. The purpose of the analysis was to compare how the practice of cannibalizations varied between squadrons on their deployments and between two types of deployment. The two types of deployments were land-based and shipboard deployments. This was accomplished by breaking the seven squadrons into the two deployment categories based on when the applicable deployment was completed. The researcher was able to determine how the practice of cannibalizations varied with deployments using these measurement parameters.

Most of the data collected were analyzed using descriptive statistics, frequency charts, scatter plots, and ratio/percentage analysis. Utilizing these tools, the researcher was able to establish patterns and variations in cannibalization among the different squadrons, and also analyze the squadron performance on a cannibalization rate basis.

In Chapter IV, descriptive statistics will be used to compare squadrons' performance based on historical data. One squadron (or group of squadrons) will be said to be ‘better’ than another on the basis of this historical data. No inferential statistics will be applied to support this comparison. In other words, the analysis will describe the relative differences between squadrons, and not attempt to predict how much of that difference might have been due to chance alone. In some cases, the magnitude of the differences will make it clear that there are assignable causes to the variation. In others, this attribution may be less well justified. Hence, when the results indicate one squadron or group of squadrons is ‘better’ than another on any metric, the reader will understand this to mean ‘historically better in this data,’ and not to contain any inference about the likelihood of the difference occurring due to chance alone. However, in many cases, this researcher will attempt to examine the data in detail, to uncover the historical reasons for the performance differences from the qualitative data describing what occurred.

In analyzing the secondary research questions, however, inferential statistics will be used. Secondary question number two required the researcher to determine how cannibalization affected aircraft availability in the different squadrons. To answer this question, a multivariate regression analysis was performed using the consolidated AMSRR and 3M data. This regression was performed using the Data Analysis tool pack in Microsoft Excel, and inferences were made about the regression results.

C. MEASURES OF CANNIBALIZATION

Naval aviation cannibalization is measured in one of two ways: The number of cannibalization actions per every 100 flight hours flown, or the number of cannibalization actions per every 100 flight sorties (Department of the Navy, 2013). A single cannibalization action can be related to the removal of a serviceable component or part from an aircraft. As a standard practice, most squadrons use the cannibalization per hundred flight hour matrix to measure their cannibalization rates. Chapter 14.2.2.1.5k of COMNAVAIROFRINST 4790.2B defines and displays this form of measurement as shown in Figure 2:

Figure 2. Cannibalization Rates.

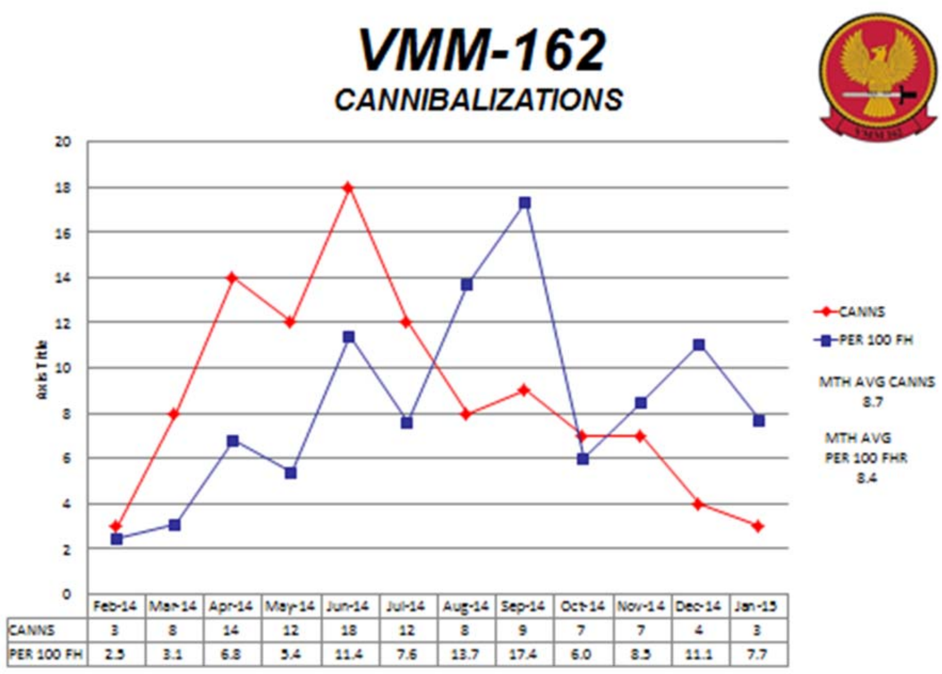
CANNS/100 FLTHRS: Measures the number of cannibalization actions necessary to support 100 flight hours. This use of 100 flight hours, as a standard divisor, is to normalize comparisons and maintain statistical consistency. Computation of this data element is as follows:

$$\text{CANNS / 100 FLTHRS} = \frac{\text{TOTAL CANN ITEMS}}{\text{(TOTAL FLTHRS / 100)}}$$

Source: Department of the Navy. (2013 Jun 15). *The Naval aviation maintenance program* (COMNAVAIRFORINST 4790.2B CH-1). Washington, DC: Headquarters Department of the Navy.

The NAMP has also established a requirement for aviation maintenance squadrons to publish their cannibalization rates in their monthly 3M summary report. Figure 3 is a sample page of VMM-162's January 2015 Monthly 3M cannibalization summary report briefed to the MAG 26 commander.

Figure 3. VMM-162 January 2015 3M Cannibalization Summary.



	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15
CANNS	3	8	14	12	18	12	8	9	7	7	4	3
PER 100 FH	2.5	3.1	6.8	5.4	11.4	7.6	13.7	17.4	6.0	8.5	11.1	7.7

Source: Eggert, N. (2015, January). *Marine Aircraft Group 26 January 2015 3M Summary*. Paper presented at Marine Aircraft Group 26, Jacksonville, NC.

D. RESEARCH SCOPE AND LIMITATIONS

The purpose of this analysis is to perform a comparative and time series analysis of cannibalization in the MV-22 community. This research will analyze cannibalization practices and trends between squadrons over time to determine how the overall process of cannibalization contributes to aircraft availability within the squadrons.

MV-22 squadrons analyzed included training and operational squadrons within the first, second and third MAWs. All squadrons that were selected for the analysis had fully transitioned to the MV-22 aircraft as of January 2015. Individual squadrons selected were VMMs 162,261,263,264,266,365, and VMMT-204 on the East Coast, and VMMs 161,163,165,166,268, and 363 on the West Coast.

This analysis excluded new squadrons that were still going through the MV-22 transition due to the lack of historical maintenance information to be able to fairly benchmark them against other established squadrons. Squadrons involved in operational testing and evaluation, special operational mission sets, and operating in a reserve status were also excluded in the comparative analysis.

This research only analyzed the squadrons under specific areas of cannibalization: Unit cannibalizations by malfunction reason code were explored to identify the various reason codes that squadrons were documenting. MMH documented by the different squadrons was also analyzed to see how the squadrons varied in the amount of MMHs exhausted for cannibalization actions. Components that were cannibalized were analyzed under the repairable and consumable categories to see how squadrons differed in cannibalizing components between the two categories. Cannibalizations by EOC code was also analyzed to identify which major EOC categories consumed the most of cannibalization tasks and to identify how that varied between the squadrons.

This research on MV-22 cannibalization was only limited to the analysis of cannibalization rates and MMH expended based on the factors previously described. Other aspects of cannibalization that are not addressed by this research include:

- The problems surrounding the logistical constraints of the naval aviation supply system that creates AWP situations. This was beyond the scope of this research.

- The negative impact of cannibalization on personnel morale in the MV-22 community.
- The long-term impacts of component cannibalizations on aircrafts.

During the aforementioned data gathering process, the researcher was able to engage in a number of background discussions with V-22 maintenance personnel and SMEs. From those conversations, the researcher was able to develop a list of recommended best cannibalization practices. While this list is not within the scope of the researcher's scientific investigation, the researcher nonetheless wanted to document the recommendations. This list of recommendations can be found in the Appendix.

E. SUMMARY

This chapter described the research methodology used in Chapter IV of the thesis. The type and sources of the data used in the thesis was explained in detail, along with the research design strategy used in analyzing the data. The tools, methods and specific V-22 squadrons included in the analysis were formally identified to set the stage for the next chapter. This chapter also explained the Navy's current method of measuring cannibalization and how this method was used in this thesis to identify which squadrons performed better at cannibalization in the community. Lastly, the scope and limitations of the thesis was addressed to explain the specific areas of cannibalization researched in this thesis.

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IV. DATA PRESENTATION AND ANALYSIS

This chapter presents and analyzes the data obtained using the data collection methods mentioned in Chapter III. MV-22 aircraft cannibalization data from 2010 to 2015 was received and analyzed to determine if there was a difference in the practice of cannibalization between the different squadrons. Throughout the five year period, the MV-22 aircraft community was still in transition as existing CH-46 aircraft squadrons progressively transitioned to the MV-22 aircraft, and was taken into consideration while performing the analysis.

A. ANALYZING DIFFERENCES IN CANNIBALIZATION PRACTICES

In an attempt to determine how cannibalization varies across squadrons, the researcher considered six categories:

- Cannibalizations by malfunction reason code
- Cannibalization maintenance man hours documented
- Cannibalization by repairable to consumable part ratio
- Cannibalization by equipment operational capability codes
- Cannibalizations per 100 flight hours
- Cannibalizations on deployment and by deployment type

1. Cannibalizations by Malfunction Reason Code

COMNAVAIRFORINST 4790.2B Change 1 has established maintenance data system malfunction codes to be used by aviation squadrons when documenting maintenance actions performed. Maintenance actions that involve cannibalization of components are documented using one of the seven cannibalization malfunction codes:

> 812: Cannibalization—removed for fault isolation/troubleshooting (unit left installed in second aircraft)
>
> 813: Cannibalization—directed by higher authority (above squadron level inter-activity transfer of equipment or item)

814: Cannibalization—operation launch/turnaround requirements (part not readily available within required time constraints)

815: Cannibalization—repairable part carried but not on hand in local supply system

816: Cannibalization—repairable part not carried in local supply system

817: Cannibalization—consumable part not carried or not in stock

818: Cannibalization—lack of available deck space /Support Equipment/ test equipment for trouble shooting, unit left installed in second aircraft. (Department of the Navy, 2013)

The five-year maintenance data received was sorted to categorize all cannibalization actions performed by the 13 squadrons into the seven cannibalization malfunction codes. Each cannibalization work order had one of the accompanying malfunction codes documented to indicate the specific reason for the cannibalization action. There were no cannibalization work orders that were found without an appropriate malfunction code. This was a good indication that the squadrons were in compliance with the NAMP and the maintenance information system was accurate in tracking malfunction codes; however, it did not guarantee the accuracy of the specific cannibalization malfunction code that was imputed on the work order. Table 3 is a depiction and breakdown of all cannibalization work orders sorted by reason malfunction codes for the seven East Coast squadrons.

Table 3. Cannibalization by Reason Malfunction Code for East Coast Squadrons.

	Cannibalization by Reason Malfunction Codes							
Squadron Unit	**812**	**813**	**814**	**815**	**816**	**817**	**818**	**Totals**
VMM-162	12	3	23	489	23	2	0	552
VMM-261	3	61	24	458	9	0	0	555
VMM-263	5	32	20	571	6	1	0	635
VMM-264	18	36	49	700	7	2	0	812
VMM-266	33	5	66	745	9	1	1	860
VMM-365	2	12	17	567	5	2	0	605
VMMT-204	2	14	25	1061	4	0	1	1107
Totals	75	163	224	4591	63	8	2	5126

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The data revealed that the vast majority of cannibalizations were performed and documented under reason code 815, because the local supply department had stocked out of those repairable parts. To determine the actual magnitude of the number of items processed under these categories, the researcher calculated the number of items processed in each category as a percentage of the total items cannibalized for each squadron. Table 4 shows the different percentages associated with these cannibalization reason codes.

Table 4. Reason Code as a Percentage of Total Items Cannibalized for East Coast Squadrons.

	Reason code as a percentage of total items cannibalized						
Squadron Unit	812	813	814	815	816	817	818
VMM-162	2.17	0.54	4.17	88.59	4.17	0.36	0.00
VMM-261	0.54	10.99	4.32	82.52	1.62	0.00	0.00
VMM-263	0.79	5.04	3.15	89.92	0.94	0.16	0.00
VMM-264	2.22	4.43	6.03	86.21	0.86	0.25	0.00
VMM-266	3.84	0.58	7.67	86.63	1.05	0.12	0.12
VMM-365	0.33	1.98	2.81	93.72	0.83	0.33	0.00
VMMT-204	0.18	1.26	2.26	95.84	0.36	0.00	0.09

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The data revealed that 82% to 95% of cannibalizations actions documented were associated with the 815 reason code, verifying the impact that parts unavailability has on individual squadrons. As discussed in the literature review, this problem does affect overall personnel retention in the DOD.

Reason code 814 (operation launch/turnaround requirements; part not readily available within required time constraints) appeared to be the second most common reason for cannibalization for all squadrons with the exception of VMMs 261 and 263. This reason code is used when cannibalization decisions were made due to a time constraint in meeting a launch requirement. To be more specific, the parts required for these work orders were on hand at the local supply department but the supply response time coupled with the time required to install the component would have delayed or scrapped the launch if a cannibalization decision had not been made.

For two squadrons, VMM-365 and VMMT-204, fewer than 3% of total items cannibalized fell under the 814 code. The two squadrons comparatively are able to successfully execute their scheduled launches with minimal cannibalization than the other squadrons. Squadrons that have established aircraft launch procedures which allow ample troubleshooting time, typically follow this pattern. For these squadrons, when a launch aircraft requires troubleshooting to reset or clear a fault discrepancy, the maintainers are often given time to isolate and repair the discrepancy to enable the scheduled aircraft to make the launch. These squadrons also typically have proficient systems troubleshooters that are proficient at resetting aircraft system logics that are able to clear the majority of fault indications without the need to replace parts or components. This concept is especially critical for a training squadron like VMMT-204 because it allows the squadron to manage its daily flight schedule while limiting the number of back-up aircraft that will be used if pilots were always allowed to move to another aircraft whenever they had faulty indications on start-up.

Cannibalization directed by higher authority is associated with reason code 813 (directed by higher authority). Of the seven squadrons, VMM-261 showed the highest in this category. While other squadrons ranged from 0% to 5 % of total items in this category, VMM-261's cannibalizations in this category accounted for 10.99% of its overall items processed. This squadron comparatively receives more direction by higher authority to cannibalize parts and components for other squadrons within or outside the MAG. Squadrons that are directed to cannibalize parts for other squadrons do not only reduce their own readiness in the process, but also exhausts significant MMHs to remove the parts for other squadrons. In the case of VMM-261, the squadron accumulated a MMH cost of 339.6 MMHs for cannibalizations in this category.

Cannibalizations of repairable parts that are not carried in the local supply system are documented using a malfunction code of 816. Of the East Coast squadrons, VMM-162 had the most in this category, even though they had the lowest in overall count of parts cannibalized. A total of 23 parts were cannibalized in this category in the five year period which was more than double what the two next higher squadrons (VMMs 261 and 266) had cannibalized. Both squadrons combined documented 18 parts in this category.

Work orders documenting the 816 malfunction code were screened to see which specific repairable parts were documented as not carried (NC) in the local supply department. The majority of part numbers documented as NC were in fact carried by the supply department but were not in stock (NIS) at the time VMM-162 placed the orders. NIS repairable components are supposed to be documented using 815 malfunction code, which should have been the case. However, since the verbiage of the 815 (repairable part carried but not on hand in local supply system) and 816 category (repairable part not carried in local supply system) almost read the same, maintainers do inadvertently document work orders under the 816 code instead of the 815. This error held true for most of the 816 work orders screened for the other East Coast squadrons as well.

Historical cannibalizations by reason code were also screened for the West Coast squadrons to compare how they varied with the East Coast squadrons. Table 5 depicts the breakdown of cannibalizations by reason code for the six squadrons analyzed on that Coast.

Table 5. Cannibalization by Reason Malfunction Code for West Coast Squadrons.

	Cannibalization by Reason Malfunction Codes							
Squadron Unit	**812**	**813**	**814**	**815**	**816**	**817**	**818**	**Totals**
VMM-161	6	6	22	625	19	11	1	690
VMM-163	2	3	23	327	7	1	0	363
VMM-165	5	5	49	227	13	0	0	299
VMM-166	3	36	16	416	3	2	0	476
VMM-268	2	2	12	79	2	0	0	166
VMM-363	1	2	45	131	3	0	1	183
Totals	19	54	167	1805	47	14	2	2177

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Squadrons on this Coast generally appeared to follow the same pattern as those on the East Coast. Across the seven reason codes, the 815 category was still the category with the highest number of removals, still indicating that the majority of items processed were repairable that were NIS. Table 6 shows the magnitude of each category to the total items cannibalized for the different squadrons.

Table 6. Reason Code as a Percentage of Total Items Cannibalized for West Coast Squadrons.

	Reason Code as a Percentage of total items cannibalized						
Squadron Unit	812	813	814	815	816	817	818
VMM-161	0.87	0.87	3.19	90.58	2.75	1.59	0.14
VMM-163	0.55	0.83	6.34	90.08	1.93	0.28	0.00
VMM-165	1.67	1.67	16.39	75.92	4.35	0.00	0.00
VMM-166	0.63	7.56	3.36	87.39	0.63	0.42	0.00
VMM-268	1.20	1.20	7.23	47.59	1.20	0.00	0.00
VMM-363	0.55	1.09	24.59	71.58	1.64	0.00	0.55

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

VMMs 165 and 363's overall cannibalized components under the 814 category was comparatively higher than the other squadrons. Percentages of overall 814 cannibalized components in those squadrons were 16.39% and 24.59% respectively, while the remaining squadrons ranged from 3% to 7% in this category. These squadrons cannibalize more parts than the others in support of turnaround and launch operations to accomplish their daily flight schedules requirements. Both of these squadrons are newer transitioned squadrons, with the majority of their 814 work orders documented within the first few years of transition. The frequency of 814 work orders in both squadrons was seen to be declining as time progressed from their transitioning stages. This was indicative of the squadron maintainers gaining more technical proficiency, enabling them to execute fight operations with minimal cannibalizations as before.

Similar to the East Coast squadrons, one squadron, VMM-166 appeared to cannibalize more parts by direction of higher authority compared to the others. Their percentage of items processed under the 813 reason code (directed by higher authority) was 7% compared to fewer than 2% for the remaining squadrons. Upon reviewing the discrepancy blocks of the historical work orders for these cannibalizations, it was discovered that all the work orders were initiated to cannibalize parts to support of the

Fall 2012 Marine Aviation Weapons and Tactics Instructor course in Yuma AZ. This training event although not a specific squadron driven exercise and away from the squadrons home base, still placed a burden on VMM-166 to remove parts from its assigned aircraft in support of the event.

2. Cannibalization by Maintenance Man Hours Documented

The researcher attempted to identify how MMHs documentation varied across the different squadrons. Each of the 13 squadrons were analyzed to see how their total MMH documented and total cannibalizations compared to the other squadrons over the five year period. Parts and components that are cannibalized expend MMHs to remove and replace the item. As such, it was expected that squadrons with higher numbers of total cannibalized components would have documented significantly more cannibalization MMHs than squadrons with less number of items processed. Table 7 displays the total count of cannibalized items and sum of MMH for both East and West Coast squadrons.

Table 7. Total Items Cannibalized and Total MMH.

East Coast Squadrons			
Squadron	Total items cannibalized	Total MMH	MMH to Cannibalization Ratio
VMM-162	552	3,703	6.7
VMM-261	555	3,939	7.1
VMM-263	635	3,624	5.7
VMM-264	812	5,670	7.0
VMM-266	860	6,497	7.6
VMM-365	605	3,736	6.2
VMMT-204	1,107	4,914	4.4
West Coast Squadrons			
Squadron	Total items cannibalized	Total MMH	MMH to Cannibalization Ratio
VMM-161	690	4,898	7.1
VMM-163	363	1,865	5.1
VMM-165	299	2,669	8.9
VMM-166	476	2,686	5.6
VMM-268	166	936	5.6
VMM-363	183	1,654	9.0

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Of the East Coast squadrons, VMM-162 cannibalized the least number of items, totaling 552 for the five year period. The total MMHs exhausted on these parts were 3,703 hours which was more than the MMH expended by VMM-263 to cannibalize 635 items. Conversely, VMMT-204 cannibalized a total of 1,107 parts, leading the other squadrons as the squadron with the highest number of cannibalizations. Their total documented MMH was 4,914 which were significantly less than what was exhausted by VMMs 264 and 266 to cannibalize 295 and 247 less parts respectively. Similar disparities among the West Coast squadrons were observed as well. VMM-165 processed a total of 299 components exhausting 2,669 MMHs, whereas VMM-166 exhausted 2,686 MMHs to process 476 parts. Even though 177 more parts were cannibalized inVMM-166 than VMM-165, documented MMHs for VMM-166 was less than that documented by VMM-165. Another squadron VMM-363 cannibalized only 17 more parts than VMM-268. These 17 parts however, accounted for a difference of 717 MMHs higher than that of VMM-268.

To understand why there were such significant variations in MMHs documented, the researcher took an approach to sample historical work orders for three components to see how MMHs were documented for these components in the different squadrons. The components selected for comparison were No.2 flight control computer (FCC), control display unit (CDU) keyboard, and a No.4 variable frequency generator (VFG) as depicted in Table 8. These components were selected based on the simple fact of easy accessibility and having no requirement to remove other components to facilitate their removal and replacement.

Each of the work orders examined from the different squadrons displayed huge variations in the number of MMHs documented. Per the data examined, MMHs required to cannibalization a No. 2 FCC ranges from 0.1 to 10.2 MMHs. Similarly, a CDU keyboard required 0.2 to 12.2 hours, while a No. 4 VFG required 0.3 to 15.1 Hours. Table 8 displays a sampled list of work orders with their Maintenance Control Numbers (MCN) for the three components selected.

Table 8. Historical Documented FCC, CDU Keyboard, and VFG MMHs.

Squadron	Component	Part Number	MCN	MMH
VMM-161	NO.2 Flight Control Computer	901-305-150-111	1ONJ413	2.4 Hours
VMM-162	NO.2 Flight Control Computer	901-305-150-111	121EIM3	0.7 Hours
VMM-163	NO.2 Flight Control Computer	901-305-150-111	1P1LNWK	7.2 Hours
VMM-165	NO.2 Flight Control Computer	901-305-150-111	1MPKLKK	0.1 Hours
VMM-166	NO.2 Flight Control Computer	901-305-150-111	29Z20E5	1.3 Hours
VMM-261	NO.2 Flight Control Computer	901-305-150-111	28QOM1Z	0.5 Hours
VMM-263	NO.2 Flight Control Computer	901-305-150-111	112GNT2	3.1 Hours
VMM-264	NO.2 Flight Control Computer	901-305-150-111	1GHKJ4P	10.2 Hours
VMM-266	NO.2 Flight Control Computer	901-305-150-111	148OB24	4.2 Hours
VMM-365	NO.2 Flight Control Computer	901-305-150-111	2MEXV7U	0.2 Hours
VMM-363	NO.2 Flight Control Computer	901-305-150-111	198CQ9N	0.4 Hours
Squadron	**Component**	**Part Number**	**MCN**	**MMH**
VMM-161	Computer Display Unit Keyboard	901-370-354-403	1ONIVO3	3.7 Hours
VMM-162	Computer Display Unit Keyboard	901-370-354-403	121EOI3	4.9 Hours
VMM-261	Computer Display Unit Keyboard	901-370-354-403	28QOUCS	0.2 Hours
VMM-264	Computer Display Unit Keyboard	901-370-354-403	1GF93RA	1.4 Hours
VMM-266	Computer Display Unit Keyboard	901-370-354-403	146D9KO	0.3 Hours
VMM-365	Computer Display Unit Keyboard	901-370-354-403	2MEW6OV	1.0 Hours
VMM-363	Computer Display Unit Keyboard	901-370-354-403	198CY1I	9.4 Hours
VMMT-204	Computer Display Unit Keyboard	901-370-354-403	00GFJA1	12.2 Hours
Squadron	**Component**	**Part Number**	**MCN**	**MMH**
VMM-163	No. 4 Variable Frequency Generator	901-375-002-117	1P1L25W	2.3 Hours
VMM-261	No. 4 Variable Frequency Generator	901-375-002-117	28QOQIB	4.0 hours
VMM-264	No. 4 Variable Frequency Generator	901-375-002-117	1GF957Y	6.9 Hours
VMM-365	No. 4 Variable Frequency Generator	901-375-002-117	2MEW6XV	9.0 Hours
VMM-363	No. 4 Variable Frequency Generator	901-375-002-117	198CQ9I	15.1 Hours
VMMT-204	No. 4 Variable Frequency Generator	901-375-002-117	00GEXT9	0.3 Hours

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Cannibalization MMHs are only meant to account for the maintenance time required to simply remove and replace a component. These documented hours should therefore have not included any additional system trouble shooting time or other maintenance time not pertaining to the component removal and replacement process. Additionally, maintenance instruction manuals also standardize removal and replacement steps for these components and should have minimized a lot of the variation in the MMHs documented.

Historical work orders for all the components were retrieved for the five year period to run a descriptive statistics on the documented MMHs for each component. Table 9 contains the results of the descriptive statistics.

Table 9. FCC, CDU Keyboard, and VFG MMH Descriptive Statistics.

FCC Statistics		*CDU Keyboard Statistics*		*VFG Statistics*	
Mean	1.9969697	Mean	2.140425532	Mean	2.29230769
Standard Error	0.26943755	Standard Error	0.358479412	Standard Error	0.72576587
Median	1.3	Median	1.4	Median	0.65
Mode	1.2	Mode	0.4	Mode	0.5
Standard Deviation	2.18892103	Standard Deviation	2.457611033	Standard Deviation	3.70069432
Sample Variance	4.79137529	Sample Variance	6.039851989	Sample Variance	13.6951385
Kurtosis	13.5438962	Kurtosis	7.050145108	Kurtosis	5.22021438
Skewness	3.2413808	Skewness	2.558048714	Skewness	2.31897602
Range	13.4	Range	12	Range	15
Minimum	0.1	Minimum	0.2	Minimum	0.1
Maximum	13.5	Maximum	12.2	Maximum	15.1
Sum	131.8	Sum	100.6	Sum	59.6
Count	66	Count	47	Count	26

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Results from the descriptive statistics revealed large standard deviations in documenting MMHs for the same components between the different squadrons. Each component's standard deviation was divided by its specific mean to calculate the coefficient of variation for the three components. The calculated results using the data resulted in coefficient of variations of 1.06, 1.14 and 1.64 for the FCC, CDU keyboard and VFG MMHs respectively. These results revealed that the MMHs documented for cannibalizing these components vary on average by over 100%, or in the case of the VFG, by 164%.

These variations in MMHs documented, means that cannibalization MMHs *reported* across the community significantly vary. Although the NAMP requires squadrons to publish and submit cannibalization MMHs as part of their monthly 3M summaries, these numbers may not accurately reflect how much time is actually exhausted to cannibalize parts and components in the community. It appears likely that the variance is caused by some degree, not by variance in work time, but by variance in what work is reported as a part of the MMH (e.g., troubleshooting time). The true magnitude of an increased workload due to cannibalization can therefore not be measured until ways are found to standardize what should and should not be counted as a cannibalization MMH.

3. Cannibalization by Repairable Parts to Consumable Parts Ratio

All the aircraft parts that were cannibalized fell under either the consumable or repairable parts categories. As already described previously, the 817 cannibalization reason code is used to document cannibalization of consumable items that are NC or NIS at the local supply department. Initial analysis of this malfunction code data suggested that only a small fraction of parts cannibalized among the squadrons were consumable parts. To be specific, only 22 out of 7,529 MV-22 parts cannibalized were identified as consumable parts. Although the vast majority of parts typically cannibalized in the community from April 2012 to March 2015 were repairable, this researcher was not convinced of the accuracy of this information and took a different approach to determine the accuracy of the malfunction code data.

The 7,529 cannibalization work orders were sorted by malfunction code and again revealed only 22 records. Analyzing the data field headers on the work orders, the researcher found a Repairable Indicator data field on each work order. Chapter 13.2.11.2 of the NAMP defines this data field as “Rpr Ind. This is automated based on WUC/UNS CM baseline. Y indicates a repairable.” Maintenance work orders are supposed to indicate this data field with a “Y” if the part removed is a repairable or an “N” if it is a consumable. The historical work orders for all 13 squadrons were sorted by this repairable indicator to separate each squadron’s cannibalization work orders into the two categories. Table 10 displays the number of repairable parts, consumable parts and the consumable part percentage of the total parts cannibalized for each of the 13 squadrons.

Table 10. Number of Cannibalizations by Consumable and Repairable Parts.

	Repairable Parts	Consumable Parts	Total	Consumable as % of total parts	Repairable to Consumable Ratio
VMM-162	354	198	552	35.87	1.8
VMM-261	393	162	555	29.19	2.4
VMM-263	440	195	635	30.71	2.3
VMM-264	569	243	812	29.93	2.3
VMM-266	682	178	860	20.70	3.8
VMM-365	464	141	605	23.31	3.3
VMMT-204	718	389	1107	35.14	1.8
VMM-161	467	223	690	47.75	2.1
VMM-163	232	131	363	56.47	1.8
VMM-165	181	118	299	65.19	1.5
VMM-166	335	141	476	42.09	2.4
VMM-268	109	57	166	52.29	1.9
VMM-363	117	66	183	56.41	1.8

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The table revealed the true magnitude of consumable versus repairable parts cannibalized in the different squadrons. Among the East Coast squadrons, consumable part cannibalizations ranged from 20% to 35% of total cannibalizations in the squadrons. Among the seven squadrons, VMMs 266 and 365 stood out as the two squadrons that cannibalized more repairable to consumable parts. The consumable to repairable ratio column shows the number of repairable parts cannibalized for each every consumable part cannibalized in each squadron. In the case of VMM-266, for every 3.8 repairable parts cannibalized, one consumable part was cannibalized in the squadron. For VMM-365, one consumable part was cannibalized for every 3.3 repairable parts cannibalized. These ratios were significantly greater than those of VMM-162 and VMMT-204 both of which had a 1.8 to one ratio of repairable to consumable parts cannibalized.

A higher repairable to consumable ratio is better in this category because it reveals squadrons that are able to minimize their consumable cannibalizations through in-house / I-level repair or fabrication of the required consumable part. This is an important capability for V-22 squadrons to have because most consumable parts on this new platform current do not have an established demand pattern to rate an allocation on supply shelves. As a result, consumable items that are NIS or NC can have an excessively longer NMCS time if it has to be sourced from Bell-Boeing or contracted out as a new fabrication requirement to a new supplier.

The West Coast squadrons comparatively cannibalized more consumables parts than their East Coast counterparts. Consumable parts processed ranged from 42% to 65% of total cannibalizations. The highest ratio on this Coast was 2.4 repairable parts for every one consumable part in the case of VMM-166. One reason for this can be attributed to the fact that all six of these squadrons transitioned to the MV-22 aircraft after all the East Coast squadrons had transitioned. In effect, they have newer aircraft in their mix of aircraft inventory, most of which have upgraded repairable parts compared to those aircraft on the East Coast. Another possible explanation for this is that the improvement in reliability of some of the MV-22 repairable parts over the past couple of years. This has caused the mean time between failure (MTBF) of some of the repairable parts to significantly increase, reducing their failure rate. This has therefore caused the gap between the number of repairable parts and consumable parts cannibalized to close, making it much more evident in the West Coast squadrons.

4. Cannibalization by Equipment Operational Capability Codes

EOC codes for the MV-22 are published in the T/M/S MESM, similar to any other aircraft platform. These codes relate an aircraft system to a specific aircraft mission that the aircraft can safely accomplish. Each aircraft discrepancy work order is assigned an EOC to identify to maintainers and aircrew, the degree of degradation to an aircraft’s mission caused by the work order, and identifies the aircraft system is responsible for the aircrafts’ mission degradation. As directed by COMNAVAIRFORINST 4790.2B CH-1, the MV-22B MESM assigns 11 EOC codes to the MV-22 aircraft systems and subsystems. The MV-22 EOC codes taken from the MV-22 MESM and a description of the code’s mission degradation to the aircraft are:

> Code C: Assign alpha character (C) of the EOC code when system(s) are inoperative preventing operations in a combat environment.
>
> Code D: Assign alpha character (D) of the EOC code when system(s) are inoperative preventing the Search and Rescue (SAR)/Medical Evacuation (MEDEVAC) mission.

Code E: Assign alpha character (E) of the EOC code when system(s) are inoperative preventing the internal cargo transport mission.

Code F: Assign alpha character (F) of the EOC code when system(s) are inoperative preventing the external cargo transport mission.

Code G: Assign alpha character (G) of the EOC code when system(s) are inoperative preventing the transport of personnel.

Code H: Assign alpha character (H) of the EOC code when system(s) are inoperative preventing operation of the aircraft to/from a shipboard environment.

Code I: Assign alpha character (I) of the EOC code when system(s) are inoperative preventing operation of the aircraft in environmental extremes.

Code J: Assign alpha character (J) of the EOC code when system(s) are inoperative preventing the conduct of the long- range or self-deployment mission.

Code K: Assign alpha character (K) of the EOC code system(s) are inoperative preventing operations in unimproved/rough terrain environments.

Code L: Assign alpha character (L) of the EOC code when system(s) are inoperative preventing operations in a day or night Instrument Meteorological Conditions (IMC) environment.

Code Z: Assign alpha character (Z) of the EOC code when system(s) are inoperative preventing the aircraft from being safely flown (Department of the Navy, 2013, pp. 1-4).

The vast majority of the cannibalization work orders screened had an assigned EOC code identifying under the aircrafts major work unit code (WUC) system, the aircraft system that was impaired and the aircrafts' mission degradation that the cannibalization work order was intended to correct. 347 work orders had no identifying Received EOC or In Work EOC code documented. Of the 11 MV-22 EOC codes, 10 of them were identified with the various cannibalization work orders. There were no work orders found with an "E" EOC code. Table 11 displays the cannibalization work orders for the squadrons, and the associated EOC code for which the cannibalization action was initiated.

Table 11. Cannibalizations by Equipment Operational Capability Codes.

Equipment Operational Capability Codes											
	C	**D**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**Z**	**NO CODE**
VMM-162	16	0	0	0	1	6	0	2	14	443	34
VMM-261	15	0	0	6	0	11	1	0	8	486	27
VMM-263	26	1	1	3	2	19	0	0	15	563	5
VMM-264	35	0	1	1	3	17	1	1	4	703	41
VMM-266	31	1	2	1	2	37	4	5	25	765	17
VMM-365	63	1	1	1	14	18	3	3	14	467	20
VMMT-204	19	0	1	1	4	14	1	2	16	886	52
VMM-161	47	3	1	0	8	23	0	2	12	516	38
VMM-163	18	4	0	0	0	8	0	0	3	300	31
VMM-165	14	2	0	0	0	11	1	0	4	234	29
VMM-166	24	0	0	1	11	11	0	0	7	361	15
VMM-268	2	0	0	1	0	0	0	0	1	63	28
VMM-363	6	0	1	0	2	1	0	0	1	162	10

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

EOC code “Z” (system(s) are inoperative preventing the aircraft from being safely flown) appeared across all squadrons as the top mission degrader and the number one reason for the majority of MV-22 cannibalizations. This was to no surprise because cannibalization actions are often performed to return NMC aircraft to MC making them safely flyable. Cannibalization actions performed against the nine remaining EOC codes are performed to regain some degree of aircraft mission operational capability, to enable the aircraft to perform a specific mission.

Cannibalizations to correct combat mission degradations, EOC code “C” (system(s) are inoperative preventing operations in a combat environment), is the second highest in the EOC breakdown. All squadrons with or without previous combat deployment history reported this code as their second highest category indicating the relative importance of this mission capability in or outside the combat environment. However, two squadrons, VMMs 161 and 365 recorded much higher removals under this category than the remaining squadrons. Both squadrons historically had completed combat deployments but not much more than was completed by the average MV-22 deployable squadron. Conversely, VMMT-204 is a non-deployable squadron but cannibalized more combat system related components than VMMs 162, 163, 165, and 261 all of which are deployable squadrons. One possible explanation for this anomaly could be the transfer of aircraft and its associated work orders from deployable squadrons into VMMT-204's custody.

Squadrons on the two Coasts also differed under other EOC categories. For EOC "D" (system(s) are inoperative preventing the search and rescue (SAR)/medical evacuation (MEDEVAC) mission) the West Coast squadrons exceeded the East in cannibalizing to support SAR/MEDEVAC missions. This was a surprising discovery considering how much more flying operations and deployments the East Coast conducted than the West Coast in that time period. For EOC "J" (system(s) are inoperative preventing the conduct of the long- range or self-deployment mission), East Coast squadrons, documented more removals in support of long-range and self-deployment missions, with VMMs 266 and 365 leading the pack in this category. This was broadly due to their history of long range self-deployment operations. Both squadrons again took the lead in cannibalizations for correcting unimproved and rough terrain environment mission degradation systems under EOC "K" (system(s) are inoperative preventing operations in unimproved/rough terrain environments).

Cannibalization of parts to correct external cargo transport discrepancies, EOC "F," was a rarity among most of the squadron and showed almost no identifiable trend. Squadrons on the East Coast recorded more removals under code "G" for troop transport missions. However, this could be attributed to the fact that the East Coast squadrons collectively have executed more deployments over the period than the West Coast squadrons and as a result have had a requirement to execute more troop transport missions than their West Coast counterparts.

VMMs 166 and 365 stood out for recording 11 and 14 cannibalizations respectively under EOC "H." These cannibalizations were performed for correcting discrepancies that prevented their assigned aircraft from operating in a shipboard environment. The researcher expected to have found a direct relationship between cannibalizations in this category and the type of historical deployments executed by the squadrons. However, this was not the case across the squadrons. VMM-365 recorded the highest removals in this category; however, historical AMSRR data and training exercise employment plan (TEEP) revealed that this squadron over the five year period did not execute a shipboard or Marine Expeditionary Unit (MEU) deployment. VMM-166 conversely showed a history of one shipboard MEU deployment and was appropriate to have cannibalizations in this category. VMM-161 was the third highest squadron with eight shipboard related system components, but again had no history of MEU deployments. This squadron recorded more removals under this category than VMMs 261,263 and 266, all of which are ship-board MEUs with multiple historical MEU deployments on file.

Cannibalizations under code "I" (system(s) are inoperative preventing operation of the aircraft in environmental extremes) and "L" (system(s) are inoperative preventing operations in a day or night instrument meteorological conditions) had several removals in those categories but did not reveal any significant trends among the squadrons. As expected, the East Coast squadrons collectively documented more removals in this category than the West Coast, commensurate with their higher total number of cannibalizations. One reason for the higher removals in these categories is the fact that these two codes are the next most significant mission degraders next to the "Z" (system(s) are inoperative preventing the aircraft from being safely flown) and "C" codes (system(s) are inoperative preventing operations in a combat environment). The two system degrader codes are also not specific to a type of aircraft mission, but are mostly required for the day to day normal operations in other than normal weather conditions.

5. Cannibalizations per 100 Flight Hours

The researcher analyzed the squadrons to see how cannibalizations varied in the community by individual cannibalization rates. Cannibalization rate as previously described is a common measure used throughout naval aviation to report up-line how individual squadrons perform on cannibalizations within their squadrons. The formula used for this calculation was the DON's COMNAVAIRFORINST 4790.2B CH-1 approved formula referenced in Chapter III. This ratio gave each squadron's number of cannibalizations performed for every 100 flight hours flown for that reporting period.

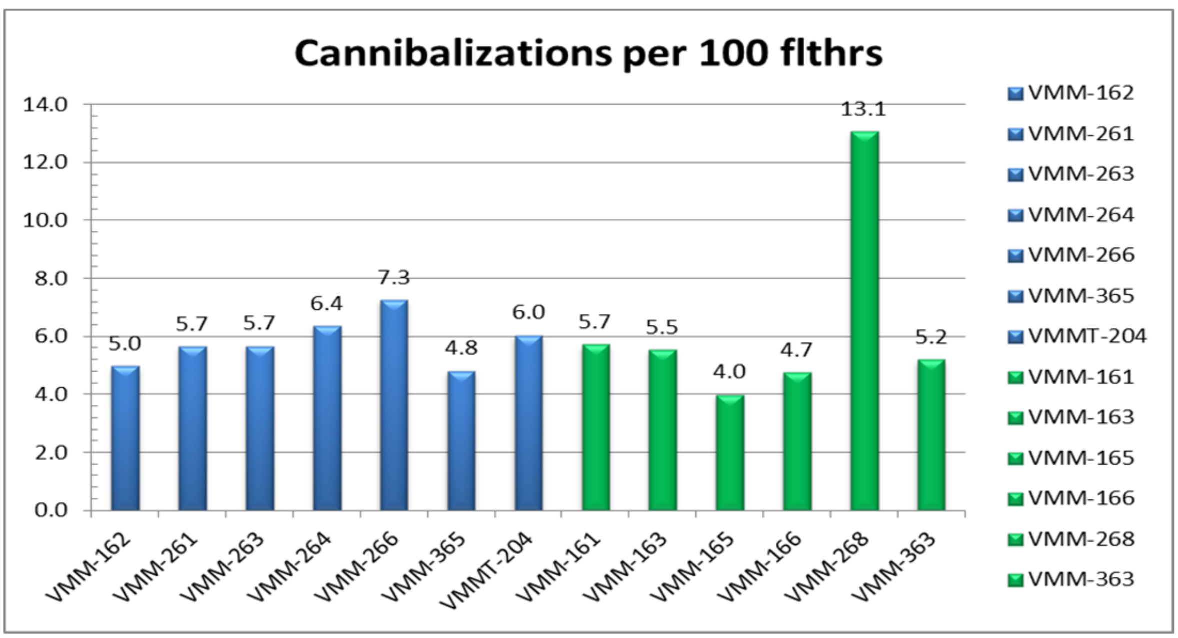
Using this formula, each squadron's rate was calculated for the five year period. Table 12 and Figure 4 depict the calculated rates for the 13 squadrons.

Table 12. Squadron Cannibalization Rates, 2010 to 2015.

	Total Number of Cannibalizations	Total Flight Hours	Cannibalizations per 100 flthrs
VMM-162	552	11,107	5.0
VMM-261	555	9,816	5.7
VMM-263	635	11,202	5.7
VMM-264	812	12,755	6.4
VMM-266	860	11,841	7.3
VMM-365	605	12,570	4.8
VMMT-204	1107	18,341	6.0
VMM-161	690	12,056	5.7
VMM-163	363	6,562	5.5
VMM-165	299	7,498	4.0
VMM-166	476	10,034	4.7
VMM-268	166	1,271	13.1
VMM-363	183	3,515	5.2

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Figure 4. Squadron Cannibalization Rates, 2010 to 2015.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Descriptive statistics performed on the cannibalization rates in Table 12 revealed a range of 3.98 to 13.06 cannibalizations per 100 flight hour across the 13 squadrons. The mean rate was 6.07 with a standard deviation of 2.25 cannibalizations per 100 flight hour. Individual mean rates for the two separate Coasts were 5.8 and 6.4 for the East and West Coasts respectively. Between the two Coasts, the West Coast squadrons comparatively performed better than the East Coast squadrons in cannibalization rates over the period.

Among the East Coast squadrons, VMM-365 outperformed the other six squadrons with a rate of 4.8 cannibalizations for every 100 flight hours flown in the five year period, while VMM-266 measured at a 7.3 per 100 flight hour. These two squadrons differed by 2.5 cannibalizations per 100 flight hour between the best and worst performing squadron on the East Coast. Four out of the seven squadrons performed better in this view, operating below the mean rate of 5.8 while VMMs 264,266 and VMMT-204 were seen to be above the mean rate on the East Coast.

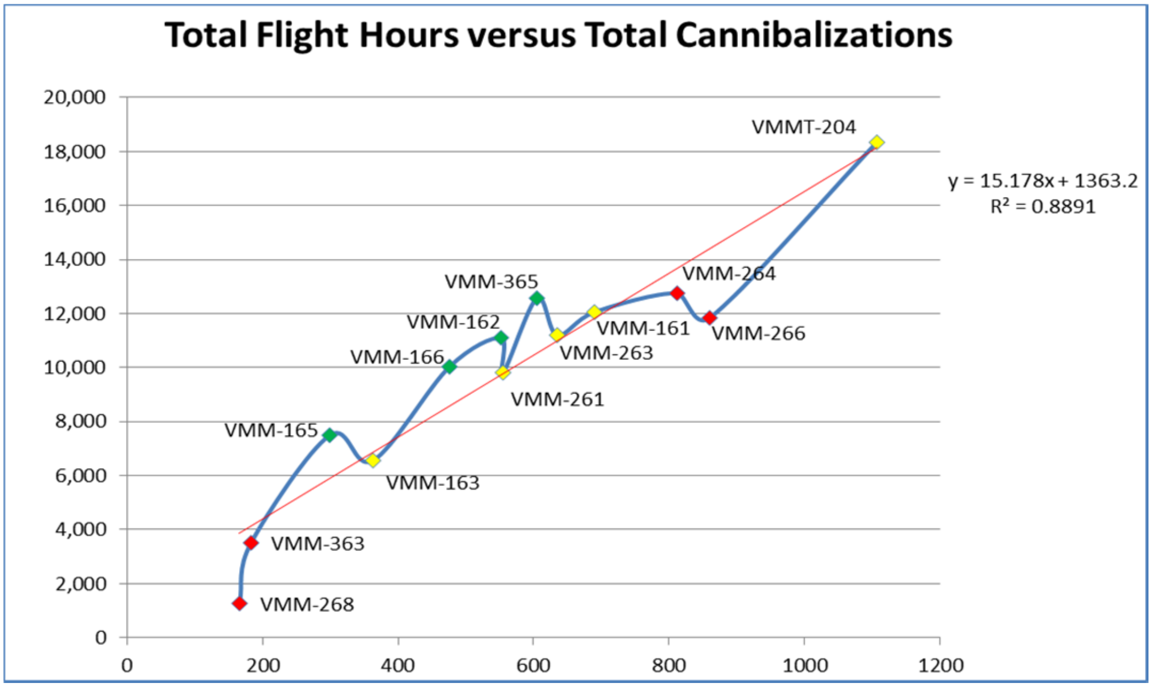
Looking at the West Coast squadrons, VMM-165 performed better than the five other squadrons with a rate of 4.0 cannibalizations per 100 flight hour. This rate was the best across all 13 squadrons and 0.8 cannibalizations per 100 flight hour lower than the 4.8 recorded by VMM-365, the best performing East Coast squadron. Comparatively, the West Coast had a much higher mean rate due to VMM-268's high rate. This squadron performed much worst across all 13 squadrons with a difference of 9.1 cannibalizations per 100 flight hour between that squadron and VMM-165, the best performing squadron.

The researcher queried all 166 historical cannibalization work orders for VMM-268 to investigate if he could uncover any significant explanations why this squadron had such a high cannibalization rate. However, every work order proved to be an actual cannibalization action taken to remove and replace a documented part number indicated on the work order. Every entry block on the work order was appropriately filled out with the work orders documented across a range of different aircraft. None of the corrective actions investigated indicated any of the work orders was initiated as an administrative action taken to correct aircraft logs and records documentation. The researcher concluded that the high cannibalization rate calculated was a true indication of the squadrons' performance and not an outlier that should be disregarded from the analysis.

The Navy's measure of cannibalization, based on the 100 flight hour formula, suggests that an aircraft squadron's cannibalization performance could be indicative of how much flying the squadron accomplishes in that period. As reveled in Table 12, some squadrons fly a lot more but cannibalize fewer parts while others that cannibalize more recorded lower flight hours. The researcher decided to investigate if there was a statistical significant correlation between a squadron's total number of cannibalizations and its total flight hours.

Using the same flight hours and number of cannibalizations data in Table 12, a correlation was run against the two data fields. Results of the correlation test revealed a Correlation Coefficient of +0.94 between the variables. A positive correlation coefficient indicates a linear uphill relationship between two variables, with coefficients of 0.7 and higher indicating a strong relationship. The calculated correlation coefficient of +0.94 revealed that there is a very strong positive linear relationship between total number of cannibalizations and total flight hours. Conceptually, this meant that the squadrons with higher flight hours should have recorded higher cannibalizations than those with lower flight hours, and those with lower flight hours should have recorded lower cannibalizations. This principle however did not hold true across all the squadrons as revealed by the data in Table 12. Figure 5 is a scatter plot of the total flight hours against total cannibalizations of all the 13 squadrons.

Figure 5. Total Flight Hours versus Total Cannibalizations Plot.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The scatter plot in Figure 5 displays each squadron and where they fall above or below the calculated trendline. The equation of the line revealed a calculated R-squared of 0.8891 for the model. An R-square, also known as the coefficient of determination, is a statistical measure of the percentage of the response variable variation that is measured by the model. In the case of this model, it explains how much variation in our number of cannibalizations response variable, is explained by the model. The calculated R-squared of 0.8891 revealed that, 88.9% of the variations in total squadron cannibalizations can be explained by the total number of flight hours accomplished by the squadron during the given time frame. The remaining variation not explained by this model may be attributed to individual squadron maintenance practices that set some squadrons apart as better performers at cannibalizing components (or it may be to chance alone).

From the model in Figure 5, squadrons that generally performed better at cannibalization during this period were VMMs 162, 165, 166, and 365. These squadrons might also be said to have had better internal maintenance practices that enable them to better manage component cannibalizations than the other squadrons. VMMs 161, 163, 261, 263, and VMMT-204 were the squadrons that were performing cannibalizations at the calculated model average, while VMMs 264,266, 268, and 363 might be considered as below average squadrons in the performance of cannibalization when considered on the per 100 flight hour basis. These squadrons may have had poor or inefficient maintenance practices that caused them to inefficiently manage their aircraft cannibalizations. As noted in Chapter III, the scope of this thesis is limited to a descriptive analysis of the historical data—the inferential tests needed to compare the performance of these squadrons has not been performed, so we cannot claim that the difference between VMM-162 and VMM-264, for example, was due to anything more than chance. However, the data clearly show that in this historical period, VMM-162 did perform better than VMM-264 in terms of cannibalizations per 100 flight hour.

6. Cannibalizations on Deployment and by Deployment Type

Deployed squadrons encounter a surge in flight operations due to increased operational tempo (OPTEMPO) when deployed away from their home base. Traditional MV-22 squadron deployments over the past five years have consisted of two main types: Shipboard deployments in support of a MEU and land-based deployments to Afghanistan in support of Operation Enduring Freedom (OEF). The researcher attempted to uncover how squadron cannibalizations varied against squadrons on the same type of deployments and how it varied between the two types of deployments. Squadrons analyzed were six East Coast squadrons and one West Coast squadron that deployed between 2010 and 2012 in support of the two deployments. This selection was done to allow for deployment theatre operational consistency and squadron mission proficiency during the period. One squadron, VMM-162 completed both types of deployment in the same period and was included to see how their practice of cannibalization as a squadron was affected by the type of deployment executed.

The land-based OEF squadrons selected were VMMs 161, 162, 264, and 365. All squadrons deployed to the same location with 12 aircraft and conducted flying operations over a six month deployment period. Shipboard MEU based squadrons selected were

VMMs 162, 261,263, and 266 all of which deployed to the same area of operation (AO) with 12 aircraft. Of the four squadrons, 162 and 261 deployed for eight months, and VMMs 263 and 266 deployed for 10 and nine months respectively. Each MEU squadron deployed aboard a different ship but operated on the same aviation consolidated allowance list (AVCAL) of supply stock posture. Table 13 shows the cannibalization data for the seven squadrons over the two types of deployment.

Table 13. MV-22 Deployment Cannibalization Data.

MV-22 Land Based Deployment Cannibalization Data									
Unit	Total PMC	Total NMC	PMC %	Repairable	Consumable	Consumable %	Total Canns	Total Flt Hrs	Cann Rate
VMM-264	20	158	0.11	167	10	0.06	178	2,345	7.6
VMM-162	10	112	0.08	113	9	0.07	122	2,888	4.2
VMM-365	21	120	0.15	103	38	0.27	141	2,977	4.7
VMM-161	11	68	0.14	75	4	0.05	79	2,114	3.7
MV-22 MEU Shipboard Deployment Cannibalization Data									
Unit	Total PMC	Total NMC	PMC %	Repairable	Consumable	Consumable %	Total Canns	Total Flt Hrs	Cann Rate
VMM-162	15	107	0.12	73	49	0.40	122	1,682	7.3
VMM-261	11	126	0.08	78	48	0.35	137	1,546	8.9
VMM-263	23	133	0.15	103	53	0.34	156	1,929	8.1
VMM-266	83	289	0.22	239	133	0.36	372	2,236	16.6

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Analyzing the land-based deployment squadrons, the average monthly number of cannibalizations for these squadrons was 21 while deployed. Referring back to Figure 5, the average monthly number of cannibalizations for VMM-162 when the squadron was operating at home base was 8.7. This increase in monthly average number of cannibalizations while deployed confirmed that higher OPTEMPO increase the need to cannibalize components.

VMM-161 proved itself as a better squadron at cannibalization than both 365 and 162 who previously had shown to perform better. The data showed that their total cannibalization for the same deployment length was more than 40% lower than that of

VMM-365. VMM 162 also performed slightly better than VMM-365 on the OEF deployment, contrary to what previous data analysis that indicated VMM-365 performed better historically, overall.

Consistent with previous analysis, VMM-264 performed the worse with a 7.6 cannibalization rate. All four squadrons on a broader scope, each recorded lower cannibalization rates on deployment than when operating at their home base.

The land-based squadrons when analyzed on a consumable to repairable basis, showed consistency between three of the four squadrons. Percentage of consumable cannibalizations to total cannibalizations for VMMs 161, 162 and 264 ranged between 5% to 7% while VMM-365 broke out at 27%. This was more than triple the number of consumable cannibalizations recorded by VMM-264.

The land-based squadrons were analyzed to see how cannibalizations were used to correct PMC and NMC maintenance discrepancies. Percentage of total cannibalizations that were used to correct PMC discrepancies between the four squadrons ranged from 8% to 15% with VMM-365 recording the highest at 15%. Squadrons that typically display a higher PMC cannibalization rate do so to strive to maintain a good portion of their aircraft in FMC status. This allows them the flexibility of easily assigning an FMC aircraft to the flight schedule rather than systematically juggle PMC aircrafts on a daily basis to find aircraft that will satisfy specific flight schedule mission requirements.

The researcher attempted to find out reasons why VMMs 161 and 162 both seemed to have performed better at cannibalization than VMM-365 in a deployment environment. A maintenance work order history and historical AMSRR reports inquiry was conducted which revealed two explanations for this: VMM-161 initially arrived in the deployment AO in July 2012 operating 12 MV-22s. As part of the OEF equipment drawdown process, the squadron effectively reduced their aircraft inventory to 10 MV-22s in August 2012, returning two aircraft to CONUS. This caused them to operate with 10 aircraft for the remainder of the deployment, contributing to their reduced total number of cannibalizations. VMM-365s’ inquiry revealed that one of their aircraft, number 166738 suffered a mishap during the deployment, causing the aircraft to become

NMC for an extended period of time. The squadrons' desire to expedite the aircrafts' return to MC status required cannibalizing several unique parts that were not stocked in the local supply system from a Phase Maintenance inducted aircraft, consequently causing their cannibalization rate to increase.

An analysis of the shipboard MEU squadrons revealed that MEU squadrons also increased in monthly average number of cannibalizations when deployed. Their calculated average number of monthly cannibalizations was 29 per month. Analyzing their rates, these MEU squadrons generally performed worse at cannibalizations than their land-based counterparts. On an individual squadron basis, VMM-162's cannibalization performance was the best between the four squadrons which was consistent with previous findings that this squadron performed better. VMMs 261 and 263 previously had been found to be on the same level of performance with a 5.7 cannibalizations per 100 flight hour for each squadron. However, when the two squadrons were put on the same type of deployment, VMM-263 was revealed to have slightly better performance. Their cannibalization rate was 8.1 compared to VMM-261's rate of 8.9. The researcher attributed this 0.9 rate differential to the two month differential in deployment lengths of the two squadrons which resulted in VMM-263's higher flight hours.

Consistent with previous findings, on these historical data, VMM-266 comparably was the worst at cannibalization between the four MEU squadrons with a 16.6 cannibalizations per 100 flight hour rate. Although this squadron was deployed a month less than VMM-263, they had a rate differential of 8.5 higher than that of VMM-263. Even though they logged 307 more flight hours in a lesser deployment timeframe than VMM-263, their total number of cannibalizations was 138% higher than that of VMM-263.

The researcher compared the two deployment types against each other and uncovered the following finding: The MEU cannibalization rates comparatively were much higher than those of the land-based deployed OEF squadrons. This suggested that MEU deployed squadrons generally perform worse at cannibalization than the land-based deployed squadrons. This finding was supported when VMM-162's MEU and OEF deployment performances were compared against each other. Their MEU cannibalization rate of 7.3 reduced to 4.2 cannibalizations per 100 flight hours when they switched to a land-based OEF deployment.

The two deployment groups were compared to see how they varied in overall percentages of consumable items cannibalized. Percentages for the MEU squadrons ranged from 34% to 40%, while the land-based squadrons ranged from 5% to 27%. This MEU range on average was more than three times higher than that of the land-based OEF deployed squadrons. This finding suggested that on a given deployment, a MEU deployed squadron will generally cannibalize more consumable parts than a land-based deployed squadron. This finding was again supported by VMM-162’s MEU and OEF data. Their MEU consumable percentage reduced from 40% to 7% when the squadron switched from the MEU to a land-based deployment.

The researcher concluded that there exists a variation in cannibalization between MV-22 squadrons when they deploy away from their home base, and that this variation is also affected even more based on the type of deployment.

B. ANALYZING COMPONENTS THAT DRIVE CANNIBALIZATION, AND HOW THOSE COMPONENTS CHANGE OVER TIME

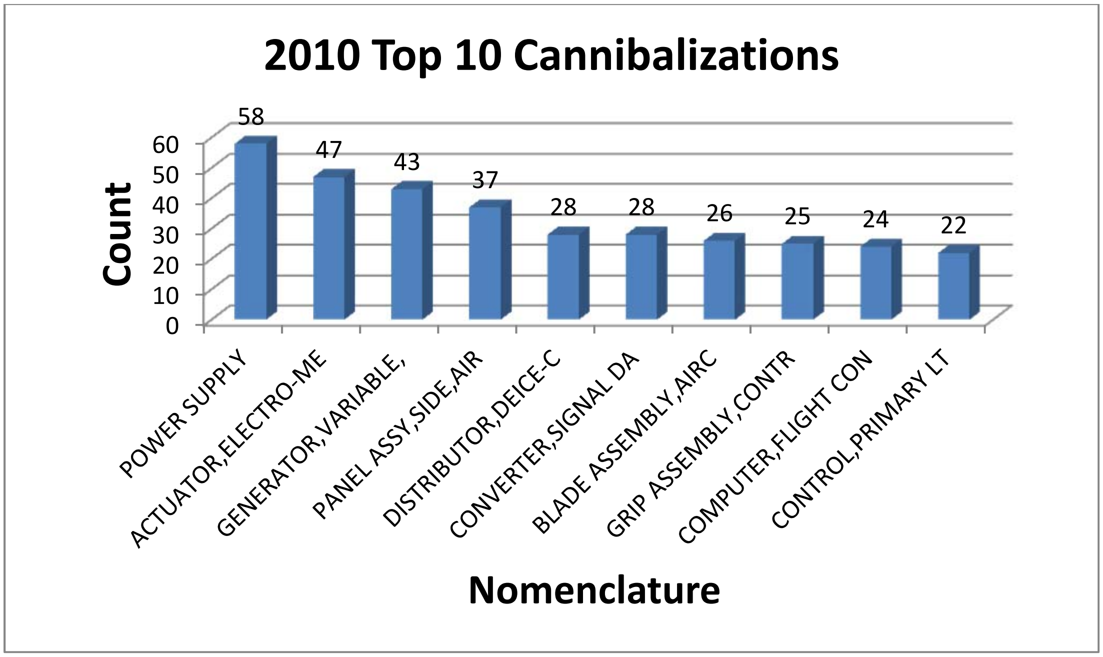
The parts and components cannibalized in the MV-22 community vary across a wide range of part numbers and national item identification numbers (NIIN). Each component part number or NIIN is assigned a nomenclature from the component manufacturer as a quick reference for identifying the type of part and the functionality provided by this component. Components cannibalized in naval aviation squadrons are tracked through the naval aviation logistics command maintenance information system (NALCOMIS). Each component cannibalized is documented on a maintenance action work order in the NALCOMIS to be later retrieved by system analysts and T/M/S Baseline Managers for identifying culprit components with reliability concerns

. The researcher utilized the five year cannibalized component data to identify specific components that drove cannibalizations in the community. This component data was sorted yearly and into a top ten frequently cannibalized list for each year. The yearly lists were then analyzed over time to see how the relative priority of each component changed from year to year and as more MV-22 squadrons were added to the community.

1. Top 10 Cannibalization Drivers, 2010

The 2010 MV-22 community consisted of nine operational squadrons and two flight test squadrons. Community-wide cannibalizations totaled 1,242 components across 85 In Reporting (IR) MV-22 aircraft, with the test squadrons only contributing to a fraction of the overall cannibalization. The top three cannibalizing squadrons for that period, VMMs 266, 365 and VMMT-204 accounted for 50.5% of the total cannibalizations. The 1,242 total items processed consisted of 190 individual component nomenclatures. Figure 6 is a frequency distribution of the top ten frequently cannibalized components for 2010.

Figure 6. Top 10 Cannibalized Components, 2010.



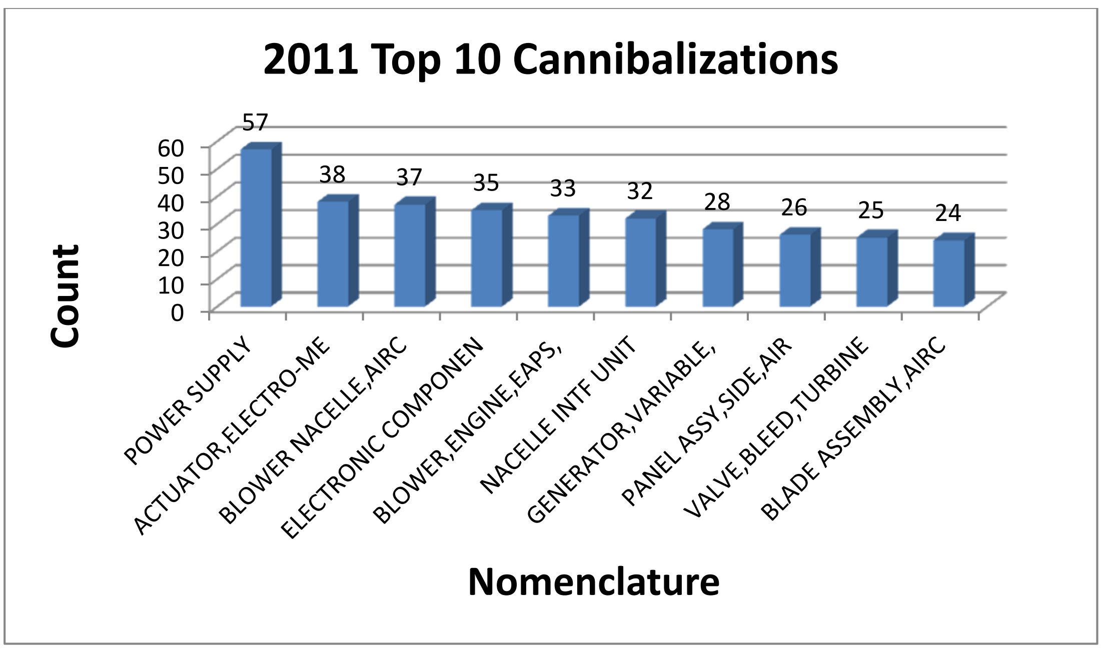
Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The top 10 frequently cannibalized components totaled 338 parts, accounting for 27% of the total number of cannibalizations. aircraft power supplies, electro-mechanical actuators and VFGs were the top three drivers of cannibalization in the community. Seven of the top 10 components were avionics related components with the remaining three related to the aircraft rotor system, flight control system and the airframe structural system. Some components in the list were identified to have more than one unit per assembly (UPA) of that component on an aircraft. Of these, blade assembly was the component with the highest UPA of six blades per aircraft and ranked 7th, while FCCs were the next highest UPA with three per aircraft and ranked 9th.

2. Top 10 Cannibalization Drivers, 2011

The aircraft community increased in size with the addition of two operational squadrons in 2011. The number of operational squadrons increased from nine to 11, resulting in 13 total squadrons by the end of 2011. Total number of cannibalized components increased from 1,242 in 2010 to 1,265 components across 105 average aircraft IR status. Figure 7 is the 2011 top 10 chart of cannibalized components.

Figure 7. Top 10 Cannibalized Components, 2011.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The 1,265 cannibalized components consisted of components across 203 nomenclatures, which was an increase of 13 line items from the 2010. These top 10 components totaled 335, accounting for 26% of the overall cannibalizations. VMM-264 moved up in ranking to join VMM-266 and VMMT-204 as the top three cannibalizing squadrons in the community, collectively accounting for 40.5% of the total community cannibalizations. This was a decrease of 10% in cannibalizations from what the top three cannibalizing squadrons recorded in 2010.

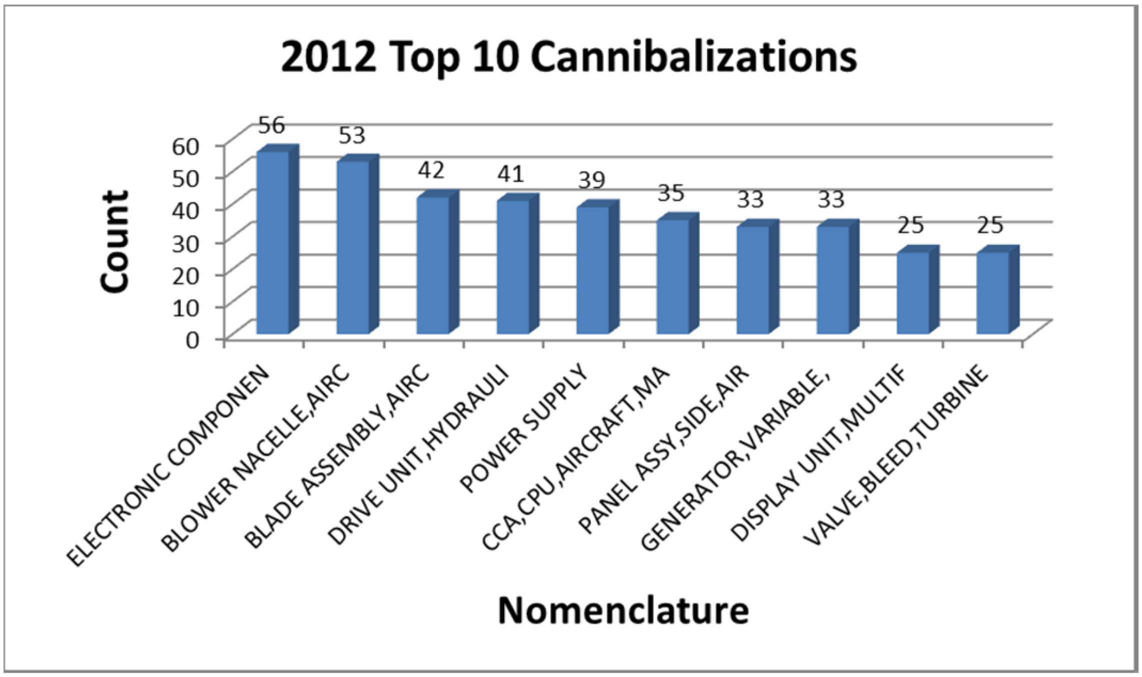
Relative component ranking on the top 10 list changed slightly from 2010 to 2011. Aircraft power supplies and electro-mechanical actuators still remained the top two cannibalized components in the community; however, actual quantities of these components decreased from that recorded in 2010. Fifty seven power supplies and 38 electro-mechanical actuators were cannibalized in 2011, compared to 58 and 47 respectively in 2010. VFG cannibalizations decreased from 43 to 28 (65%), moving it from 3rd to 7th position. Meanwhile, a new requirement for engine nacelle blowers made it to the 3rd place. Additional fleet cannibalization requirements for electronic components, bleed turbine valves, and nacelle interface units (NIU) also increased, pushing them up the list of drivers into the top 10 category.

All 2010 top 10 components that remained on the 2011 list decreased in quantities between the two years even with the addition of two new squadrons and the corresponding increase in average number of IR aircraft. None of the 2010 top 10 components moved up in relative position on the 2011 list. Four components, Central Deice Distributer (CDD), signal data converter (SDC), grip control assemblies and FCCs made it off the 2010 top 10 list due to reduced cannibalization requirements.

3. Top 10 Cannibalization Drivers, 2012

Two squadrons joined the community in 2012 increasing the size of the community to 15 MV-22 squadrons. This caused the average IR inventory of aircraft to increase from 105 to 136 MV-22 aircraft, a 29.5% increase. The total count of cannibalized components increased by 5% from 1,265 in 2011 to 1,337 cannibalized components in 2012 with the increases in aircraft inventory. The number of nomenclatures cannibalized decreased from 201 to 190, with VMMs 164, 266 and 161 as the top three cannibalizing squadrons. These squadrons now accounted for 38% of total community cannibalizations, a decrease of 2% from 2011. VMM-161 moved into the top three cannibalizing squadron category bumping VMMT-204 out of that category for the first time. Figure 8 is the 2012 top 10 cannibalized component chart.

Figure 8. Top 10 Cannibalized Components, 2012.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The 2012 list of top 10 drivers comparatively showed more significant variations than the prior year, and accounted for 28% of total cannibalizations in the community. Aircraft power supply moved from the 1st to the 5th position as cannibalization requirements from the previous year decreased from 57 to 39. Simultaneously, electronic component requirements increased moving it in place as the year’s top cannibalization driver. Electro-mechanical actuators held the 2nd position in 2011; however, decreasing requirements in 2012 moved it off the top 10 list to the 28th position in the hierarchy. Engine nacelle blowers also moved up the hierarchy to the 2nd place, while Engine Air

Particulate System (EAPS) blowers reclined down to 35th position as a result of 21 fewer requisitions.

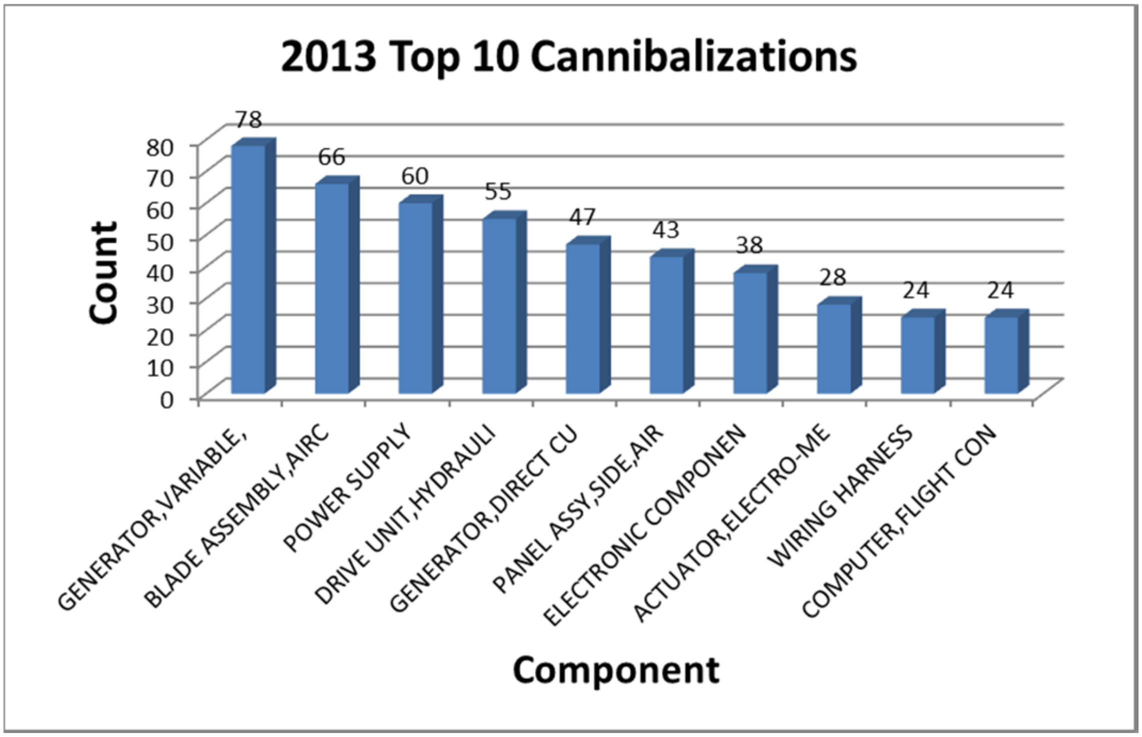
Aircraft blades and VFGs continued to remain high cannibalization drivers over the three year period. From 26 blades cannibalized in 2010, the quantity decreased to 24 in 2011 and spiked to 53 in 2012 moving it in place as the third highest driver. This was an increase of 75% in cannibalization activity for this component over the one year period. VFGs also showed cyclic activities from 43 in 2010 to 28 in 2011 and increased again to 33 in 2012.

Two components, aircraft side panels and turbine bleed valves, showed fairly consistent activity from 2011 and continued to remain on the top 10 list for 2012, while multi-function display (MFD) unit also made its way from 22nd to 9th place in hierarchy.

4. Top 10 Cannibalization Drivers, 2013

Three additional squadrons joined the MV-22 community in 2013, increasing the size from 15 to 18 squadrons. With this increase, the average number of IR MV-22 aircraft increased by 30% from 143 in 2012 to 174 by the end of 2013. This marginal higher increase in size compared to the previous years. However, it did not reflect a significant spike in cannibalization activity, as the squadrons added included one non-operational squadron, HMX-1. Total community-wide cannibalization activity increased to 1,394, a 4% increase with VMMs 163, 165, and VMMT-204 as the top three cannibalizing squadrons. With VMMT-204 moving back into the top three squadrons, the three squadrons now accounted for 26% of the total cannibalization activity. Figure 9 is the 2013 top 10 cannibalized component chart.

Figure 9. MV-22 Top 10 Cannibalized Components, 2013.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The 2013 top 10 components compared to the previous years, showed a much higher marginal increase in total quantity and overall percentage of total cannibalizations. The total count of activity making this list was 463 cannibalizations across 204 nomenclatures, and accounted for 33% of the overall cannibalization activity. This percentage comparably was the highest calculated among the top 10 category from 2010 to 2013.

Six of the 10 components on were repeats from the 2012 list. Of these, VFGs jumped from 8th position in 2011 to the 1st position in 2012, making it the top cannibalization driver. This significant rise in hierarchy was as a result of a 136% increase in cannibalizations from 33 in 2011 to 78 VFGs cannibalized in 2012. This marginal increase in activity was the highest seen among any of the historical top 10 components from one year to the next.

Activity for aircraft blade assemblies continued to increase in this period, again moving it up from 3rd place in 2012 to 2nd place in 2013. From 46 requirements in 2012, community-wide cannibalization activities resulted in 66 additional requirements in 2013; a marginal increase of 57% from the previous year. In a conservative assumption that all 66 cannibalized blades were consolidated against few aircraft, this component alone would have accounted for 11 aircraft that were held in NMC status for that period.

Aircraft power supply and hydraulic drive units both made their way higher up to the 3rd and 4th positions respectively. From 39 requirements the previous year to 60 requirements in 2013, the operational need to cannibalize power supplies spiked by 56% in the community, while the hydraulic drive units increased by 34%, due to a marginal increase in 14 components.

Direct current generators, also known as constant frequency generators (CFG), appeared on the top 10 list in 2013 for the first time in the four year period. The operational need to cannibalize this component cycled from 10 CFGs cannibalized in 2010 to five in 2011, but then increased to 17 requirements in 2012. This increase in demand continued through into 2013, spiking up to 47 generators, an increase of 176% from the 2012 quantity.

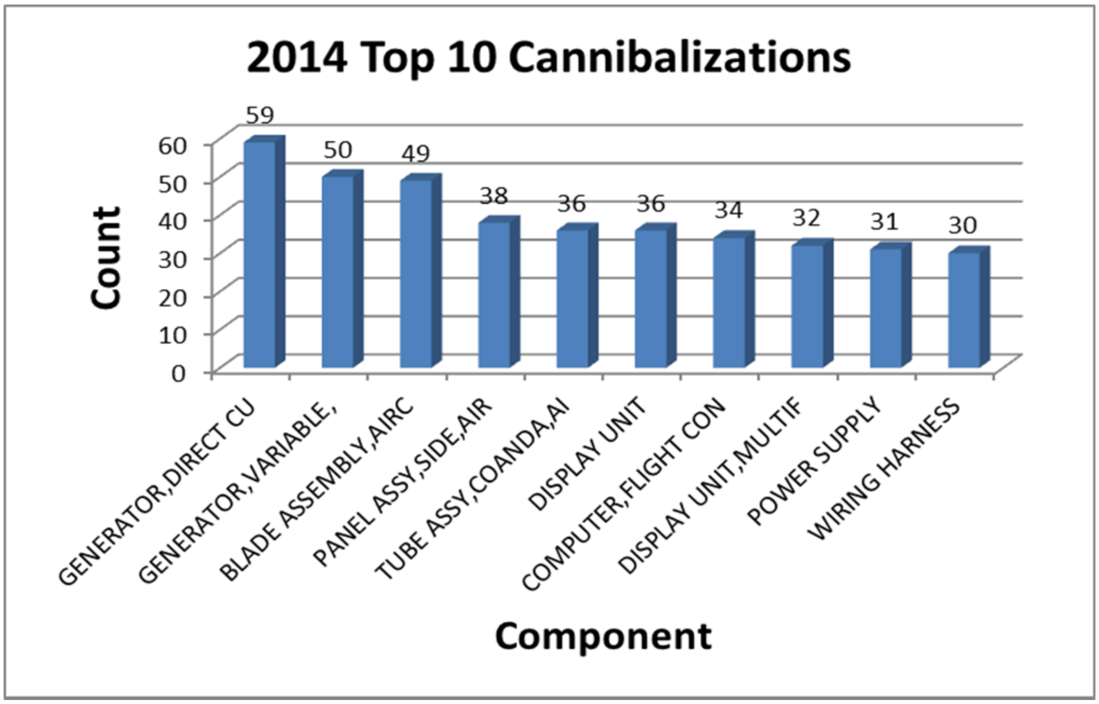
Two components, FCCs and electro-mechanical actuators made their way back into the top 10 hierarchy after both being off the list for a few years. The last appearances on the list for these components were 2010 for FCCs and 2011 for the actuators respectively. Both 2013 requirement numbers for these components were however lower than were recorded at their last appearance in the top 10 list.

Aircraft wire harnesses also made its first appearance on the list in the four year period as a result of a fleet requirement to cannibalize 24 harnesses. Similar to most components on the list, fleet requirements to cannibalize these harnesses creeped from 8 in 2010 to 11 and 13 in 2011 and 2012 respectively leading to its first appearance in 2013.

5. Top 10 Cannibalization Drivers, 2014

The 2014 community increased with the addition of one operational squadron, increasing the size of the community to 19 squadrons. Average IR aircraft increased from 174 in 2013 to 198. This was an increase of 14% and a comparatively smaller increase than was seen in 2013. This smaller marginal increase resulted in a much higher increase in cannibalization activity in the community. Community-wide cannibalizations for the year totaled 1,528, a 10% increase from 2013. This was the highest increase in cannibalization activity recorded over the five year period. Figure 10 is the Top 10 list for 2014.

Figure 10. MV-22 Top 10 Cannibalized Components, 2014.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The drivers for 2014 accounted for 395 of the year's cannibalization activity and 25% of the total community cannibalization requirements. Six components on the list were repeats from 2013, three of which had been carried through from 2010 to 2014. Of these six components, three of them showed increases in activity while the other three showed decreases in activity, causing them to relatively move down in hierarchy.

The two types of aircraft generators, VFGs and CFGs coincidentally became the two top drivers of cannibalization in the community. CFGs pushed up from 5th position in 2013 to become the year's top cannibalization driver. This position among the top three drivers was the first for the CFG over the five year period. From 47 in 2013 to 59 in 2014, a fleet cannibalization requirement for CFGs increased by 26%. Conversely, VFG cannibalization requirements decreased by 36% from 78 in 2013 to 50 in 2014 moving it down from 1st to 2nd position.

Aircraft blade assemblies although moving down from 2nd to 3rd place, continued to be a major driver in the community over the five year period. For the first time during the observed period, blade cannibalization activity decreased by 26%, which was the most significant decrease in this components history, considering the yearly marginal increases in additional squadrons and IR aircraft.

Aircraft panel assemblies continued to remain in the top drivers in 2014 with a small decrease of nine removals from 2013. This component consistently through the five year timeframe, cycled in the number of panels cannibalized, and did not reveal a steady increase proportional to the increase in community size and IR aircraft over the period.

Two components, aircraft Coanda Tube assemblies and CDUs made their way into the top 10 category for the first time with significant increases from recorded historical quantities. From three Coanda Tubes removed in both 2012 and 2013, the community's requirement to cannibalize this component increased to 36 in 2014. This was an increase of 12 times the normal cannibalized quantity, and the biggest spike observed among any of the top 10 components across the years. CDU cannibalization requirements increased by 176% as 2013 quantities increased from 13 to 36 in 2014. Unlike the Coanda Tubes, this component had consistently showed yearly cannibalizations ranging from nine to 16 since 2010, but spiked to 36 in 2014.

Activity for FCC continued to increase between the two years, causing a marginal increase of 10 FCCs in 2014, moving it up in hierarchy from 10th to 7th position. A forward look into 2015 recorded cannibalizations showed 14 FCCs cannibalized as of 30 June 2015, and will most likely remain as a top driver in 2015 if this 2015 historical pattern continues throughout the year.

MFDs reappeared as a top 10 driver for the second time in the five year period. The last appearance for this component was 2012, ranking 9th that year with a quantity of 25. Although this quantity increased to 26 in 2013, other more significant components pushed it down in ranking to 18th position in 2013 until a larger marginal increase of 10 additional squadrons caused it to become a major driver again.

Aircraft power supplies for the first time over the five year period, showed its most significant decrease in fleet cannibalization requirements. From its highest ever recorded quantity of 60 in 2013, the 2014 data revealed a reduction of 48% with only 31 components cannibalized for that year. Its 2014 position in 9th place among the top 10 was the lowest this component had ever reclined over the five year observed period.

Wiring harness continued to remain a top driver after its first appearance on the 2013 top 10 list. Fleet activity for this component however increased from 24 to 30 over the one year period but moved down in hierarchy to the 10th position. However, this component might not remain a top cannibalization driver in 2015 since a forward look into 2015 cannibalization data showed a quantity of only six harnesses cannibalized as of 30 June 2015.

6. Top Five Readiness Degrader Components, 2010 to 2014

Across the five year observed period the community’s top five components in terms of average number of components cannibalized per year were Power Supplies, VFGs, blade assemblies, panel assemblies and electronic components. The yearly and average number of cannibalizations per year for the components is displayed in Table 14.

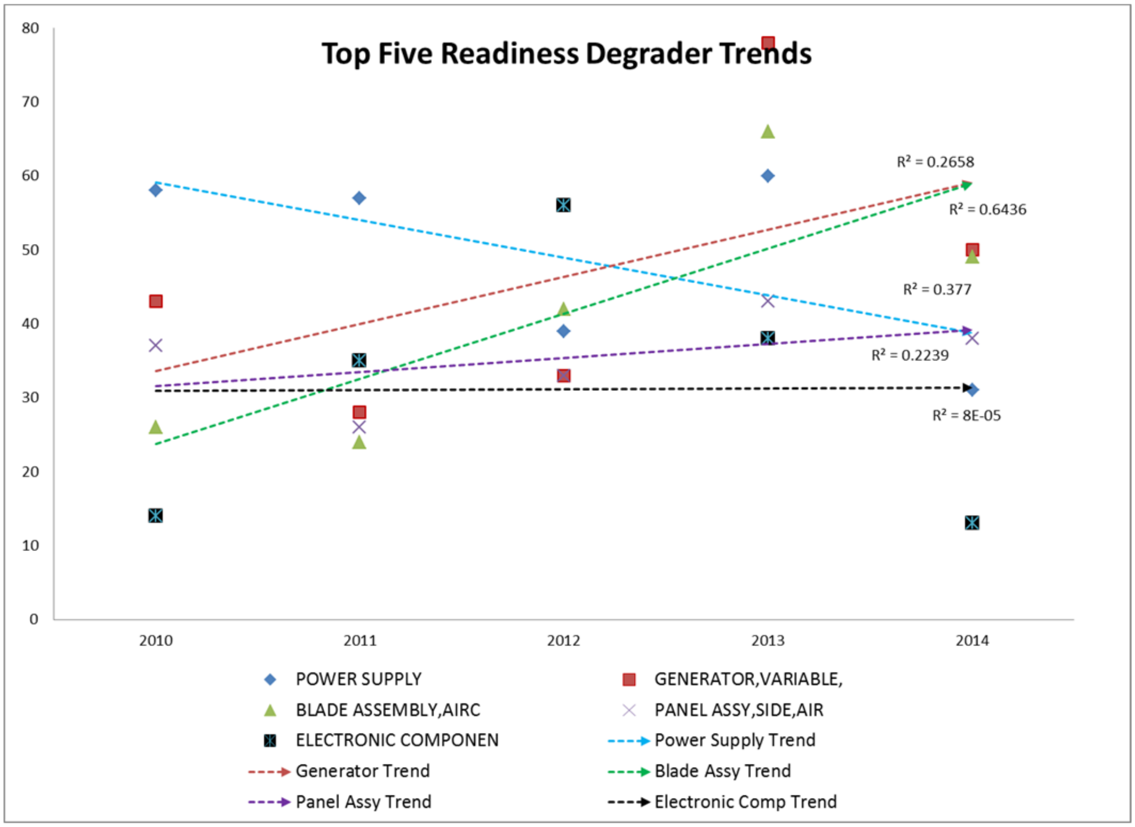
Table 14. Top Five Degrader Component Cannibalizations, 2010 to 2014.

2010 to 2014 Top Five Readiness Degrader Components							
Nomenclature	**2010**	**2011**	**2012**	**2013**	**2014**	**Average**	**Ranking**
POWER SUPPLY	58	57	39	60	31	49	1st
GENERATOR,VARIABLE,	43	28	33	78	50	46	2nd
BLADE ASSEMBLY,AIRC	26	24	42	66	49	41	3rd
PANEL ASSY,SIDE,AIR	37	26	33	43	38	35	4th
ELECTRONIC COMPONENT	14	35	56	38	13	31	5th

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Power supplies ranked first among all MV-22 cannibalized components with the highest average number of cannibalizations. Subsequent ranking for the remaining four components are displayed in Table 14. The first four ranking components appeared each year as top 10 drivers, while Electronic components only appeared in three of the five years. Although it did not appear yearly as a top 10 driver, its overall cumulative average among the other components cannibalized in the community was high enough to move it into 5th place. Figure 11 is a scatter plot of the cumulative yearly cannibalizations with each individual component’s trendline.

Figure 11. Top Five Readiness Degrader Trends, 2010 to 2014.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Figure 11 graphically depicts how the top five degraders have trended over the last five year period, giving an indication of which direction they might be expected to head in the follow-on years.

Power supplies, although the top degrader of the period, showed the most significant improvement and was the only downward trending among the five components. Even though there appeared to be a significant spike in 2013, the 2014 figure showed a significant reduction allowing for its continued downward trend. A forward look into 2015 cannibalization data revealed a quantity of one power supply cannibalized as of 30 June 2015. If this trend is maintained throughout the year, this component for the first time will not appear among the major cannibalization driver category in 2015.

Aircraft blade assemblies had the most upward trend among the five components with an R-Squared value of 0.64 for the trendline. This R-squared was the strongest among all five components indicating a strong goodness of fit of the trendline. The upward trend indicates that this component's cannibalization problem is getting worse as the community and number of flying activities continues to increase. A forward look into 2015 cannibalization data revealed that 25 blades had been cannibalized as of 30 June 2015, confirming a high chance that this component will continue to remain a top degrader for 2015 if the trend continues.

VFGs looked to also have an upward trend but with a much lower R-Squared. This component had a cyclic trend from the raw data and did not show much of a progress in terms of how good or bad the components' cannibalization problem was getting. Based on the 2015 data, recorded number of VFG cannibalizations as of 30 June 2015 was 23. This component can be anticipated to have roughly about the same number of cannibalizations at the end of 2015 as it did in 2014 and will remain a top degrader.

Panel assemblies showed a slight upward trend with a low R-Squared value of 0.22. The slight upward trend indicates this component continued to be a problem and showed no improvements in cannibalization activity over the period. This component also is likely to maintain its trend and continue to be a top degrader in 2015 since 17 panel assemblies had been cannibalized as of 30 June 2015.

Electronic components showed no directional trend over the five year period. The significant problem causing the spike in 2012 cannibalization activity seemed to have been resolved and is anticipated to continue with its directionless trend over the next year. Eight panel assemblies were shown to have been cannibalized as of 30 June 2015, indicating an anticipated number of less than 20 cannibalizations by end of 2015 if the 2015 trend continues. It is unclear if this component will remain a top degrader in 2015 and should be monitored for any significant spikes in activity.

7. Worst Trending Components, 2010 to 2014

Among the 21 components that appeared across all yearly top 10 lists, five components showed to be the worst trending components in terms of the slopes of their individual trendlines. These components need the most scrutiny between the other drivers since all showed significant spikes in recent cannibalization activity. Table 15 is the yearly cannibalizations and calculated slopes of these five components:

Table 15. Five Worst Trending Components, 2010 to 2014.

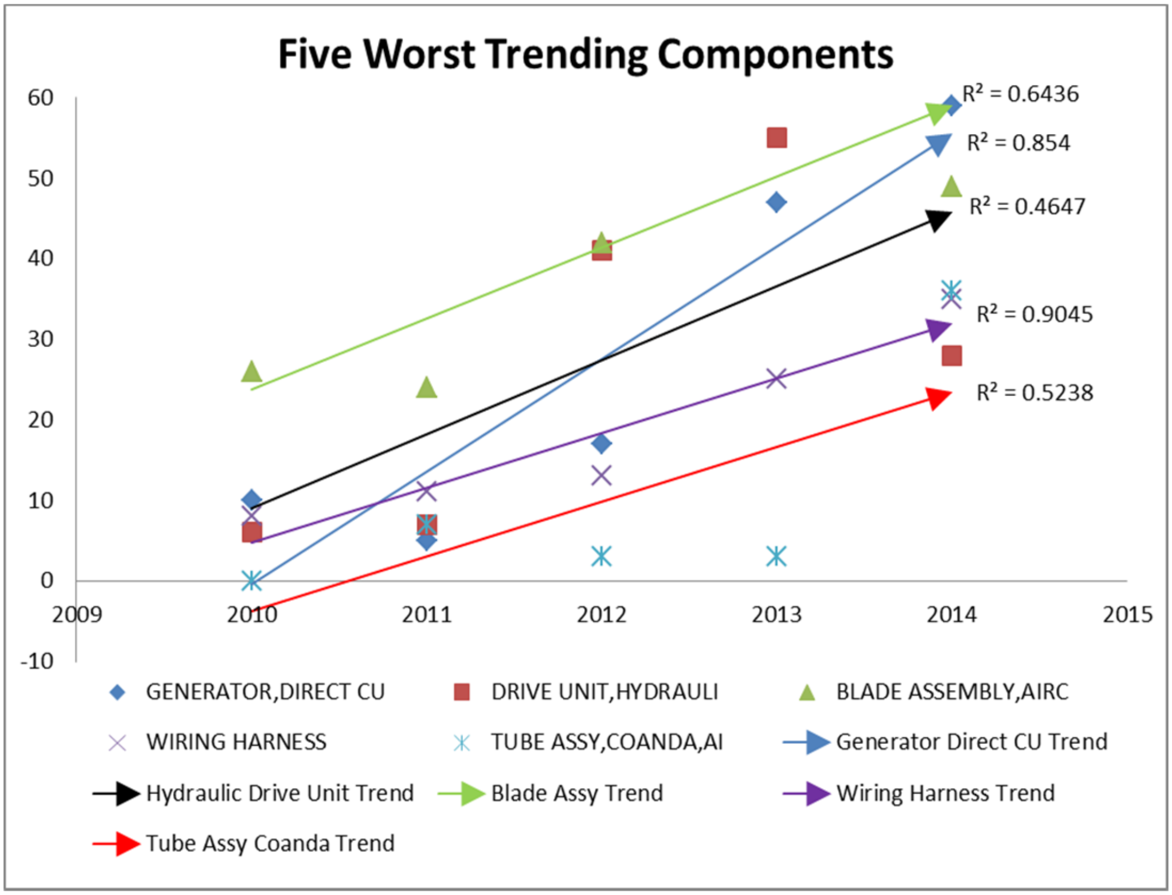
2010 to 2014 Five Worst Trending Components							
Nomenclature	2010	2011	2012	2013	2014	Slope	Rank
GENERATOR,DIRECT CU	10	5	17	47	59	14	1st
DRIVE UNIT,HYDRAULI	6	7	41	55	28	9.2	2nd
BLADE ASSEMBLY,AIRC	26	24	42	66	49	8.8	3rd
WIRING HARNESS	8	11	13	25	35	6.8	4th
TUBE ASSY,COANDA,AI	0	7	3	3	36	6.8	5th

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Of these components, blade assembly was the only component to have consistently appeared every year as a top readiness degrader as previously identified. direct current generator, hydraulic drive unit and wiring harnesses all had appeared in two of the five top 10 degrader lists, while Coanda Tube assemblies only appeared once recently in 2014.

These components statistically evolved as the worst trending due to significant spikes in recent cannibalization activities, causing their trendlines to be much steeper relative to the other 16 components. These components should be giving the most scrutiny and monitored since all of these significant spikes happened between 2013 and 2014 giving these components the potential to become major fleet degraders if not formally addressed and resolved. Figure 12 is a scatter plot of the five components.

Figure 12. Five Worst Trending Components Plot.



Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

Direct current generators had the worst slope of the five components and should warrant the immediate attention of the supply system working group (SSWG) and the component's item manger (IM). The associated trendline displays the steepness of this line in comparison to the other components, and the displayed R-Squared of 0.854 indicates a strong fit of this line to the plotted data points. This component's recent spike in activity was quite alarming and was one of the worst spikes seen among all the driver components. This component will most likely continue to be a top degrader since the 2015 data showed 23 generators cannibalized as of 30 June 2015.

Hydraulic drive unit was the second-to-worst trending component again due to recently increased cannibalization activity in the past few years. Even though the R-squared value of 0.4647 for the trendline is not as strong as the other four components, the calculated slope of 9.2 makes this trend very significant to also warrant immediate attention by the SSWG and the IM to address any reliability issues or supply constraints that might exist.

Aircraft blade assembly as depicted in Figure 12 was the third worst trending component. This component as already discussed previously, warrants immediate attention since the problem looks to be getting worse based on the average number of cannibalizations per year. As already addressed, each MV-22 has six aircraft blades installed all of which spin and mostly wear at the same rate. This raises the potential of wearing out all six blades concurrently and can significantly cause more sporadic spikes in component demand and cannibalization activity if the blades for a specific lot of aircraft all start becoming worn out concurrently.

The trendline for wiring harness had the highest R-squared value of 0.9045 indicating a very good fit of the line around the plots. With a trend of 6.8 and the component's consistent recent increases in activity, this trend is bad and needs to be monitored to avoid a surprise spike in demand and uncontrollable increase in cannibalization activity. A sample of discrepancy maintenance work orders cross-referenced with their associated cannibalization work orders revealed that most of the harnesses were cannibalized to replace excessively worn out harnesses that were beyond repair capability. This can quickly become a huge fleet degrader as aircraft continue to accumulate more flight hours. A look at the 2015 cannibalization data showed 21 harnesses cannibalized as of 30 June 2015, potentially still remaining a top degrader.

Coanda Tube assemblies also had a bad upward trend with a slope of 6.8. Even though the R-squared of 0.5238 is not as high as some of the other components, the significant spike from three cannibalizations to 36 in 2014 raises an alarm for potential continued spikes ahead. As of 30 June 2015, 15 Coanda Tubes had been reported as cannibalized. If this 2015 trend continues to the end of the year, this component will once again likely become a major degrader for 2015.

8. Top 10 Driver Comparisons between Two Squadrons

The data for two squadrons, VMM-161 and VMM-268 were compared to see how much their individual cannibalization drivers as separate squadrons, varied from each other. Both squadrons assessed were selected from the West Coast and compared during their first year as transitioned MV-22 squadrons to nominalize the effects of aircraft age, operational tempo, and individual squadron maintenance proficiency. For the two squadrons, 2010 and 2014 were the first years as transitioned squadrons for VMM-161 and 268 respectively.

From January to December 2010, VMM-161 cannibalized a total of 83 aircraft components consisting of 41 separate part number items. VMM-268 conversely, cannibalized a total of 66 aircraft components consisting of 40 part number items from January to December 2014. Each squadron's cannibalized components were sorted into the top 10 drivers to see their respective drivers during that period. Table 16 is the top 10 cannibalizations for both squadrons in their first transition year.

Table 16. VMM-161 and VMM-268 Top Ten Cannibalizations.

VMM-161 Top Ten Cannibalizations for 2010			VMM-268 Top Ten Cannibalizations for 2014	
Components	Count		Components	Count
GRIP ASSEMBLY,CONTR	6		WIRING HARNESS	4
INTERFACE UNIT,AUTO	5		DISPLAY UNIT	3
GENERATOR,VARIABLE,	4		GENERATOR,VARIABLE,	3
BLOWER,ENGINE,EAPS,	4		DISPLAY UNIT,MULTIF	2
FAIRING ASSEMBLY,AI	3		DISPLAY UNIT,DEU,AI	2
ACTUATOR,ELECTRO-ME	3		VALVE ASSEMBLY,MANI	2
COMPUTER,FLIGHT CON	3		TUBE ASSEMBLY,METAL	2
CONTROL UNIT,IC,AIR	3		CONTROL COLUMN,AIRC	2
DISPLAY UNIT,MULTIF	3		HARNESS,ELECTRICAL,	2
CONTROL ASSY LANDING	2		HOSE,AIR DUCT	2

Adapted from Naval Air Systems Command (NAVAIR) 6.8.2.1 data analyst, personal communication, June 5, 2015.

The top 10 cannibalization drivers for both squadrons varied considerably between the two time periods, with only two components, VFG and MFD units common to both squadrons. For VMM-161, the combined top 10 list of components accounted for 43% of the squadrons overall cannibalization, while VMM-268's top 10 accounted for 36% of their total cannibalizations. Between the two squadrons, 81 combined nomenclatures were cannibalized; of this number, only nine nomenclatures were common to both squadrons. The remaining 71 component part numbers varied between the two squadrons and did not cross reference as being cannibalized by both squadrons.

The two squadrons were compared at the same phase of their transitioning periods with each operating aircraft that were received from Bell-Boeing aircraft production plant. Even though the received aircraft should have all accumulated about the same airframe hours during the period of observation, the list of components could also have varied for two reasons. First, some components installed in the 2014 aircraft deliveries were upgraded components and had better reliability compared to those that were received in the 2010 aircraft deliveries. Second, the supply logistics system improved over the four year time gap, causing VMM-268 not to experience most of the same driver degraders that the community dealt with back in 2010.

C. ANALYZING HOW CANNIBALIZATION AFFECTS AVAILABILITY

High readiness demands was a major reasons identified why naval aviation squadrons practice aircraft cannibalization. As previously discussed, maintenance managers use this practice to consolidate multiple NMCS discrepancies against a few aircraft to increase their MC rate, thereby increasing the number of aircraft available to support flight operations.

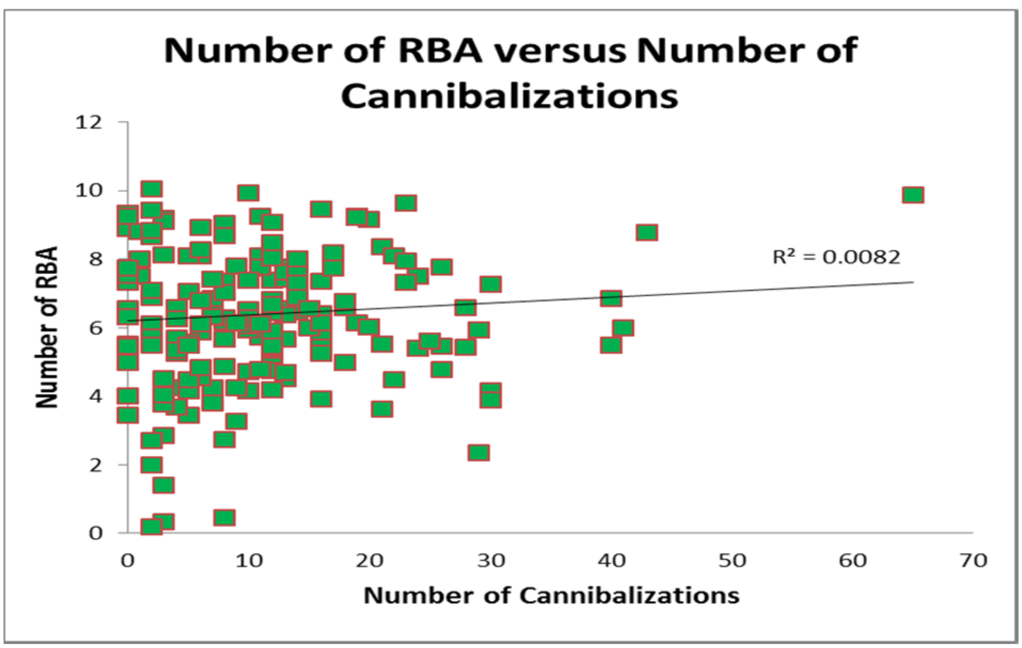
Chapter 10 of Jones (2006) defines Availability as "The probability that an item is in an operable and committable state when called for at an unknown (random) time" (p. 10.1). In the naval aviation community, aircraft that are in an operable state are classified as MC aircraft. However, not all MC aircraft are in a committable state to be put toward operational flights. This is because aircraft that require functional check flights (FCF) are also calculated as part of the number of MC aircraft. An aircraft that is operable and committable to an operational flight is classified as a ready basic aircraft (RBA) in the naval aviation community.

The researcher attempted to establish a statistical relationship between RBA and number of cannibalizations, to uncover how the number of RBA is affected by the number of cannibalizations performed within in a given period. To accomplish this, the consolidated 2014 monthly AMSRR and 3M matrix was utilized. This matrix contained all 2014 monthly aircraft readiness measurement parameters as well as 3M data for all the MV-22 operational squadrons.

A correlation between the RBA column and the number of cannibalizations column was run, and revealed a correlation coefficient of 0.1392. As previously discussed, a correlation coefficient establishes the linear relationship between two variables. Coefficients of 0.3 and below indicate a weak positive relationship between the two variables. In this this case, the calculated coefficient of 0.1392 indicated a very weak to almost no linear relationship between RBA and the number of cannibalizations performed.

A scatter plot of the two variables was produced in Figure 13 to see the dispersion and examine if there was a goodness of fit for a linear trendline on the plots.

Figure 13. Number of RBA versus Number of Cannibalizations Plot.



Adapted from Marine Aircraft Group 26 MV-22 current readiness analyst, personal communication, May 5, 2015.

Figure 13 showed no correlation or significant linear relationship between RBA and the number of cannibalizations performed. It showed no clear evidence to indicate that the number of RBA increases or decreases with activity of the number of parts cannibalized. The R-squared value of 0.0082 for the trendline was very weak, indicating a poor fit of the trendline on the plotted points.

To further investigate the effect of number of cannibalizations on RBA, a multivariate regression was performed with RBA as the dependent variable, against seven independent variables. The seven independent variables selected were number of aircraft assigned, number of aircraft in out of reporting (OOR) status, number of MC aircraft, NMCM-scheduled hours, NMCM-unscheduled hours, NMCS hours, and number of cannibalizations. Using a significance level of 0.05, the regression produced the output results in Table 17.

Table 17. Summary Regression Output 1 (RBA versus Cannibalizations, Assigned, OOR, MC, NMCM-S, NMCM-U, NMCS).

SUMMARY OUTPUT								
RBA versus Cannibalizations, Assigned, OOR, MC, NMCM-U, NMCM-S, NMCS								
Regression Statistics								
Multiple R	0.972605464							
R Square	0.945961388							
Adjusted R Square	0.944280187							
Standard Error	0.486834868							
Observations	233							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	7	933.5016657	133.3574	562.6699302	9.8287E-139			
Residual	225	53.32684238	0.237008					
Total	232	986.8285081						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.297490005	0.136419794	-2.1807	0.030242617	-0.566313857	-0.028666153	-0.566313857	-0.028666153
Cannibalizations	0.001554027	0.003500403	0.443957	0.657500543	-0.005343739	0.008451794	-0.005343739	0.008451794
Assigned	0.323881656	0.047788687	6.777371	1.06031E-10	0.229711019	0.418052294	0.229711019	0.418052294
OOR	-0.37858158	0.049630576	-7.62799	6.67265E-13	-0.476381776	-0.280781385	-0.476381776	-0.280781385
MC	0.655721849	0.048352042	13.56141	5.114E-31	0.560441084	0.751002614	0.560441084	0.751002614
NMCM-U	-0.438463923	0.066227246	-6.6206	2.59272E-10	-0.56896891	-0.307958936	-0.56896891	-0.307958936
NMCM-S	-0.407183438	0.218409539	-1.86431	0.063580261	-0.83757328	0.023206404	-0.83757328	0.023206404
NMCS	-0.321095416	0.056950404	-5.63816	5.12398E-08	-0.433319797	-0.208871036	-0.433319797	-0.208871036

Adapted from Marine Aircraft Group 26 MV-22 current readiness analyst, personal communication, May 5, 2015.

The summary Analysis of Variance (ANOVA) output in Table 17 proved the regression model to be a very good model of the independent variables against the RBA dependent variable. The model's coefficient of determination or R-squared value of 0.9460 indicated that approximately 95 % of the variability in RBA was explained by the independent variables in the model. The approximately 5% unexplained variability could be attributed to individual squadron maintenance practices and other factures not captured in this model.

The model's F-Statistic value proved the model to be a very significant model. An F-Statistic value tests the probability that all the regression coefficients are zero, to allow acceptance or rejection of a null hypothesis. In the case of this model, the F-statistic value of 9.829E-139 proved that there was almost a 0% probability that all of our regression coefficients are zero, allowing us to reject the null hypothesis and consequently making the model a very significant model.

The p-value of the number of cannibalizations (0.6575) indicates that the number of cannibalizations is not significant in determining availability. This finding however is not consistent with previous literature and current naval aviation mindset of using cannibalization to increase aircraft availability.

A correlation test of the independent variables was performed to see if a case of possible multicollinearity existed between the cannibalization variable and any of the other six independent variables. Results from the correlation test identified possible multicollinearity between cannibalizations and number of aircraft assigned, as well as with the NMCS variable. Table 18 is the output correlation matrix of the independent variables.

Table 18. Correlation Matrix of Independent Variables.

	CANNIBALIZATIONS	OOR	NMCM-U	NMCM-S	NMCS	ASSIGNED	MC
CANNIBALIZATIONS	1						
OOR	0.0803342	1					
NMCM-U	0.172919833	0.232678885	1				
NMCM-S	0.024526796	0.010932312	0.252730552	1			
NMCS	0.311462648	0.005495464	0.414510319	-0.00850484	1		
ASSIGNED	0.24662689	0.763694434	0.475484372	0.059438557	0.348102873	1	
MC	0.14998697	0.212215018	0.053916074	-0.041440016	-0.039476949	0.628642446	1

Adapted from Marine Aircraft Group 26 MV-22 current readiness analyst, personal communication, May 5, 2015.

This matrix revealed that the two variables were highly correlated with the cannibalization variable. This high correlation intuitively was possible because a squadron's number of cannibalizations can be expected to increase as their number of assigned aircraft is increased and vice versa. On the other hand, a squadron's accumulated NMCS hours can be expected to increase as more parts are cannibalized. This is because cannibalization actions are taken to temporarily resolve an AWP situation for maintenance actions that are already sitting in a NMCS status.

The data for the two identified variables were removed to see if the P-value of the cannibalization variable would change with a new ANOVA test. A new regression with the dependent RBA variable against the five remaining independent variables produced the summary output in Table 19.

Table 19. Summary Regression Output 2 (RBA versus Cannibalizations, OOR, MC, NMCM-U, NMCM-S).

SUMMARY OUTPUT								
RBA versus Cannibalizations, OOR, MC, NMCM-U, NMCM-S								
Regression Statistics								
Multiple R	0.966917548							
R Square	0.934929546							
Adjusted R Square	0.933496276							
Standard Error	0.531863069							
Observations	233							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	5	922.6151286	184.523	652.3052854	1.7443E-132			
Residual	227	64.21337949	0.282878					
Total	232	986.8285081						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.116660165	0.134867507	-0.865	0.387952909	-0.382412476	0.149092145	-0.382412476	0.149092145
Cannibalizations	0.001522255	0.0036664	0.415191	0.678394444	-0.005702274	0.008746785	-0.005702274	0.008746785
OOR	-0.055443066	0.014988311	-3.69909	0.000271476	-0.084977076	-0.025909055	-0.084977076	-0.025909055
MC	0.965230374	0.017287469	55.8341	1.3699E-134	0.931165942	0.999294805	0.931165942	0.999294805
NMCM-U	-0.141244717	0.049154547	-2.87348	0.004444916	-0.238102253	-0.04438718	-0.238102253	-0.04438718
NMCM-S	-0.147112936	0.232609452	-0.63245	0.527731944	-0.605462769	0.311236897	-0.605462769	0.311236897

Adapted from Marine Aircraft Group 26 MV-22 current readiness analyst, personal communication, May 5, 2015.

The output ANOVA model with the five independent variables still proved to be a very significant model, The F-statistical significance increased slightly from the previous 9.8287E-139 to 1.744E-132 but still maintained its integrity as a very significant model. The R-squared value also decreased from the previous 0.9460 to 0.9349, thereby increasing the model's unexplained variability in RBA to approximately 7%. The P-value for cannibalization however increased from 0.6575 to 0.6784, still maintaining our original inference that number of cannibalizations has little to no effect on a squadron's RBA or aircraft availability. This inference again intuitively made sense due to, but not limited to, some of the following reasons:

Not all work orders initiated at the squadron level to cannibalize components turn out to be successful. Some of the components end up breaking during the attempted removal and installation process due to either maintenance error or the complexity of the removal and installation process. This, therefore, causes the attempted cannibalization action to not have the desired increasing effect on the number of RBA aircraft.

Some aircraft components as already discussed require removing other components to facilitate the cannibalization maintenance action. The associated risk of breaking any of the removal to FOM components is real and happens quite often on any aviation platform. This again can increase the amount of time that a NMC aircraft can remain in that status until the discrepancy is corrected.

Cannibalizing a part from one aircraft to another often breaks the integrity of an already functioning system on the donor aircraft. These actions sometimes introduces new discrepancy maintenance actions that can require further system troubleshooting long after the cannibalized part is received from the supply system. This ultimately lengthens the NMC status of the donor aircraft and effectively maintaining the aircraft's non-RBA status.

Cannibalizing a part can effectively return an aircraft from NMC to MC status; however, the aircraft can immediately become NMC again for another discrepancy not related to the original discrepancy. This results in the cannibalization action consequently showing just momentarily, the increasing effect of the cannibalization action on aircraft availability.

Lastly, cannibalizing a component from an aircraft, often opens the door to cannibalize additional needed components from an already NMCS cannibalized aircraft. This in effect also holds the cannibalized aircraft in a NMC status for longer periods than might have been anticipated, ultimately maintaining the aircrafts non RBA status.

In conclusion, it appeared that cannibalizations have no significant main effect on fleet aircraft availability. Cannibalizations may interact with other variables to create a modest effect on availability, however, that effect is not tested in this thesis.

D. SUMMARY

This chapter presented and analyzed into detail, the different data collected from the sources described in Chapter III. Using the data, research strategy and various tools/techniques mentioned in Chapter III, each of the research questions identified in Chapter I was systematically investigated and the results thereof, presented in tabular and graphical format. Staying within the scope of the thesis, each or the researchers proposed area of investigation has been explored. The conclusions and recommendations of the research will be presented in Chapter V.

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V. CONCLUSIONS AND RECOMMENDATIONS

This chapter of the thesis provides the conclusions and recommendations that resulted from the analysis of MV-22 aircraft cannibalization in Chapter IV. The research examined 13 MV-22 squadrons, to investigate how the practice of cannibalization varied in the community, which aircraft components drove cannibalizations, and lastly, how cannibalization affected aircraft availability.

A. CONCLUSIONS

The following are the conclusions drawn from the researcher's analysis:

Among the NAMP's seven cannibalization malfunction codes, 815 (Repairable part carried but not on hand in local supply system) was the top-most reason why MV-22 squadrons cannibalize. Reason code 814 (part not readily available within the required time constraint) was the second-most reason why squadrons cannibalize. Reason code 813 (inter-squadron cannibalizations directed by higher authority) was the third-most reason for cannibalizations in the community. This pattern of cannibalization was observed to be a common trend in the community between the two coasts observed. However, other significant variations in cannibalizations were observed at the individual squadron level in the other codes.

The analysis revealed that some particular squadrons consistently receive more direction by higher authority to perform inter-squadron cannibalizations (code 813) more so than others. In the researcher's opinion, and based of his personal experience, squadrons with higher aircraft readiness rates or lower in priority on training exercise employment plans (TEEP) typically receive more direction to perform inter-squadron cannibalization to support squadrons with lower aircraft readiness or those higher in TEEP priority. Although this is not a fair practice for the "donor" squadron, the researcher believes this is how the community worked around some of its initial logistical challenges to get the V-22 program where it is today.

Another significant observation made was in the documentation of repairable cannibalizations under the 815 and 816 malfunction codes. The analysis revealed that some squadron maintainers inaccurately select the wrong code when documenting repairable cannibalizations. This is due to the close resemblance in the verbiage of the two codes in the NALCOMIS, making it appear that some squadrons cannibalize more “unique” repairable parts that are not carried in the local supply systems. A recommendation to correct this issue is provided in the Recommendations Section.

Accumulated cannibalization MMHs documented by the selected squadrons showed huge variations from each other. Even when analyzed on a similar component basis, the MMHs documented for cannibalizing the same component showed significantly large variations from squadron to squadron. However, the exact reasons for these large variations could not be uncovered through this research. In the researcher’s opinion, two possible causes exist for these large variations: (1) Some squadrons might be over or under documenting their MMHs, or (2) these documented MMHs are in fact accurate, indicating that squadrons that document lower MMHs for removing components are more technically proficient at cannibalization. Until the real reasons for these significant variations are uncovered, the researcher believes it would be impractical to use cannibalization MMHs as a metric for comparing squadron performance.

Cannibalization of consumable parts versus repairable parts varied widely in the community. On a percentage of consumable to repairable basis, the analysis revealed that the West Coast squadrons generally cannibalized more consumables parts and less repairable parts than the East Coast squadrons. The researcher believes the reason for this is the majority of newer aircraft found in the West Coast fleet compared to the East Coast fleet as a result of their different transition periods. The newer aircraft on the West Coast, based on the researchers experience and opinion, have much newer and upgraded repairable components which typically fail less often than those found in the older East Coast aircraft fleet. Effectively, the West Coast squadrons cannibalize less repairable parts than the East Coast squadrons. Additionally, MALS-16 on the West Coast does not have the same V-22 I-level resident expertise and capabilities as MALS-26 on the East Coast when it comes to fabricating some peculiar V-22 consumable parts. This causes those West Coast squadrons to often resort to cannibalizing those peculiar consumable parts that cannot be easily fabricated at their on-site MALS.

Cannibalization actions taken to correct aircraft degraded systems under the 11 equipment operational capability (EOC) codes varied widely in the community. As anticipated, it was uncovered that cannibalization to correct NMC (Z-coded) degraded systems was the number one driver of cannibalizations in all squadrons observed. This supports previously written literature that squadrons perform cannibalization to return non-flyable aircraft to flyable status.

Squadrons also cannibalized considerably to correct PMC degraded aircraft systems. All squadrons analyzed performed significant cannibalizations to regain combat mission, environmental extreme, and day/night instruments meteorological condition (IMC) capabilities on their PMC aircraft. Although PMC aircraft are technically mission capable, the magnitude of cannibalizations observed goes to support that squadrons also exhaust a considerable amount of maintenance hours to get PMC aircraft into FMC status for flying specific mission profiles. Based on how these PMC cannibalizations varied from squadron to squadron, it is believed that some squadrons have an internal drive to cannibalize in order to maintain specific number of FMC aircraft to keep them operationally ready at all times.

When measured on a cannibalization rate basis, the West Coast V-22 squadrons generally performed better (lower rate) than the East Coast squadrons. When ranked on an average basis, VMMs 162,165,166, and 365 were found to be above average squadrons. VMMs 161,163,263,261, and VMMT-204 were found to be average squadrons, while VMMs 264,266,268, and 363 were found to be below average squadrons at cannibalization. Although identifying the specific causes for the observed differences is beyond the scope of this research, there are multiple potential factors that could have caused the differences. These factors are discussed under the Recommendations Section.

MV-22 squadrons show increases in cannibalization rates when deployed due to increased OPTEMPO. MEU shipboard deployed squadrons were observed to generally have much higher cannibalization rates than the land based deployed squadrons. As supported by the analysis, with other things being equal, MEU shipboard squadrons can be expected to cannibalize more parts than land-based deployed squadrons. These squadrons should therefore be better prepared and postured to better support their shipboard deployments. The research also consequently revealed that cannibalization rates for land based deployed squadrons can also be expected to increase if the squadrons rotate next into a MEU shipboard deployment.

The shipboard deployed squadrons, for unknown reasons, were also observed to cannibalize a much higher number of consumable parts than their land based deployed counterparts. These squadrons should therefore be better prepared with fully replenished pre-expended consumable bins and I-level support capabilities prior to deploying to better support them afloat.

Across the wide range of MV-22 aircraft components, power supplies, VFG, blade assemblies, panel assemblies and electronic components were found to be the top five readiness degraders respectively over the five year observed period. These components evidently caused the vast majority of V-22 cannibalizations in the community. Of these five components, VFGs and blade assemblies consistently showed an increasing trend in cannibalizations from 2010 to 2014. Persistently upward trending rates of these components may indicate problems due to part shortages, poor manufacturer reliability, inadequately written maintenance troubleshooting steps and poor squadron maintenance practices. These two components should therefore receive the attention of V-22 logisticians, IMs and the V-22 SSWG.

Direct current generators, hydraulic drive units, blade assemblies, wiring harnesses, and Coanda Tube assemblies were observed to be the worst trending cannibalized components. These components, although not all major readiness degraders, were the top five parts that showed the worst increasing trend in cannibalization among all cannibalized V-22 parts. Their worse consistent upward trending through 2014 is a cause for alarm to indicate they have a greater potential to cause major readiness issues in the near future if not quickly addressed. These components should receive the immediate attention of V-22 logisticians, IMs and the V-22 SSWG.

MV-22 cannibalizations are known to be performed with the intent of increasing aircraft availability in the squadrons; however, statistical tests performed in the research revealed that cannibalizations have little to no effect on MV-22 aircraft availability. Cannibalizations, however, may interact with other variables to create a modest effect on squadron-level aircraft availability, or the variance in squadron-level aircraft availability but squadron-level effects were not tested in this research. The analysis in this thesis which showed that squadron flying hours was the biggest determinant of cannibalization might be seen as providing partial support for this idea. Since the analysis was correlational and not causal, it might be claimed that the analysis shows increased cannibalization leads to greater flight hours—rather than the other way around. However, this would need to be further explored in later research.

B. RECOMMENDATIONS

The current optimized NALCOMIS system has seen significant improvements from the legacy system; however, glitches still exist in the system which prevents accurate documentation of cannibalization actions. In reviewing the data, 347 cannibalization work orders were found without an identifying EOC code. Components are cannibalized to either correct NMC or PMC discrepancies; the system should therefore be corrected to prevent documentation of cannibalizations without a corresponding EOC code.

The true magnitude of consumable parts cannibalized in the MV-22 community is currently not accurately reflected by retrieving the 817 consumable malfunction code data. Sorting cannibalization work orders by Repairable Indicator to manually separate the repairable work orders from the consumable work orders is currently the only way to accurately capture the number of consumable parts cannibalized. The system should be corrected to accurately track consumable cannibalizations by its appropriate 817 malfunction code as required by the NAMP.

Due to slight similarities in the verbiage of the 815 and 816 codes, maintainers sometimes inaccurately document cannibalizations by selecting the wrong codes. A system modification to the verbiage of the two codes might be appropriate to assist maintainers in selecting the correct code and prevent further inaccurate documentation.

Squadrons report cannibalization MMHs as required by the NAMP. However, as discussed in the conclusions, huge variations exist between squadrons in documenting the required amount of MMHs used to cannibalize the same MV-22 components. The specific reasons for these variations in MMHs were not discovered in this research. However, the researcher believes the current cannibalization MMHs reported by squadrons should not be used as an appropriate metric to measure the true labor hour cost of cannibalization in the community, until MMHs reported or the MMH documentation process has been vetted to be accurate. If found not to be accurate, a more appropriate method to tease out the precise amount of labor hours used in cannibalizing components from the current MMHs documentation may be required.

C. RECOMMENDATIONS FOR FURTHER RESEARCH

The underlying rationale for any cannibalization is to improve availability, but this research found no significant relationship between cannibalization rates and availability. Further research is needed to determine how cannibalization interacts with other variables to impact MV-22 aircraft availability at the squadron level.

A more in-depth study is required to determine why MV-22 MEU deployed shipboard squadrons generally have higher cannibalization rates than land based deployed squadrons, even though shipboard AVCALs are widely believed to be better postured than land-based deployable pack-ups

Further research is required to determine why the cannibalization MMHs documented for removing the same MV-22 components varies significantly from squadron to squadron, and to investigate the accuracy of those reported MMHs.

Some MV-22 squadrons were observed to perform much better at cannibalization than other squadrons. Many factors including the age of aircraft, the internal maintenance practices, the internal maintenance management, and the maintenance technical proficiencies can all contribute to better cannibalization practices. A more in-depth study is required to determine why some MV-22 squadrons perform better at cannibalization than others.

APPENDIX. RECOMMENDED MV-22 CANNIBALIZATION BEST PRACTICES

This list of recommended MV-22 cannibalization best practices was developed by the researcher from a number of background conversations held with V-22 maintenance personnel and SMEs during the data gathering process.

- Meticulously select a donor aircraft that will facilitate only a few cannibalizations as possible. This requires carefully examining the impacts of the supply requisition's estimated delivery date (EDD) on the donor aircraft. For example, a requirement to cannibalize a part for an outstanding requisition that has an EDD of 30 Days should not be cannibalized from an aircraft that is anticipated to become MC within the next two weeks as it will prolong the NMC status of the donor aircraft. A cannibalization decision like this is a recipe to generate a hangar queen aircraft as it opens the door to cannibalize other needed parts that have longer EDDs.

- Choosing a donor aircraft that minimizes the maintenance hours required to remove the cannibalizing part. All squadron assigned aircraft undergo corrective and preventative maintenance consistently that require opening up various aircraft access panels. When a need arises to cannibalize a part, maintenance managers need to carefully analyze all aircraft undergoing maintenance to identify which aircraft may already be opened up and provides a quick and easy access to remove the required part. This eliminates the requirement to dedicate maintenance hours to the removal of access panels on the desired donor aircraft, and shortening the overall cannibalization process.

- Limit cannibalization of parts that require removal of other components to facilitate the maintenance action. The MV-22 aircraft is a complex aircraft with various parts that are sometimes not very easily accessible. Decisions to cannibalize parts that require FOM components often lead to secondary damages to other components, additional consumable material requirements, and the risk of damaging the part desired to be cannibalized. This also often leads to premature failure of the secondary components that were removed to facilitate the process.

- Choosing a donor aircraft that has a guaranteed good working component is very important to avoid wasting MMHs. Most MV-22 installed components progressively provide indication of anticipated failure before they completely fail. Parts in this category that have indicated potential failure through intermittent faults and codes are not good candidates to cannibalize. This is because their failures are often accelerated by the forced removal, and are better off if left installed in their original aircraft. A decision to still cannibalize components in this category only temporarily adds a MC aircraft till the components ultimate failure.

- Cannibalization of components that require FCFs or that that require removal of other FCF required components should be carefully evaluated to ensure the decision is warranted. Most MV-22 FCF requirements are very exhaustive and more than often identify several other parts that were not anticipated to be bad. Cannibalizing parts in this category forces the donor aircraft to undergo FCFs that can potentially increase the maintenance workload for the donor aircraft due to unanticipated discrepancies. Additionally, cannibalizations that will require rotor track and balance can often commit the donor aircraft to undergo multiple FCFs to smooth out rotor balancing, which can hold the aircraft in a non RBA status for days until it passes the FCF.

- Minimize or if possible, ignore decisions to cannibalize airframe related structural parts. A significant portion of V-22 airframe structural parts are riveted to the airframe and assume the form of the specific airframe they are attached to. Several attempts made in the community to cannibalize such parts have often ended up damaging additional parts because the cannibalized part from the donor aircraft did not line up correctly to the new aircraft. Maintainers in a desperate effort to make the parts fit on the new aircraft can often cause additional damage to the cannibalized part, or in an even worse scenario, cause major damage to the new aircrafts airframe.

- Cannibalization of avionics components that are quick to remove and reinstall should be closely monitored and tightly controlled. The tendency for V-22 maintenance personnel to always want to cannibalize an avionics component on this avionics intensive platform is always very high. This practice if not monitored, breeds bad maintenance troubleshooting and fault isolation practices that lead to improperly identifying functioning components as being defective and requiring replacement. Since the part is easy to remove and readily available from another aircraft, the wrong call is often made to cannibalize this part, ultimately leading to the replacement of the wrong parts and the turn-in of RFI parts back into the repair cycle.

- Cannibalization of engine exhaust related components in the infra-red section (IRS) should be performed only as a last resort. Due to the significant heat damage caused by the aircraft exhaust, components in this general area are not good candidates for cannibalization since they often have already sustained significant heat damage since their installation. Forcefully opening up an IRS section to cannibalize parts often results in several other IRS related parts from the donor aircraft needing to be turned in for repair due to heat damage. The only recommended exception is if the donor aircrafts IRS section is already opened up for a scheduled inspection.

- Cannibalization of components that prevents accessibility to other areas of the donor aircraft or will impair the mobility of the donor aircraft should be carefully thought through in order not to negatively impact other maintenance actions that might need to be performed while the donor aircraft is in a NMCS status. This concept if not carefully reasoned through can prevent scheduled and non-scheduled inspections from being completed on the donor aircraft, increasing its workload. This can significantly increase its NMC time even after the AWP requisition is received.

- Cannibalization of parts from aircraft that are undergoing phased maintenance inspections should be carefully timed with the inspection schedule. Phase inspections, although usually longer in duration than other scheduled inspections, can be significantly delayed during the inspection period if the timing for outstanding cannibalized requisitions is not accurately planned with the inspection schedule. This can create a substantial backlog in the squadron’s phase inspection schedule and can often create long term effects in reducing the squadron’s total available aircraft hours.

- Verbal communicating with the aviation supply department to re-confirm or re-verify the accurate status of an outstanding requisition can often make the difference between a good and a wasted cannibalization decision. Supply data system in-accuracies, coupled with inventory discrepancies and changing supply status codes often can lead to making a cannibalization decision, only to have the outstanding requisition delivered immediately following the cannibalization action. This leads to wasted MMHs that could have been avoided if proper steps were taken to confirm the requisitions accurate status.

- The MMHs required to cannibalize a specific components should always play a vital role in making a decision to cannibalize. A part that requires a few hours to about half a maintenance shift to cannibalize can often be deemed an acceptable risk, while a part that requires a whole shift to cannibalize should require a legitimate and justified mission need. These MMHs required should also be compared against the transit time of the outstanding requisition to weigh the cost and benefit of the cannibalization decision. As an example, a requisition in shipping status that will arrive in three days should not be cannibalized if the MMHs required to cannibalize is two days; this would result in wasted MMHs that was not correctly justified.

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