IMPROVING KNOWLEDGE OF C-130 AIRCRAFT CONDITION:
A HIGH VELOCITY MAINTENANCE CASE STUDY

THESIS

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Abstract

High Velocity Maintenance (HVM) seems poised to revolutionize the way the Air Force schedules and performs depot-level maintenance on its aircraft. The four tenets of HVM, Known Condition of the Aircraft, Supportability, Daily Standard Work, and High Burn Rate, provide the basis for the Air Force's Air Logistics Centers (ALCs) to improve the quality of planning and scheduling that goes into each aircraft's depot maintenance visit. These tenets have been implemented at Warner Robins ALC as part of the C-130 depot maintenance process. While HVM is in active implementation there, much remains to be documented on how the process works in a practical way.

This research is a case study that explores the way maintenance information systems and work unit codes are used to facilitate HVM on the C-130 line at Warner Robins ALC. This research focuses on the Center's implementation of improving knowledge of each aircraft's condition prior to its induction into depot. This is investigated here through a combination of documentation analysis, archival records review, interviews, and direct observations. This research includes exploring how an aircraft's maintenance history is compiled and considered in the depot planning process as well as the way that information flows from field-level maintenance units to enterprise-level information systems to where they are used as part of the depot planning process.

Acknowledgments

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Marcus R. McWilliams

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I. Introduction

Background

Since 2007, Warner Robins Air Logistics Center (ALC) has been operating its C-130 depot maintenance line under the new High Velocity Maintenance (HVM) initiative framework. HVM started as an Air Force Materiel Command program designed to increase aircraft availability by improving maintenance practices and speeding throughput of aircraft through depot-level maintenance activities. Its goal is to take an enterprise view of improving maintenance and to integrate requirements with infrastructure, materiel support, and information technology (IT).

The first tenet of HVM is having a "Known Condition of the Aircraft" prior to induction into the Programmed Depot Maintenance (PDM) process. The myriad of forms and information systems that are used to catalogue and record maintenance actions and outstanding maintenance discrepancies present a challenge to depot maintenance planners in trying to achieve a known condition of the aircraft. Currently, this is overcome through a detailed analysis of available maintenance data sources and a physical inspection of the aircraft, all completed prior to the aircraft being inducted into PDM.

Research Objectives

The goal of this research is to identify and explore the ways in which Maintenance Information Systems (MIS) and Work Unit Codes (WUC) facilitate the flow of an aircraft through the depot maintenance process. The intended outcome of this research is to be able to paint a complete picture of how the HVM process works to fully understand aircraft health through the use of compiled maintenance data and HVM-specific, targeted physical aircraft inspections.

Problem Statement

How are Maintenance Information Systems and Work Unit Codes used to facilitate the flow of aircraft through the PDM/HVM process?

Research Questions

The goal of this research is to identify and explore the ways in which maintenance information systems and work unit codes facilitate the flow of an aircraft through the schedule maintenance process. Pursuant to that goal, the following research questions were identified. The answers to these questions will assist in building a complete picture that will achieve the research objectives.

- Research Question #1: How do Maintenance Information Systems capture maintenance data that is relevant to the PDM/HVM process?
- Research Question #2: How are Work Unit Codes captured and used in Maintenance Information Systems?
- Research Question #3: Who are the users and customers of relevant Maintenance Information Systems?
- Research Question #4: How are Maintenance Information Systems used to manage aircraft flow through the PDM/HVM process?
- Research Question #5: How can the integration between different Maintenance Information Systems be improved to facilitate HVM?

Methodology

This research is a case study experimental design intended to focus on the contemporary events of the Air Force's High Velocity Maintenance process for C-130 depot maintenance. This research uses a combination of documentation, archival records, interviews, and direct observations in order to achieve the stated research goals. This research will be limited in scope to the C-130 depot maintenance process in place at the Warner Robins Air Logistics Center.

Scope, Assumptions, and Limitations

This research will primarily be limited the C-130 depot maintenance. While HVM principles are actively being applied to multiple weapon systems, the C-130 was the first aircraft to undergo the transformation from traditional Programmed Depot Maintenance to High-Velocity Maintenance, and thus is a much more mature product in terms of HVM integration than any other aircraft. Many of the processes that are considered crucial to making HVM work have already been implemented in the C-130 program, therefore making it the ideal candidate for ongoing study and research.

Summary

The Air Force and Air Force Material Command are counting on HVM to improve the throughput of C-130 aircraft through depot maintenance. By improving the knowledge of an aircraft's condition before it arrives at the depot, planners are able to better prepare for the maintenance actions that will be taken, improving the ALC's performance. A case study, this research will examine the methods undertaken by Warner Robins ALC to increase their knowledge of aircraft condition; what maintenance information systems they use, and how the information from it is examined, catalogued, and utilized. An understanding of the methods used under C-130 HVM may lead to possibilities for depot maintenance improvements across multiple weapon systems.

II. Literature Review

Chapter Overview

The purpose of this chapter is to discuss the relevant literature regarding the concept and implementation of High Velocity Maintenance as a way of performing depot-level aircraft maintenance. Also to be discussed are the key maintenance information systems being used, as well as how work unit codes are utilized in the aircraft maintenance community.

High Velocity Maintenance

By the mid-2000s the Air Force was having an increasingly hard time meeting Combatant Commander's requirements for aircraft availability for use in ongoing contingency operations in Iraq and Afghanistan. Increases in operating and maintenance costs that came with operating an increasingly aged fleet as well as continued high operations tempos and a reduced active duty force size combined to make meeting the availability requirements for combat aircraft more difficult than ever in recent history (Warner Robins Air Logistics Center HVM Team, 2008). This was readily apparent in the Air Force's C-130 fleet, which continued to experience heavy demands as an intra-theater airlifter. The demands were even more strenuous for Air Force Special Operations Command's low-density high-demand fleet of specially equipped MC-130 transports and AC-130 gunships.

The existing heavy (depot) maintenance interval for C-130 aircraft meant that each aircraft visited the Air Logistics Center for repairs approximately every 60 months. These long intervals were seen as one reason that PDM aircraft delivery targets/dates were not being met. After multiple combat deployments to harsh environments and undergoing 5 years of constant heavy use, aircraft were reporting to the depot for heavy maintenance with far more damage and areas requiring repair than were planned in the scheduled depot maintenance process. A "must fix now" mentality at the ALCs as well as long lead-times for unscheduled or unexpected replacement parts was driving up service times at the depots. The concept of HVM was driven out of necessity to get PDM service times under control and get more aircraft back into users' hands and out of the repair pipeline (Warner Robins Air Logistics Center HVM Team, 2008).

High Velocity Maintenance as an operating concept is much more than just accomplishing depot maintenance more quickly; it is actually a fundamental change in the Air Force's approach to depot maintenance (Branson, 2011). HVM's goal is to take an enterprise view of improving maintenance and to integrate requirements with infrastructure, materiel support, and information technology (Warner Robins Air Logistics Center, 2009). HVM was developed starting in 2007 by a team from Air Force Materiel Command's Warner Robins Air Logistics Center. The High Performance Team (HPT), comprised of subject matter experts from a range of functional areas mapped the current state of depot maintenance operations and looked at processes that were experiencing difficulty. They then explored heavy maintenance operations in the commercial sector, including American Airlines, Cascade Aerospace, and TIMCO Aviation Services (Warner Robins Air Logistics Center HVM Team, 2008).

The team's research indicated three areas where commercial aviation heavy maintenance differed from USAF depot maintenance practices that enabled them to achieve much higher mission capable rates and move aircraft through depot-level maintenance at a much higher rate.

First, commercial aviation entities are very successful at accurately defining and planning for daily work requirements. Strict adherence to a production schedule and these accurate daily work requirements meant that touch-labor or “burn” rates of 500-900 worker-hours per day per aircraft were achievable. Under traditional Air Force PDM, aircraft are not fully inspected to finalize depot requirements until the aircraft arrives at the depot. According to Warner Robins ALC, that initial Evaluation and Inspection can take upwards of 60 days! The depot’s inability to quickly and accurately assess an aircraft’s condition upon its arrival at depot makes the development of requirements for man and materials extremely difficult. In comparison to commercial aviation, C-130 depot maintenance burn rates averaged between 145 and 220 hours per day (Llantada, 2011).

Additionally, until being realigned under the HVM consturct, there was little interaction between the aircraft’s weapon system progrm office engineers and the depot planners and maintainers at the ALC. This meant that changes to maintenance requirements made by both parties were being done with incomplete data (Mobley, 2011).

The second area of improvement identified was the mechanic-centric focus of commercial maintenance practices. This way of operating meant that mechanics could stay focused on the task at hand with all required parts, tools, and equipment pre-positioned or brought to them as needed. This is accomplished through the use of pre-built task kits and andon signaling. Andons are a type of visual control that displays the current state of work, a system pioneered by Toyota but now used in many industries (Toyota Motor Manufacturing Kentucky, Inc., 2006). Commercial industry also heavily scripts mechanic's tasks in order to reduce variation in work processes. In comparison, traditional PDM practices allow mechanics a high degree of flexibility with the order in which repair tasks are accomplished, letting mechanics choose what they want to work on any given day. This means that maintenance tasks may be accomplished in a less-than-optimum order and that mechanics spend lots of time searching for tools, equipment, and parts. These factors contribute the PDM's traditionally low burn rate when compared with commercial industry (Mobley, 2011, Llantada, 2011).

The third factor identified by the HPT was the commercial sector's enterprise approach to heavy maintenance operations. Enterprise Resource Planning (ERP) information systems allow them to easily collect and maintain the information required to choreograph maintenance activities (Llantada, 2011). While some newer USAF information systems, such as the Reliability and Maintainability System allow for a higher degree of enterprise-wide visibility, most legacy systems still operate in a functional vacuum.

These findings, along with the Air Force's unique needs and operating structure led to the creation of the Four Tenets of HVM, the construct under which HVM would be achieved at the ALCs (Llantada, 2011).

1. Known Condition of Aircraft: A joint ALC and weapon system program office effort will pour over all available maintenance records for each aircraft prior to its depot induction. When possible, a field inspection of the aircraft will be conducted to further identify potential problem areas.

2. Supportability: Emphasis is on building task kits for accomplishing each depot maintenance task. Kits will include all the parts, tools, PPE, etc. required to accomplish a specific task and will be pre-packaged and pre-positioned rather than the mechanic having to retrieve each piece individually.
3. Daily Standard Work: Under traditional PDM, the mechanics have a large degree of freedom to choose which tasks to accomplish on any given day. The idea of daily standard work is to intentionally sequence maintenance tasks in an optimal sequence and provide the mechanics with all the needed tools, equipment, and facilities to do them.
4. Burn Rate: Having Daily Standard Work means that mechanics spend more time working on the aircraft and less on other duties. Also, by consolidating manning to work fewer aircraft at once, the total time needed to accomplish PDM is decreased. The total man-hours required do not decrease, but because the touch-labor rate is higher on a given aircraft, it is essentially able to be turned faster.

Figure 1 illustrates the four tenets as they fit in the HVM construct. This construct provides the basis on which Warner Robins ALC has integrated their HVM program into C-130 depot maintenance.

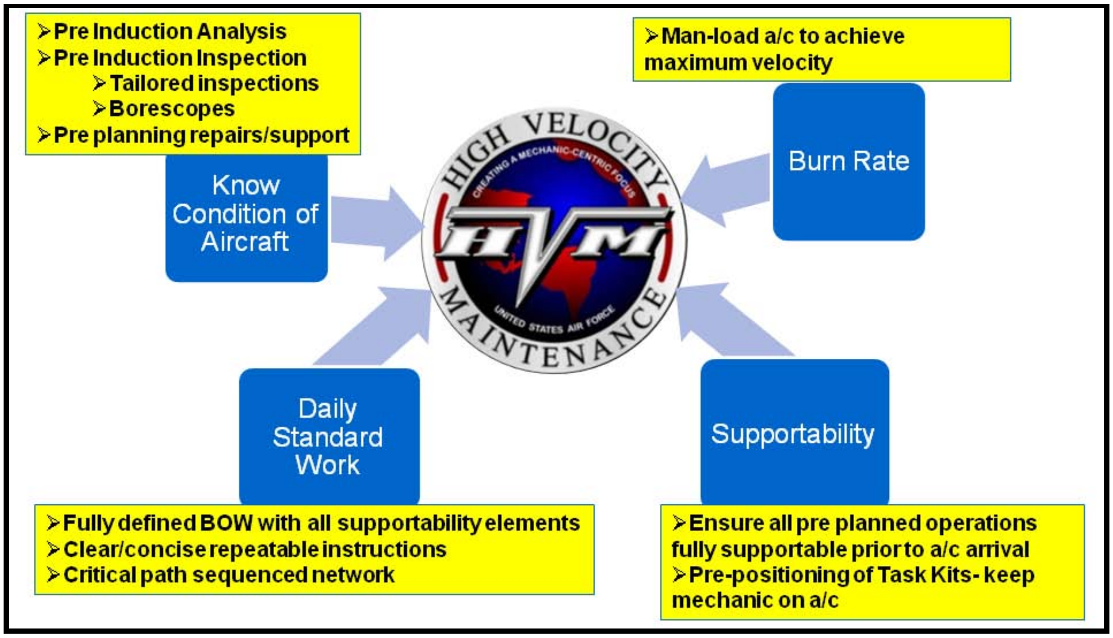

Figure 1 Tenets of HVM (Mobley, 2012)

The current scheduled depot maintenance intervals for all C-130 variants range from as short as 54 months for MC-130E and AC-130H variants to as long as 69 months for C-130E, H, and J models. C-130 depot maintenance intervals are shown in detail in Figure 2. One of the original goals of HVM was to divide the standard PDM package into four segments and synchronize them with the existing C-130 Isochronal (ISO) inspection schedule. Under this plan, C-130s would visit the depot every 14-16 months instead of every 54-69 months, and the ISO inspections scheduled for those intervals would be conducted at the depot by depot maintenance personnel. Additionally, the standard depot maintenance work package would be divided up and done in segments along aircraft system lines (Llantada, Maj R., USAF, 2011).

Designation	Interval
WR-ALC Aircraft:	
C-130E/H (PACAF)	54
MC-130E, AC-130H	54
NC-130A, MC-130H, WC- 130H, MC-130P, AC-130U	60
LC-130H, HC-130N/P	69**/***
NC-130H, EC-130E, EC-130H, C-130E, C-130H	69***
C-130J, CC-130J, EC-130J, WC-130J	69***

Figure 2 C-130 PDM Schedule (United States Air Force, 2010)

Under this framework, the depot maintenance interval for any given component would remain the same; however, the aircraft would visit the depot more frequently. The WR-ALC HVM office believes that the ISO inspections could be accomplished during PDM with no additional man hours. This is due to the fact that the work package for an ISO is less rigorous than that of PDM and contains mostly inspection items that can be accomplished while the aircraft is already down for PDM. However, as of December 2011, that plan has been scrapped. AFMC is hesitant to make wholesale changes to the depot maintenance process based on a concept that is not yet proven to work for AF depot maintenance operations. The plan for the immediate future is to continue to put the tenets of HVM into place, allowing the benefits of improved known condition of aircraft, better supportability, daily standard work, and higher burn rate to increase aircraft throughput at the ALC. At this junction there are no plans to incorporate ISOs into PDM or to break PDM into 4 segments anytime in the near future, if ever (Mobley, 2011). Figure 3 contrasts the traditional scheduled maintenance intervals with the current state of C-130 PDM/HVM.

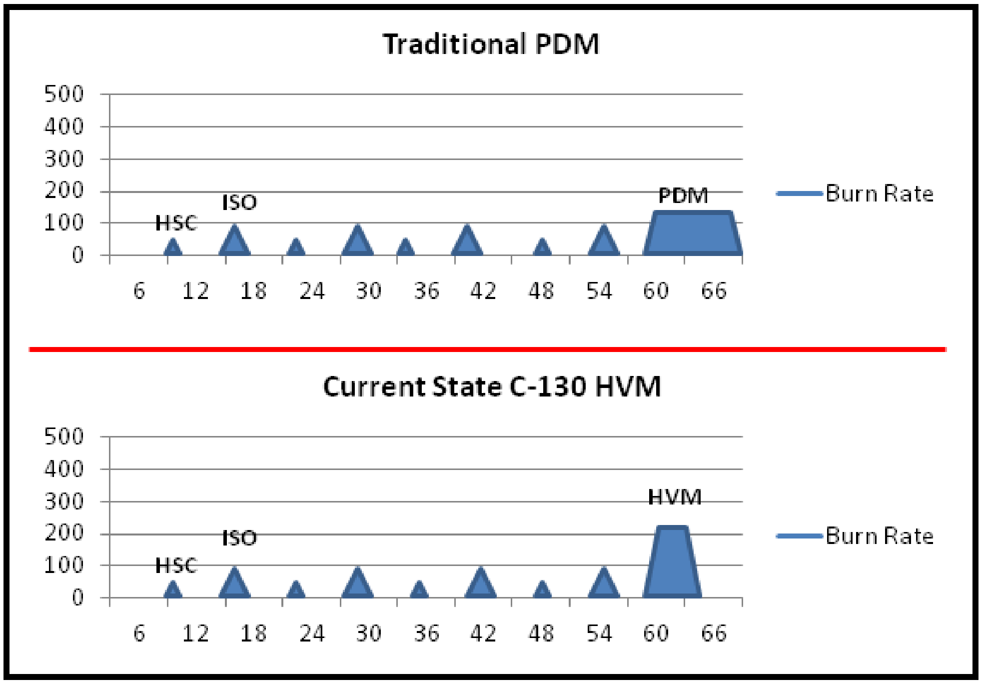

Figure 3 PDM to HVM Transition (Mobley, 2011)

Need for Improvements in Air Force Maintenance

Beyond the empirical evidence of low depot maintenance throughput rates and lower than required aircraft availability rates, there is evidence to suggest that improvements in maintenance practices are needed by the Air Force to control growing maintenance costs and that improving knowledge of an aircrafts condition can significantly improve maintenance and reliability performance.

A 2006 study by the RAND Corporation of maintenance costs for aging fleets suggest that as a general rule, maintenance costs per flight hour tend to increase over time as an aircraft ages. Their analysis of 10 previous aircraft aging studies showed 9 of the 10 studies indicated an increase in maintenance costs as aircraft age goes up. The results of their specific analysis are somewhat limited in generalizability because its focus was on the commercial airline sector which tends to operate fleets that have a much younger average age than USAF fleets. Nevertheless, their analysis showed that maintenance costs do in fact increase, especially for airframe maintenance, as an aircraft ages. However, their analysis does not support the assumption that maintenance costs continue to increase *rapidly* as aircraft age. As Figure 4 illustrates, costs tend to increase in a near-linear fashion over the first 25 years of an aircraft's life (Dixon, 2006). For refernce, the average age of Air Force C-130s is approximately 25 years (Llantada, 2011).

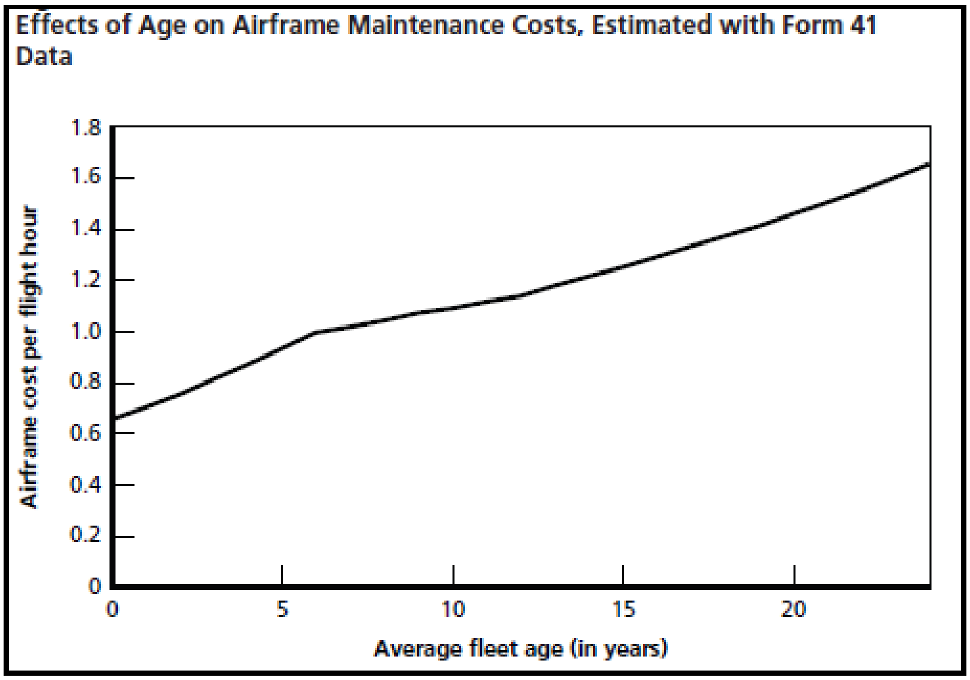

Figure 4 Maintenance Burden vs. Fleet Age (Dixon, 2006)

Analysis of more commercial airline maintenance data also indicates an increasing cost trend, adjusted for inflation, over the last decade. This effect compounds with the AF's aging fleet could indicate a continued increase in maintenance costs over the coming years. Figure 5 shows the increasing trend of maintenance costs per flight hour over the last 7 years indicated by one such commercial aviation study.

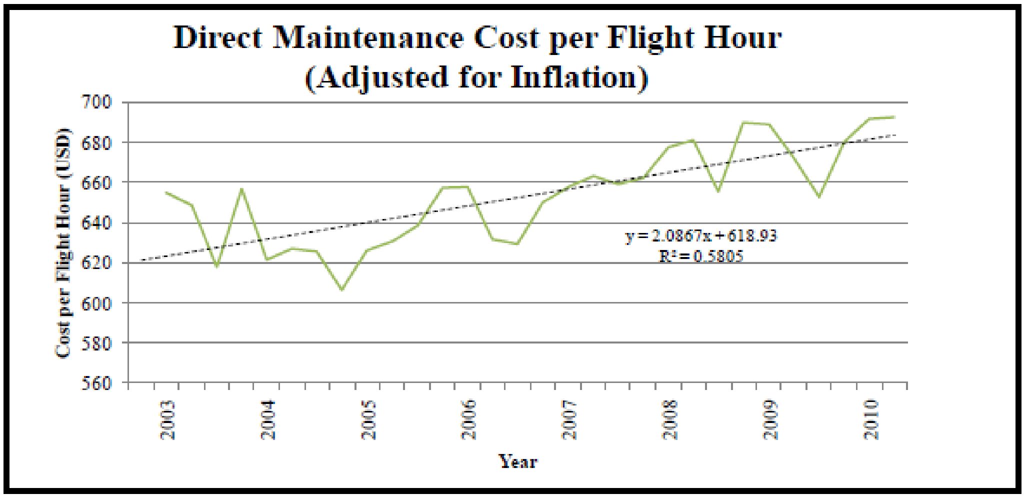

Figure 5 Maintenance Costs per Flight Hour (Dupuy, Wesely, & Jenkins, 2011)

Dupuy, Wesely, and Jenkins (2011) used a simulation approach to explore the trade-offs of different aircraft maintenance approaches. They compared three different maintenance approaches on the basis of two measureables:

1. Cost: measured by estimated costs for infrastructure, aircraft, and facilities
2. Performance: measured by number of parts needing replacement.

Approach 1: Preventative Maintenance – Parts are replaced on a schedule basis, based on expected life span, whether they have failed or not. Parts that fail before their expected life span is up will be replaced as well.

Approach 2: Condition-Based with on ground IT interface – Sensors on the board the aircraft detect faults that, when the aircraft land and the sensor data is downloaded by ground crews, indicate what needs to be replaced.

Approach 3: Condition-Based with in-flight IT interface – Sensors on board the aircraft detect faults that, while the aircraft is still flying, are transferred to ground crews. Parts are replaced when the plane lands.

A discrete event simulation analysis showed that the Condition-Based maintenance approach with on-ground IT interface had the highest overall value based on efficiency and total cost. In comparison, the preventative maintenance approach had a lower cost but worse performance while the in-flight transfer approach had a much higher cost, due mostly to additional IT infrastructure requirements, but only marginally higher performance (Dupuy, Wesely, & Jenkins, 2011). The top performing condition-based maintenance with on-ground fault notification is most similar to how the C-130 HVM approach is structured. Newer aircraft such as the B-1 and F-22 are equipped with more sophisticated Integrated Health Management sensors and, under this simulation, would be captured by the in-flight transfer approach.

With the Air Force's rapidly aging fleet of aircraft and the C-130 fleet averaging about 25 years old, maintenance costs fleet-wide are sure to continue to grow over time making improvements to the Air Force's scheduled maintenance program an absolute necessity in a budget constrained environment (Llantada, 2011). The HVM construct in place for C-130 depot maintenance at Warner Robins ALC is supported both in theory and by example as being both cost effective and efficient.

Maintenance Information Systems

Maintenance Information Systems (MIS) are systems in place to support the broader Air Force objective of Maintenance Data Documentation (MDD). The MDD process is in place to collect, store, and retrieve base-level, depot-level, and contractor-type maintenance data. This data is used to support the Air Force's equipment maintenance program, reliability and maintainability improvement program, and maintenance management system procedures (United States Air Force, 2009). Air Force Instruction (AFI) 21-101, Aircraft and Equipment Maintenance Management, defines Maintenance Information Systems as systems that "support and enable maintenance business processes. MIS will be used to document maintenance actions and determine fleet health." The Air Force maintains a plethora of MIS for use across various commands, airframes, and functional lines. Those that are most critical to the C-130 HVM process will be discussed here.

The newest MIS to go into widespread use is the Integrated Maintenance Data System (IMDS). IMDS is intended to be an Air Force enterprise-level automated maintenance management system for multiple weapon systems. IMDS automates aircraft history and provides a common interface for entering and retrieving base-level maintenance data for other logistics management systems. While not yet rolled out to all weapon systems, IMDS is in place and being used by field units using F-22, V-22, F-15, and C-130 aircraft as well as ballistic missile maintenance units. IMDS also interfaces with various other maintenance systems including the Logistics Composite Model (LCOM), Standard Base Supply System (SBSS), Reliability and Maintainability System (REMIS), Point-of-Maintenance (POMX) infrastructure, and others (Nance, 2011).

IMDS has also incorporated several other older/legacy maintenance functions into its sub-systems. Time Compliance Technical Orders (TCTOs) for example can now be totally managed within IMDS for supported weapon systems. The same is true for AFTO Form 781s A, J, and K (Nance, 2011). Ultimately, IMDS is intended to become the sole MIS that field units use to record maintenance actions for supported weapon systems. In this role it replaces legacy systems such as the Core Automated Mainteanance System (CAMS) and G081 (CAMS for Mobility) (Nance, 2011).

While IMDS is the primary field-level operating MIS it is not the only source for enterprise level maintenance data. The REMIS (G099) system is designed to "accumulate data and provide information necessary to support the AF equipment maintenance program outlined in AFI 21-101. REMIS will provide accurate, near real-time data accessibility to all levels of management" (United States Air Force, 2009). REMIS is considered the authoritative data source for maintenance data Air Force-wide. The ALCs use REMIS to retrieve aircraft maintenance data to facillitate depot maintenance scheduling (Cain, 2011).

There are several other sources of MDD that have proven critical to implementing HVM. Although not MIS in their own right, these forms of documentation provide information that is vital to achieving a true known condition of an aircraft.

<u>Form 107 Technical Assistance Request:</u> A Form 107 Technical Assistance Request is filed by a field unit as an official request for assistance from the aircraft's system program office. This occours when a needed repair is outside the scope of what is covered in the aircraft's maintenance documentation. Upon receiving the request, engineers from the program office attempt to diagnose the problem and provide guidance on an appropriate repair that can be conducted at the field level. The repair may be a permanent fix, but it also may be a temporary one that is just enough to allow the aircraft to fly to a better equiped repair facility for further repairs. Because of the non-standard nature of these repairs, maintaining the Form 107s is vital to understanding the true nature of the state of the aircraft. While the repair taken will be documented in IMDS (or

the appropriate MIS), the specific engineering guidance given is only maintained within the Form 107 itself (Hill, 2011).

Form 202 Technical Assistance Request: Simlar to a Form 107, the Form 202 Technical Assistance Request is a request for engineering help from the system program office. However, the Form 202 originates at the depot rather than the field level. Form 202s are initiated when the need for a repair is discovered while the aircraft is undergoing depot maintenance. The engineering guidance given is the same as it would be with a Form 107, but because the depot maintainers do not use IMDS to record maintenance actions, recording the action taken where field users can view it has proven to be somewhat problematic (Hill, 2011).

Time Compliance Technical Order (TCTO): TCTOs are used to document all permanent modifications, update changes and retrofit changes to standard Air Force weapon systems (United States Air Force, 2010). The TCTO reporting system that is integrated into IMDS is used by field unit maintainers to assess the status of TCTOs against an aircraft. Through this reconciliation process TCTOs can be scheduled and incorporated into the base-level maintenance program or deferred until the aircraft visits the depot and accomplished there. However, because some TCTOs can involve significant repair or modification to the aircraft and as such can only be accomplished at depot or in a depot-level repair environment, knowledge and planning of these needs is critical to achieving on-time delivery for depot mainteance planners (Ethridge, 2012). At the enterprise level, TCTO management and tracking is accomplished via REMIS (United States Air Force, 2009).

Logistics Transformation

In recent years the Air Force has attempted to streamline its information system jungle by devoloping an ERP system, the Expeditionary Combat Support System (ECSS). ECSS is intended to consolidate and/or link every aspect of Air Force logistics and supply chain management into one single software solution (Computer Sciences Corporation, 2010). When implemented, ECSS will provide the Air Force with a standardized logistics operating picture through a single source of data. The Air Force logistics community will hopefully be able to decrease costs, increase effectiveness, and ultimately improve support of warfighters everywhere (United States Air Force, 2012). ECSS is being designed to provide new or improved capabilities in the following areas (United States Air Force, 2009):

- Advanced Planning & Scheduling
- Bills of Materials
- Budgeting
- Customer Relationship Management/Order Management
- Decision Support
- Distribution and Transportation
- Document Management
- Facilities Management
- Maintenance, Repair, and Overhaul
- Material Management & Logistics Financials
- Product Lifecycle Management

- Quality Control

However, ERP adoption is hardly an easy undertaking. Less than 10% of companies that attempt an an ERP changeover complete the process on-time, within-budget, and with measurable benefits delivered (Hamilton, 2007). Unsurprisingly, the Air Force's development of ECSS has been plagued with numerous setbacks and cost overruns. In fact there are doubts, even at senior Air Force levels, that the system will ever come to fruition (Shephard Group Limited, 2012).

Fortunately, the future of Air Force logistics transformation does not rest soely on the success or failure of ECSS as an IT interface. ECSS (as well as HVM) is just a part of the Air Force's Expeditionary Logistics for the 21st Century initiative, eLog21. eLog21 is a transformation strategy that aims to change logistics processes and IT systems Air Force wide. The goal of the eLog21 program is to ultimately increase equipment availability and reduce operations and support cost (United States Air Force). eLog21 is being implimented through multiple strategic initiatives, intended to provide eight end-state capabilities to improve warfighter support (United States Air Force, 2010).

1. Air Force-Wide Logistics Planning
2. Optimized Resources
3. Optimized Repair Planning
4. Total Asset Visability
5. Logistics Netcentricity
6. Data Accuracy
7. Centralized Asset Management

8. Preditive Maintenance

As part of eLog21, the System Lifecycle Management Program (SLIM) exists to bring together various process improvement activities from an enterprise viewpoint. SLIM's goal is to standardize and improve upon processes that monitor and assess weapon system performance with the intent of facilitating proactive weapon system management throughout the entire system's life cycle. The SLIM framework includes numerous pieces that add to the aircraft health picture including maintenance data collection, condition monitoring, reliability-centered maintenance, condition-based maintenance, and prognostics. SLIM is not intended to directly implement new tools or processes for data collectio/storage, only to identify and define requirements for IT system interfaces for legacy systems, ECSS, and other enterprise-level processes. Figure 6 depicts the Air Force Logistics Transformation program structure (Ovalles, 2010).

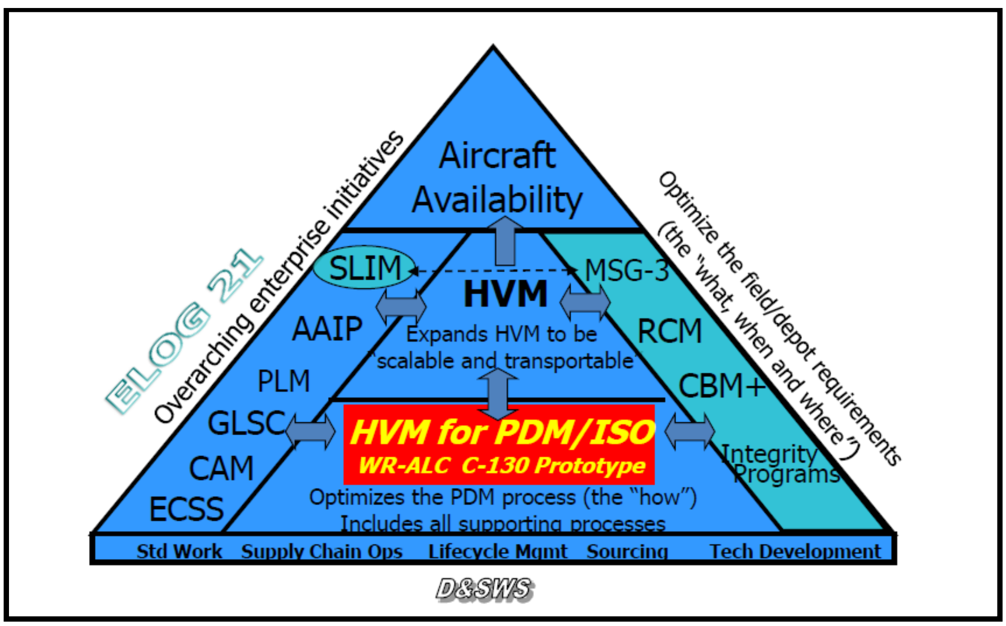

Figure 6 Air Force Logistics Transformation (Ovalles, 2010)

Work Unit Codes

Work Unit Codes (WUCs) are five-digit codes that are used to identify a system, subsystem, or component on which some maintenance action is required or has been accomplished (Servidio, 2008). WUCs are intended to provide a standard method for sorting maintenance data (United States Air Force, 2009).

The first two characters of the WUC identify the end item of equipment and are tailored to each weapon system. These system codes identify functional systems such a flight controls, airframe, fuel system, or powerplant, etc. Figure 7 is an example of a few sample two-digit work unit codes and the primary aircraft systems they represent.

45	Hydraulic systems	Hydraulic pressure sources, their associated control, regulating devices, indicating and warning instrumentation.
46	Fuel systems	Internal and external tanks, refueling and defueling equipment, distribution systems and associated instrumentation.
47	Oxygen systems	Installed equipment for the storage, servicing and distribution of breathing oxygen for the crew and passengers.

Figure 7 Example WUC System Codes (U.S. Department of Defense, 1992)

The third and fourth characters of the WUC indentify subsystems or major assemblies while the fifth character normally indentifies a reparable item, although there are exceptions (United States Air Force, 2009).

These codes are used in all notable maintenance data documentation systems to organize, catalogue, and sort maintenance data. There are used extensively in reliability and maintainability analysis, allowing weapon system program office engineers to track failures rates over time of specific components or systems and adjust maintenance or replacement intervals accordingly.

Summary

Increasing maintenance costs and low aircraft availability for use in contingency operations are driving the need to improve Air Force depot level maintenance. HVM is a fundamental change in the way the Air Force conducts depot maintenance. It requires close coordination between ALC depot maintenance planners and the aircraft system program offices as well as detailed analysis of an aircraft's condition and a fully scripted plan for performing maintenance actions once the aircraft arrives. To date, the C-130 depot maintenance line at Warner Robins ALC has implemented much of the HVM framework and is trying to improve on-time delivery of aircraft through careful planning and analysis and improved worker burn rate. Various maintenance information systems and the work unit codes feed them are of great use to depot maintenance planners in the pursuit of achieving the goals of HVM.

III. Methodology

Chapter Overview

The purpose of this chapter is to discuss the methodology employed in this research study, the scope of the research, the specific questions that this research attempts to answer, and the assumptions and limitations by which this research has been bound.

Research Design

Research design is a crucial element for the successful outcome of any research venture. When seeking to choose the correct research design for a study it is important to consider three items (Boley, 1997):

1. What is the research question being asked?
2. What scope of control over events is necessary?
3. What is the context of the topic being studied?

Dr. Robert Yin identifies a framework for selecting research design in *Case Study Research: Design and Methods* based on these three questions.

Strategy	Form of Research Question	Requires Control of Behavioral Events?	Focuses on Contemporary Events?
Experiment	how, why?	Yes	Yes
Survey	who, what, where, how many, how much?	No	Yes
Archival analysis	who, what, where, how many, how much?	No	Yes/No
History	how, why?	No	No
Case study	how, why?	No	Yes

Figure 8 Design of Experiment (Yin, 2003)

Form of Research Question: The focus of this research is to identify how maintenance information systems and work unit cods are being used to facilitate the flow of aircraft through the programmed depot maintenance and high velocity maintenance process at Warner Robins Air Logistics Center. These are chiefly “how” and “why” questions, ruling out Survey and Archival Analysis as research strategies.

Control of Behavioral Events: This research is interested in exploring actions that are already in place and seeing how current processes are taking place. As an outsider in the HVM process, this researcher has no control over any events. Thus, the Experimental research strategy is ruled out.

Focus on Contemporary Events: While historical events have certainly had an impact on the way that the Air Force does maintenance, including the new HVM initiatives, this research is concerned with the contemporary events of how HVM is being accomplished, not with the historical conditions that lead to its creation. This focus on contemporary events means that History is eliminated as a research strategy.

The remaining available research strategy is that of the case study. A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2003). For this research, the contemporary phenomenon is the C-130 HVM program and its context is the way the Air Force plans and conducts depot maintenance. A research framework, based on the High-Velocity Maintenance construct developed by the Warner Robins Air Logistics Center team, is presented in Figure 9.

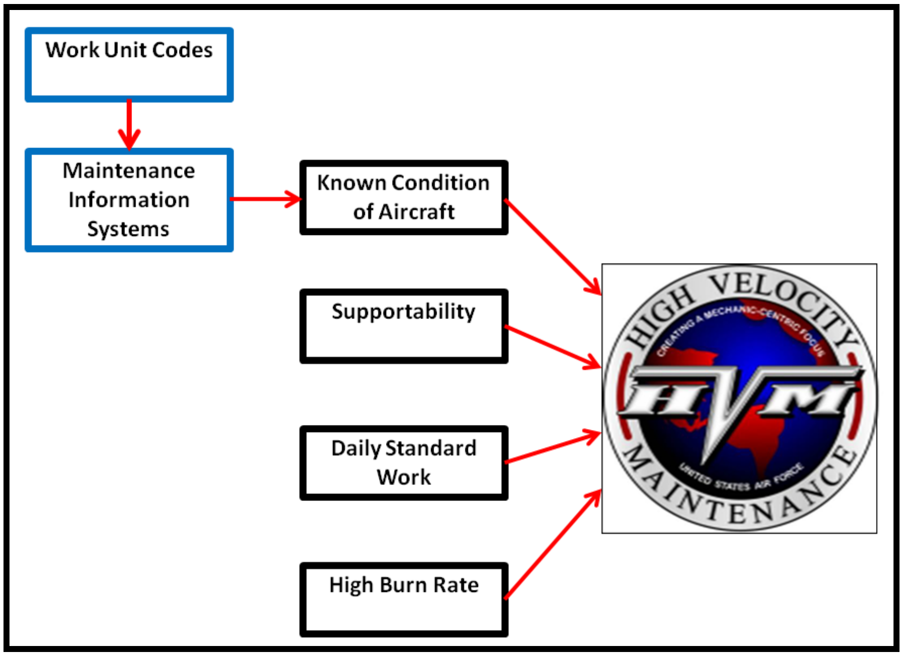

Figure 9 Research Framework

Research Instruments

In case study research, data can be found in a variety of sources. Yin introduces six important sources of research data in *Case Study Research: Design and Methods* (Yin, 2003).

1. Documentation
2. Archival Records
3. Interviews
4. Direct Observations
5. Participant Observation
6. Physical Artifacts

This research uses a combination of documentation, archival records, interviews, and direct observations in order to achieve the stated research goals.

- The documentation and archival records reviewed were from a variety of sources including Air Force Instructions and Technical Orders as well as documents produced as part of or relating to the HVM process. Aircraft maintenance data as well as aircraft condition reports prepared as part of the HVM process were used for analysis.
- Informational interviews were conducted with AFMC representatives from the High Velocity Maintenance office at Wright-Patterson AFB as well the C-130 HVM office at Warner Robins Air Logistics Center in order to seek factual observations of undocumented processes and to clarify existing knowledge on the topic. These interviews were largely semi-structured, with the line of questioning based on the area of expertise and experience of the interviewee. A total of 5 interviews were conducted as part of this research.
- Direct observation was used to document an aircraft inspection that was taking place as part of the HVM process that takes place before an aircraft arrives at depot. This particular aircraft being inspected was a MC-130H located at Hurlbert Field, FL.

In combination, these sources of data are used to form a strong case for the research objectives. The information gleaned using these research instruments was compiled and cross-referenced in order to build a complete picture of maintenance information system and work unit code usage in the HVM process.

Research Question Review

The goal of this research is to identify and explore the ways in which Maintenance Information Systems and Work Unit Codes facilitate the flow of an aircraft through the schedule maintenance process. Pursuant to that goal, the following research questions were identified:

- Research Question #1: How do Maintenance Information Systems capture maintenance data that is relevant to the PDM/HVM process?
- Research Question #2: How are Work Unit Codes captured and used in Maintenance Information Systems?
- Research Question #3: Who are the users and customers of relevant Maintenance Information Systems?
- Research Question #4: How are Maintenance Information Systems used to manage aircraft flow through the PDM/HVM process?
- Research Question #5: How can the integration between different Maintenance Information Systems be improved to facilitate HVM?

Scope, Assumptions, and Limitations

This research will primarily be limited to the C-130 depot maintenance process for several reasons. The C-130 was the first aircraft to undergo the transformation from traditional Programmed Depot Maintenance to High-Velocity Maintenance, and thus is a much more mature product, in the HVM sense, than any other aircraft. Many of the processes that are considered crucial to making HVM work have already been implemented in the C-130 program, therefore making it the ideal candidate for ongoing study and research. While numerous other weapon systems are currently pursuing or implementing programs that incorporate many of the same elements as High-Velocity Maintenance (such as Maintenance Steering Group-3 on the C-5), the C-130 community is so far the only weapon system to have fully implemented most of the planned processes and is beginning to see the benefits take effect.

Summary

This research is a case study experimental design designed to focus on the contemporary events of the Air Force's High Velocity Maintenance process for aircraft depot maintenance. The goal of this research is to identify and explore the ways in which Maintenance Information Systems and Work Unit Codes facilitate the flow of an aircraft through the depot maintenance process. This research uses a combination of documentation, archival records, interviews, and direct observations in order to achieve the stated research goals. This research will be limited in scope to the C-130 depot maintenance process in place at the Warner Robins Air Logistics Center.

IV. Results

Chapter Overview

The purpose of this chapter is to discuss the research findings that were discovered during the case study investigation that was described in Chapter III. The findings are separated functionally, in the same way that the data is used in real world applications. The process of implementing HVM for C-130s at Warner Robins Air Logistics Center relies heavily on the analysis of maintenance data documentation. This information is sorted, consolidated, and used in two related but distinct areas: the analysis and summarizing of an aircraft's maintenance condition prior to induction into depot, the Pre-Analysis Assessment (PAA), and a physical inspection and report of an aircraft's condition prior to induction into depot, the Pre-Induction Inspection (PII).

The PAA process at Warner Robins, completed by personnel from the C-130 system program office and depot maintenance planners, takes about a week long to go from raw data to a finished report usable for PDM planning. The PII process takes approximately another week to complete, and cannot begin until the PAA process is finished. For fiscal year 2012, Warner Robins has 39 C-130s scheduled to undergo PDM.

Pre-Analysis Assessment

The pre-analysis assessment is a report created by the Warner Robins ALC depot maintenance team that contains all significant maintenance actions and aircraft modifications that have occurred on an aircraft since its last depot maintenance cycle. This report is referred to by several different names including pre-analysis assessment and pre-induction analysis report (PAR), but all refer to the same method of scouring available maintenance data and the distillation of it into a report that will be useful to depot maintenance planners in their efforts to achieve a known condition of an aircraft before it arrives at the depot. The pre-analysis assessment report is used for three purposes (Mobley, Chief, C-130 HVM Office, Warner Robins ALC, 2011):

1. To identify recurring problems on a particular MDS
2. To identify potential problem areas on a specific tail number and tailor an aircraft inspection to hit those areas
3. Identify MDS trends that could drive changes to the PDM work package

Because this report covers all aircraft systems and is compiled using data from various Maintenance Information Systems, work unit codes are crucial to breaking down the maintenance data into a useable report. An individual C-130 aircraft may acquire as many as 15,000-25,000 individual maintenance action entries in IMDS over the ~60 months between visits to the ALC for depot maintenance. In order to reduce the amount data that ALC personnel have to scour through in the search for significant maintenance items, the Warner Robins C-130 HVM team has come up with a data-mining software tool that parses the maintenance data and pulls out line items that are unlikely to include data that is relevant to depot maintenance planners. This leaves a much more manageable 1,000-3,000 maintenance line items for HVM personnel to sort through. This ALC-devised software solution is undergoing the process to be patented by the Air Force and thus cannot be discussed in detail here due to the wide releasability of this research (Hill, 2011, Cain, 2011).

While field-units use IMDS exclusively for the documentation of maintenance actions, this systems is not in use at the depot. ALC personnel instead retrieve field-level maintenance data from the Reliability and Maintainability System, REMIS, or the Special Operations Forces Reliability and Maintainability System, A400, for use in the pre-analysis assessment. Once the data has been retrieved and pared down using their custom tool, engineers from the C-130 system program office take over to read and evaluate the remaining 1,000-3,000 lines of maintenance data to search for significant events (Cain, 2011). This engineering analysis is a crucial process because it takes the expertise of someone familiar with the C-130 aircraft to evaluate whether items listed in the aircraft's maintenance history could impact the PDM schedule or not. Items that are considered not significant are discarded, while items that could impact PDM are marked for inclusion in the pre-analysis assessment report (Hill, 2011).

As the significant maintenance action items, ones that could affect the PDM schedule, are separated from the insignificant items, each one is evaluated to come up with a PDM risk assessment that will go into the pre-analysis report. This risk assessment is based off of the MIL-STD-882 hazard risk index matrix but is adapted to evaluate the possible PDM impacts for the various aircraft systems and subsystems. The resulting PDM risk matrix (see Figure 10) is used to evaluate all such potential problem areas as indicated by the maintenance data analysis. Items that are considered likely to be an issue and also would likely cause a time delay in the PDM schedule are rated "High." Items not likely to be an issue and not likely to cause a PDM delay are rated "Low" (Ethridge, 2012).

	Probability of Failure		
PDM Schd Impact	High	Med	Low
High			
Med			
Low			

Figure 10 PDM Risk Matrix (KIHOMAC, Inc., 2011)

As each of the potential problem maintenance items is assessed for PDM risk, they are also sorted by work unit code into their individual aircraft systems and subsystems. This allows a complete picture of an aircrafts health to be presented in a visual format. Figure 11 depicts the final report produced for a C-130H aircraft, with all of the potential maintenance issues from IMDS (as pulled from the A400 maintenance information system) identified by 2-digit work unit code. This example report identifies 12 potential PDM delays; 7 in airframe, 4 in flight controls, and 1 in fuel system, none rated higher than a low-medium risk to PDM.

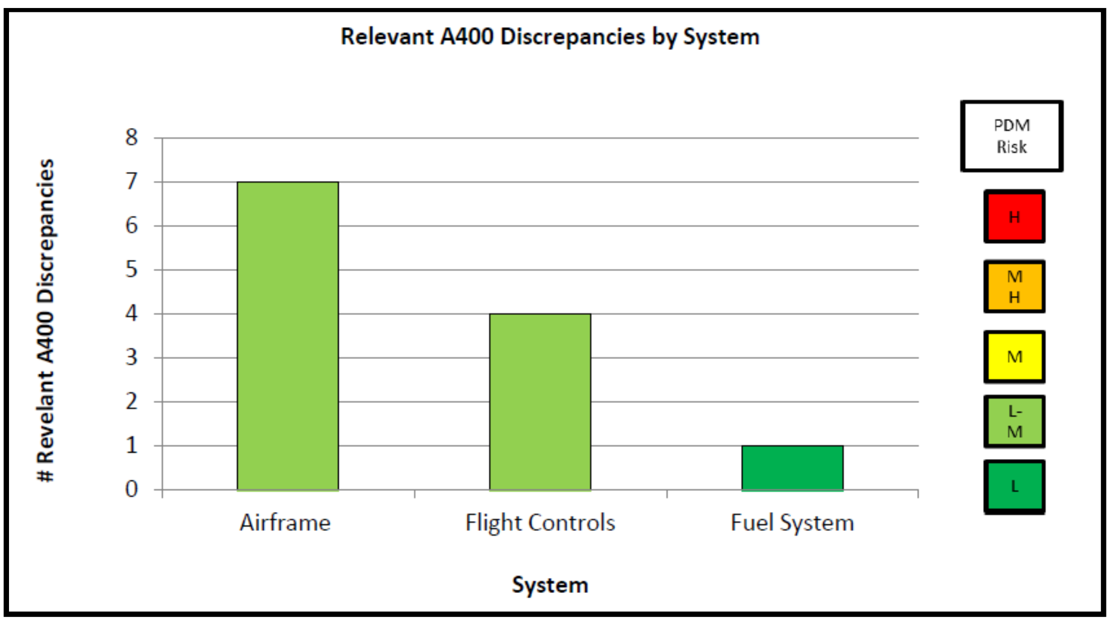

Figure 11 Relevant A400 Discrepancies by System (KIHOMAC, Inc., 2011)

To complete the pre-analysis assessment phase and produce the final report, this level of maintenance data analysis is conducted for maintenance data documentation from 4 sources. Visual depictions similar to Figure 11 will are included in the final pre-analysis assessment report summarizing the findings from each source of maintenance data (KIHOMAC, Inc., 2011). The 4 sources of PAA data are:

1. IMDS maintenance data
2. Field-level Technical Assistance Request (Form 107) data
3. Depot-level Technical Assistance Request (Form 202) data
4. Maintenance Work Request (MWR) data from the ALC's PDM/SS interface

At Warner Robins, this maintenance data is pulled from several different sources. As mentioned previously, the field-level IMDS maintenance data for C-130s comes from either REMIS or the Special Ops-oriented A400 system. Technical Assistance Requests, Form 107s and 202s, are pulled from a maintenance information system called AirCat, an ALC-specific system. Maintenance Work Requests, add-ons to the standard PDM work package, can be retrieved from the ALC's PDM scheduling system, PDM/SS. Maintenance Work Requests include Form 103s, which are field-level maintenance actions that have been deferred to be completed at depot.

When it comes to predicting what maintenance issues might present extra difficulty in PDM, the most critical information is usually derived from the Form 107 and Form 202 Technical Assistance Requests. These requests exist purely because the maintenance issue they cover is a non-standard repair that is beyond the scope of regular field-level maintenance. It is these non-standard repairs that often present the most difficulty in PDM, as the repaired area may require additional depot-level work to make the repair permanent or to improve the existing repair. And because these additional repairs are outside of the scope of the standard PDM package, they can often cause delays in returning an aircraft to the field on time (Hill, 2011). Figure 12 depicts a technical assistance request noted as a potential medium-high PDM risk in the final pre-analysis assessment report. This is a repair that depot maintenance planners will look at closely to evaluate for potential issues. This area will also be looked at during the pre-induction inspection phase.

TAR #	Sys WUC	Sys	Comp WUC	Comp	Discrepancy (TARs)	Disposition	Analysis	ACI	Pre-ACI PDM Risk	Post-ACI PDM Risk	Recomm
2010-02009	11000	Airframe	11270	LH MLG POD SKIN	Our NDI technician has confirmed that all but three stiffeners are cracked on the LH FWD MLG pod skins (3 total panels P/N 389878 - 123,-127,-129, please see attachment). Request guidance on repair or to replace panels, or fly as is until next scheduled PDM.	Stop-drill the cracks with a #10 drill bit and corrosion seal IAW TOs 1C-130A-3 and 1-1-691. Annotate this temp repair in the aircraft forms. To properly stop-drill the cracks, it may be necessary to remove the Hi-Lok and some spot - welds to place a protective plate between the cracked part and the skin. Replace all drilled out spot-welds with monel rivets.	Found three crack stiffeners in the LH Fwd MLG pod skins requiring replacement at PDM.	Request evaluation and permanent repair during next PDM.	Med-High	TBD	Pending ACI

Figure 12 PAA Discrepancy Detail Example (KIHOMAC, Inc., 2011)

Another important pre-analysis assessment task is the reviewing of outstanding Time Compliance Technical Orders for each aircraft. TCTOs that have not been completed by field level maintenance units can be added on to the depot maintenance work package to be completed during PDM. Reviewing these discrepancies in advance allows depot maintenance planners to ensure that the required material and equipment is provided to depot maintainers to accomplish the additional repairs/modifications.

The pre-analysis assessment is intended to be completed for every aircraft prior to depot induction. This is possible because it is accomplished in-house at the ALC. However, because of budgetary restrictions, the next phase, the pre-induction inspection, is only done as funds are available (Hill, 2011).

Pre-Induction Inspection

The pre-induction inspection program was developed by the Warner Robins C-130 HVM team as a follow-up measure to the pre-analysis assessment discussed in the previous section. Pre-induction inspection is a targeted physical and non-destructive inspection of an aircraft that occurs 6-9 months before its scheduled induction into depot maintenance. The PII program is essentially an expansion of the existing Analytical Condition Inspection (ACI) program that is mandated by TO 00-25-4, Depot Maintenance of Aerospace Vehicles and Training Equipment. ACIs are in-depth physical condition inspections that are required to be accomplished on a representative sample of MDS aircraft in order to uncover hidden defects that are not detectable through normal inspection programs. For C-130 variants, an ACI sample size of 10-11% of the fleet is required during the depot maintenance cycle (United States Air Force, 2010). The pre-induction inspection program essentially takes this to the next level.

The goal for the PII program is to inspect as many aircraft prior to their induction into depot as possible. This comes down to a funding issue, as currently PII is funded by the ALC's maintenance organization and is conducted by a government contractor. The contracted company, currently Intergraph Government Solutions, sub-contracts with KIHOMAC, Inc. who hires workers skilled in C-130 maintenance and repair to conduct the inspection in the field. This setup allows for inspections to be conducted by qualified personnel whenever funds are available, without impacting the ability of the ALC maintenance organization to operate at peak efficiency since they aren't giving up any personnel to go conduct an outside inspection (Mobley, Chief, C-130 HVM Office, Warner Robins ALC, 2011).

Since the pre-induction inspection involves looking at areas not normally touched during routine field maintenance, the inspection can be conducted much faster when an aircraft is already in a hanger and de-paneled for a scheduled inspection. For that reason, whenever possible, the pre-induction inspection is scheduled to synchronize with a Home Station Check or Isochronal inspection. Synchronizing the inspection significantly decreases the burden on the aircraft's home maintenance unit for preparation and also ensures that the required support equipment is available and in place (Ethridge, 2012).

There are two parts to the pre-induction inspection. The first involves a pre-planned work package consisting of 94 inspection items. These 94 items are inspected on every C-130 aircraft, regardless of condition or aircraft history. This work package is custom designed for the PII process and was developed by the C-130 HVM team at Warner Robins ALC. It includes looking at areas that have traditionally been surprises during PDM and also areas that have been problem areas on the MDS. Examples include using a non-destructive borescope to look under the floor panels in the cargo compartment and inside the wing flaps for corrosion; areas where if problems are discovered unexpectedly during PDM, significant delays could result (Ethridge, 2012).

Figure 13 depicts a sample page from the PII work package that indicates the area of the aircraft to be examined and the method by which to examine it.

Insert 4mm video scope into drain holes of forward fuselage in NLG wheel well. Inspect for cracks, corrosion, loose or missing fasteners and general condition. (Reference Figure 2)

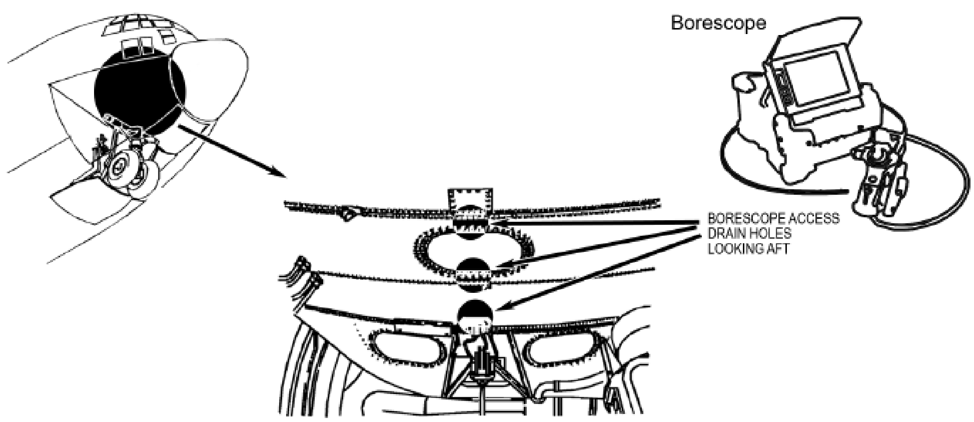

Fig 2. NLG Wheel Well Borescope Access

Figure 13 Sample PII Work Card

The second part of the pre-induction inspection involves tailoring a series of inspections to look at the potential problem areas highlighted in the pre-analysis assessment. Each item discussed in the pre-analysis assessment report, or Pre-Induction Analysis Report, is followed up in this inspection. PII personnel inspect each potential problem area and update the original pre-analysis assessment with actual findings and recommendations to mitigate any potential impacts to the PDM schedule (Ethridge, 2012). The final pre-induction inspection report updates the assessed risk to PDM for each discrepancy. Figure 14 depicts same discrepancy noted in the pre-analysis assessment report from Figure 12, but here it has been updated with the results from the PII.

TAR #	Comp	Discrepancy (TARs)	Disposition	Analysis	ACI	Pre-ACI PDM Risk	Post-ACI PDM Risk	Recommendation /Comments
2010-02009	LT MLG POD SKIN	Our NDI technician has confirmed that all but three stiffeners are cracked on the LT FWD MLG pod skins (3 total panels P/N 389878 -123,-127,-129, please see attachment). Request guidance on repair or to replace panels, or fly as is until next scheduled PDM.	Stop-drill the cracks with a #10 drill bit and corrosion seal IAW TOs 1C-130A-3 and 1-1-691. Annotate this temp repair in the aircraft forms. To properly stop-drill the cracks, it may be necessary to remove the Hi-Lok and some spot -welds to place a protective plate between the cracked part and the skin. Replace all drilled out spot-welds with monel rivets.	Found three crack stiffeners in the LH Fwd MLG pod skins requiring replacement at PDM.	Request evaluation and permanent repair during next PDM.	Med	Low/ Med	Inspected LH fwd MLG pod and found 14 stiffeners with stop drilled cracks. Risk will be downgraded to low-med. This will be a 103 input for next PDM.

Figure 14 PII Discrepancy Follow-up Example (KIHOMAC, Inc., 2011)

The final PII report summarizes the initial findings noted in the pre-analysis phase and updates each item with the results of the physical inspection. The anticipated risk to the PDM schedule is also updated for each item based on the results of the physical aircraft inspection. Any new discrepancies or problem areas discovered during the PII are also noted and rated for PDM risk. The final report is then submitted to depot maintenance planners to aid them in the scheduling process for that particular aircraft.

HVM Process Outcomes

The first tenant of HVM is to achieve a known condition of the aircraft before it comes to depot for maintenance. The pre-analysis assessment and pre-induction inspection processes that have been implemented by the Warner Robins ALC C-130 HVM office are intended to achieve just that. Through a detailed analysis of existing maintenance data and a specific, targeted inspection of the aircraft, depot maintenance planners are able to achieve a strong knowledge of the true condition of an aircraft, months before its arrival at depot. This knowledge enables depot planners to ensure that 2 of the other HVM tenants, Daily Standard Work and Supportability, are achievable and planned for. Figure 15 shows an influence diagram that indicates how the PAA and PII reports feed into the depot maintenance planning and execution process.

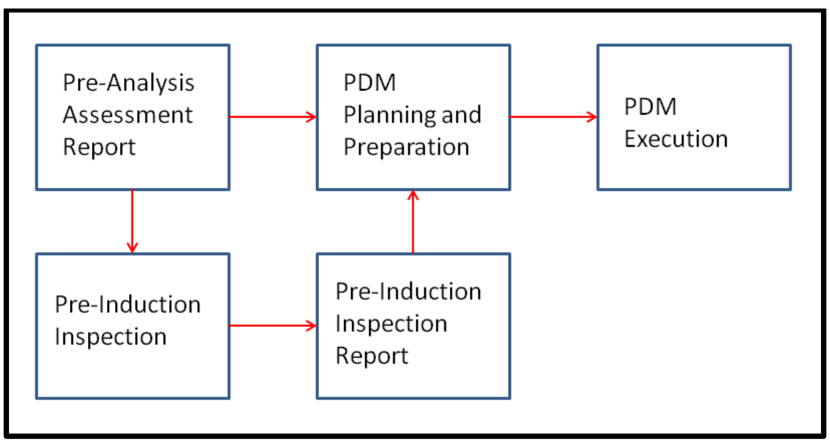

Figure 15 PAA & PII Influence Diagram

Since implementing the HVM tenets, Warner Robins ALC has been able to show significant improvements in C-130 PDM performance (Mobley, 2012):

- Work-in-Progress has been reduced by 30%
- Aircraft flow days have been reduced by 25%

- C-130 touch-labor rates have increased 75%

While the ultimate HVM goals for C-130 PDM remain far off, the progress made so far is encouraging. AFMC continues to explore ways to implement the HVM tenets across all three of its ALCs with the goal of improving depot maintenance on all weapon systems.

Flow of Information

Understanding the flow of information is as important to improving the PDM process as understanding the current state of the HVM process discussed in the previous section. While the HVM tenets may be exportable to other weapon systems, the particulars on information systems used and how the maintenance documentation is transformed and used will be unique. While the overall concept is the same, the particulars will differ across weapon systems.

The information flow for C-130s begins at the field level aircraft maintenance units. There, IMDS is used exclusively to document maintenance actions, manage TCTOs and deferred maintenance. All maintenance data documentation from IMDS is pulled into the Air Force's enterprise-level maintenance information system, REMIS. At the depot, information is retrieved from REMIS using the A400 Special Ops Reliability and Maintainability System. Other information, such as outstanding TCTOs and maintenance actions deferred to depot, flow to the PDM/SS system. AirCat is used to manage and view technical assistance requests from the field and the depot. All of these systems roll the information they supply, through the PAA and PII reports, into the PDM planning process along with the PDM requirements set forth by the Maintenance

Requirements Review Board (MRRB) process. The MRRB is an Air Force panel that assures all valid depot level maintenance requirements are evaluated and scheduled each fiscal year (United States Air Force, 2010). Figure 16 visually depicts this information flow for C-130 PDM.

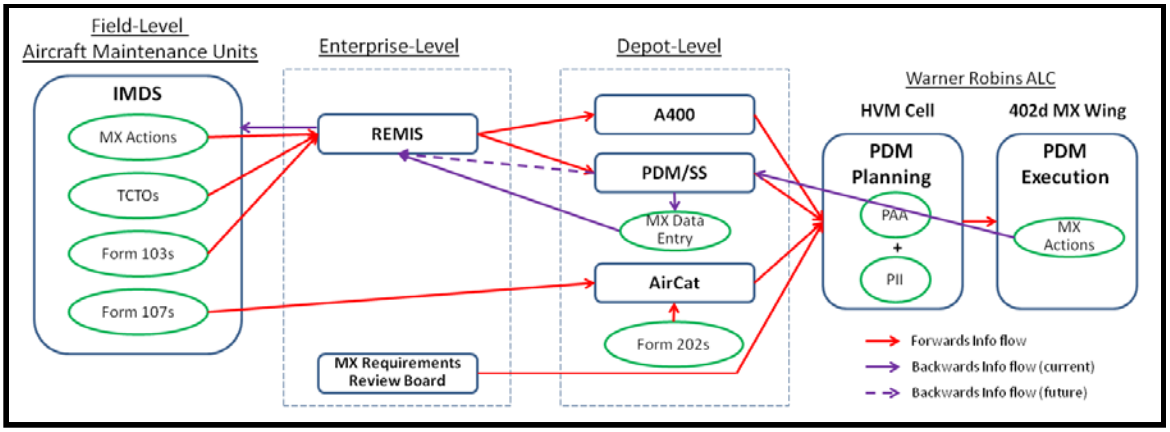

Figure 16 C-130 PDM Information Flow

It is worth noting that for maintenance actions taken during PDM, documentation is supposed to be input into REMIS where it is then accessible to field units when needed through IMDS (Hill, 2011). This is also shown in Figure 16. However, ensuring that documentation is completed when work is done has been a challenging for the ALCs. Currently, all maintenance work done during C-130 PDM at Warner Robins is given to data entry clerks to manually enter directly into REMIS. The Warner Robins HVM team hopes to have a new interface built that will allow the PDM work that is currently captured in PDM/SS to flow directly into REMIS autonomously. This will cut down on manpower costs for data entry and provide the needed visibility of aircraft condition to field-level maintenance units (Cain, 2012).

Summary

The idea of increasing PDM throughput by improving the knowledge of an aircraft's condition prior to its input into depot maintenance is one that is being enthusiastically pursued under HVM. To understand the condition of an aircraft, C-130 depot maintenance planners conduct two important reviews of all available maintenance data for an aircraft. The first review is a maintenance history and documentation review, the pre-analysis assessment, that looks at all available aircraft maintenance history and attempts to determine what items or areas could affect PDM. The second is a physical inspection of the aircraft, the pre-induction inspection, which looks at common problem areas as well as areas indicated as potential problems indicated in the pre-analysis assessment. Together, these reports create a powerful picture of aircraft health and condition that allow depot maintenance planners to much more accurately predict where problems will occur during PDM and to have the necessary parts on hand to make timely repairs.

V. Conclusions and Recommendations

Chapter Overview

The purpose of this research was to identify and explore the ways in which Maintenance Information Systems and Work Unit Codes facilitate the flow of an aircraft through the schedule maintenance process. This chapter will answer the research questions posed in the first chapter, discuss any remaining unanswered questions, and indicate areas for future research.

Conclusions of Research

It is not yet apparent what the future for expanded HVM operations across the Air Force's three Air Logistics Centers will look like, however at Warner Robins ALC, the use of HVM in the C-130 PDM line has shown improvement in reducing work-in-progress inventory and aircraft service times as well as in increasing burn rates (Mobley, 2012). Even if the full HVM process is not incorporated into other weapon systems, some elements of the HVM process can certainly be introduced to drive improvements in depot level maintenance. The collaboration and cooperation between depot maintenance planners and the weapon system program office that HVM has brought about in the C-130 community has lead to improvements in maintaining a working knowledge of an aircraft's condition. This has improved the amount of information available for reliability and maintainability analysis by the weapon system program office and for PDM planning by depot maintenance personnel.

Based on this research effort, the following relevant maintenance data is captured during the HVM process:

- Maintenance actions recorded in IMDS within the last depot cycle
- Non-standard field repairs aided by Technical Assistance Request within the last depot cycle
- Non-standard depot repairs aided by Technical Assistance Request within the last depot cycle
- Add-on Maintenance Work Requests processed in PDM/SS as part of the current depot cycle

These pieces of maintenance documentation form the basis for providing an aircraft condition report that is specifically useful in planning for and performing depot maintenance.

Answers to Research Questions

Research Question #1: How do Maintenance Information Systems capture maintenance data that is relevant to the PDM/HVM process? Despite the new processes brought about under High Velocity Maintenance and the availability of modern information technology, the critical work of maintenance data documentation still relies on aircraft maintenance airmen and civilians properly inputting maintenance actions into the appropriate information system. At the field level IMDS is used to input all maintenance actions as well as manage Time Compliance Technical Orders, TCTOs. Particularly in IMDS, the timely and accurate recording of maintenance actions along with the work unit codes of the systems and subsystems being worked on allow for the HVM process to proceed. At the depot level, this information is dissected in a time consuming process that requires an analyst that is experienced in C-130 maintenance procedures and operations to identify the truly relevant data.

Research Question #2: How are Work Unit Codes captured and used in Maintenance Information Systems? Work unit codes are utilized in every relevant maintenance information system as part of both repair tracking and for reliability and maintainability analysis. Each weapon system has its own set of work unit codes that can be referenced in the respective "Work Unit Code Manual." Field-level maintainers use these codes when inputting maintenance actions taken. Following the manual when referencing those repairs and maintenance actions allows system program office engineers and depot maintenance planners to understand and interpret the information that field level maintainers have input.

Research Question #3: Who are the users and customers of relevant Maintenance Information Systems? For most maintenance information systems, the users are the field-level maintenance units that are inputting maintenance actions and repairs. The aircraft's system program office engineers and depot maintenance planners can be considered the customers, since they are the primary users of the *outputs* from these systems. Figure 17 shows a brief breakdown of field maintenance systems versus depot systems and the way information is exchanged between them. Figure 16 in Chapter IV presents a more detailed view of the information flow.

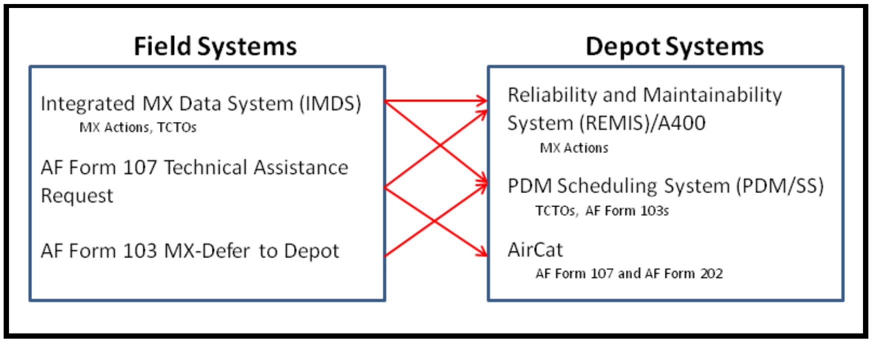

Figure 17 Field vs. Depot Maintenance Information Systems

Research Question #4: How are Maintenance Information Systems used to manage aircraft flow through the PDM/HVM process? The pre-analysis assessment and the pre-induction inspection discussed in detail in Chapter III are the key elements in managing aircraft flow through the HVM process. The pre-analysis assessment and pre-induction inspection create a detailed picture of the overall health of an aircraft well before it arrives at the depot. This gives depot planners enough time to fully script the PDM work package, tailoring it for a specific tail. It allows gives the ALC time to source any long lead-time parts and have appropriate spares on hand for when the aircraft arrives.

Research Question #5: How can the integration between different Maintenance Information Systems be improved to facilitate HVM? Currently, much of the aircraft maintenance information related to the PDM and HVM processes are available via just two systems: IMDS for the field-level users, and REMIS for the depot-level users. However, since the HVM processes of building a knowledgeable status of aircraft condition requires more than just basic maintenance data, access to other systems such as AirCat and PDM/SS is required. True integration of all of these systems is unlikely to occur short of an all-encompassing ERP software solution. It is possible that this could occur if ECSS is ever fully developed and fielded, but short of that it will continue to be a piecemeal process.

Answer to Problem Statement

"How are Maintenance Information Systems and Work Unit Codes used to facilitate the flow of aircraft through the PDM/HVM process?" The process that allows for HVM begins with field-level maintenance units. Each maintenance action taken by the field units on an aircraft are documented in IMDS using the work unit code for the system being worked on and a description of the action taken. Proper usage of work unit codes and accurate documentation of maintenance actions taken are absolutely vital to the maintenance data documentation process, especially as the march towards PDM progresses. IMDS feeds this maintenance documentation into the Air Force's enterprise maintenance information system, REMIS. From there it can be retrieved and reviewed, along with technical assistance requests and TCTOs, by depot maintenance planners and aircraft system program office personnel. This review process is tedious work that requires knowledgeable personnel that are familiar with both C-130 maintenance and depot operations, and who are capable of identifying potential problems within the maintenance data when they see them. Once all the available maintenance data has been pulled from the MIS, sorted by WUC, and evaluated for potential PDM impacts, the information is all put into a pre-analysis assessment report that will aid depot maintenance planners in scheduling the aircraft's PDM. This report identifies any system or subsystem on the aircraft that may need repairs outside the scope of the standard PDM work package. By performing this analysis early, 6-9 months before the aircraft is supposed to arrive at depot, gives the ALC time to procure any spare parts or equipment needed for repairs that are not already on hand. It also gives the ALC a chance to source repair items that are no longer being stocked and/or have very long lead times. This hopefully means the necessary parts will all be on hand when the aircraft arrives at depot a few months later. When funding is available from the depot's maintenance wing, an additional analysis phase can be performed: an inspection team is sent to do a follow-up physical evaluation of the aircraft in the field. This pre-induction inspection looks at both areas of the aircraft that are known to be problem areas on the MDS and also any area indicated as a potential problem in the PAA report. The results from this inspection provides another layer of information that will aid depot maintenance planners in making sure the Supportability, Daily Standard Work, and High Burn Rate tenets of HVM are planned for and achievable by the ALC. Figure 18 depicts how the flow of maintenance information ties together the stages of analysis, planning, and execution that go into PDM.

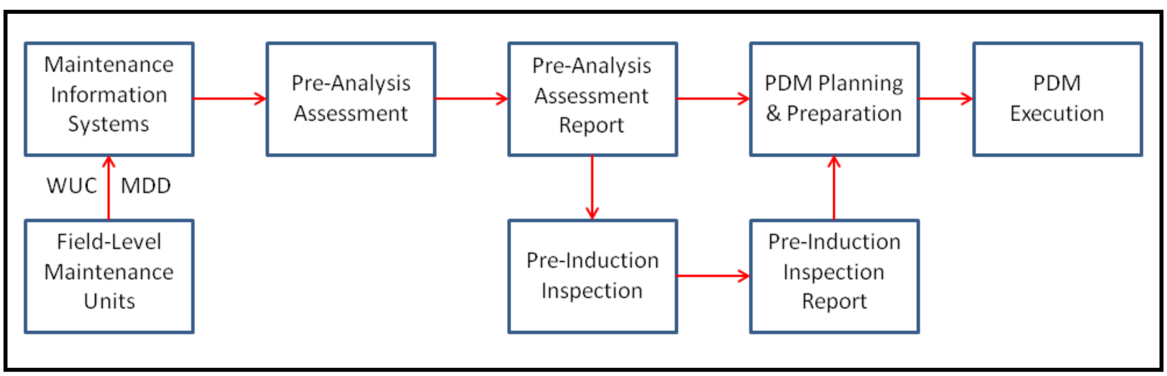

Figure 18 HVM Influence Diagram

Recommendations for Future Research

There are a number of areas related to future HVM development that are ripe for additional research. In a culture of continuous improvement there is always room to improve upon an existing process, but when it comes to HVM there is also the question of how the HVM concept will migrate across weapon systems and be integrated into depot maintenance operations at the Air Force's three Air Logistics Centers. The following bullets are some of the unanswered questions that persist regarding the future of HVM in depot maintenance operations:

- Can ECSS or another ERP solution fully integrate existing maintenance information systems to improve data availability for PDM planning?
- How can the information gathered during the HVM process be preserved for access during future PDM cycles?
- Can the success of HVM be investigated by a post-depot analysis of the aircraft and its documentation to assess actions taken?
- What are the possibilities for improving weapon system program office and maintenance cooperation across other weapon systems?
- How can the HVM construct be utilized across other weapon systems to improve PDM performance and reduce variability?
- How can the maintenance actions taken during depot maintenance be recorded so that they are visible across the maintenance enterprise?

Expanding HVM research to address some of these questions will aid in AFMC decision makers' ability to make well informed decisions regarding the future and potential for expansion of HVM operating tenets. These research areas also cover topics that could impact the way depot maintenance is performed over the coming decades.

Additionally, this research has identified the following types of maintenance data that are not captured during the HVM process. While this maintenance data may not be applicable to the current PDM cycle (which is why it may be left out of the HVM data collection process), it is relevant to the overall maintenance record for an aircraft.

- Maintenance actions recorded in IMDS before the last depot cycle
- Maintenance actions performed during PDM from any previous depot visit
- Non-standard field repairs aided by Technical Assistance Request before the last depot cycle
- Non-standard depot repairs aided by Technical Assistance Request before the last depot cycle
- Any aircraft discrepancies not recorded in an integrated MIS

While beyond the scope of how HVM can aid in the management of PDM flow, these information pieces are relevant to the larger Air Force goal of increased aircraft availability through logistics transformation. With the eventual long-term adoption of an Air Force-wide ERP system still uncertain the leg-work of analyzing and interpreting maintenance data is left to be done by hand by system program office engineers. An eventual ERP solution (or enterprise maintenance IT system) should be wide-ranging and smart enough to retrieve maintenance data from all available MIS, interpret it, and provide PDM planners and program office personnel with a working knowledge of each aircraft's health condition. It is worth noting that while the current ECSS design does not provide for an automated maintenance data collection process that is capable of analyzing and interpreting maintenance info, the System Lifecycle Integrity Management initiatives currently being work by Headquarters AF/A4ID are working towards providing a framework for an enterprise-level aircraft health record (Morgan, 2012). Additional research into these initiatives should prove fruitful to AFMC's aircraft lifecycle management program.

Summary

This chapter reviewed the research effort and addressed the research questions proposed by this research. The problem statement was also address. The methods employed by field maintenance units and Warner Robins ALC to facilitate HVM and improve the PDM process were discussed, including the PAA and PII process as well as the maintenance information systems used and the way information flows amongst them. Possible areas for future research were discussed that should aid in the development of the HVM and PDM processes as well as the Air Force's logistics transformation.

Improving Knowledge of C-130 Aircraft Condition: A High Velocity Maintenance Case Study

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Department of Operational Sciences (ENS)
Air Force Institute of Technology

INTRODUCTION

High Velocity Maintenance (HVM) seems poised to revolutionize the way the Air Force schedules and performs depot-level maintenance on its aircraft. The four tenets of HVM provide the basis for the Air Force's Air Logistics Centers (ALCs) to improve the quality of planning and scheduling that goes into each aircraft's depot maintenance cycle. These tenets have been implemented at the Warner Robins ALC as part of the C-130 depot maintenance process. While HVM is in active implementation there, much remains to be documented on how the process works in a practical way.

This research focuses on Warner Robins ALC's implementation of improving knowledge of each aircraft's condition prior to its induction into depot. This research includes exploring how an aircraft's maintenance history is compiled and considered in the depot planning process as well as the way that information flows from field-level maintenance units to enterprise-level information systems to where they are used as part of the depot planning process.

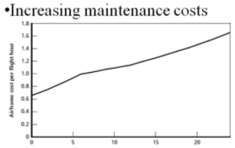
PROBLEM STATEMENT

- *How are Maintenance Information Systems and Work Unit Codes used to facilitate the flow of aircraft through the PDM/HVM process?*

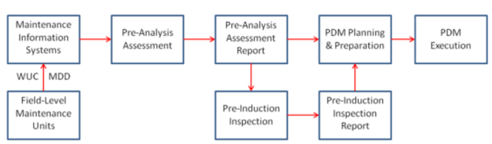
NEED FOR PDM IMPROVEMENTS

- Low aircraft availability rates
- Rough operating conditions
- Too much WIP at depots
- High C-130 ops tempo
- Stressed airframes/
- Parts unavailability
- Battle damage

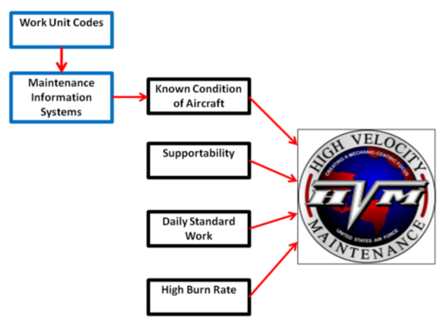
- Increasing maintenance costs



HVM PROCESS MAP



RESEARCH FRAMEWORK



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HVM MAINTENANCE DATA ANALYSIS ACTIONS

Pre-Analysis Assessment (PAA)
- ALC and SPO collaboration
- SPO engineers analyze aircraft maintenance records
  - IMDS, TCTOs, TARs, etc.
- Potential delays to PDM ID'd
- Problems rated for risk to PDM
- Results used in PDM planning

Pre-Induction Inspection (PII)
- Field-inspection of aircraft
- 6-9 months prior to PDM start
- 94-item checklist
  - Common MDS problem areas
- Also inspect areas identified in pre-analysis assessment
- PDM risk results updated

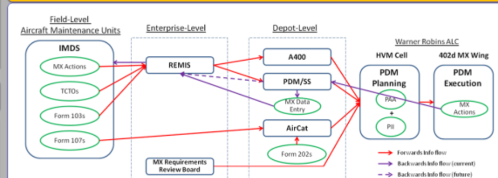
PDM Schd Impact	Probability of Failure: High	Med	Low
High			
Med			
Low			

Figure 1 PDM Risk Matrix

(green)	Not applicable or Low (Negligible)
(light green)	Low-Medium
(yellow)	Medium
(orange)	Medium-to-High
(red)	High

Figure 2 PDM Risk Color Code

HVM INFORMATION FLOW



FUTURE RESEARCH

- Can maintenance information systems be integrated under ECSS or another future ERP or enterprise-level maintenance system?
- How can the information gathered during the HVM process be preserved for access during future PDM cycles?
- How can the HVM construct be utilized across other weapon systems to improve PDM performance and reduce variability?
- How can the maintenance actions taken during depot maintenance be recorded so that they are visible across the maintenance enterprise?
- What will be required from ECSS or another future ERP or enterprise-level maintenance system in order to create and preserve a permanent record of aircraft health?

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14. ABSTRACT

High Velocity Maintenance (HVM) seems poised to revolutionize the way the Air Force schedules and performs depot-level maintenance on its aircraft. The four tenets of HVM, Known Condition of the Aircraft, Supportability, Daily Standard Work, and High Burn Rate, provide the basis for the Air Force's Air Logistics Centers (ALCs) to improve the quality of planning and scheduling that goes into each aircraft's depot maintenance visit. These tenets have been implemented at Warner Robins ALC as part of the C-130 depot maintenance process. While HVM is in active implementation there, much remains to be documented on how the process works in a practical way.

This research is a case study that explores the way maintenance information systems and work unit codes are used to facilitate HVM on the C-130 line at Warner Robins ALC. This research focuses on the Center's implementation of improving knowledge of each aircraft's condition prior to its induction into depot. This is investigated here through a combination of documentation analysis, archival records review, interviews, and direct observations. This research includes exploring how an aircraft's maintenance history is compiled and considered in the depot planning process as well as the way that information flows from field-level maintenance units to enterprise-level information systems to where they are used as part of the depot planning process.

15. SUBJECT TERMS

High Velocity Maintenance, Depot Maintenance, Maintenance Information Systems, Work Unit Codes, C-130 Maintenance

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