3-2006

Implementing Reliability-Centered Maintenance Analysis in A revised Preventive Maintenance Program for the F-15

Michael H. Martin

IMPLEMENTING RELIABILITY-CENTERED MAINTENANCE ANALYSIS IN A REVISED PREVENTIVE MAINTENANCE PROGRAM FOR THE F-15

THESIS

Michael H. Martin, Chief Master Sergeant, USAF

AFIT/GLM/ENS/06-08

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GLM/ENS/06-08

IMPLEMENTING RELIABILITY-CENTERED MAINTENANCE ANALYSIS IN A REVISED PREVENTIVE MAINTENANCE PROGRAM FOR THE F-15

THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

Michael H. Martin, BS

Chief Master Sergeant, USAF

March 2006

AFIT/GLM/ENS/06-08

IMPLEMENTING RELIABILITY-CENTERED MAINTENANCE ANALYSIS IN A REVISED PREVENTIVE MAINTENANCE PROGRAM FOR THE F-15

Michael H. Martin, BS
Chief Master Sergeant, USAF

Approved:

Dr. William Cunningham (Chairman) date

Dr. Alan Johnson (Member) date

AFIT/GLM/ENS/06-08

Abstract

Reliability-centered maintenance is an approach to analyzing how and when equipment fails in order to maintain a desired level of performance or functionality. It employs the use of failure modes, effects and criticality analysis to rank order potential failures, and combines this rank order with the use of a prescribed decision logic process to determine what preventive maintenance tasks should be performed and when. Reliability-centered maintenance analysis has been used by the United States Navy, the United States Coast Guard, and commercial airlines to develop and update preventive maintenance programs for their aircraft for many years. While the United States Air Force has prescribed the use of reliability-centered maintenance analysis to develop preventive maintenance programs for new acquisitions, the use of this analysis to revise and update preventive maintenance programs on existing aircraft is relatively new. Once the analysis yields maintenance tasks and intervals, this analysis must be successfully implemented in a revised preventive maintenance program in order to be effective. This research proposes a solution to successfully implement reliability-centered maintenance analysis results in a revised preventive maintenance program for the F-15 weapons system.

Acknowledgments

I would like to express my sincere appreciation to the numerous maintenance professionals I have been fortunate enough to work with during my Air Force career. From supervisors to trainees to co-workers to trainees, the people in the Air Force accomplish the mission. It is in an effort to help these professionals as they continue to be tasked with accomplishing more with continually diminishing time and resources that I have undertaken this research.

I am indebted to Mr. Hugh Darsey of the 330th Fighter Sustainment Group at Robins Air Force Base, Georgia for allowing my to assist in a very small way in the important work he and his colleagues are doing. The reliability-centered maintenance being performed will not only enable the F-15 to carry on accomplishing the missions it is tasked with in a safe and effective manner, it will enable the maintainers to better focus their time and talents on the tasks that matter.

Dr. William Cunningham and Dr. Alan Johnson have provided me the perfect mix of latitude and guidance in accomplishing this research, and I am very thankful to them for knowing me well enough to provide that mix.

My family is at the heart of everything I do, and to my wife, son and daughter, as always, without your love, support, and encouragement, I am nothing.

Michael H. Martin

Table of Contents

Page

List of Figures

List of Tables

Page

IMPLEMENTING RELIABILITY-CENTERED MAINTENANCE ANALYSIS IN A REVISED PREVENTIVE MAINTENANCE PROGRAM FOR THE F-15

I. Introduction

Background

An ounce of prevention is worth a pound of cure. This adage has been traced to use as early as the thirteenth century. The fact that it is still widely accepted and used today is a testament to not only its simplicity, but its universal applicability. It is certainly applicable in the field of aircraft maintenance, where the failure of a single component in flight can cost huge amounts of money and, in the worst possible scenario, lives. Preventing failures before they happen is one of the key concepts upon which a preventive maintenance program is built. However, there are numerous reasons why it is important to make good decisions about which maintenance actions to perform and which not to perform. Performing any maintenance introduces inherent risks that must be weighed against the intended benefit of performing the maintenance. Errors by maintenance personnel, wear and tear on items during disassembly and re-assembly, and the fact that rework of a component could actually place it in a higher failure portion of its life cycle than it was in before the rework must all be considered. Additionally, the cost of performing preventive maintenance must be taken into account. It may not feasible to spend $20 performing preventive maintenance on a part that costs $2 to replace. Indeed, if there are no safety implications when the part fails, the best course of action may be no preventive maintenance at all. The frequency of intended preventive maintenance actions must also be calculated, again taking into account the component or system's failure distribution, if known.

Most courses in reliability contain a description of the classic bathtub curve model of how a component's failure rate changes with time. The initial, steep part of the curve depicts the phenomenon known as infant mortality, when the component experiences a high failure rate during the initial burn-in period. After burn-in, the bathtub curve enters the service life portion, where the failure rate remains relatively stable and low. At the end of the component's life cycle, as it wears out, the failure rate again increases, completing the right side of the bathtub curve. This bathtub curve is applicable to so many components and systems that over the years, it became the standard model for failure rate upon which preventive maintenance programs were developed. A relatively recent development in reliability theory and the development of preventive maintenance programs is the idea of reliability-centered maintenance, or RCM. "The RCM process entails asking seven questions about the asset or system under review, as follows:

- what are the functions and associated performance standards of the asset in its present operating context?
- in what ways does it fail to fulfil [sic] its functions?
- what causes each functional failure?
- what happens when each failure occurs?
- in what way does each failure matter?
- what can be done to predict or prevent each failure?
- what should be done if a suitable proactive task cannot be found?" (Moubray, 1997:7)

So reliability-centered maintenance, instead of concerning itself with preservation of the component, concerns itself with preservation of the function of the component, and only focuses on those actions that preserve the component's function. This clarity of focus, when applied to the preventive maintenance of a complex system such as a weapons system, can lead to a much more efficient and effective preventive maintenance program.

The process of establishing a preventive maintenance program as part of the acquisition of a new weapons system is clearly laid out in various Department of Defense and Air Force publications. The process of revising or updating the preventive maintenance program for an existing weapons system is not nearly as clear-cut. Though mandated for use Department of Defense (DoD)-wide in 1978, many system program offices (SPOs) are still in the process of incorporating reliability-centered maintenance as the primary analysis tool in the development of preventive maintenance programs. The 330th Fighter Sustainment Group has recently completed analysis on several major sub-systems for the F-15, including fuels, flight controls, environmental control systems, and landing gear. The next step will be to take this analysis, which provides answers to the questions: What actions to perform? and When to perform the actions?, and incorporate it into a comprehensive, updated preventive maintenance program for the F-15.

Problem Statement

The reliability-centered maintenance analysis currently being performed by the 330th Fighter Sustainment Group will do nothing to augment the safety and reliability of the F-15 weapons system if not successfully integrated into an effective preventive maintenance program.

Research Question

The focus of this research effort is to answer the research question: How can the reliability-centered maintenance analysis being performed for the 330th Fighter

Sustainment Group be successfully implemented in a revised preventive maintenance program for the F-15?

Investigative Questions

To answer the research question, this research addresses the following investigative questions:

1. How have the United States Navy, the United States Coast Guard, other Air Force organizations and Northwest Airlines performed reliability-centered maintenance analysis?
2. How have the United States Navy, the United States Coast Guard, other Air Force organizations and Northwest Airlines implemented their reliability-centered maintenance analysis in a revised PM program?
3. What characteristics, actions, and decisions were instrumental to the success of the other reliability-centered maintenance implementations?
4. What problems were encountered in the other implementations, and how were they eliminated or mitigated?
5. How can these successful actions and decisions be combined and applied to an effective reliability-centered maintenance implementation for the F-15?

Methodology

Through a literature review, this researcher gained an in-depth understanding of reliability-centered maintenance, its origins, concepts, methods, and implementation steps. An understanding of the development of preventive maintenance programs was also gained through a review of available literature. An analysis of the Navy's reliability-centered maintenance and implementation of that maintenance into a preventive maintenance program was performed via a collective case study. This included reviewing the available literature from the analysis and program development, and interviews with those involved in the analysis and program development for the E-3, A-7 and AV-8B weapons systems. A collective case study of the analysis and development of preventive maintenance programs for other airframes, including the C-5 and C-141 yielded an understanding of the salient characteristics of the programs, as well as the important differences between them, and provided insight as to which aspects are applicable to a preventive maintenance program for the F-15. A case study of the implementation of reliability-centered maintenance analysis by Northwest Airlines provided another perspective on the use of reliability-centered maintenance analysis in the development of a revised preventive maintenance program commercial airlines. By employing the insight and understanding of reliability-centered maintenance analysis and implementation gained during the literature review, and synthesizing this information with an in-depth analysis of the preventive maintenance programs for these other programs, an understanding of how to successfully incorporate the analysis being done at the 330th Fighter Sustainment Group into an effective preventive maintenance program for the F-15 was gained.

Limitations and Scope

Due to a limited amount of available time and available resources for travel, certain concessions had to be made during the course of this research. While a case study involves an extended, in-depth analysis of a process, the depth of experience to be gained on any portion of this collective case study will be limited because the reliability-centered maintenance implementations studied will have already occurred. Additionally, though it would be desirable to implement the proposed solution and analyze the results, the timing for presentation and defense of this thesis will not allow for this to happen, and would certainly not afford enough time to evaluate whether or not the implementation of the preventive maintenance program is successful.

The data for this research was collected in the form of interviews. One limitation of interviews is in the area of objectivity – there is a tendency to blur actual observations with interpretations of those observations. In order to mitigate this risk all interviews were digitally recorded, with prior permission from the interviewees, in their entirety. The full transcripts of the interviews are included as appendices to the text of this thesis report.

As to scope, this research is limited to the successful implementation of a preventive maintenance program for the F-15 weapons system, not all Air Force weapons systems. This is largely because of the wide disparity between maintenance concepts, processes and procedures from one airframe to another throughout the Air Force inventory. While there was not time for research so broad in scope, numerous opportunities for follow-on research resulted from this research and are included in the final chapter.

Summary

In an era when resources are becoming increasingly scarce and mission requirements increasingly diverse, the Air Force must continue to search for more efficient methods of mission accomplishment. To that end, reliability-centered maintenance analysis has been mandated for use in the development of preventive maintenance programs not only for new acquisitions, but also for existing weapons systems. As the analysis is completed, the next challenge will be to successfully implement the results of this analysis into an effective preventive maintenance program for the F-15. This research offers a solution to this challenge, based on a synthesis of reliability-centered maintenance understanding, personal experience and lessons learned from the experiences of professionals in the fields of reliability engineering and aircraft maintenance from other preventive maintenance program developments and implementations.

II. Literature Review

Chapter Overview

Preventive maintenance has become an accepted practice in many different industries as a cost-effective means of preserving the value and function of various types of equipment, increasing reliability and preventing equipment failure. Preventive maintenance programs are developed based on a variety of different inputs and factors. The concept of reliability is embedded in the concept of preventive maintenance, since a primary goal of preventive maintenance is to improve or increase the reliability of a component or a system. Reliability-centered maintenance is a concept that has largely replaced the historical notion of one reliability curve that fits everything, the most widely accepted graphical representation being the famous bathtub curve. In addition, instead of focusing on preventing equipment, components, or systems from breaking, reliability-centered maintenance focuses on enabling the equipment, component or system to perform certain necessary functions. The acceptance and adoption of the concepts of reliability-centered maintenance have caused wholesale changes in the development of preventive maintenance programs. Since this research deals with finding a way to successfully use reliability-centered maintenance analysis in a revised preventive maintenance program for the F-15, it is important to first gain an understanding of preventive maintenance, reliability theory, and the evolution of reliability-centered maintenance. After exploring these concepts, this chapter next contains an examination of the current uses of reliability-centered maintenance in the Department of Defense.

Finally, it closes with an overview of the reliability-centered maintenance analysis that has already been performed for the F-15.

Preventive Maintenance

There are many different definitions of preventive maintenance. Mann (1976:1) provided a starting point for a general definition when he stated:

> For purposes of discussion, maintenance is usually categorized on a "when" basis: emergency maintenance denotes that the work must be done in the immediate future; routine maintenance normally denotes that the work must be done in the finite, foreseeable future; and preventive maintenance denotes maintenance that is carried out in accordance with a planned schedule.

This use of the term preventive maintenance introduces the ideas of planning and scheduling as they relate to preventive maintenance. Mann delineates different kinds of maintenance based on when they are performed, with preventive maintenance being performed according to a pre-planned schedule. From the fact that preventive maintenance is pre-planned, it follows that preventive maintenance is proactive, not reactive. In other words, it is performed not because a condition or an event occurred (i.e., a reaction to an event or condition), but because a certain pre-designated time or usage criteria has been met. This time-driven component is supported by Mobley, who states "…all preventive maintenance management programs are time-driven. In other words, maintenance tasks are based on elapsed time or hours of operation" (Mobley, 1990:3). In his textbook on reliability and maintainability, Charles Ebeling (2000:189) defines preventive maintenance as "scheduled downtime, usually periodical, in which a well-defined set of tasks, such as inspection and repair, replacement, cleaning, lubrication, adjustment, and alignment, are performed." Again, the concept of a schedule is incorporated, but Ebeling goes into much more detail about the types of actions performed under the umbrella of preventive maintenance. The thought of a well-defined set of tasks leads one to the notion that the preventive maintenance actions are thought out and specified in detail ahead of time. This concept is important, because one of the most important tasks in developing a preventive maintenance program that follows from this concept is determining which actions to perform (and which not to perform) as part of the preventive maintenance program. Though this concept may seem intuitive, "many otherwise well-managed companies rate an 'F' for maintenance management; they simply 'fail' to manage maintenance. Companies that would go broke if they did not carefully plan and schedule production work do not recognize that maintenance work needs the same approach" (Hartmann, 1987:vii). The United States Air Force (Department of the Air Force, 2003a:A-4) has defined preventive maintenance for Air Force aerospace vehicles as:

> the normal upkeep and preservation of equipment through systematic inspection, detection and correction of discrepancies to prevent failures, to verify serviceability, or to restore complete serviceability of equipment that has been subjected to usage, wear and tear, or deterioration caused by environmental elements.

This definition introduces the concept of preventing failures, which, by definition, increases a component's or a system's reliability. A commonly accepted definition of reliability is "the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions" (Ebeling, 2000:5). Reliability is defined a bit differently by the Air Force (Department of the Air Force, 2003b:24) as "[t]he ability of a system or component to perform its required functions under stated conditions for a specified period of time." Comparing these definitions of reliability shows us the common focus of a system (or component) being able to perform required functions. Bringing all these definitions and their salient characteristics together, we can see the basic tenets of preventive maintenance as maintenance actions, usually performed on a scheduled basis, aimed at increasing a system's ability to perform its required functions.

Having defined preventive maintenance, it is also important to understand why we perform preventive maintenance. Smith (1993:11) provides three reasons for performing preventive maintenance: "1. prevent failure 2. detect onset of failure 3. discover a hidden failure." Again, this perspective points us back to the definition of preventive maintenance, especially increasing a system's ability to perform its required functions. By preventing failure in the first place, a system will be afforded more of an ability to perform its required functions. By detecting the onset of failure, maintenance technicians and managers have more insight as to how to effectively and efficiently schedule maintenance and repair actions that will minimize down time, thus enabling the system to better perform its intended functions. A hidden failure involves "equipment items – or possibly a whole subsystem or system – that could experience failure and, in the *normal* course of operation, no one would know that such failure has occurred" (Smith, 1993:14). Thus, discovery of hidden failures enables the maintenance manager to increase system reliability by repairing hidden failures before they impact the system's functionality. These three reasons for performing preventive maintenance can be closely tied to some of the expected benefits. Mann (1976:98) provides a long list of benefits from performing preventive maintenance, including: minimum maintenance costs, enabling maintenance to be performed when it is convenient, less downtime, and increased safety.

Not surprisingly, the common applications of preventive maintenance have evolved along with the majority of products, machinery, and systems requiring preventive maintenance. "Since the 1930's, the evolution of maintenance can be traced through three generations" (Moubray, 1997:2). During the first generation, most equipment was simple and over-designed for the tasks it was to perform. Resultantly, the only maintenance requirements were routine servicing and lubrication. Moving into the 1950's, the second generation saw more dependence upon more complex machinery. This heightened dependence meant that when machinery broke, the effects were more profound. "This led to the idea that equipment failures could and should be prevented, which led in turn to the concept of preventive maintenance" (Moubray, 1997:2). With the interdependence and lowered tolerance for variation in production schedules brought about by such logistics topics as just-in-time, lean, and inventory reduction, "equipment failures are now increasingly likely to interfere with the operation of an entire facility" and "the growth of mechanization and automation has meant that reliability and availability are now also key issues" (Moubray, 1997:3). Finally, the degree of specialization required to maintain today's automated equipment has in large part been responsible for a huge increase in the cost of performing maintenance. "In some industries, it is now the second highest or even the highest element of operating costs" (Moubray, 1997:4).

To set the stage for tying this discussion of preventive maintenance to the concept of reliability-centered maintenance, it is important to understand more about the concept of reliability and how it has evolved.

Reliability Theory

"The early roots of reliability engineering trace back to the 1940s and 1950s. Much of its origin resides in the early work with electronic populations where it was found that early failures (or infant mortalities) occurred for some period of time at a high but decreasing rate until the population would settle into a long period of constant failure rate" (Smith, 1993:44). Most people are familiar with this concept as related to electronic devices. When purchasing an electronic item, most failures occur in the early use of the item. Once an electronic item has passed this infant mortality stage, it can generally be relied upon to function normally for an extended period of time. This idea leads to the concept of burn-in, where an electronic product is operated by the manufacturer for a specified period of time before it is shipped to the consumer. "Those items that have survived will have a MTTF greater than the MTTF of the original items because the early failures would have been eliminated" (Ebeling, 2000:312). After this long period of a constant failure rate, some components and systems will eventually reach a point where a sharp increase in failure rate occurs. Again referring to electronic components, Smith (1993:44) states "[i]t was also observed that some devices (e.g., tubes) would finally reach some point in their operating life where the failure rate would start to quickly kill off the surviving population." This increase in failure rate can logically be connected to components in a system reaching their designed service life expectancy. A visual representation of this type of lifetime failure behavior "is the well-known *bathtub curve*" (Smith, 1993:44). "Systems having this hazard rate function experience decreasing failure rates early in their life cycle (infant mortality), followed by a nearly constant failure rate (useful life), followed by an increasing failure rate (wearout)" (Ebeling, 2000:31).

The concept of the bathtub curve-shaped failure curve was widely accepted in what Moubray (1997:2) calls the first two of three generations in the evolution of maintenance.

> The First Generation covers the period up to World War II…the prevention of equipment failure was not a very high priority in the minds of most managers. At the same time, most equipment was simple and much of it was over-designed. As a result, there was no need for systematic maintenance of any sort beyond simple cleaning, servicing and lubrication routines (Moubray, 1997:2).

The second generation is further described:

> By the 1950's machines of all types were more numerous and more complex. Industry was beginning to depend on them. As this dependence grew, downtime came into sharper focus. This led to the idea that equipment failures could and should be prevented, which led in turn to the concept of *preventive maintenance* (Moubray, 1997:2).

As the concept of preventive maintenance gained acceptance and was widely implemented, the bathtub curve was still largely recognized as all-encompassing enough to be used as a basis for most preventive maintenance programs. Maintenance, according to Moubray (1997:3-4), continued to evolve into the third generation, characterized by downtime constraints aggravated by just-in-time operating philosophies, reliability and availability becoming key issues, failures having more serious safety and environmental consequences, and the costs of maintenance continuing to rise. Another key development in this third generation came in the form of questions as to whether the bathtub curve was truly one-size-fits-all:

> However, Third Generation research has revealed that not one or two but six failure patterns actually occur in practice…although they may be done exactly as planned, a great many traditionally-derived maintenance tasks achieve nothing, while some are actively counterproductive and even dangerous. This is especially true of many tasks done in the name or preventive maintenance (Moubray, 1997:4).

Others in the fields of reliability and maintainability came to appreciate what the research Moubray referenced was reporting, and began to investigate its ramifications further:

> True, some devices may follow its [the bathtub curve's] general shape, but the fact is that more has been assumed along those lines than has actually been measured and proven to be the case. As those with even a cursory knowledge of statistics and reliability theory can attest, this is not surprising, because large sample sizes are required in order to accurately develop the population age-reliability characteristics of any given device, component, or system (Smith, 1993:44).

In fact, it can be shown that six separate failure function curves exist which more accurately depict the failure rate functions of aircraft equipment (Figure 1). While they all share at least some of the same three general properties of the bathtub curve, each implies different preferred maintenance and overhaul techniques due to the differences.

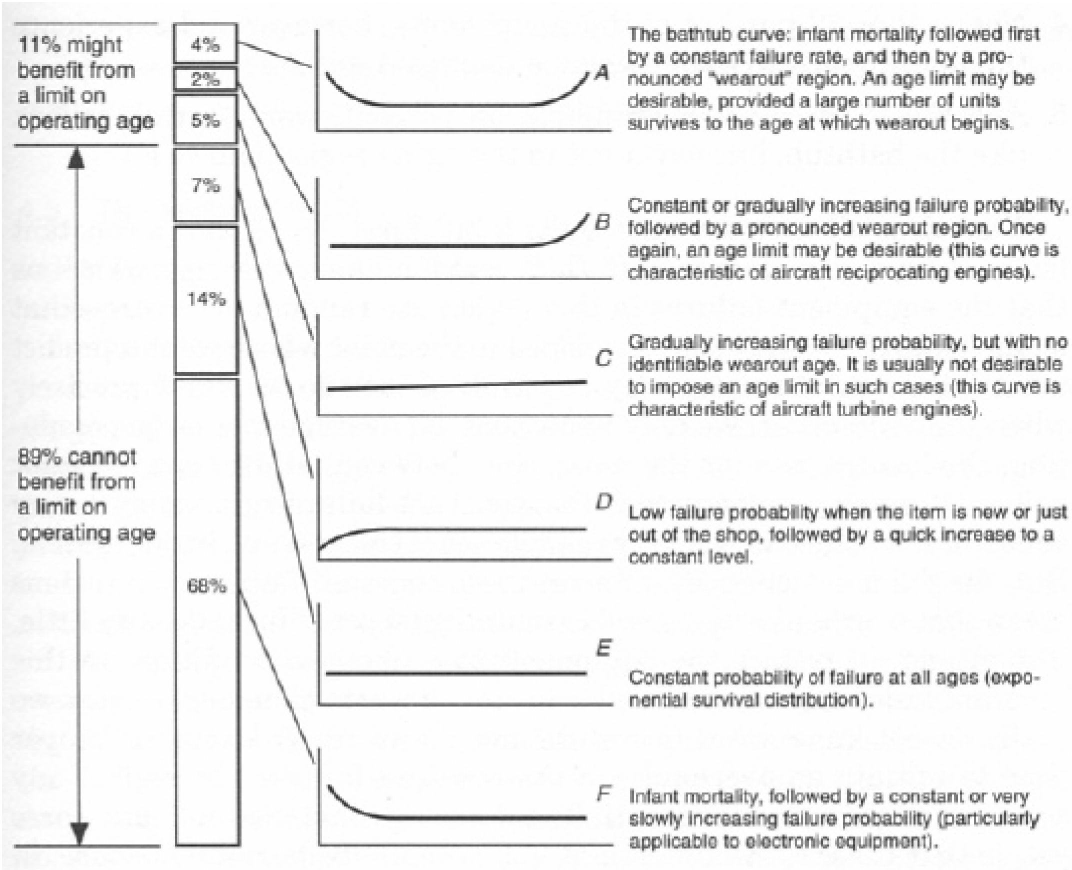

Figure 1. Age-reliability patterns for non-structural aircraft equipment (Smith, 1993:45)

As seen in Figure 1, only approximately 4% of aircraft equipment had failure functions that could be accurately characterized by the bathtub curve. Even more significant, a full 89% of aircraft equipment, because of its failure function, can not benefit from a limit on operating age, according to Smith. This is important, because use of the bathtub curve implies that by overhauling or replacing components immediately prior to the time in the part's life cycle where it reaches the increasing failure rate part of the curve, a maintainer is doing the best they can to efficiently maintain system function. However, since 89% of aircraft equipment actually does not have this increasing failure rate toward the end of the reliability curve, this approach is not warranted. Smith (1993:46) recounts other eye opening concepts that use of the six reliability curves brings to light:

> First, recall that a constant failure rate region (curves A,B,D,E, and F all have this region) means that the equipment failures in this region are random in nature – that is, the state of the art is not developed to the point where we can predict what failure mechanisms may be involved, nor do we know precisely when they will occur. In this constant-value region, overhaul is usually a waste of money because we really do not know what to restore, nor do we really know the proper time to initiate an overhaul. Second, and worse yet, is that these overhaul actions will actually be harmful because, in our haste to restore the equipment to new, pristine conditions, we have inadvertently pushed it back into the infant-mortality region of the curve.

These developments, in part, were instrumental in the development of a new strategy for developing, analyzing, and implementing preventive maintenance programs. Another key issue that drove the development of a new strategy was the complexity of new aircraft being brought into service in the 1960s. The 747, as an example, was a quantum leap from previous aircraft in terms of its size and complexity. Says Anthony Smith (1993:47):

> The recognized size of the 747 (three times as many passengers as the 707 or DC-8), its new engines (the large, high bypass ratio fan jet), and its many technology advances in structures, avionics, and the like, all led the FAA to initially take the position that preventive maintenance on the 747 would be very extensive – so extensive, in fact, that the airlines could not likely operate this airplane in a profitable fashion.

Clearly a new strategy would have to be employed to develop a preventive maintenance program that ensured the utmost safety and reliability of the aircraft, while maximizing the efficiency of the maintenance actions and inspections performed. The new strategy, which came from the commercial aviation field, has come to be known as reliability-centered maintenance.

Reliability-Centered Maintenance

As stated above, the 747 jumbo jet, with its huge size, redundant systems, technological advances, and resulting complexity, force the airlines who would operate the new jets to start from scratch when developing a preventive maintenance program that would be accepted by the Federal Aviation administration and meet the airlines' stringent safety guidelines while not being so expensive to operate that it would put the airlines out of business. The major carriers could see that the 747 was about to revolutionize the industry, and that, in order to stay competitive, they would have to operate the new jumbo in a cost-effective manner. To that end, the airlines began to look at a myriad of new ideas as to how to develop an efficient, effective preventive maintenance program for the new jets.

> At United Airlines an effort was made to coordinate what had been learned from these various activities and define a generally applicable approach to the design of maintenance programs. A rudimentary decision-diagram technique was devised in 1965 and was refined over the next few years. This technique was eventually embodied in a document published under the title Handbook*: Maintenance Evaluation and Program Development,* generally known as MSG-1 (Nowlan and Heap, 1979:4-5).

Smith (1993:48) adds:

> What resulted from this effort was…a whole new approach that employed a decision-tree process for ranking PM tasks that were necessary to preserve critical aircraft functions during flight. This new technique for structuring PM programs was defined in MSG-1 (Maintenance Steering Group-1) for the 747, and was subsequently approved by the FAA.

After the inception of MSG-1, the industry further refined the new concepts in additional iterations:

> Subsequent improvements in the decision-diagram led in 1970 to a second document, *MSG-2: Airline/Manufacturer Maintenance Program Planning Document*, which was used to develop the scheduled-maintenance programs for the Lockheed 1011 and the Douglas DC-10. The objective of the techniques outlined by MSG-1 and MSG-2 was to develop a scheduled-maintenance program that assured the maximum safety and reliability of which the equipment was capable and would meet this requirement and the lowest cost (Nowlan and Heap, 1979:5).

Being in the business of operating and maintaining numerous aircraft of various types, the Department of Defense started paying serious attention to the new ideas the commercial aviation industry was developing. "In 1972, these ideas were first applied by United Airlines under Department of Defense (DOD) contract to the Navy P-3 and S-3 aircraft and, in 1974, to the Air Force F-4J. In 1975, DOD directed that the MSG concept be labeled 'Reliability-Centered Maintenance,' and that it be applied to all major military systems" (Smith, 1993:48).

Having gone through 30+ years of evolution, the salient features of reliability-centered maintenance are now mostly agreed upon. Smith (1993:49-51) describes four basic features of reliability-centered maintenance. The first feature is "[t]he primary objective of reliability-centered maintenance is to preserve system function" (Smith, 1993:49). In contrast to earlier preventive maintenance philosophies whose aim was to prevent failure, reliability-centered maintenance recognizes that failure is not always preventable and that, in some cases, attempting to prevent failure actually causes failure earlier than if the system were left alone. Take, for instance, curves A and F in Figure 2.1. Performing preventive maintenance in the form of an overhaul when the system or component is in the flat part of the curve would actually bring the system back to the infant mortality part of the curve where failures are more likely. Additionally, every system or component is not equally important, so the PM program should not devote resources to prevent failure or loss of function on equipment that has little impact on the function of the system when it does fail. The second feature states "[s]ince the primary objective is to preserve system function, then *loss of function or functional failure* is the next item of consideration" (Smith, 1993:50). Considering functional failure means looking at the actual equipment in the system, and analyzing it for all possible ways in which it could fail to perform its required function. Feature three states "[i]n the reliability-centered maintenance process, where our primary objective is to preserve system function, we have the opportunity to decide, in a very systematic way, just what order or priority we wish to assign in allocating budgets and resources. Thus, we want to *prioritize the importance of the failure modes*" (Smith, 1993:50). This feature brings to light the efficiency factor in reliability-centered maintenance analysis. By prioritizing, or rank ordering, the ways each component or system can fail, we can address those with the most severe impact on system functionality first, and lessen the time and energy spent on failures or degradations that have little or no significant impact on system functionality. Smith's (1993:51) fourth feature of reliability-centered maintenance is "Each potential PM task must be judged as being 'applicable and effective.' *Applicable* means that if the task is performed, it will in fact accomplish one of the three reasons for doing PM (i.e., prevent or mitigate failure, detect onset of a failure, or discover a hidden failure). *Effective* means that we are willing to spend the resources to do it." Of importance in these definitions is that Smith combines the traditional meaning of efficient in his definition of effective.

Merriam-Webster Online (2006) defines efficiency as "productive of desired effects; *especially* **:** productive without waste." It is the aspect of eliminating or minimizing waste that is most often associated with efficiency, while effectiveness is usually associated with completeness, or accuracy. Smith uses the one word, effective, to connote the efficiency aspect by stating that a willingness to expend resources to perform the task must exist. This definition points not only to the ability of the task to get the job done (effectiveness), but also the idea that money will not be expended needlessly (efficiency). This nuance in Smith's definition is important to understand as we continue to explore what reliability-centered maintenance is, and this theme will resurface. The concept of applicability and effectiveness is not limited to Smith, as Nowlan and Heap (1979:8) stated 14 years earlier "proposed tasks are evaluated according to specific criteria of applicability and effectiveness."

Another area of convergence over the years has resulted in the accepted definitions of reliability-centered maintenance being quite similar. Kelly (1997:218) claims "[i]n reliability-centered maintenance maintenance strategy is formulated via a structured framework of analysis aimed, in principle, at ensuring the attainment of a system's *inherent reliability*, i.e. the reliability that it was designed to attain." Nowlan and Heap (1979:2) stated "reliability-centered maintenance refers to a scheduled maintenance program designed to realize the inherent reliability capabilities of equipment." Moubray (1997:7) defines reliability-centered maintenance as "a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context." Both Kelly and Moubray refer to a process, or a structured framework of analysis. This process must be followed in order to end up with the schedule of maintenance actions to be performed. Performance of these maintenance actions on the assigned schedule should allow the equipment to attain close to its inherent reliability.

Further description of how realization of this inherent reliability is to be approached is contained in the various reasons for performing reliability-centered maintenance, or the desired outcomes of reliability-centered maintenance. Pham (2001:154) states

> The premise of reliability-centered maintenance is that a more efficient and effective life-cycle maintenance program for equipment can be developed by addressing individual component failure modes, the consequences of failures, and the actual preventive maintenance tasks to be done. The primary objective of reliability-centered maintenance is to preserve equipment function by preserving component operation.

In order to achieve this more efficient and effective program, reliability-centered maintenance adheres to a slightly different overarching concept of the purpose of preventive maintenance. As stated earlier, reliability-centered maintenance does not seek to prevent failures, it seeks to preserve the critical functions of components and systems.

The way in which reliability-centered maintenance seeks to preserve this critical function was summed up in a general sense by reliability-centered maintenance pioneers Nowlan and Heap (1979:6) in their DoD-sponsored report on reliability-centered maintenance: “The principles of reliability-centered maintenance stem from a rigorous examination of certain questions that are often taken for granted:

- How does a failure occur?
- What are its consequences?
- What good can preventive maintenance do?”

These three basic questions have been further refined and developed into what have become known as the seven basic questions of reliability-centered maintenance. Moubray (1997:7) states

> The reliability-centered maintenance process entails asking seven questions about the asset or system under review, as follows:
>
> - what are the functions and associated performance standards of the asset in its present operating context?
> - in what ways does it fail to fulfil [sic] its functions?
> - what causes each functional failure?
> - what happens when each failure occurs?
> - in what way does each failure matter?
> - what can be done to predict or prevent each failure?
> - what should be done if a suitable proactive task cannot be found?

As Moubray states, answering these seven questions forms the framework of the reliability-centered maintenance process. The first question is answered by defining the functions of each component or system, depending on the level of the analysis. Defining the functions must be done in a thorough and specific enough manner to allow downstream analysis of the possible failures associated with these functions. "Functions should be described such that loss of that function has one effect whenever possible. If more than one effect is possible from the loss of the function, the function may need to be separated into two or more functions" (Wyle, 2004:A-x). Additionally, functions are specifically defined and include performance metrics where applicable. For instance, the function of a fuel pump might be correctly defined as: provide a constant125 pounds/square inch pressure of jet fuel at a variable volume between 8 gallons/minute and 200 gallons/minute.

Determining how a system or component fails to fulfill its functions is the first step in a process called Failure Modes, Effects, and Criticality Analysis (FMECA). In fact, questions two through five (What are the functional failures? What causes each functional failure? What is the effect of each functional failure? How critical is each functional failure?) are all answered through the course of performing the failure modes, effects and criticality analysis.

> In the FMEA process, every mode of failure or malfunction of each component of the system must be considered. Then the effects of the failure are determined in order to assess the ultimate effect on the system performance. Criticality is the combination of probability of failure occurrence and the level of severity. It may be the best way to assess the effect of a failure mode on the reliability of a component. The failure mode, effects, and criticality analysis (FMECA) is probably the most widely used and most effective design reliability analysis method (Dai and Wang, 1992:178).

To paraphrase the failure modes, effects and criticality analysis process, then, every function that was identified in answering the first question is examined, and every possible way in which this function could fail is listed. Recall that for each function, the description was such that it provided quantifiable performance metrics. A functional failure, then, is “defined in terms of a deviation from the quantified performance standard provided by the function” (Wyle, 2004:A-x). To further define terms, “a failure mode is what went wrong; a failure cause is why the failure occurred in the first place, and the failure effect is how the failure impacts the equipment” (Pham, 2001:161). Developing a list of every possible failure mode for each of the previously named functions serves to answer question two and three. Subsequently, every failure mode is analyzed for its effect on the system. The effects of the failure modes answer question four. These effects of the failure modes can be then be used to rank the failure modes into categories of criticality. The most widely used system of categorization employs a two-step process. The purpose of the first step is to “separate hidden failure modes from evident failure modes” (Society of Automotive Engineers, 1999:Section 5), and the second step should “clearly distinguish events (failure modes and multiple failures) that have safety and/or environmental consequences from those that only have economic consequences (operational and non-operational consequences” (Society of Automotive Engineers, 1999:Section 5). The criticality analysis portion of the failure modes, effects and criticality analysis answers question five. This process is depicted in Figure 2. Note that while Figure 2 is derived from the logic tree analysis used for a manufacturing plant, the logic is universally applicable to any failure modes, effects and criticality analysis.

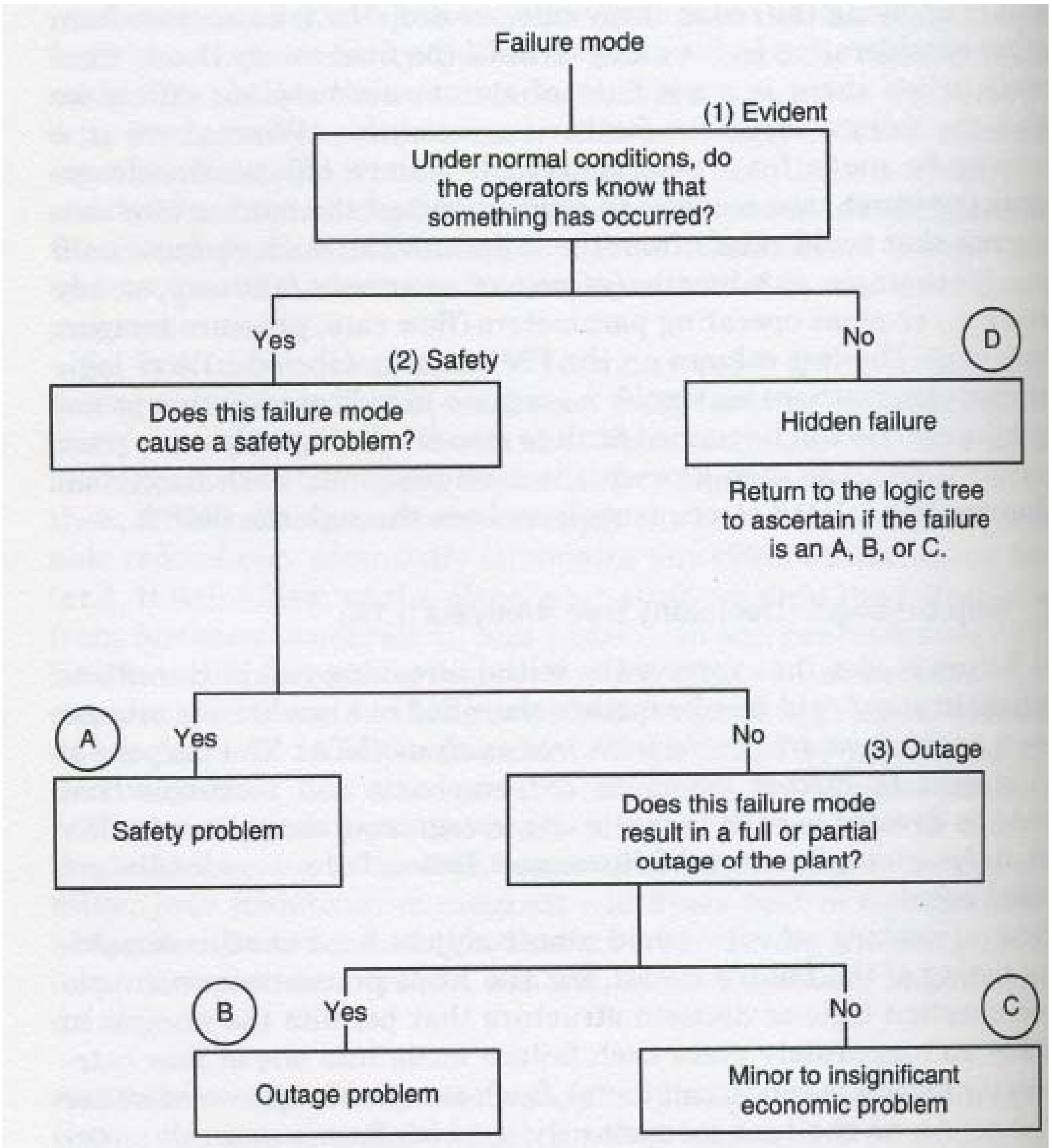

Figure 2 – Logic Tree Analysis for the Failure Modes, Effects and Criticality Process (Smith, 1993:93)

"So, we usually choose to address PM priorities as:

1. A or D/A
2. B or D/B
3. C or D/C" (Smith, 1993:93)

The reliability-centered maintenance analysis process then moves on to question six: what can be done to predict or prevent each failure? Again, a decision tree is employed to determine which (if any) preventive maintenance tasks can be applied to predict or prevent the failure modes identified through failure modes, effects and criticality analysis as deserving attention. This process is called task selection. It is important to understand a bit more about the types of tasks employed in a preventive maintenance program.

Typically, preventive maintenance tasks are broken down into four categories: time-directed (TD), condition-directed (CD), failure-finding (FF), and run-to-failure (RTF). It is immediately obvious that run-to-failure involves no preventive maintenance at all. This is not an oversight, but intended, since some failure modes may be so insignificant or have such a non-critical, negligible impact on the component or system's function that it is actually preferable to allow the equipment to run-to-failure, and then employ corrective maintenance as the method of choice. Since this is a conscious decision made as part of a preventive maintenance program, run-to-failure is included as the fourth category of preventive maintenance tasks. Time-directed tasks are

> aimed directly at failure prevention or retardation. The keys to categorizing a task as time-directed are:
> (1) the task action and its periodicity are preset and will occur without any further input when the preset time occurs,
> (2) the action is known to directly provide failure prevention or retardation benefits, and
> (3) the task action requires some form of intrusion into the equipment (Smith, 1993:12)

Condition-directed tasks are

> aimed at detecting the onset of a failure or failure symptom. The keys to classifying a task as CD are:
> (1) we can identify a measurable parameter that correlates with failure onset,
> (2) we can also specify a value of that parameter when action may be taken before full failure occurs, and

(3) the task action is nonintrusive with respect to the equipment
(Smith, 1993:13)

If a failure mode is identified as hidden, or not evident to the operator, it is called a hidden failure. Recall from Figure 2 that hidden failures may range in criticality from safety-related to minor/insignificant. In the occurrence of hidden failures, “we find it most beneficial to exercise a prescheduled option to check and see if all is in proper working order. We call such an option a *failure-finding* (FF) task” (Smith, 1993:14). With the four categories of tasks available, a roadmap such as the one depicted in Figure 3 is employed to match the correct task with each failure mode from the FMECA. Note that this roadmap employs the same categorization system for failure modes used in Figure 2: A or D/A – Evident/hidden safety problem, B or D/B – Evident/hidden outage problem (full loss of functionality), and C or D/C – Evident/hidden minor or insignificant problem.

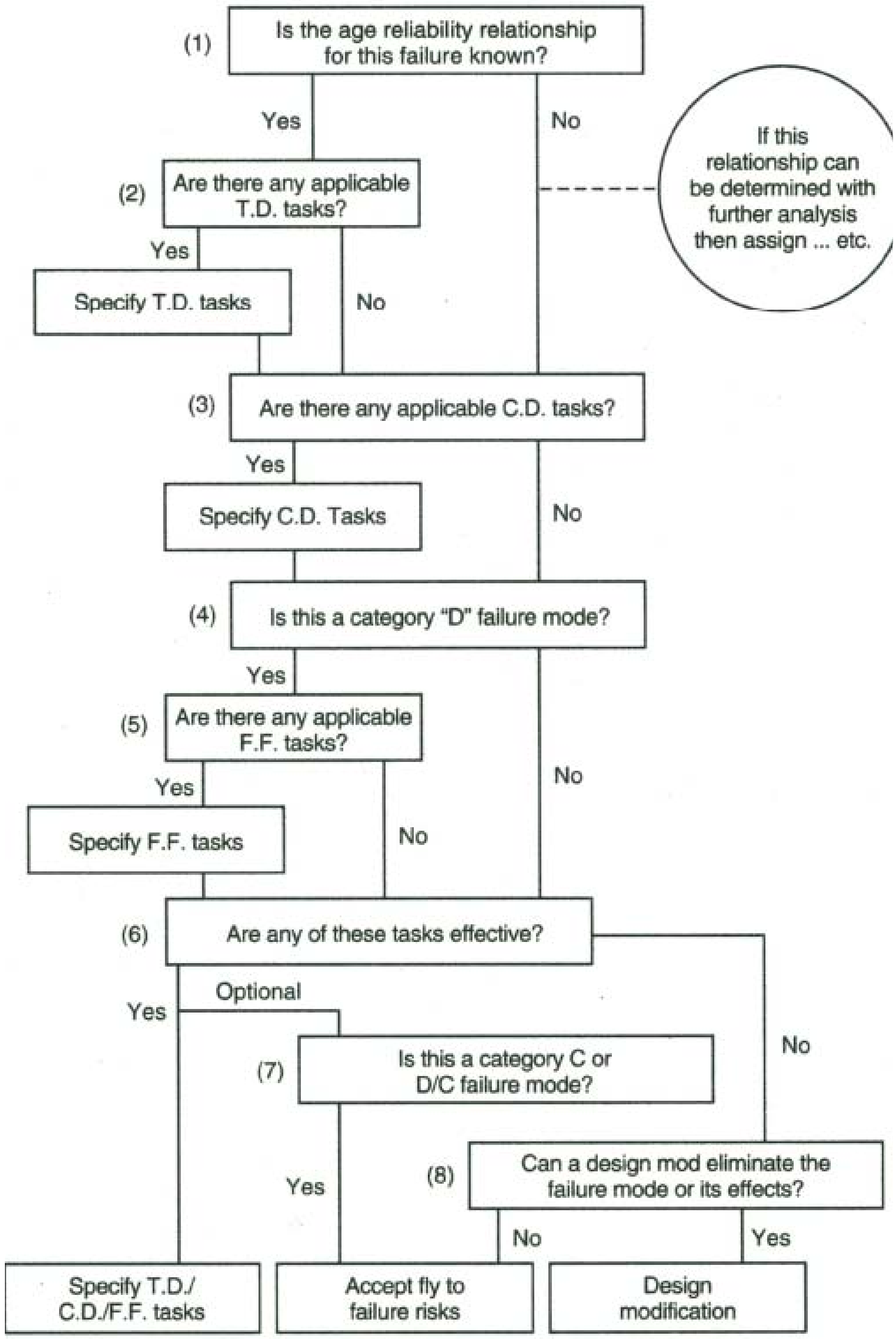

Figure 3. – Task Selection Roadmap (Smith, 1993:95)

Given the goal of the reliability-centered maintenance process, preserving system functionality, this roadmap should make sense. Following the logic, if a time-directed task is applicable and effective in preventing a given failure mode, it should be employed first, since time-directed tasks are aimed at preventing failure in the first place. Note, however, that it is important to once again understand Smith's definition of effective in order to employ Smith's task selection process accurately. Without understanding the implied facet of efficiency in Smith's definition of effective as it applies to using a time-directed task first, other reliability-centered maintenance subject matter experts such as Nowlan and Heap would disagree with Smith's logic tree. In order to be used first, the time-directed task must also be efficient, according to Nowlan and Heap (1979:56), because "[w]henever an on-condition task is applicable, it is the most desirable type of preventive maintenance. Not only does it avoid the premature removal of units that are still in satisfactory condition, but the cost of correcting potential failures is often far less than the cost of correcting functional failures, especially those that cause extensive secondary damage." Moving on with Smith's logic, if no time-directed task is applicable, effective and efficient, then a condition-directed task should be considered, since condition-directed tasks are used to restore functionality after degradation is encountered, but before full loss of functionality occurs. Next, a determination as to whether the failure mode is hidden or evident is made. If an applicable failure-finding task is effective in detecting the hidden failure mode, then it should be applied. By following this logic tree, suitable preventive tasks are aligned with each failure mode. Again, reliability-centered maintenance is not designed to be overprotective, or inefficient. According to Nowlan and Heap (1979:8)

> Each scheduled maintenance task in an reliability-centered maintenance program is generated for an identifiable and explicit reason. The consequences of each failure possibility are evaluated, and the failures are then classified according to the severity of their consequences. Then for all significant items – those whose failure involves operating safety or has major economic consequences – proposed tasks are evaluated according to specific criteria of applicability and effectiveness. The resulting scheduled-maintenance program thus includes all the tasks necessary to protect safety and operating reliability, and only the tasks that will accomplish this objective.

This last sentence points again to the efficiency aspect of reliability-centered maintenance, in that only the tasks that actually are proven to contribute to safety and operating reliability are included. In this way, reliability-centered maintenance has the potential to achieve huge cost savings over less efficient methods of task selection for preventive maintenance programs, and the methodology in selecting the tasks with reliability-centered maintenance is both sound and proven.

Once tasks are selected, they must be assigned a frequency or interval at which to be performed. For new systems, the frequency is assigned based on design engineering data or manufacturer's quality control and pilot testing data, combined with an accepted form of statistical analysis of failure rates, such as fitting and application of a Weibull curve. For in-service systems, the maintenance management information system is queried for data relating to a particular failure mode. A mean time between failures (MTBF) can then be calculated based on the in-service times of the components listed in the query. In the case of the reliability-centered maintenance analysis performed by Wyle Laboratories on the F-15, "Whenever possible, REMIS, AFKS, G050, G021, Depot data, and other pertinent database should be used to calculate MTBF. Where limited data is available, default methods, Weibull, or other statistical techniques may be used" (Wyle, 2004:Axii). Another option to address the situation where sufficient data does not exist to calculate an inspection or maintenance interval is to recommend age exploration (AE). Smith (1993:188) provides a good illustration of the age exploration process:

> Say our initial overhaul interval for a fan motor is 3 years. When we do the first overhaul, we meticulously inspect and record the condition of the motor and all of its parts and assemblies where aging and wearout are thought to be possible. If our inspection reveals no such wearout or aging signs, when the next fan motor comes due for overhaul, we automatically increased the interval by 10 percent (or more), and repeat the process, continuing until, on one of the overhauls, we see the incipient signs of wearout or aging. At this point, we stop the AE process, perhaps back off by 10 percent, and define this as our final task interval.

At this point in the reliability-centered maintenance analysis process, we have identified and prioritized failure modes, and have used a logic tree process to assign tasks and periods at which to accomplish these tasks to most failure modes. There will remain, however, some failure modes for which an applicable and effective task has not been found.

The seventh question remains to be answered: what should be done if a suitable proactive task cannot be found? "When an item cannot benefit from scheduled maintenance, in some cases product improvement may be necessary before the equipment goes into service" (Nowlan and Heap, 1979:70). If the failure mode is not critical enough to be addressed specifically, run-to-failure should be considered (as per Smith's definition of run-to-failure tasks above).

Having discussed the methodology of reliability-centered maintenance analysis, the next key area to be covered is how to prepare to implement the results of this analysis. One key component of this preparation is task packaging, and another is the change management aspect. The two facets of task packaging are grouping the recommended tasks together to make them manageable and efficient to perform, and clearly directing exactly what is to be performed. Moubray (1997:212) addresses the change management component as well as both of these task packaging facets:

> [I]n order to derive the maximum long-term benefit from reliability-centered maintenance, steps must be taken to implement the recommendations on a formal basis. These steps should ensure that:
>
> - all the recommendations are approved formally by the managers with overall responsibility for the assets
> - all routine tasks are described clearly and concisely
> - all actions which call for once-off changes (to designs, to the way the asset is operated or to the capability of operators and maintainers) are identified and implemented correctly
> - routine tasks and operating procedure changes are incorporated into appropriate work packages
> - the work packages and once-off changes are implemented. Specifically , this in turn entails:
>   - incorporating the work packages into systems which ensure that they will to [sic] be performed by the right people at the right time and that they will be done correctly
>   - ensuring that any faults found are dealt with speedily

Nowlan and Heap (1979:284) address the consolidation facet of task packaging, stating "[a]ll the task intervals we have discussed so far have been based on the individual requirements of each item under consideration. The control of these individual tasks is greatly simplified by grouping the tasks into work packages that can be applied to the entire aircraft, to an installed engine, or to a removable assembly." "Usually the objective in packaging is to consolidate the work into as few check intervals as possible without unduly compromising the desired task intervals" (Nowlan and Heap, 1979:285). As to the specific direction facet of task packaging, Smith (1993:25) states "[t]he task specification is the instrument by which we assure that a complete technical definition and direction is provided to the implementing maintenance organization as to what exactly is required. It is the key transitional document form the ideal to the real world."

By providing a specific description of exactly what maintenance or inspection actions are to be performed, in a format and manner that makes it intuitive and natural for the maintainer to grasp and apply, the reliability-centered maintenance analyst or engineer ensures the spirit and intent of their preventive maintenance program actually gets carried out. The things to be considered in formulating such a description are "tooling, spare parts, vendor support, training, documents and drawings, make/buy decisions (i.e., in-house versus contracted work), test equipment, scheduling, regulatory requirements, etc." (Smith, 1993:25). In addition to ensuring the preventive maintenance program is performed as it was intended, another benefit of clearly describing the task during packaging is "the risk inherent to PM activities can be controlled and greatly reduced by assuring the development of technically sound and complete task specifications and procedures" (Smith, 1993:25).

Use of Reliability-Centered Maintenance by Government Agencies

Having seen what the private sector, especially the commercial aviation business, has developed and experienced with reliability-centered maintenance is a useful start to understanding what is needed for this research. The next area to explore involves an understanding of how different military agencies have adopted reliability-centered maintenance and put it to use in preventive maintenance programs for their aircraft. While the Army employs reliability-centered maintenance, to varying degrees, in maintenance of their facilities, it is similar to the Air Force in that it is just beginning to use reliability-centered maintenance analysis as a basis for revision of the preventive maintenance for its fleet of helicopters. As such, the first part of this section will focus on the use of reliability-centered maintenance by the Navy. A review of current Air Force guidance, policies and practices will follow.

Department of Defense Directive 4151.18, Maintenance of Military Materiel, is a reference intended "to establish policies and assign responsibilities for the performance of DoD materiel maintenance, including maintenance of weapon systems, hardware, equipment, software, or any combination thereof and for both organic and contract sources of repair" (Department of Defense, 2004:1). Much of the language in this directive is familiar after becoming familiar with the terminology used in reliability-centered maintenance analysis. The section on general policy states "Maintenance programs for DoD materiel shall be structured and managed to achieve *inherent performance*, *safety* and *reliability* levels of the materiel" (Department of Defense, 2004:2). In the section on initial program development, the directive states "programs shall consist of applicable and effective tasks for addressing the failure modes and effects using reliability-centered analysis" (Department of Defense, 2004:3). The section covering life-cycle maintenance, or maintenance of in-use systems, states

> Maintenance programs for materiel maintained for the Department of Defense shall facilitate, collect, and analyze maintenance-related reliability data. The programs shall include sufficient analytic capability for identifying needed adjustments based on operating experience, materiel condition, and requirements for reliability, maintainability and supportability modifications, and changes to training curricula or delivery methods. The programs shall provide maintenance activities the means for assessing information generated by prognostic and diagnostic capabilities and for taking appropriate maintenance actions (Department of Defense, 2004:6).

Though this direction does not specifically mention reliability-centered maintenance, the aspects of analyzing reliability data, adjusting based on operating experience and reliability requirements, and taking appropriate maintenance actions are straight from the reliability-centered maintenance playbook.

The Navy leads the way in the Department of Defense in the use of reliability-centered maintenance analysis for preventive maintenance program development for their aircraft. NAVAIR, the Naval Air Systems Command, is charged with developing, acquiring, and supporting naval aeronautical and related technology systems. NAVAIR has published two key documents that define how reliability-centered maintenance will be performed and implemented in their command. NAVAIR Instruction 4790.20A, *Reliability Centered Maintenance Program*, establishes policy for the use of reliability-centered maintenance analysis in development of its preventive maintenance programs. The instruction states “[t]he reliability-centered maintenance process should be used to develop, justify and sustain all PM requirements” (Naval Air Systems Command, 1999:2). It is “applicable to all new procurement and in-service aircraft, systems, and Support Equipment (SE), including their modification, during all life cycle phases and levels of maintenance” (Naval Air Systems Command, 1999:1). It places emphasis on “aggressively pursuing all opportunities to apply reliability-centered maintenance principles to ensure safety, readiness, and affordability or naval aviation systems through justified Preventive Maintenance (PM) tasks” (Naval Air Systems Command, 1999:1). In this respect it echoes Smith’s fourth feature of reliability-centered maintenance. The selection of affordable and justified preventive maintenance tasks which ensure safety and readiness referred to in the NAVAIR instruction correlate directly with Smith’s (and Nowlan and Heap’s) requirement for tasks to be applicable and effective. The instruction goes on to delineate responsibilities, including the requirement for program managers to “plan and budget for funding necessary to implement and sustain reliability-centered maintenance program requirements” (Naval Air Systems Command, 1999:4).

The second key document that NAVAIR has published in support of its reliability-centered maintenance program is NAVAIR 00-25-403, *Guidelines for the Naval Aviation Reliability-Centered Maintenance Process*. This 122-page document is a management manual designed to be “the primary guidance document for anyone tasked with implementing an RCM program or performing RCM analysis” (Naval Air Systems Command, 2003:9). In the area of reliability-centered maintenance program management, sections on reliability-centered maintenance during acquisition, reliability-centered maintenance team establishment, scoping the analysis, and training and certification are found. The next chapter describes, in detail, the reliability-centered maintenance analysis process. The chapter on implementation covers packaging preventive maintenance tasks, implementation of other actions such as run-to-fail, re-design and age exploration. The next chapter deals with sustainment of the program, from the perspectives of sustaining the analysis, as well as assessing the program’s effectiveness in terms of cost avoidance, operational readiness, and amount of maintenance performed. There are two appendices, the first of which outlines an example reliability-centered maintenance program plan. The second details task interval determination procedures, including Weibull analysis and methods for estimating potential for failure to functional failure intervals.

NAVAIR has also posted a website, called the Reliability Centered Maintenance Homepage. In addition to listing and providing links to all the applicable NAVAIR reliability-centered maintenance guidance, a version of the software NAVAIR uses to perform reliability-centered maintenance analysis is available for anyone to download. This software, called the "Integrated Reliability-Centered Maintenance System (IRCMS) program is a software tool that was created to assist the reliability-centered maintenance (RCM) analyst in performing and documenting reliability-centered maintenance analyses for Naval Air Systems Command (NAVAIR) programs" (Naval Air Systems Command, 2006:1). Another link on the website details courses offered by NAVAIR aimed at both analysts and maintenance managers.

Finally, the website has a link to information on the NAVAIR reliability-centered maintenance Steering Committee. The Steering Committee's chartered purpose is

> to develop and refine processes and tools to effectively implement and sustain reliability-centered maintenance. They will define reliability-centered maintenance processes that result in effective and affordable maintenance programs and recommend other actions for safety, reliability, and readiness improvements. This will be accomplished by the regular and timely exchange of technical information; assessment of implementation and execution; establishment of common outcome metrics and periodic review of program health; management of training and certification programs; and oversight and development of tools and processes to assist personnel assigned to perform reliability-centered maintenance on all types of NAVAIR equipment. It is also the objective of the reliability-centered maintenance Steering Committee to coordinate with the stakeholders of other NAVAIR processes and initiatives. The Steering Committee will also coordinate with other Department of Defense agencies, academia, private industry, and international armed forces/organizations to develop standard reliability-centered maintenance procedures and share information for the benefit of all concerned. (Director, 2004:3).

This charter points to the fact that the Navy has firmly espoused the concept of reliability-centered maintenance, and not only plans to use it within NAVAIR across the board, but that NAVAIR intends to be a leading force in the continued development and proliferation of reliability-centered maintenance throughout other defense agencies, commercial enterprises, and academia, and is indicative of the level of support NAVAIR gives reliability-centered maintenance and how deeply entrenched reliability-centered maintenance is in the way NAVAIR does business. The Steering Committee holds its own regularly scheduled meetings, but members of the committee also attend and participate in reliability-centered maintenance events and symposiums, forums and working groups around the world.

The Air Force's support of and direction regarding the use of reliability-centered maintenance essentially stems from Air Force Materiel Command Instruction 21-103, *Reliability-Centered Maintenance (RCM) Programs*. This seven-page instruction states as its governing policy "[t]he organization initiating new developments or modifications will develop the initial inspection and maintenance requirements based on an reliability-centered maintenance analysis, unless a waiver has been granted by HQ USAF" (Salyer, 1994:2). For the procedure to be followed for this mandated reliability-centered maintenance analysis, as well as the decision logic to be used during the failure modes, effects and criticality analysis, the instruction refers to MIL-STD-1843, a military standard that was rescinded over 10 years ago. Sections of the instruction are determinedly vague, such as the section on task interval determination, where it states:

> The decision logic process must be supplemented with inspection interval analysis to provide an effective inspection program. Since the frequency greatly determines the amount of work expended in a maintenance program, place as much emphasis on this determination as on the selection process. An initial interval must be established for all new inspections and the interval for an established inspection will require review and analysis for possible refinement (Salyer, 1994:5).

Air Force Technical Order 00-20-1, *Aerospace Equipment Maintenance Inspection, Documentation, Policies and Procedures*, covers the inspection requirements for Air Force aircraft. It states "[c]hanges to prescribed inspection intervals, concepts or requirements will be made by the SM [single manager] only after thorough analysis of data obtained from the Maintenance Information System (MIS) using appropriate Reliability Centered Maintenance Analysis (reliability-centered maintenanceA)" (Department of the Air Force, 2003:2-2). No further reference to reliability-centered maintenance is contained in this technical order. Air Force Policy Document 21-1, *Air and Space Maintenance*, prescribes the policy that the 21-series Air Force Instructions, which deal with air and space maintenance, are derived from. The only mention of reliability-centered maintenance in this nine-page policy directive is a definition in the appendix, which reads "Reliability-Centered Maintenance—A logical discipline for developing a scheduled-maintenance program that will realize the inherent reliability levels of complex equipment at minimum cost" (Department of the Air Force, 2003c:6). Air Force Instruction 21-101, *Aerospace Equipment Maintenance Management*, refers to reliability-centered maintenance in the section on Aircraft Information Program (AIP), asserting that the AIP supports reliability-centered maintenance (Department of the Air Force, 2004:346). No further mention of reliability-centered maintenance is found in this instruction. Air Force Instruction 21-118, *Improving Air and Space Equipment Reliability and Maintainability*, "provides guidance and procedures for improving the reliability and maintainability (R&M) of fielded air and space equipment through the use of Maintenance Data Documentation (MDD) analysis, Deficiency Reporting (DR), and

Product Improvement Working Groups (PIWG)" (Department of the Air Force, 2003b:1). It makes no mention of reliability-centered maintenance.

When a new chief engineer was assigned to the 330th Fighter Sustainment Group in 2002, he brought with him a wealth of experience and knowledge from his previous jobs. One area he was particularly well-versed in was reliability-centered maintenance, especially as it was used as the basis of the Functional System Integrity Program (FSIP) on the C-141 aircraft, which is the system program office the chief engineer came from. He asked his new team of engineers what type of program was in place to monitor and adjust inspection times and preventive maintenance actions, and was disappointed to find that there was no such system in place. His team of engineers was given marching orders to develop a system, and this led them to begin reliability-centered maintenance analysis on the F-15 in order to revise the current preventive maintenance program into a more analysis-based, cost-effective system. After some initial research, the lead engineer found that the Navy was using reliability-centered maintenance exclusively as the basis of its preventive maintenance programs, and that the Navy had heavily relied on Wyle Laboratories, a contractor, to perform their reliability-centered maintenance analysis in instances where the Navy organization was not qualified or experienced enough to perform their own analysis. Wyle Laboratories was subsequently "tasked by the F-15 System Program Office (SPO) to perform a Versatile Reliability-Centered Maintenance (VRCM) analysis on the F-15 Eagle aircraft. The analyses would be confined initially to the Environmental Control System (ECS), Landing Gear, Fuel, and Flight Control systems" (Wyle Laboratories, 2004:1). The selection of these four systems was a result of analysis done by the engineers at the 330th Fighter Sustainment Group. The result of this analysis was

> a list of systems in priority order based on total man-hour expenditures, total unscheduled man-hour expenditures, aborts, and Mean Time Between Failures (MTBF). Data was obtained from REMIS and ranked at the 2-digit WUC level. The relative weight for each parameter was added together to achieve a total weight (Wyle Laboratories, 2004:A-vi).

The environmental control system, landing gear, fuels and structures were the top four on the prioritized list, but since the analysis of the structural system would be so time- and resource-consuming, it was decided to substitute flight controls for structures in the initial list of four systems. Analysis is currently being performed on the remaining systems, including structures, and is scheduled to be completed in the calendar year 2006/2007 timeframe.

In order to begin the analysis, certain ground rules and assumptions had to be made, some in order to initialize the Versatile Reliability-Centered Maintenance System software, and some to establish a common starting point or framework from which to proceed. Table 1 contains a list of these default values.

Table 1 – Default Values Used in Versatile Reliability-Centered Maintenance Analysis of F-15 Systems (Wyle Laboratories, 2004:A-i-ii)

Aircraft:	**F-15**
Aircraft Acronym Code:	Eagle
End Item:	F-15 Aircraft
Aircraft MDS:	Population as of October 2003:
F-15A	102
F-15B	20
F-15C	341
F-15D	54
F-15E	221
F-15A/D Hours Flown (1998 to Sep 2003)	744,562.2 Flight Hours
Sorties Flown	499,155
Average Sortie Duration	1.5 Flight Hours
Average no. of Aircraft	517
Average Yearly Flight Hours (1998-2002)	129,743.9 Flight Hours
Average Usage Rate per year (FH/AC/year)	129,743.9/517 = 250 FH/AC/year
Average Usage Rate per month (FH/AC/month)	129,743.9/517/12 = 20.9 FH/AC/month
F-15E Hours Flown (1998 to Sep 2003)	336,967 Flight Hours
Sorties Flown	187,910
Average Sortie Duration	1.8 Flight Hours
Average no. of Aircraft	214
Average Yearly Flight Hours (1998-2002)	56,424.7 Flight Hours
Average Usage Rate per year (FH/AC/year)	56,424.7/214 = 263.6 FH/AC/year
Average Usage Rate per month (FH/AC/month)	56,424.7/214/12 = 21.9 FH/AC/mo.
Total Hours Flown (F-15A/E)	1,081,529.2 Flight Hours
Total Sorties Flown	687,065 Flight Hours
Average Sortie Duration	1.6 Flight Hours
Combined Average Usage Rate per month (FH/AC/month)	20.9 + 21.9 = 48.2/2 = 21.4 FH/AC/mo.
Fatigue Design Life: F-15A-D	8,000 Flight Hours
F-15E	16,000 Flight Hours
Labor Rates: F-15A-E (O & I-Levels) F-15A-E (Depot Level)	$47.46/hr $112.95/hr (average)

In order to establish the severity priorities necessary to categorize failure modes, the "F-15 System Safety Program Plan which is on contract between the F-15 SPO and Boeing Aircraft" (Wyle Laboratories, 2004:A-iii) was used as a starting point. These classifications are contained in Table 2.

Table 2 – Hazard Severity Categories (Wyle Laboratories, 2004:A-iii)

DESCRIPTION	CATEGORY	MISHAP DEFINITION
Catastrophic	1	May cause fatal injury or system loss, or property damage over $1M.
Critical	2	May cause severe injury or major system damage which leads to a mission abort or property damage over $200K.
Marginal	3	May cause minor injury or minor system damage which leads to mission degradation or property damage over $20K.
Negligible	4	Will result in less than minor injury or less than minor system damage which leads to an unscheduled maintenance action or property damage under $20K.

These hazard severity categories were subsequently combined with the probability categories in Table 3 to yield the hazard risk index contained in Table 4 and the associated corrective action criteria in Table 5.

Table 3 – Hazard Probability Classification (Wyle Laboratories, 2004:A-iv)

PROBABILITY	LEVEL	DESCRIPTION	NO. OF OCCURRENCES**
Frequent	A	Continuously experienced	More than 100
Probable	B	Will occur frequently	10-100
Occasional	C	Will occur several times	1-10
Remote	D	Unlikely, but can reasonably be expected to occur.	0.1-1.0
Improbable	E	Unlikely to occur, but possible.	Less than 0.1
** Per 100,000 flight hours.			

Table 4 – Hazard Risk Index (Wyle Laboratories, 2004:A-iv)

PROBABILITY	CATEGORY			
	Catastrophic 1	Critical 2	Marginal 3	Negligible 4
Frequent A	1A	2A	3A	4A
Probable B	1B	2B	3B	4B
Occasional C	1C	2C	3C	4C
Remote D	1D	2D	3D	4D
Improbable E	1E	2E	3E	4E

Table 5 – Corrective Action Criteria (Wyle Laboratories, 2004:A-iv)

HAZARD RISK INDEX		CORRECTIVE ACTION
1A, 1B, 1C, 2A, 2B	Unacceptable risk.	Mandatory correction, elimination or control. Requires acceptance by Higher Management (beyond the F-15 SPO) if not corrected.
1D, 2C, 3A	Undesirable risk.	Attempt should be made to eliminate or control. Requires program management approval for risk acceptance and concurrence by F-15 SPO program management.
1E, 2D, 3B, 3C	Acceptable risk.	F-15 SPO program management awareness recommended.
2E, 3D, 3E, 4A, 4B, 4C, 4D, 4E	Acceptable risk.	No action required.

Having identified the severity categorization system described above, analysis proceeded following these four steps:

Step 1 – Hardware Breakdown
F-15 SPO prioritized systems will be entered into a new VRCMS project file by the analyst.
Enter subsystems in the VRCMS hardware breakdown screen for above systems.
All reliability-centered maintenance analysis will be performed at the system or subsystem level except in special cases as directed by the F-15 SPO Engineer.
F-15 SPO RCM Lead Engineer (and/or designated engineer) will approve system/subsystem hardware breakdown.

Step 2 – Functions and functional failures
Identify all subsystem functions (per section III below) for all items requiring RCM analysis and enter in VRCMS.
Functions will be developed from system descriptions in T.O.s and Flight Manual.
Significant function selection shall be in accordance with AFMC Instruction 21-103.
F-15 SPO RCM Lead Engineer (and/or designated engineer) will approve all functions and functional failures.

Step 3 – Failure mode identification
All reasonably likely failure modes will be identified based on the following criteria.
FM that have occurred in the past.
FM protected by scheduled maintenance.
FM not from above but considered reasonably likely to occur.
Failure effects will be based on the aircraft as the end item.
F-15 SPO RCM Lead Engineer (and/or designated engineer) will approve all failure modes.

Step 4 – Perform analysis
Team approach: in-process coordination with the F-15 SPO and operators/maintainers, approval by failure mode prior to delivery.
Periodic "progress" deliverables.
Steps 2 and 3 will be performed concurrently (Wyle Laboratories, 2004:A-ix)

Combining the labor costs listed in Table 1 and the cost avoidance realized by not performing maintenance and/or replacing parts as recommended by the analysis, Wyle Laboratories was able to calculate estimated cost avoidance values for the four systems analyzed. Successful implementation of the results of the analysis performed would result in annual cost avoidance of $1,305,720.80 for the ECS system (Wyle Laboratories, 2004:26), ~$43M for the flight control system (Wyle Laboratories, 2005a:16), $7,802,317.30 for the fuels system (Wyle Laboratories, 2005b:42) and $9,426,551.16 for the landing gear system (Wyle Laboratories, 2005c:58). The total annual cost avoidance possible by successfully implementing the results of the reliability-centered maintenance analysis on these four systems calculated by Wyle Laboratories is approximately $61.5M.

Summary

This chapter opened with a discussion of preventive maintenance, and moved into the subject of reliability theory, specifically as it applies to the development of a preventive maintenance program. A detailed description of reliability-centered maintenance then followed, including the evolution and history of reliability-centered maintenance, key features of reliability-centered maintenance, and the process of reliability-centered maintenance. A look at how other governmental agencies approach reliability-centered maintenance from a policy and guidance perspective was used to provide a comparison to existing Air Force policy and direction (or, more accurately, the lack thereof) regarding the use of reliability-centered maintenance. Finally, this chapter closed with a description of the analysis performed by Wyle Laboratories on behalf of the 330th Fighter Sustainment Group. While analysis is ongoing, analysis on four major systems has been completed. The methodology employed by Wyle Labs was consistent throughout the four systems.

III. Methodology

Chapter Overview

"The research process follows a basic format. No matter which academic discipline gives rise to the research endeavor, the general research procedure is fundamentally the same" (Leedy and Ormrod, 2001:91). Though the basic process is the same, the specific methodology used to collect the data and analyze this data will greatly depend upon the type of data that must be collected. The type of data, of course, depends upon the research and investigative questions to be answered. "In planning the research design, therefore, it is extremely important for the researcher not only to choose a viable research problem but also to consider the kinds of data an investigation of the problem will required and feasible means of collecting and interpreting those data" (Leedy and Ormrod, 2001:93). This chapter will describe and examine the research design employed for this thesis, a discussion of the validity and reliability of the methods employed, the type of data collected and the data collection method, and a description of the data analysis technique employed.

Research Design

"Colloquially, a research design is *a logical plan for getting from here to there*, where *here* may be defined as the initial set of questions to be answered, and *there* is some set of conclusions (answers) about the questions (Yin, 2003:20)." For this research, *here* is defined by the research and investigative questions posed. *There* is comprised of the synthesis of the data analysis that answers those questions. The research design chosen was the multiple, or collective case study. The remainder of this section will discuss and justify that choice.

When this topic for research was chosen, it was with the understanding that the use of reliability-centered maintenance analysis to update the preventive maintenance program for an existing weapons system in the Air Force was a relatively new concept. Though the Air component of the United States Navy (NAVAIR), the United States Coast Guard, and the commercial aviation industry have extensively relied on reliability-centered maintenance-based preventive maintenance programs for their aircraft for many years, the Air Force is only starting to explore its use in this capacity. By employing the case study design, the intent was to explore what worked (and what didn't work) in commercial aviation, NAVAIR, the Coast Guard, and those Air Force SPOs that are starting to implement reliability-centered maintenance analysis, and synthesize the common features into a viable implementation for the reliability-centered maintenance analysis being performed by the 330th Fighter Sustainment Group. The case study as a research design is ideal for this purpose as Yin (2003:1) states, "[a]s a research strategy, the case study is used in many situations to contribute to our knowledge of individual, group, organizational, social, political, and related phenomena."

Table 6 - Relevant Situations for Different Research Strategies (Yin, 2003:5)

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

Yin (2003:1) further states "case studies are the preferred strategy when the 'how' or 'why' questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context." This research endeavor met all three of these criteria. The research question fundamental to this effort is ***How*** can the reliability-centered maintenance analysis being performed by the 330th Fighter Sustainment Group be successfully implemented in a revised preventive maintenance program for the F-15? An investigator, or researcher, could have little or no control over the effort that is underway at the 330th Fighter Sustainment Group to revise the F-15's preventive maintenance program based on the results of reliability-centered maintenance analysis. Neither could a researcher have any control over the way the Navy, Coast Guard, other Air Force organizations, or the commercial aviation industry had employed reliability-centered maintenance analysis in the past. Since the reliability-centered maintenance analysis is still ongoing at the 330th Fighter Sustainment Group, and since this analysis is yet to be implemented, the events are certainly contemporary, and have a real-life context. Meeting these three criteria strongly supports the use of the case study methodology in this research.

Since there are "certain features common to all research" (Leedy and Ormrod, 2001:94), examining this research project from the perspective of these common features will be a helpful addition to a discussion and justification of the methodology employed. Leedy and Ormrod (2001:94) list four common features of research: universality, replication, control, and measurement. Because of the research and investigative questions this project was designed to answer, data that was primarily qualitative in nature was collected. As a result, the way this research design fulfills these four features is not as cut and dried as it might be for a research design that relied exclusively on quantitative data, but these criteria still serve as a good starting point for describing and justifying the research design.

To be considered universal, a "research project should be such that it could be carried out by any competent person" (Leedy and Ormrod, 2001:94). Since this research relies on the analysis of data collected through interviews to form a collective case study, and since these interviews were not exclusive in any way relating to access granted, any competent person could also be expected to carry out this same research. The contact list used is not exclusive, and the subject matter experts interviewed are available to any researcher or practitioner who seeks them out. The path that led to contact with these six interviewees for this research was an evolutionary process. After initial contact with the sponsor, the lead engineer at the 330th Fighter Sustainment Group was able to provide contact information for two other engineers in the C-141/C-5 sustainment SPO (interviewees #3 and #4). Interviewee #3 was able to provide contact with interviewee #5, who had experience with Northwest Airlines and was currently working as a contractor with the C-5 SPO. After searching the internet for reliability-centered maintenance-related information, contact was made with a third party whose name and e-mail address were on an reliability-centered maintenance website. The website stated that this individual had experience with the NAVAIR Reliability-Centered Maintenance Steering Committee. Contact with this third party yielded contact information for interviewees #1 and #2, the NAVAIR Reliability &Maintainability Lead and the NAVAIR Reliability-Centered Maintenance Steering Committee Chair. Attendance at a reliability-centered maintenance summit hosted at Air Force Materiel Command Headquarters provided contact with interviewee #6.

Replication refers to how repeatable the research is. Since the data collected from the subject matter experts who were interviewed is mostly historical, another researcher asking the same questions this researcher asked should expect to get the same answers. The concept of replication does, however, bring up one of the inherent danger areas in interviewing to collect qualitative data. It is crucial that the interviewer, in an effort to remain objective and meet the intent of the characteristic of replication, must not lead the interviewee. To this end, an attempt was made to interject as little as possible in the interviews as they were conducted, even to the point of not asking questions unless necessary. Though the interview process started out with a basic list of questions that used for every interview, the interviewee was allowed to answer them as the interview progressed. If, therefore, in the course of their discussion, they had already fully answered questions that were further down the list, the interviewer would keep quiet and let the interviewee continue in their discussion. This technique was useful in maintaining objectivity, and, therefore, affording a good chance of replication.

“The researcher must isolate, or control, those factors that are central to the research problem” (Leedy and Ormrod, 2001:94). Though this factor is much more prevalent and critical in an experimental research design, or when collecting quantitative data, it is still an important consideration for qualitative data collection such as that performed in the course of this research. Again, starting with a list of questions to be asked of each interviewee was helpful in keeping the interview on track, and not going off on tangents that would not help answer the research and investigative questions at hand. At the same time, the interview format affords the flexibility to explore different ideas and avenues as they come up in the course of the interview. This flexibility was very helpful as the interviews progressed, and necessary breadth of perspective was gained from each interviewee during the course of the interviews.

Leedy and Ormrod (2001:94) state “the data should be susceptible to measurement”. One method of measurement is comparison, and that is the primary method of measurement chosen for use in this research endeavor. By asking the same questions of the subject matter experts interviewed during the course of this research, it was possible to compare their answers against each other. In this way, it was possible to measure one response against another or one response against a group of responses to the same question. This measurement was very helpful as the reearch progressed the data collection phase to the data analysis phase, where organization and categorization of the collected data were important first steps.

Validity and Reliability

Many researchers, academics and practitioners agree "the development of case study designs needs to maximize four conditions related to design quality: (a) construct validity, (b) internal validity (for explanatory or causal case studies only), (c) external validity, and (d) reliability (Yin, 2003:19)." Again, though not as clear-cut as research that uses quantitative data, the case study utilizing qualitative data, if properly designed, should satisfy all four of these conditions.

Construct validity is defined as "the extent to which an instrument measures a characteristic that cannot be directly observed but must instead be inferred from patterns in people's behavior" (Leedy and Ormrod, 2001:98). In other words, a design that meets the definition of construct validity would be designed, or constructed, in such a way that it measures what it was intended to measure. Through employing the collective case study design and relying on interviews with subject matter experts in the field of aircraft maintenance, the questions used in this collective case study are designed to measure what actions and decisions were actually beneficial in implementing reliability-centered maintenance analysis into preventive maintenance programs for various aircraft.

"The internal validity of a research study is the extent to which its design and the data that it yields allow the researcher to draw accurate conclusions about cause-and-effect and other relationships within the data" (Leedy and Ormrod, 2001:103-104). This researcher sought to determine which actions and decisions contributed to the successful implementation of reliability-centered maintenance analysis in preventive maintenance programs. One strategy recommended by Leedy and Ormrod to meet the criteria of internal validity is triangulation. To employ the strategy of triangulation, "[m]ultiple sources of data are collected with the hope that they all converge to support a particular hypothesis or theory. This approach is especially common in qualitative research" (Leedy and Ormrod, 2001:105). The design of multiple case studies employs this strategy of triangulation, and was used specifically to find commonality in the responses of numerous subject matter experts to the same questions, thus adding internal validity to the overall design.

"The external validity of a research study is the extent to which its results apply to situations beyond the study itself – in other words, the extent to which the conclusions drawn can be generalized to other contexts" (Leedy and Ormrod, 2001:105). One of the strategies used to enhance this external generalizability is the use of a representative sample (Leedy and Ormrod, 2001:105-106). Given the particular category of aircraft maintenance at which this research is aimed, interviewing subject matter experts from the Air Force, the Navy, the Coast Guard and commercial aviation constitutes a representative sample of the broader category of aircraft maintenance, from which inferences about the category can then be made. Leedy and Ormrod (2001:106) call this an example of inductive reasoning. Deductive logic and inductive reasoning are two of the cognitive tools developed over the past several millennia to help better understand the unknown (Leedy and Ormrod, 2001:34). While deductive logic involves the use of an "if-this-then-that logic" (Leedy and Ormrod, 2001:34) that begins with widely accepted or self-evident premises, and proceeds from these premises to a logical conclusion, inductive reasoning begins with an observation. For instance, if you put your hand immediately over the flame of a candle, you get burned. No matter how many times you repeat this action, the result is the same. You may then hypothesize that if you put any combustible material immediately over the flame of a candle, it will ignite. This is an example of inductive reasoning. Inductive reasoning is the cognitive tool used in the case study design of this research. The approach employed was to find a pattern in successful implementations of reliability-centered maintenance analysis in other venues and use the recurring themes, ideas, or concepts to develop an effective Air Force reliability-centered maintenance implementation for the F-15.

Yin (2003:34) defines reliability as "demonstrating that the operations of a study – such as the data collection procedures – can be repeated, with the same results", and recommends use of the case study protocol and developing a case study database (see Table 7) as tactics to increase this reliability. In this research, the case study protocol recommended by Yin (2003:69) was used. Yin (2003:69) advocates a protocol containing: an overview of the case study project, field procedures, case study questions, and a guide for the case study report.

Table 7 - Case Study Tactics for Four Design Tests (Yin, 2003:34)

Tests	Case Study Tactic	Phase of research in which tactic occurs
Construct validity	• Use multiple sources of evidence	data collection
	• Establish chain of evidence	data collection
	• Have key informants review draft case study report	composition
Internal validity	• Do pattern-matching	data analysis
	• Do explanation-building	data analysis
	• Address rival explanations	data analysis
	• Use logic models	data analysis
External validity	• Use theory in single-case studies	research design
	• Use replication logic in multiple-case studies	research design
Reliability	• Use case study protocol	data collection
	• Develop case study database	data collection

To develop an overview of the case study project, Leedy and Ormrod's (2001:60-63) process for constructing the research proposal was followed. In order to identify the research and investigative questions for the research, discussions with the sponsor were held. Additionally, the sponsor was able to provide detail as to what actions led up to the requirement for this research. This overview of this case study project was developed at the outset, and is documented in Chapter 1 of this thesis. Similarly, the guide for the case study report was provided in the form of the Style Guide for AFIT Theses and Dissertations, May 2005, and this guide has been adhered to throughout this report. Having complied with these components of the case study protocol, we move on to the field procedures and case study questions.

The field procedures include "access to the case study 'sites', general sources of information, and procedural reminders" (Yin, 2003:69). My early research into the topic area led me to the selection of possible interviewees, which will be discussed in place of the sites referred to by Yin, since my case studies were performed as interviews of subject matter experts, not as visits to physical locations. My search for interest in sponsoring my research project led me to interaction with a Lead Engineer at the 330th Fighter Sustainment Group, and as he was assigned to be my point of contact, or sponsor, he became my logical first interviewee. Our subsequent conversations led me to other sources of information in the areas of Air Force and commercial aviation use of reliability-centered maintenance. During an internet search for literature review material on the subject of reliability-centered maintenance, a website that referenced the NAVAIR Reliability-Centered Maintenance Steering Group was found. Following the contact link on the website allowed contact with two members of the Steering Group's executive committee, who agreed to be interviewed. The information encountered during the literature review for this research formed a comprehensive list of sources of general information which was used to formulate interview questions and to gain enough of an understanding of what reliability-centered maintenance is and is not to be able to comprehend what the interviewees were likely to discuss so that the researcher could intelligently lead the interview and make sure the required information was collected. As to procedural reminders, Yin (2003:72) cautions "[t]he nature of the interview is much more open-ended, and an interviewee may not necessarily cooperate fully in answering the questions." The procedural reminders, therefore, should exist to assist the researcher in collecting the data they set out to collect, not veering too far off course, and certainly not omitting or missing any data they intended or needed to collect. The case study questions are a key means to accomplish this focus for interviews.

"The protocol's questions, in essence, are your reminders regarding the information that needs to be collected and why" (Yin, 2003:74). As more was learned about the evolution of reliability-centered maintenance and its use, not only in the aircraft industry, but in other areas such as plant maintenance, a list of questions was developed. The list was developed such that the questions would be suitable to bring out those salient characteristics of reliability-centered maintenance implementations that might be applicable in answering the research question. As the literature review process was continued, the list of questions lengthened, and then was cut, in order to better focus on the aspects of reliability-centered maintenance implementations which were applicable to answering the research question. Before these questions could be effectively used to gain the needed insight, the list had to be organized. Yin (2003:74) recommends "every question should be accompanied by a list of likely sources of evidence." Since the list of possible contacts was being generated at the same time the literature review was being performed, this was an iterative process. The list was repeatedly reviewed, and with each review, possible sources of the information to answer the question were added. Eventually, this process led to four separate lists of questions, sorted by probable source. These four lists became the questions used to gather data in the interviews, and are found at Appendix A.

Yin (2003:97) recommends adhering to three principles to maximize the benefits gained from the source of evidence employed in the data collection, and to establish "the construct validity and reliability of the case study evidence." These principles are: (1) use multiple sources of evidence, (2) create a case study database, and (3) maintain a chain of evidence (Yin, 2003:97-105). To support the first principle, using multiple sources of evidence, Yin (2003:97-98) refers to the idea of “triangulation,” stating “the most important advantage presented by using multiple sources of evidence is the development of *converging lines of inquiry*.” Leedy and Ormrod (2001:105) support this concept when they define triangulation, stating “[m]ultiple sources of data are collected with the hope that they all converge to support a particular hypothesis or theory.” Since the aim of this research is to analyze and synthesize data from various reliability-centered maintenance implementations into an effective implementation for the F-15, the concept of triangulation is integral to the methodology employed.

Yin (2003:101-102) states “a case study database increases markedly the reliability of the entire case study,” but states “[t]oo often, the case study data are synonymous with the narrative presented in the case study report, and a critical reader has no recourse if he or she wants to inspect the raw data that led to the case study’s conclusions.” Again, every interview conducted during the course of this research was digitally recorded and transcribed. These transcriptions are available in their entirety in Appendices B-G.

Finally, Yin (2003:105) tells the researcher to “maintain a chain of evidence”, “similar to that used in forensic investigations,” asserting this chain of evidence will “increase the reliability of the information in a case study.” In order to meet the requirements of this principle, the derivation of the methodology employed has been listed in this chapter, the case study protocol used has been described in detail, the evolution of the case study questions used has been illustrated, and the verbatim responses to these questions gained during the interviews have been transcribed and provided.

Data and Data Collection

One of the first considerations for researcher who has settled upon a research question is what type of data to collect. There are two basic divisions of data: quantitative and qualitative. Leedy and Ormrod (2001:101) state "quantitative research is used to answer questions about relationships among measured variables with the purpose of explaining, predicting, and controlling phenomena." On the other hand, "qualitative research is typically used to answer questions about the complex nature of phenomena, often with the purpose of describing and understanding the phenomena from the participants' point of view" (Leedy and Ormrod, 2001:101). Given the research question to be answered here, it is logical that the data collected would be primarily qualitative data. The result of the reliability-centered maintenance analysis being performed by Wyle Labs on behalf of the 330th Fighter Sustainment Group is a mix of qualitative and quantitative data. However, this data, while it forms the basis for this research and is therefore important as a foundation for the research effort, is not the primary data used to answer the research question. The primary data collected during the interviews is qualitative data. It is this qualitative data which, after collection, analysis, and synthesis, is the primary source of uncovering the answer to the research question.

Leedy and Ormrod (2001:149) list "observations, interviews, documents (e.g. newspaper articles), past records (e.g. previous test scores), and audiovisual materials" as data sources for the case study. Yin (2003:85) cites six sources of evidence: "documentation, archival records, interviews, direct observations, participant-observation, and physical artifacts." While documents were very useful in the literature review stage of this research, only a few of the many documents reviewed were actually helpful in answering the research question. NAVAIR Management Manual 00-25-403, Guidelines for the Naval Aviation Reliability-Centered Maintenance Process is one such example, since it details NAVAIR guidance for how reliability-centered maintenance should be employed in the maintenance of Navy aircraft. Because successfully and completely answering the research question involved gathering information on numerous reliability-centered maintenance implementations, all of which happened in the past, the people who played key roles and were intimately involved with the process form the key pool of valid information sources. The fact that the implementations used as data sources happened in the past made direct observation impossible, but the people involved in those implementations are still available. Similarly, the other data sources recommended by the authors were either impractical or not applicable. As a result, the interview was the most logical choice for data collection for this research.

It is important to note that case study interviews do not follow the rigid, structured setup commonly employed by journalists. Marshall and Rossman (1989:82) state "[t]ypically, qualitative in-depth interviews are much more like conversations than formal, structured interviews. The researcher explores a few general topics to help uncover the participant's meaning perspective, but otherwise respects how the participant frames and structures the responses." "The interviews will appear to be guided conversations rather than structured queries" supports Yin (2003:89), who goes on to define three types of case study interviews: the open-ended, the focused interview, and the survey (Yin, 2003:89-91. "A second type of interview is a *focused interview*, in which a respondent is interviewed for a short period of time – an hour, for example. In such cases, the interviews may still remain open-ended and assume a conversational manner, but you are more likely to be following a certain set of questions derived from the case study protocol." A decision to primarily employ this focused interview technique was made, using the lists of previously developed questions as a starting point, then allowing the interview to flow naturally as an open-ended conversation, referring back to the question list to ensure all the required material was covered before ending the interview. Yin (2003:92) cautions interviews are "subject to the common problems of bias, poor recall, and poor or inaccurate articulation." To combat these problems, a digital voice recorder was used to record every interview conducted in its entirety. Yin (2003:92) advocates recording interviews to improve the accuracy of the data collected during the interview, but further cautions about the use of recording devices, stating:

> However, a recording device should never be used when (a) an interviewee refuses permission or appears uncomfortable in its presence, (b) there is no specific plan for transcribing or systematically listening to the contents of the electronic record – a process that takes enormous time and energy, (c) the investigator is clumsy enough with mechanical devices that the recording creates distractions during the interview itself, or (d) the investigator thinks that the recording device is a substitute for 'listening' closely throughout the course of an interview.

To address these concerns, each interviewee was asked for permission to record the interview prior to starting to record, the transcription was used as the first part of the analysis of the data, the function and setup of the recording equipment was checked before each interview, and the interviewee that was ensured that the interviewer was focused on the conversation by interjecting acknowledgement often during the interview. In this manner, the benefits of accuracy were achieved, avoiding bias and recall issues, while negating the possible negative consequences of using recording equipment. As a result of this forethought and preparation, no mechanical difficulties, missed conversations, or awkward disruptions were encountered during the course of conducting and recording the interviews.

Data Analysis Methodology

Yin (2003:116-137) lists five possible specific analytic techniques for case study research. These techniques are: pattern matching, explanation building, time-series analysis, logic models, and cross-case synthesis. Pattern matching “compares an empirically based pattern with a predicted one (or with several alternative predictions). If the patterns coincide, the results can help a case study to strengthen its internal validity” (Yin, 2003:116). Since this research employed the collective case study design to search for commonalities between successful reliability-centered maintenance implementations in various venues, no predicted pattern was supposed or developed, and the pattern matching analysis technique was not employed. The explanation building technique was also not selected, since it is a ”special type of pattern matching” (Yin, 2003:120). Time-series analysis utilizes “the match between a trend of data points compared to (a) a theoretically significant trend…(b) some rival trend…versus (c) any other trend” (Yin, 2003:124). Since the interviews conducted to collect data for this research relied on the memories and experiences of subject matter experts and their experiences with reliability-centered maintenance implementations, there were no hard and fast time-specific series of events to rely on. For this reason, use of the time-series analysis was inappropriate. The logic model technique starts with the researcher proposing a “repeated cause-and-effect pattern” (Yin, 2003:127) of events and actions over time that lead to an outcome or end state. “[T]he case study analysis would organize the empirical data to support (or to challenge) this logic model" (Yin, 2003:128). This analytic technique was not chosen because "[a] key ingredient is the claimed existence of repeated cause-and-effect sequences of events, all linked together" (Yin, 2003:128), and this research made no such claims at the outset.

Cross-case synthesis was chosen as the analytic technique to be employed for this research. "This technique is especially relevant if…a case study consists of at least two cases" (Yin, 2003: 133). This technique "treats each individual case study as a separate study" and helps to synthesize ideas and concepts by "aggregating findings across a series of individual studies" (Yin, 2003:134). One method recommended by Yin to accomplish the cross-case synthesis is the use of word tables "that display the data from the individual cases according to some uniform framework" (Yin, 2003:134). Once various word tables were constructed and examined, "the analysis of the entire collection of word tables enabled the study to draw cross-case conclusions" (Yin, 2003:135). Yin goes on to point out that a danger in using cross-case synthesis is that it relies "strongly on argumentative interpretation" (Yin, 2003:137), but also points out "this method is directly analogous to cross-experiment interpretations" (Yin, 2003:137) and the key to countering this danger is "to develop strong, plausible, and fair arguments that are supported by the data" (Yin, 2003:137). In order to facilitate organizing the data from the six interviews conducted in this research, the data analysis technique specified for case study research forwarded by Leedy and Ormrod (2001:150) was employed. They list the following five steps as typical for data analysis in case studies:

1. Organization of details about the case.
2. Categorization of data.
3. Interpretation of single instances.

4. Identification of patterns.
5. Synthesis and generalizations.

These five steps were followed in the analysis of the data for this research.

The first step in organizing the details of the cases was transcription of the digitally recorded interviews. Though this was a long, tedious process, it also afforded the opportunity to closely analyze the responses to the questions and initially identify common and recurring themes.

Categorization of the data was accomplished by using the investigative questions as a framework. Word tables were created to search for data that pertained to each of the investigative questions. Again, the investigative questions for this research are:

1. How have the United States Navy, the United States Coast Guard, other Air Force organizations and Northwest Airlines performed reliability-centered maintenance analysis?
2. How the United States Navy, the United States Coast Guard, other Air Force organizations and Northwest Airlines implemented reliability-centered maintenance analysis in a revised PM program?
3. What characteristics, actions, and decisions were instrumental to the success of the other reliability-centered maintenance implementations?
4. What problems were encountered in the other implementations, and how were they eliminated or mitigated?
5. How can these successful actions and decisions be combined and applied to an effective reliability-centered maintenance implementation for the F-15?

A word table cataloguing reliability-centered maintenance analysis methodologies utilized by the interviewees was constructed to help answer investigative question one. A second table that catalogued how the analysis was used was constructed to help answer question two. Two word tables, one that listed essential elements of success and one that listed how these elements of success were accomplished, were created to help answer question three. Two word tables, one that listed problems encountered and one that listed the solution(s) to these problems, were created to help answer question four. Once the blank tables were constructed, the transcript of each interview was reviewed six times, a separate review to gather data that pertained to the each of the six tables that was being filled during that particular review. The completed word tables are shown as Tables 8 through 14.

Once the word tables were completed, analysis continued by reviewing Tables 10 through 13, which contained the essential elements for success, the means of acquiring each element, the roadblocks encountered, and the solutions to those roadblocks. This review was performed to search for both single instances and recurring themes and ideas. Unless a single instance of an essential element of success was clearly shown to be significant, it was not included in further analysis. Those items that showed up in more than one line of the word table, i.e., ideas, essential elements of success, roadblocks, and solutions to roadblocks that were evident in more than one interview were further analyzed as possible elements to the solution for the F-15 implementation. The result of this step in the analysis was a final list of essential elements of success with how these elements were accomplished, and a list of potential roadblocks with how these problems were eliminated or mitigated by the interviewees. These lists are shown in Table 14.

The final step was synthesis, where these ideas were applied to the specifics of the F-15 implementation in order to answer the research question. In addition to the knowledge attained during the research process, the experience of the researcher as a career maintainer in the Air Force was a primary tool used during the synthesis phase. In addition to the items gleaned from the word tables, the concerns of the lead engineer in the 330th Fighter Sustainment Group who initiated the reliability-centered maintenance analysis and the project manager from Wyle Labs who oversaw the analysis were incorporated to ensure the problems they foresaw were addressed. These concerns were:

- Air Force data collection in the Core Automated Maintenance System (CAMS) is not clean enough to be relied on for analysis – this problem has already been overcome by the data analysis team at Wyle Labs performing a line by line scrub of the data. The concern was listed more as a desire to have a better data collection system, since that would make future data analysis much less labor intensive.
- Air Combat Command (DRA-15) buy-in, specifically their potential concerns with safety and reliability of aircraft
- Lack of Air Force-level guidance resulting in reliability-centered maintenance falling into disuse as it currently has or lack of consistency in the way reliability-centered maintenance analysis is performed and used in the Air Force.
    - Lack of consistency resulting in other SPOs denouncing reliability-centered maintenance when whatever process they are using is compared to the reliability-centered maintenance analysis for the F-15.
- Continued funding for a sustained reliability-centered maintenance program

The ACC (DRA-15) buy-in concern is similar to the leadership buy-in which showed up on both the essential items word table and the potential roadblocks word table. The concern over lack of Air Force-level guidance, and the sub-concern of lack of consistency directly relate to the essential element of the NAVAIR 00-25-403 guidance. The concern of funding to sustain the program also directly correlates to the same issue in the word tables. Having ensured the concerns of the program manager and lead engineer would be considered in the recommended solution, it was time to synthesize the recommended actions listed above into a recommended solution for the F-15. The results of this analysis are contained in Chapter Four.

Human Subjects Information

As the data collection for this research relied solely upon interviews with subject matter experts in the area of reliability-centered maintenance implementation in preventive maintenance programs, an exemption from the human experimentation requirements contained in Air Force Instruction (AFI) 40-402 was applied for and granted.

Summary

In this chapter, the use of the collective case study as the research design employed for this thesis were discussed and justified. Additionally, the collection of qualitative data as the most effective means of answering the research question posed was supported. A discussion of the ways in which this research methodology met the requirements of validity and reliability followed. Finally, the data collection method employed was described in detail and substantiated. Having dealt with methodology issues for the research itself and the data collection process, we move on to the analysis of the data collected.

IV. Analysis and Results

Chapter Overview

In this chapter, the data collected during the course of the multiple case study conducted for this research effort will be analyzed, and the results of this analysis will be synthesized to answer the fundamental question of this research: How can the reliability-centered maintenance analysis being performed for the F-15 system program office be successfully implemented in a revised preventive maintenance program for the F-15? The analysis will be broken down into the investigative questions posed to develop the answer to the research question:

6. How have the United States Navy, the United States Coast Guard, other Air Force organizations and Northwest Airlines performed reliability-centered maintenance analysis?
7. How the United States Navy, the United States Coast Guard, other Air Force organizations and Northwest Airlines implemented their reliability-centered maintenance analysis in a revised preventive maintenance program?
8. What characteristics, actions, and decisions were instrumental to the success of the other reliability-centered maintenance implementations?
9. What problems were encountered in the other implementations, and how were they eliminated or mitigated?
10. How can these successful actions and decisions be combined and applied to an effective reliability-centered maintenance implementation for the F-15?

Investigative Question One

How have the U.S. Navy, the U.S. Coast Guard, other Air Force organizations and Northwest Airlines performed reliability-centered maintenance analysis?

In order to effectively apply lessons learned, successful elements and methods to mitigate problems from other reliability-centered maintenance applications, it is important to understand how those applications compare to the application of the analysis being performed for the 330th Fighter Sustainment Group. The word table below, Table 8, shows the salient characteristics of the reliability-centered maintenance analysis methods employed by the six interviewees.

Table 8 – Word Table for How Analysis Was Performed

Interviewee	How was reliability-centered maintenance analysis performed?
1	- Failure modes and effects analysis + tailored MSG-2 logic for AV-8B
2	- MSG-2 derivative for A-7 - MSG-2 with IMC for E-6
3	- Adapted Aircraft Structural Integrity Program techniques including Weibull analysis to functional systems analysis on C-141 - Failure modes, effects and criticality analysis with MSG-3 decision logic on C-5
4	- Adapted Aircraft Structural Integrity Program techniques and modified MSG-2 logic on C-141
5	- MSG-2 and MSG-3 analysis on 747, DC-9 and DC-10 - MSG-3 analysis on C-5
6	- Modified MSG-3 logic tree with Weibull analysis of historical data (no failure modes, effects and criticality analysis) on H-60, H-65, C-130 and HU-25 aircraft

The analysis methods employed by the interviewees vary widely. All contain some variation of either MSG-2 or MSG-3 logic used in concert with various data analysis methods, including failure modes, effects and criticality analysis, failure modes and effects analysis, and Weibull analysis of historical data. Failure modes, effects and criticality analysis and failure modes effects analysis were discussed in the literature review on reliability-centered maintenance. Weibull analysis involves collecting data on failure times, and then analyzing this data and fitting a Weibull curve to the data in order to predict when failures are likely occur. In comparison, the analysis being performed by Wyle Labs uses their Versatile Reliability-Centered Maintenance System (VRCMS) software suite, which implements the decision logic in Society of Automotive Engineers Standard JA1011, *Society of Automotive Engineers Evaluation Criteria for Reliability-Centered Maintenance Processes*, and has been adapted directly from NAVAIR's Integrated Reliability-Centered Maintenance System (Integrated Reliability-Centered Maintenance System) software package. The Integrated Reliability-Centered Maintenance System was developed to implement the decision logic in NAVAIR 00-25-403, *Guidelines for the Naval Aviation Reliability-Centered Maintenance Process*. The guidelines in NAVAIR 00-25-403, in turn, were developed using Society of Automotive Engineers Standard JA1011 as a reference. Since Society of Automotive Engineers Standard JA1011 was developed to "evaluate any process that purports to be an reliability-centered maintenance process, in order to determine whether it is a true reliability-centered maintenance process" (Society of Automotive Engineers, 1999), it is reasonable to assume that variations of MSG-2 and MSG-3 decision logic, upon which the standards listed in Society of Automotive Engineers Standard JA1011 were based, are at least similar enough to the analysis performed by Wyle Labs as to facilitate comparison of their salient characteristics. The differences in how these analyses were implemented, however, warrant further discussion.

Investigative Question Two

How have the United States Navy, the United States Coast Guard, other Air Force organizations and Northwest Airlines implemented reliability-centered maintenance analysis in a revised preventive maintenance program?

Despite the commonality displayed in the analysis techniques employed by the six interviewees, the way the analysis was used varies significantly. The results of the data analysis for investigative question two are contained in Table 9.

Table 9 – Word Table for How Analysis Was Used

Interviewee	How was analysis used?
1	Revised preventive maintenance program for AV-8A to develop preventive maintenance program for new AV-8B
2	Revised preventive maintenance program for A-7 Revised preventive maintenance program for E-6
3	Used to predict failures, estimate mean time between failure and reliability, rank order components or systems by work unit code as to which needed most attention, and repackaged maintenance intervals or performed “zero time” overhaul for C-141 Used to evaluate maintenance tasks currently contained on work card decks (ISO inspections) to facilitate revision of preventive maintenance program, including lengthening programmed depot maintenance input cycle for C-5
4	Used to predict failures, estimate mean time between failure and reliability, rank order components or systems by work unit code as to which needed most attention, and repackaged maintenance intervals or performed “zero time” overhaul
5	Developed and revised preventive maintenance program for 747-400, DC-9 and DC-10 Used to revise preventive maintenance program and support recommendation of lengthening programmed depot maintenance cycle for C-5
6	Used to revise preventive maintenance programs for H-60, H-65, C-130 and HU-25 aircraft

While the analyses of interviewees one, two, five and six were used to develop and revise preventive maintenance programs, the analyses performed by interviewees three (on the C-141) and four were used only to target systems and components for attention in an effort to improve reliability and/or predict the failure time or rate. In this respect, the use of the analysis is appreciably different for interviewees three (on the C-141) and four, and the use of their reliability-centered maintenance analysis is not applicable to answering investigative question two. Coincidentally, they are also the two interviewees that are solely involved with Air Force applications of reliability-centered maintenance. Interviewees from the Navy, the Coast Guard, and commercial aviation all used their analysis to revise their preventive maintenance programs using some variant of MSG-2 or MSG-3 logic, as did interviewee three on the C-5 aircraft. Also important to note is the fact that interviewee 6 did not use failure modes, effects and criticality analysis to identify failure modes to be analyzed, but instead used analysis of historical data, sometimes by mere consensus, as a means to identify opportunities to apply the decision logic. Again, none of these differences are such that they present a problem with applying common themes to a solution for the F-15, but an understanding of the differences is important in order to put the differences in techniques utilized and the results of those techniques into proper perspective. In formulating a response to investigative question two, only the data from the word tables for interviewee one, two, three (only as related to the C-5), five and six will be used to answer investigative questions three, four and five.

Investigative Question Three

What characteristics, actions, and decisions were instrumental to the success of the other reliability-centered maintenance implementations?

Table 10 contains the data gathered from the six interviewees pertaining to essential elements of success for their reliability-centered maintenance implementations.

Table 10 – Essential Elements of Successful Reliability-Centered Maintenance Implementation

Interviewee	What were essential elements of successful implementation?
1	- Resource support - Leadership support at program management and HQ NAVAIR levels - Fleet maintainer participation
2	- Business Case - Navy leadership support - Written guidance on how to conduct reliability-centered maintenance analysis and implementation
3	- Still ongoing, none given
4	- Upper management/leadership support - Grass roots support from maintainers in the field
5	- Cleansed data - Business case - Engineering sharing view of reality from maintainers' perspective - Continuous program with constant data collection, re-evaluation and updates - Leadership commitment and support
6	- Minimum resource expenditure - Involvement of field personnel in evaluating proposed changes before implementation

Since the reliability-centered maintenance analysis conducted by interviewees three and four were not used to revise an existing preventive maintenance program, the data from interviewees three (as related to the C-141) and four will not be used to answer this investigative question. In the remaining four interviews, leadership support and maintainer participation are listed in three as an essential element of success. The remaining listed elements, along with the frequency they are listed, are: business case (2), resource support (1), written guidance (1), cleansed data (1), and continuous nature of program (1). Thus, leadership commitment, maintainer participation and a successful business case showed up in more than one interview as an essential element of success. Combining these frequencies with the experience of the researcher, these items all make sense for inclusion in the F-15 solution.

Without leadership support, Air Force units quickly find themselves in a position where necessary prioritization means a program will not get the time, attention, and resources necessary to see it through. Because of the scarcity of resources throughout the Department of Defense, and continued efforts to reduce the manpower pool of the Air Force to meet end strength goals, leadership support is vital to any program or effort being continued.

Since responsibility for the successful execution of the preventive maintenance program falls on maintainers, maintainer participation is essential for the success of a revised preventive maintenance program. Educating the maintainers and involving them in the process not only ensures the program designed by the engineers is the same one that gets implemented, it also gives the maintainers a sense of ownership and understanding in the new program, which are vital to reduce their innate resistance to change.

Presentation of a successful business case is also vital in an environment of scarce resources, since the business case justifies both the leadership commitment and resource allocation necessary to successfully implement the program. Fortunately, the 330th

Fighter Sustainment Group has already built a few business cases, including a component review on the rate sensing assembly (RSA), a component review on the oxygen system regulator, a review of the flight control and landing gear rigging procedures and a component review of the horizontal stabilator servoactuator assembly. The recommendations from any one or all of these reviews could be implemented with limited up-front resource expenditure, and the favorable expected results would prove the value of reliability-centered maintenance analysis to leadership, middle management and maintainers in the field, thus providing the desired business case.

The remaining items were all given only once, and thus deserve more scrutiny before determining whether or not they warrant consideration for inclusion in the F-15 solution, since triangulation of data greatly contributes to the validity of the research and its outcomes. To effectively consider these singularly occurring elements, it is beneficial to also look at how they were achieved. The data on how these essential elements were achieved is contained in Table 11.

Table 11 – How the Essential Elements Were Facilitated or Achieved

Interviewee	How were these elements facilitated or created?
1	- Cost avoidance data to show the benefits far exceeded the costs - Visits by leadership to show them what was being done and how it was beneficial - Direct involvement of those maintainers and officers most familiar with weapons system in maintenance analysis and implementation
2	- Used reliability-centered maintenance to counter rising depot costs by determining proper interval for programmed depot maintenance - Written statement from the Chief of Naval Operations supporting the Integrated Maintenance Concept based on reliability-centered maintenance, letters from engineering/logistics admirals supporting reliability-centered maintenance when necessary - NAVAIR 00-25-403, Reliability-Centered Maintenance Handbook and, to a lesser degree, NAVAIR Instruction 4790.12a, which mandates use of reliability-centered maintenance for all preventive maintenance program changes
3	- N/A
4	- Engineer on Air Force Materiel Command staff who supported program and translated benefits to general officer - Effective communication of program to maintainers as it was developing. Also, retired maintainers on engineering staff that were known and respected by maintainers in the field.
5	- Functional teams with practical experience to drill down data to root causes via a line by line review of all data in data collection system - Show cost avoidance data as soon as it's available - Interaction and effective communication between preventive maintenance program engineers and maintainers - Leadership commitment and strong facilitation to implement and maintain program - Pre-existing, reinforced by bringing each new commander up to speed on program when they took office
6	- Reliance on field personnel to make decisions based on historical data using revised MSG-3 logic vs. failure modes, effects and criticality analysis and MSG-3 by engineers - Prime unit for affected weapons system consulted for input before recommendation for change made to Coast Guard leadership

Resource support is only listed once as an essential element of success. However, the lack of sustained funding is also listed as a significant problem by another interviewee. Additionally, it was a specific concern of the lead engineer at the 330th Fighter

Sustainment Group. For these reasons, sustained resource support is recommended for inclusion in the F-15 solution.

Though written guidance was only given by one interviewer as an essential element of success, it warrants consideration for inclusion in the solution proposed by this research. In the experience of the researcher, programs without specific written guidance do not succeed in the Air Force. Though the Air Force has gone from a regulation-based society to an instruction-based one, written guidance is still essential in fielding any program that will be implemented on more than one occasion. Air Force instructions spell out the things that Air Force leadership thinks are important enough to be done the same way every time they are accomplished. Aircraft maintenance, vehicle maintenance, civil engineering, security forces, personnel, and every other functional area in the Air Force codify the expectations of the airmen in their fields in the form of written instructions. In the absence of written instructions, personnel at all levels implement what they think will work best resulting in stove-piped processes which do not interact effectively with processes in other functional areas. With the scope of this research limited to a solution for the F-15, however, Air Force-level guidance mandating the use of reliability-centered maintenance for all preventive maintenance program development and revision is premature. Once the business case(s) garner support for the F-15 solution, and implementation of the reliability-centered maintenance analysis for the F-15 yields a greatly improved preventive maintenance program, Air Force-level guidance should be considered.

The use of cleansed data and a continuous program, while each listed once as essential elements of successful implementation, are actually components of a true reliability-centered maintenance analysis procedure. Both of these components were included in the Versatile Reliability-Centered Maintenance analysis performed by Wyle Labs for the 330th Fighter Sustainment Group, and so do not need to be re-addressed in the implementation phase.

Minimum resource expenditure was also listed once as an essential element of success, but it was accomplished by choosing not to use failure modes, effects and criticality analysis as an integral part of the decision logic. Since the Versatile Reliability-Centered Maintenance analysis being performed by Wyle Labs does use failure modes, effects and criticality analysis, and since review of available literature and the data contained in the interviews strongly supports the use of failure modes, effects and criticality analysis in the reliability-centered maintenance analysis process, the resources expended to perform failure modes, effects and criticality analysis are fully justified. While every effort should be made to expend resources as frugally and as efficiently as possible, not performing failure modes, effects and criticality analysis as part of the reliability-centered maintenance analysis should not be considered as an option for the F-15 solution.

Investigative Question Four

What problems were encountered in the other implementations, and how were they eliminated or mitigated?

The key problems encountered by the interviewees during their respective reliability-centered maintenance implementations are listed in Table 12.

Table 12 – Roadblocks/Problems Encountered

Interviewee	What were roadblocks/problems?
1	- Lack of program management-level buy in and resource support due to lack of effective communication between program management and engineering - Lack of fleet maintainer buy-in
2	- Lack of maintainer buy-in - Lack of funding for a sustained program - Difficulty in maintaining consistency across programs (weapons systems)
3	- Convoluted approval process for implementation of analysis (three page list of offices that have to coordinate/approve) - Revision of tech data format to include job procedure specifics in multiple locations violates existing instructions
4	
5	- Resistance to change throughout organization
6	- Resistance to program by upper management

The solutions employed or observed by the interviewees to eliminate or mitigate the impact of these problems are shown in Table 13.

Table 13 – Solutions to Implementation Problems

Interviewee	How were the roadblocks/problems dealt with?
1	- Not fixed, but NAVAIR Steering Committee is attempting to solve by facilitating communication and education on benefits of properly implemented reliability-centered maintenance analysis - Education and involvement in process
2	- Involved maintainers in process - Education of leadership that, to be successful, the program must be continuous, and the savings will outweigh the costs - NAVAIR provides Integrated Reliability-Centered Maintenance System software free
3	- Upper management/leadership buy-in to promote top-down flow of approval - Interim use of paper tech data stating intent of regulations are met by having electronic updates linked to all tech data that contains each procedure. Long-term plan is to use electronic tech data exclusively.
4	
5	- Education and training, reinforced by leadership commitment
6	- Business case made with individual component (H-65 gearbox overhaul time)

Resistance to change was identified as a key problem by interviewee five, and interviewee six identified resistance to the program by upper management. The basis of the resistance that interviewee six encountered was concern that the program would be a waste of time, so that resistance also falls under resistance to change. The program management-level buy-in identified by interviewee one was primarily caused by lack of effective communication between engineering and program management, and, while it does fall under the category of resistance to change, the attempted solution by the NAVAIR Steering Committee is to facilitate communication and education. Since the solution proposed by interviewee five incorporates education and training, reinforced by leadership commitment, the resistance encountered by interviewee one can be categorized under the same umbrella as that encountered by interviewee five. Thus, resistance to change is included in the list of potential problems to be addressed in the F-15 solution.

Lack of maintainer buy-in was identified as problematic by two interviewees, and as such deserves inclusion in the F-15 solution. However, maintainer buy-in is already included as an essential item for success, so while it does not need to be listed as a potential problem, the solutions listed by the interviewees who encountered lack of maintainer buy-in as a problem should be considered in the F-15 solution.

Lack of funding and necessary revision of tech data that violates the current technical order format instructions were each listed once as key problem areas. The resource funding issue has been included as a necessary key element of successful implementation. The revised tech data format is not an issue in the F-15 solution, since the intended rewrite of the -6 Inspection Manual for the F-15 will be accomplished by the 330th Fighter Sustainment Group as part of the reliability-centered maintenance implementation, and this rewrite will not include procedural guidance that violates the current Air Force guidelines on technical order format.

Investigative Question Five

How can these successful actions and decisions be combined and applied to an effective reliability-centered maintenance implementation for the F-15?

As stated in Chapter 3, the first step in synthesizing the data collected via the multiple case studies into information applicable to answering the research question was analysis of the data in the word tables from investigative questions three and four. The first sub-step of this first step corresponds to Leedy and Ormrod's (2001:150) third step of case study data analysis: "Interpretation of single instances," which involves examining the available data for "the specific meanings that they might have in relation to the case." Since this is a multiple case study, a single occurrence or mention of an element which was deemed essential to success by an interviewee needed to be examined in order to determine whether it did, or did not, warrant consideration as an essential element of success for the F-15 reliability-centered maintenance implementation. This process was begun when the word tables were examined individually and in pairs to answer the previous investigative questions, and the single instances of essential items for success and potential problems were analyzed and either included or deleted for consideration during that stage of the analysis.

Leedy and Ormrod's (2001:150) next step in case study analysis is "[i]dentification of patterns." This step was also accomplished as the individual word tables were analyzed, and items identified by more than one interviewee were all selected for inclusion on the list of items that should be incorporated into the F-15 solution.

The final step in Leedy and Ormrod's (2001:150) analysis framework is "[s]ynthesis and generalizations." The first sub-step in this analysis to accomplish this synthesis is to bring together all the items that were selected for inclusion in the F-15 solution from the previous steps, as well as how these essential elements were achieved and how the problems were addressed. This information is contained in Table 14.

Table 14 – List of Recommended Components to be Addressed in F-15 Solution and Given Means to Achieve, Acquire or Attain Each Essential Item and Given Methods to Solve Problems

Essential Elements	**Means of Achieving Essential Elements**
Leadership Support	- Visits by leadership to show them what was being done and how it was beneficial - Written statement from CNO supporting IMC based on RCM, letters from engineering/logistics admirals supporting reliability-centered maintenance when necessary - Pre-existing, reinforced by bringing each new commander up to speed on program when they took office
Maintainer Participation	- Direct involvement of those maintainers and officers most familiar with weapons system in maintenance analysis and implementation - Interaction and effective communication between preventive maintenance program engineers and maintainers - Prime unit for affected weapons system consulted for input before recommendation for change made to Coast Guard leadership - Education and involvement in process - Involved maintainers in process
Successful Business Case	- Used reliability-centered maintenance to counter rising depot costs by determining proper interval for programmed depot maintenance - Show cost avoidance data as soon as it's available - Business case made with individual component (H-65 gearbox overhaul time)
Sustained Resource Support	- Cost avoidance data to show the benefits far exceeded the costs - Education of leadership that, to be successful, the program must be continuous, and the savings will outweigh the costs
Key Problem Areas	**Solutions Utilized to Counter Problem Areas**
Resistance to Change	- Education and training, reinforced by leadership commitment - Business case made with individual component (H-65 gearbox overhaul time)

Summary

The keys to success, problems encountered and solutions offered to those problems by the six interviewees were gleaned from the text of the interviews conducted and categorized by investigative question in word table format. These key elements were then considered for inclusion in the F-15 solution, and consolidated into Table 14, which contains the keys to successful implementation offered by the interviewees along with how the interviewees achieved these essential elements. Additionally, the one consistent problem encountered, resistance to change, along with how the interviewees mitigated its negative effects were added to the table. The inclusion of these essential items, along with addressing resistance to change, form the basis of a successful implementation of reliability-centered maintenance analysis in a revised preventive maintenance program for the F-15.

V. Conclusions and Recommendations

Chapter Overview

The preceding chapter answered the five investigative questions used to answer the research question posed by this research effort. In this chapter, the answers to the investigative questions will be synthesized to answer the research question by making recommendations to ensure the successful implementation of the reliability-centered maintenance analysis being performed on behalf of the 330th Fighter Sustainment Group. In addition, recommendations for future research will be made.

Recommendations

Table 4.7 contains the recommended elements of a successful implementation of the reliability-centered maintenance analysis being performed on behalf of the 330th Fighter Sustainment Group for the F-15. These essential elements are: leadership support, maintainer participation, successful presentation of a business case, sustained resource support and a response to the anticipated problem area of resistance to change. In order to determine specifically how to best achieve each of these elements, further analysis of the methods the interviewers used was combined with personal experience of the researcher and the specified concerns and desires of the research sponsor.

Leadership Support

Leadership support was gained by the interviewees by bringing leadership to their site for educational update visits and tailored briefings to incoming commanders to familiarize them with the program. This support was evidenced to one interviewee in the form of written policy directives from Navy leadership. The level of leadership support that was expressed as a concern by the lead engineer is the DRA-15 office at Headquarters Air Combat Command. Since DRA-15 is an Air Combat Command unit and the 330th Fighter Sustainment Group is an Air Force Materiel Command unit, it is first important for the Air Force Materiel Command leadership to have buy-in on the implementation of the reliability-centered maintenance analysis. Since Air Force Materiel Command recently hosted a Reliability-Centered Maintenance Summit to discuss how best to proceed with the use of reliability-centered maintenance analysis throughout the Air Force, there appears to be support for the use of reliability-centered maintenance. However, this support may be limited to the directorates directly involved in using reliability-centered maintenance techniques, and senior leadership support is necessary. This can best be accomplished, as evidenced by the interviewees, though the education, training, and involvement of Air Force Materiel Command leadership in not only the specifics of the reliability-centered maintenance process Wyle Labs is performing, but in the basics of reliability-centered maintenance. Several opportunities exist for this basic reliability-centered maintenance training. The Air Force Institute of Technology's School of Systems and Logistics currently offers a course in reliability-centered maintenance. This two-day course, LOG 033, Reliability-Centered Maintenance Engine Workshop, while originally created for the propulsion community, gives a comprehensive overview of RCM fundamentals, and is ideal to educate leadership on what reliability-centered maintenance is, how it is used and the benefits that can be derived from it. Additionally, NAVAIR offers training courses in reliability-centered maintenance. These resources offer possibilities for more formalized training in the basics of reliability-centered maintenance, and should be utilized as the 330th Fighter Sustainment Group sees fit. In addition, briefings by the engineers in the 330th Fighter Sustainment Group and the contractors from Wyle Labs performing the analysis should be given to 330th Fighter Sustainment Group leadership and Air Force Materiel Command leadership before giving these same briefings to DRA-15.

Maintainer Participation

Maintainer participation was accomplished by the interviewees through consulting with maintainers during the analysis process, providing education and training to the maintainers and interaction and effective communication between the engineers performing the analysis and field-level maintainers. Wyle Labs has already involved maintainers from the 159th Fighter Wing of the Louisiana National Guard in New Orleans; the 33d Fighter Wing from Eglin Air Force Base, Florida; the 4th Fighter Wing from Seymour Johnson Air Force Base, North Carolina and the 1st Fighter Wing from Langley Air Force Base, Virginia during their ongoing reliability-centered maintenance analysis. As the changes to the -6 Inspection Manual for the F-15 are published, this fact should be communicated to the rest of the F-15 maintenance fleet, including active, Guard and Reserve units who maintain F-15s. Additionally, F-15 maintainers should be educated on what reliability-centered maintenance is and why it was used to revise the preventive maintenance program for the F-15. While the level of formal training afforded by the Air Force Institute of Technology and NAVAIR is not necessary for this purpose, local Quality Assurance offices could publish Quality Assurance Flashes with standardized information from the 330th Fighter Sustainment Group and Wyle Labs as to what reliability-centered maintenance is, why the reliability-centered maintenance analysis was performed for the F-15, how the implementation of that analysis will change the F-15's preventive maintenance program, and sources of additional information, to include the training briefings available on the NAVAIR website. Additionally, the Career Development Course courseware for F-15 maintenance Air Force Specialty Codes could be updated to contain background on what reliability-centered maintenance is, how it is used, and the impact maintainers can have on the cleanliness of the data used to make decisions by ensuring accuracy when completing jobs in the Core Automated Maintenance System and Computerized Fault Reporting System maintenance data collection systems. Finally, a short course on reliability-centered maintenance could be added to the annual recurring training (commonly referred to as block training) required for troops with aircraft maintenance Air Force Specialty Codes.

Successful Business Case

The interviewees presented successful business cases in support of their reliability-centered maintenance analysis implementations primarily by demonstrating cost avoidance and cost savings realized through individual component or program implementations. Since Wyle Labs has already performed numerous component reviews in addition to the four system level reviews already completed, there are choices available for the 330th Fighter Sustainment Group to use for implementation and presentation of a successful business case prior to the implementation of the analysis results for the major systems in a revised preventive maintenance program. It is recommended the 330th Fighter Sustainment Group choose one of these component reviews immediately, gain approval and implement the recommended changes and compare the actual cost avoidance/savings realized to those projected by the analysis. This comparison should then be used to further bolster the case for implementing the major systems analysis in a revised preventive maintenance program.

Sustained Resource Support

Sustained resource support was secured by the interviewees via educating leadership and publishing cost avoidance data which showed the program saved more money than was expended to execute it. Since leadership education will be accomplished to achieve leadership support, that aspect of achieving sustained resource support will be accomplished, as long as the requirement for sustained funding is included in that education. In addition to publicizing the cost avoidance realized through implementation of the selected business case, the 330th Fighter Sustainment Group should collect cost avoidance data for the implementation of the major systems analysis recommendations in a revised preventive maintenance program and publicize the continuing cost avoidance realized by the implementation. This continuing success story should provide continued resource support for a continuous reliability-centered maintenance program for the F-15.

Resistance to Change

The interviewees who listed resistance to change as a major obstacle were able to overcome it by education, leadership support and presentation of a successful business case. Since all of these solutions are part of accomplishing the essential items identified above, the 330th Fighter Sustainment Group should be able to successfully counter the inevitable resistance to change they encounter by recognizing that it will be encountered, remaining vigilant for signs of resistance to change, proactively applying the methods listed above and actively and effectively communicating with all the agencies who are involved in changing the -6 inspection requirements for the F-15.

Conclusions

Implementation of the recommendations supported by this research will enable the 330th Fighter Sustainment Group to successfully implement the reliability-centered maintenance analysis being performed by Wyle Labs in a revised preventive maintenance program for the F-15. This research is important for a number of reasons. First, the money that has been spent performing the analysis will be wasted if the analysis is not used to revise the current preventive maintenance program for the F-15. Second, a potential cost avoidance of around $61.5M per year can be realized by successfully implementing the changes the analysis recommends. Third, the successful implementation of this analysis for the F-15 could serve as a business case for other weapons system sustainment offices to justify using reliability-centered maintenance to revise their preventive maintenance programs, resulting in significantly more savings and cost avoidance for the Air Force. Finally, the business case presented could motivate Air Force leadership to transform the Air Force to an organization that relies exclusively on reliability-centered maintenance analysis as the basis of its preventive maintenance programs.

Recommendations for Future Research

While the scope of this research is a solution to successfully implement a revised preventive maintenance program for the F-15 based on reliability-centered maintenance analysis, future research into how to effectively transform the Air Force into an organization that supports reliability-centered maintenance as the only basis for preventive maintenance program development and revision, as does NAVAIR, should be undertaken. The standardized use of reliability-centered maintenance-based preventive maintenance programs throughout the Air Force should result in significant cost avoidance and savings.

Since reliability-centered maintenance is being applied to more and more diverse areas, such as facility maintenance, manufacturing equipment maintenance and vehicle maintenance, research into how best to incorporate reliability-centered maintenance analysis into existing Air Force preventive maintenance programs in these and other areas could prove useful.

If the Air Force can successfully transform to mandating reliability-centered maintenance as the foundation for all preventive maintenance programs, the resultant commonality of data format in maintenance information systems would be useful as the Air Force continues to pursue an enterprise-wide information system. Research on how best to incorporate the transformation to reliability-centered maintenance throughout the Air Force along with the transformation to the eLog 21 construct could not only facilitate the incorporation of reliability-centered maintenance as the Air Force's method of choice for preventive maintenance program development, but could also prove useful in facilitating the eLog 21 transformation.

Since many Air Force organizations are performing what they call reliability-centered maintenance, another area for useful future research would be to study why there are so many variations in what Air Force organizations consider to be reliability-centered maintenance, including how these pseudo-methodologies came to be employed and whether they could be transformed to true reliability-centered maintenance process. A study of how these variations might affect the Air Force's ability to successfully transform to an organization that supports reliability-centered maintenance as the only basis for preventive maintenance program development and revision would be useful.

The Air Force's current method of data collection, the Core Automated Maintenance System (CAMS) is not user friendly and has been scheduled for replacement by various new information systems over time. The current maintenance information system slated to replace the Core Automated Maintenance System is the Integrated Maintenance Data System (IMDS). Though originally slated to replace the Core Automated Maintenance System in 1997, the Integrated Maintenance Data System is still not fully operational. Research into the proposed design and functionality of the Integrated Maintenance Data System and how this design and functionality could be improved to better accommodate the use of reliability-centered maintenance data collection and analysis would be very beneficial.

There are many elements of the Core Automated Maintenance System's data that necessitate time-intensive and costly scrubbing before the data can be used for reliability-centered maintenance analysis. Research into the effects of such maintenance actions as cannibalization and removal to facilitate other maintenance could save time and money in future iterations of analysis based on this data.

As the Department of Defense continues to seek joint solutions for future weapons systems, such as the Joint Strike Fighter and the F-22, research into the requirements for a joint maintenance data collection database tailored specifically for reliability-centered maintenance analysis could prove very useful and cost effective for future preventive maintenance program development across the Department of Defense.

Research Summary

Reliability-Centered Maintenance provides a framework for developing and sustaining an efficient, effective preventive maintenance program for many different applications. Though its roots are in commercial aviation, reliability-centered maintenance has since been successfully applied to vehicle, plant, and mass transit applications. Through the course of this research, the researcher has gained an understanding and an appreciation of reliability-centered maintenance and how successful a preventive maintenance program based on reliability-centered maintenance analysis can be. It is therefore the sincere wish of this researcher that the recommendations forwarded in answering the question of this research be applied successfully and a revised preventive maintenance program for the F-15 based on the reliability-centered maintenance analysis being performed by Wyle Labs becomes a reality.

Appendix A Interview Questions

Interview Questions Regarding RCM Analysis

1. What was the scope and purpose of the RCM analysis you were/are involved in?

2. What drove the use of RCM analysis?

3. What was your involvement in the RCM analysis?

4. What guidance did you have going into the analysis?

5. How far were you instructed to take the RCM analysis (i.e. task packaging, full implementation, etc.)?

6. What difficulties did you experience during the analysis? How did you resolve these difficulties?

7. Do you feel these difficulties will have an impact on the effectiveness of the implementation? If so, how can this impact be mitigated?

8. What do you feel were the strengths of this analysis?

Interview Questions Regarding RCM Implementation

1. What program(s) have you been involved with that contained RCM analysis and/or implementation?

2. What was your level of involvement/primary role with the program?

3. From your perspective, what went will with the implementation?

4. From your perspective, what went poorly with the implementation?

5. From your perspective, what went “other than as planned” with the implementation?

6. What was your impression of the commitment level by the leadership of the organization to the RCM implementation you were involved in?

7. What actions, guidance, correspondence, direction, etc. did you see that supported this level of leadership commitment?

8. Do you think the level of leadership commitment you experienced helped or hindered the RCM implementation? How and why?

9. How familiar/involved were you with the actual RCM analysis process that was used?

Appendix B Interview One

Interviewer: “The research that I'm doing, the evolution of it was, originally I was looking at trying to incorporate some lean concepts and methodology into the F-15 phase inspection process. And when I finally got an Air Force organization that was interested in my research and willing to sponsor it, I was assigned to Mr. XXXX XXXX who is a lead engineer in the F-15 System Program Office at Warner Robins in Georgia. The first conversation that we had, I sent him my thesis proposal, and he said, ‘I understand what you're looking at doing and I'm happy to help, I’ve been assigned to help you, but I'm not really a lean proponent, and I don't have that much experience with lean. Just for GPs let me tell you what I'm involved in, and maybe this might lead you down a different track.’ Well, the F-15 System Program Office had recently begun performing RCM analysis on the F-15, taking all that historical data, doing FMECA analysis, and then involving field subject matter experts to make sure that the data was good enough to use, in an effort to revise the preventive maintenance program on the F-15 based on RCM analysis. So whereas my initial thesis topic was given these inspection items, if we take for granted that they're the right ones to look at how to most efficiently accomplish the inspection. What Mr. Darcy was involved with was not assuming that the inspection items were correct and instead starting from scratch and saying hey, let's look at…there is a very good chance that a lot of the things that we inspect never break, and therefore we’re wasting time, not being efficient. And also there may be some important things that are breaking that are critical that we’re not looking at, and if we looked at them or did a time change on them or at least an age exploration on them, we would be a lot more efficient and effective in the way we do our inspections. So that seemed to be a lot more down my alley as far as aircraft maintenance; I have 20 years in the Air Force doing aircraft maintenance on the practitioner side of things. And so I said, ‘This lean thing sounded like a good academic exercise, but, what you guys are doing in the system program office there with the F-15 sounds a lot closer to the heart of what I'm interested in and where my experience lies.’ So Mr. XXXX said, ‘We’re already pretty happy with the analysis that were performing.’’ They hired a contractor, Wyle Labs, who are based in Jacksonville, and I think the Navy has done some good work with them as well.”

Interviewee: “Yes, they have.”

Interviewer: “So they hired contractor, Wyle Labs, to do the analysis for them. Mr. Darcy's concern was hey, this is kind of a new thing in the Air Force because, while the Air Force has espoused the idea of RCM as the basis for developing a preventive maintenance program for new acquisitions for a few years, we have not necessarily used it yet, to revise the preventive maintenance program for an existing platform. So his concern was we’re doing all this great work getting this RCM analysis, but if we don't effectively implement this stuff, it's all wasted time and energy and money. So he said, ‘What we would like you to do is do some research on how can we most effectively implement this RCM analysis that we’re performing into a revised preventive maintenance program for the F-15.’ So to that end, I was fortunate enough to do an Internet search and get in touch with Mr. XXXX XXXX, and he pointed me in your direction and let me know about the whole Navy RCM steering group concept, which has been great info. I've spoken with Mr. XXXX XXXX for the Navy perspective on things. I've also gotten in touch for some of the other Air Force System Program Offices who are just starting down the road for RCM and talked to them about some of the challenges they've experienced and how they've overcome them. I also got hooked up with one of the contractors who is currently working with the C-5 Program Office. He has a lot of experience, not only with working with the Air Force, but when he was in the civilian sector with Northwest and how they implemented RCM into their preventive maintenance programs. So my hope is then to perform a collective case study and analyze what's worked for people what hasn't worked for people and what the common critical components were for successful implementation. And I hope to roll them into a plan for how we can effectively use the RCM analysis that they're doing into a new preventive maintenance program for the F-15."

Interviewee: "Sounds great."

Interviewer: "So it's a pretty exciting project, and so far as going pretty well."

Interviewee: "Great."

Interviewer: "So, along those lines, just for background, what are your experiences with reliability-centered maintenance? How did you kind of first-come into the use of reliability-centered maintenance, and what has your experience with it been?"

Interviewee: "My first employment was with the AV-8B program, the Harrier program, and basically they were developed using what we called a tailored MSG-2 logic. So in their maintenance planning documents, they basically had the pseudo-FEMA and a tailored MSG-2 logic. That was what determined their maintenance requirements. I came to work with the program in the '85 timeframe. And basically I started out as a structures subsystem engineer and working with that process, supporting it, and then after a couple of years they designated me as the age exploration lead for the program.

Because basically, we had a lot of default answers within the analysis… we had the AV-8A aircraft, which a lot of the design was grandfathered into the AV-8B system. There are a lot of new technology type systems that were designed as well. And we wanted to collect some data in regards to those systems. We had about 25% of the aircraft was composite. Besides the F-18 which had a few flight control surfaces that were composite, we were one of the major users of composites, and we wanted to do some inspections on those areas as well."

Interviewer: "Was the AV-8B considered a new acquisition, then? Was it different enough from the A?"

Interviewee: "Yes, it was a fairly significant change from the A technology. The technology was leaps and bounds above what we have known and especially the avionics and flight control systems and things of that sort. The basic operations of the systems such as for VSTOL, and the nozzle system and things were similar; better materials, and things of that sort, different bearings being used. So those are areas we also wanted to keep our eyes on and collect some good operational data. Kind of like you talk about for the F-15."

Interviewer: "So you were developing an initial preventive maintenance program for the new, well, what was considered a new airframe, the AV-8B?"

Interviewee: "Exactly. In the maintenance planning process, and using the FEMA that was in that and the tailored MSG-2 logic we did identify maintenance requirements. Some requirements grandfathered from the aircraft, some were new requirements and we were very much involved in that process with McDonnell Douglas at that time. We periodically had gotten together with them and were developing a maintenance plan for going through the logic to determine the maintenance requirements were meeting with McDonnell Douglas engineers, logisticians, as well as fleet maintainers very frequently on these different maintenance plans and subsystems, to go in and come to consensus on the maintenance requirements and the analysis."

Interviewer: "So did McDonnell Douglas have an initial set of hey, here's what we recommend for inspection and maintenance, preventive maintenance type actions as the manufacturer?"

Interviewee: "Yes they did a very good job. They were one of the, and still in my mind, one of the best prime efforts from an RCM standpoint."

Interviewer: "So they used RCM for their initial hack, too?"

Interviewer: "Well, it was the tailored MSG-2 logic. It wasn't classical RCM, but they did stick to that logic, and did a good job with interacting with us, especially with our experience on the As, AV-8As. We provided a lot of great feedback in regards to operational data and things of that sort. So we worked very well together looking at that data in the operations of the systems and together coming up with the, coming to a consensus on the maintenance requirements to use and the maintenance plan, the logic we had in there."

Interviewer: "Did you encounter any situations where the recommendations of your group differed significantly from what McDonnell Douglas's initial recommendations were?"

Interviewee: "Yes, we had some areas where we had maybe more concern in some areas than they did, and these weren't necessarily safety areas, but maybe some areas that were where the design was grandfathered for the B to the A, I mean from the A to the B. And we had concerns on the operations of these areas and a lot of these areas required excessive maintenance and were more an operational or economic consequence than a safety consequence. And a lot of those areas were put under the age exploration program to gather data and then come back and revisit those areas."

Interviewer: "That's an interesting aspect - so you ended up concentrating on the age exploration aspect?"

Interviewee: "Yes, we had a very extensive age program; we actually had aircraft we were bringing into the depot and doing major disassembly and inspection. Like I said, we were…being that this was the first large effort with the composites, we had a lot of NDIs that we were performing on critical composite areas. The entire wing is pretty much composite, except for the spars and the ribs and attach fittings, but the skins and a lot of the major parts were composite. So we were doing a large-scale C-scan area where we could scan the entire wing. We were using the, when McDonnell Douglas built the wing for example, as well as the other composite components they would do their initial NDIs at the factory and you know you had areas that had voids and things of that sort, and they had engineering buy off on those areas and then we would get those records from them. And then as we did our NDIs, our C-scans, we could compare these areas to make sure that none of these voids were resulting delams or growing in any way whatsoever."

Interviewer: "With the airframe or the weapon system being operational during that time while you are performing their age exploration, how did you determine the operational preventive maintenance program requirements for those areas that you were doing age exploration on?"

Interviewee: “Some of those had scheduled inspections that we were performing as well, and some just had age exploration inspections on them, and so it was a combination of that. Some areas we were performing age on areas that did not have scheduled inspections to validate whether we needed a scheduled inspection and on some of the areas we had scheduled inspections, but we were using age to validate whether it was justified or whether the interval was correct.”

Interviewer: “The initial four subsystems that they've done on the F-15, they’ve had quite a few instances where they’ve recommend age exploration, because there's just not enough data to make a good call on what they need to do.”

Interviewee: “Exactly, and we had the same situation we had some default answers where we would go conservative on the interval and perform that but just having a scheduled inspections where if we were just hands-off if the fleet was performing these inspections and collecting the information in a very large but very crude data collection system, we still would not get the quantitative information that we needed to go in and make an engineering assessment on these areas, so we had a lot of hands-on engineering age exploration involvement, where even some of the inspections we were very much in tune with what was occurring. Basically, the fleet, we had our squadrons at Cherry Point, which is where we’re relocated of course, and then the other squadrons were located in Yuma, Arizona, and we actually had a liaison engineer, who we put at Yuma to also help with the inspections and help with the data collection effort, because that's where we had seen some shortfalls from the fleet maintainers. You know, the turnover rate and they’re just not tuned into what we were trying to gather and not in the process or the duties of collecting quantitative data using calipers and things of that sort. We had our flight control systems, we had free play inspections we were performing those because they were significantly redesigned with new bearings and control linkages and such, so we wanted to… we defaulted to scheduled inspection intervals, but we had age exploration as well with the engineers involved with collecting the free play data to determine how the flight control systems were performing. And we found a lot of that information, a lot of the default intervals basically were from F-18 experience. A lot of the bearings and controls and the system design was similar to the F-18 program, with which McDonnell Douglas had more experience. Some of those default intervals were based on F-18 experience. For flight controls, for example, what we found is the majority of the flight control systems were performing better than expected. We moved a lot of the intervals to the right may be twofold if I can recall. On some areas such as the yaw control systems, the rudder - we had reliability problems with those areas, so the age exploration data actually resulted in a redesign to those areas to make those bearings and attach areas more reliable."

Interviewer: "You bring up a couple of interesting points there. First of all, talking about in the 1985 time frame, it's easy to take for granted that computers are used and software is used to help you crunch all the data that you collect a back in those days that wasn't the case. You probably had a heck of a time just maintaining your database."

Interviewee: "Exactly, our fleet system, 3M-Data, now Combs. They pursued a lot of improvements with that - well, what they call improvements with that as far as their ability to collect the information or the user interface to download and assess that information, but still, the quantitative information that you need when you're looking at flight control inspections for example, the free play. You know, what is the free play for this bearing, what is the free play for this linkage? That type of data collection is not the fleet's forte. They're more focused on removing and replacing the component and getting aircraft ready for flight. When you tell them that they've got eight hours of inspections that they need to go to the flight control system and perform, they kind of frown upon that."

Interviewer: "Understand. The other interesting point you brought up was the idea of data cleanliness and scrubbing the data. I can imagine you came across a lot of challenges. Again, coming from an aircraft maintenance background, I've been the guy who's trying to get off work at the end of a 12 hour shift and plug whatever the computer will take in to the data collection system just to get the heck out of there. How did you address those challenges?"

Interviewee: "Like I said there was a lot of engineering hands-on involvement."

Interviewer: "What a mostly in education effort, or?"

Interviewee: "Mainly involved with helping collect the information. The initial goal was to try to use like the bulletin process to get the inspection data, have an age exploration bulletin that we would send out and, you know, have them go out and get the inspections for us. And we tried that for a while. We were not getting the quantitative data that we needed. We would get the data feedback sheets back from these bulletins and, just looking at the data you could tell that they had inspected incorrectly or didn't know how to read the calipers, or something of that sort. So we quickly moved away from the fleet, basically. We pretty much defaulted to the fleet doing the go, no-go-type inspections for us, is it good, is it bad, versus trying to prompt them to collect this quantitative, numerical data for us, that wasn't successful at all. And due to that we wound up having a lot more engineering involvement in helping collect that data. And being that we have the engineering support team here at Cherry Point, and Cherry Point received the fleet leader aircraft that worked very well for us. We could just go down the street, a couple of blocks and participate in the data collection. And then like I said, we had a very intensive age exploration program where we were bringing the aircraft into the depot side itself and doing these inspections and disassemblies and NDIs with the engineers on hand, and the engineer who was involved was also the engineer who was assessing the data and analyzing the failure modes. And he knew firsthand what the analysis needed to show."

Interviewer: "You used the term fleet leader aircraft. Did you have one airframe that was just pretty much flying the heck out of it so you could perform the age exploration inspections on that aircraft?"

Interviewee: "We had numerous aircraft in our age, what we called the age depot program. Basically we had identified… We took a look at the inspections, failure modes that we were addressing, and the criticality of those failure modes. And based on the criticality, we went in and identified three different sample sizes: 21, 25 and 41. 41 of course being for the safety/ critical areas we were monitoring under age. And we had basically we would look at fleet leader aircraft, 21, 25 or 41 for the sample sizes and the inspections that we were investigating in the failure modes we're inspecting for and so we had a significant fleet leader program."

Interviewer: "Was the Navy kind of wholeheartedly espousing the RCM concept that banner was a still pretty new for the Navy?"

Interviewee: "It was fairly new for the Navy. The AV-8B was one of the first programs that took it to heart and actually tried to do it correctly. The F-18 started off on that path, and of course McDonnell Douglas was trying to use the process as well and promote the process. I don't think the Navy side on the F-18 took it to heart like we did on the AV-8B program; they didn't maintain it and sustain it like we did. Here we are in 2005, and they're still have, I mean they are still marching towards a very active RCM program. It's a very dynamic and proactive program. The F-18 basically, we are trying to help them, the steering committee is trying to help them maybe get their baseline analysis up to the point where it should be. So they have not been as successful as the AV-8B program in maintaining the process."

Interviewer: "That's surprising to me, because I figured with as well-established as RCM is in NAVAIR, I mean you've got 00-25-403, which seems like a very significant step in standardizing the process across the board."

Interviewee: "Exactly when it's not a problem with the shortfall in the process or buy-in to the process. Especially down at the engineering logistics working level, it's trying to execute it. It's mainly at the program management level and their buy-in and their support of it from a resource standpoint. The AV-8B had excellent support and communication between program management and the engineering logistics team. They took RCM as the hub of everything they did, to ensure that we had an active data collection, analysis and feedback program. So that's why they've been so successful. The F-18, I think was less successful in that resource being provided to them to execute it."

Interviewer: "Are you able to demonstrate from the AV-8B program being now, what 18, close to 20 years old are you able to demonstrate a business case based on what you've done to show that using the RCM is cost effective in the long run?"

Interviewee: “Oh yes, as you can imagine to get resources you have to justify to the nth degree to the funding source that those resources will be put to good use. So we have always had a very active stay on top of the scenario and looking at things, the unscheduled and scheduled maintenance trends. Looking at the cost benefit to some of the things we've implemented based on performing RCM correctly, which is collecting the data, analyzing the data, and then using the decision logic to come up with the right solution to the failure mode you're addressing. So we spent a lot of time doing that and our local management supported that and program management at headquarters believed in the local management. So basically, that support was there and we just made sure that they stayed in tune with what we were doing here, and with the turnover that you have in program management. We had new program managers coming into the program, and we would make sure that we got in at the beginning when they first took that duty. And we got in there and make sure they understood what we were doing down here and got them started off on the right foot from day one. We were very active in doing that.”

Interviewer: “One of the important things you talked about was having that leadership commitment to the program. What specific actions, guidance, or correspondence-type things did you see that supported that leadership commitment to what you were doing?”

Interviewee: “What we would do is basically we would schedule leadership to come to our site. One of the most successful ways of doing that was having them come here and we'd show them firsthand the data were collecting, the analysis. We showed them the components that we were doing the data collection and analysis efforts on. We showed them the things that we had done. I won’t call it a show-and-tell, but that is probably the closest thing. And that was very successful, doing that. Not just program management, but you know Admiral's double-0, be it Admiral XXXX or others. We had them come down here and show them what we were doing. And they always left with a positive view of the process. And that usually resulted in the resources continuing to help us execute it. We did have a few years on the program where money got significantly tight, and we didn't have the resources to continue the sustainment process like we had been. And we were able to also show during that time frame, how things like maintenance - unscheduled maintenance rose, operational readiness of the aircraft dropped, and we had a lot of problems that we weren't properly staying on top of. And that really did adversely affect the readiness of the aircraft."

Interviewer: "Resources are always a challenge. What other kind of challenges did you face with the initial implementation on the AV-8B?"

Interviewer: "Resources would be the main one. Trying to get some others to understand, others that were involved with our process, like the fleet maintainers. Trying to get them to understand hey here's the process we use to justify maintenance tasks and their intervals. The process prior to that and a lot of other programs was basically, you know, having the ultimate or having some major maintenance meeting. Maintainers and others come in and say, 'I saw this and, therefore I want to implement this new maintenance task.' And unless you have this engineering-based decision logic process, unless you have everyone using that, or at least understanding it at a minimum, because you know, we don't just implement tasks because you've seen a problem. We had to collect data and we show that there is a certain failure mode, we run it through the process, and then we determine what's the best solution for it. So we had to educate people on that. I mentioned the age exploration depot inductions. And the depot, basically, they're in the mindset of when an asset comes into our facility basically, we totally disassemble it and we rework it to a like new condition, and then we turn it around as quickly as possible to get back to the customer. It took awhile to educate them on here's our spec, here's what we're doing. We're inspecting these areas to collect engineering data. So we can monitor these areas and make the right decision, we're not here just to rework this asset. So that took awhile to get them in the proper mindset for that."

Interviewer: "Did you have a champion in the fleet maintenance community or was a direct interaction between the engineering folks in the maintainers?"

Interviewee: "It was direct interaction like I said we were in a good situation that we were here with the fleet here at Cherry Point, and also having engineers at Yuma to monitor that situation. So we had a good rapport with them, as we had transitioned from the AV-8A to the B in that rapport was there as well, based on our previous working relationship with them on the A aircraft as well. And one thing that was important, as I mentioned earlier is that we were working with McDonnell Douglas on developing these requirements and going through the maintenance analysis. We had fleet maintainers participate in that. We ensured that the maintenance officers as well as the maintainers who were most experienced with those assets were part of that process. So we prompted buy-in right from the get-go."

Interviewer: "Anything else from the AV-8B experience you think would be important as far as crossing over to what I'm trying to do here?"

Interviewee: "I can't really think of anything additional right now. I'll kind of sleep on that and if I do come up with something I give you some feedback on it. I think I've pretty much captured most of the points."

Interviewer: “Now if I understand correctly, you're now the NAVAIR R&M lead. How have you seen the analysis techniques and the application of RCM analysis evolve in the Navy since your initial experience with the AV-8B?”

Interviewee: “We’ve made some progress in regards to our initial documents, MIL handbook 266 and MILSTD-2173. Having a steering committee, which are practitioners as well as engineers, knowledgeable of statistical techniques and data analysis techniques, having a steering committee that can get together and discuss some of these real-world concerns or issues has been very beneficial. Having that steering committee, which can make more consistent how we’re performing the process across all of our assets and all the different sites has been very beneficial.”

Interviewer: “How long is that steering committee been stood up?”

Interviewee: “We've probably been in operation, I’d say close to 10 years. I'm not sure when we first started, but we had, I’d call it maybe an informal pseudo-steering committee way back then, and we've made it more formal and more recognized in the NAVAIR community as we've moved along.”

Interviewer: “Was there specific burning platform that kind of forced the initial standup of that committee or was it kind of a general consensus among the practitioners and engineers who said this would be a good thing for us?”

Interviewee: “Yes, it was a general consensus. At all the sites there was some level of RCM being performed, and we had champions at each of the sites: myself a Cherry Point, down at JAX we had XXXX and some of the other engineers. And they were working level engineers on their respective programs. So it was kind of happening at all the different sites. We had a couple of champions at the headquarters, who also kept involvement in the steering committee and our efforts and also would carry the flag for us to the management at headquarters when we needed support. So it kind of all just unfolded. It wasn't really a concerted, planned effort in the beginning that here's where we want to go with this. As we coordinated more with each other, we saw the need to have a more formal steering committee. And that's what we developed. And it has been very beneficial."

Interviewer: "Which do you think came first then: the formation of this steering committing or the commitment of NAVAIR leadership to RCM? Or do you think they kind of developed at the same time?"

Interviewee: "I think the pseudo, informal steering committee, as far as the working level personnel at the sites coordinating with each other and making headquarters in our leadership at headquarters, aware that we needed to sustain and keep this going that we needed to ensure that the program was provided resources that this is the only way we knew to do it properly. So I think that the informal working level personnel and bending the ear of leadership at headquarters, I think basically is what prompted it most to evolve and into a formal, recognized process."

Interviewer: "And now do you feel that the RCM steering committee is still crucial to the successful application of RCM throughout NAVAIR, or do you think it's kind of a good thing to have but not as critical now that you have had the ball rolling?"

Interviewee: "It's probably less critical. In regards to the day-to-day needs of it, but we do have a lot of things that we deal with on legacy programs, as far as maybe some people not using the process correctly or trying to do something else that we sometimes get wind of and we'll step in and support that. Or the fact that the program is not supporting what they're trying to do and we'll help in that regard. On the new acquisitions side, it's been very beneficial on programs like the VXX and JSF and the heavy lift replacement acquisitions. We're trying to get more involved with UAVs as well. And that's where what we've done with myself as the national R&M lead, and basically brought… one of my main goals is to bring the acquisition engineering side into the fold and have them understand that the things that's being done during the acquisition process basically need to be done in a way so that it feeds into what we're doing in sustainment, such as, as they develop a FMECA on the F-22 program during acquisition they need to do it in such a way that that data can be properly used during the sustainment process. So we've been very much involved to try to promote that."

Interviewer: "Concurrent engineering type stuff."

Interviewee: "Exactly. Well, sometimes our experience with a lot of the primes is that they've been doing FMECA and things for many years and their focus is on the design of the asset. And sometimes what they're doing for those products is not useful, when we receive that analysis, in regards to looking at it from a maintenance analysis standpoint. And we try to get in there and make them understand that we can develop this, for example, FMECA product in a certain way so that it can be used for your design and redesign efforts as well as to support our maintenance analysis efforts. So that's the type of thing that we've had some success in."

Interviewer: "When you initially were standing up this pseudo steering committee I would imagine that you probably had some program management offices that were already on board with RCM and some that maybe had a different way of developing their maintenance requirements. Did you encounter any resistance from some of the offices saying, ‘Hey, we’re pretty happy with the way we’re doing things and we don't think that going to RCM is the way to go? And if you did encounter that, how did you get them on board?”

Interviewee: “I don't recall any serious concerns from any of the programs in regards to not wanting to play. I mean some were, maybe they were less knowledgeable of the process and how it was being done on other programs, but they really didn't say, basically ‘We’re doing it this way, and that's how we're going to continue to do it. You go and do your RCM thing. That's not going to work for us.’ We really didn't have any barriers such as that.”

Interviewer: “Is that because you already had the hammer at that point do you think? The ability to say, ‘Hey this is a way we’re playing ball now?’ You think maybe once they figured out what the whole RCM thing was about they said, ‘Hey, this makes sense to me’?

Interviewee: “Yeah, I think it was a combination of…they were busy doing their thing and really didn't put much emphasis or focus on it and others were like, well it does make sense. And like I said earlier, the main reason that programs wouldn't promote the process or play is due to lack of resources. And that's understandable, if they've got an organization where their engineering logistics are basically working in a reactive mode where they're just trying to put out the brush fires on a daily basis. I mean, it's understandable when you say well, I mean, it is more effort. It's a lot more effort in their eyes, and it really is to be honest with you. They're going through a logic engineering decision process to make their engineering decisions. And basically just using the RCM process and documenting it, having an audit trail, those additional things I think they perceive to be a lot more workload than it really was. The data collection side of it is more intensive and resource intensive and some couldn't support that to the degree that they needed to, but we're really didn't have any naysayers who said now we don't play in this process. And it was fairly successful and as headquarters came more on board and help promote the process more, which usually resulted in more resources being given to the programs that were lacking, then that made the whole situation a lot better."

Interviewer: "Sure that makes sense. Well, Sir, that's all I have for you at this point."

Appendix C Interview Two

Interviewer: “Just to kind of start things off, the basis of my research is: the F-15 System Program Office has commissioned a contractor to perform reliability-centered maintenance analysis on historical data for the F-15 aircraft and their intent is to use this analysis to revise the preventive maintenance program for the F-15. Essentially I guess what they started with, like a lot of at least the Air Force airframes do; they started with a structural integrity program and buildings around that. And now they're starting to get something that's more data-based. Something that they can back up.”

Interviewee: “Well just to let you know, I'm familiar with it to a degree not into the details of the F-15 effort because the contractor that supporting Warner Robins, Wyle Labs, is actually stationed out here in Jacksonville, and is using many of the same procedures that we use.”

Interviewer: “I think that was one of the big selling points for the F-15 SPO when they chose Wyle Labs, that they have a lot of experience dealing with the Navy with RCM and I think that, at least from what I've read the Navy is certainly leading the way as far as actually using RCM to develop preventive maintenance programs for the aircraft. Has it been that way for quite awhile to your knowledge?”

Interviewee: “I think it has been as best I can determine what apparently occurred was there was a lot of emphasis on RCM back in the 70s, and including through the 80s to a degree. Air Force developed the 1843 spec; if you’ve done some history research you’re familiar with that. It was largely developed off an MSG-2 type of approach and one of the things about 1843, and even the current Air Force guidance documents is that they don't give much in terms of how do you develop intervals? And one of the things that the Navy did back in the mid-80s was to try to develop some concepts on not only how you apply the logic but how you would use that logic to actually develop maintenance programs, and so where as the Air Force stayed with the 1843, which is a lot more subjective, a lot less numerical methods and that kind of thing, he Navy developed the MIL STD 2173, which was more statistically and mathematically driven than some of the other methodologies. And so when they were canceled in the early 90s, the Navy didn't want to lose the procedures that they had developed in the 2173, and so we partnered with SAE and developed the JA1011, which you're probably familiar with. And from that, then we also updated our 403 to what you're familiar with currently. So we've kind of kept alive whereas, as you can tell I'm certainly no Air Force expert, but it certainly appears as a after some initial efforts in the Air Force back in probably the 80s, it appears as if the RCM effort kind of became an unfunded effort. It didn't go away out of the specifications, but it became, I guess, a lower priority and unfunded and many of the programs went back to let's make our best guess in terms of maintenance programs based on the best information we have, but they lost some of the discipline in the process."

Interviewer: "Why do you think it took such a strong foothold in the Navy?"

Interviewee: "I think it really was the effort of a few individuals I'll be honest with you, I think it could have easily fallen the way that the Air Force in the Army went, I think there were just a few people who were sold on the concept and kept it alive. One of the things that helped us was in the mid-90s, we started to see our depot costs escalating, and one of the things, one of the approaches to trying to combat that was to go back and do some RCM analysis of the underlying requirements and establish some fixed periods for aircraft rework and repair, and so that kind of infused some new life into the Navy activities under what we called the integrated maintenance concept. I don't know if you've done much research on that, but basically what that was was... I don't know what the current Air Force philosophy is, but our depot maintenance intervals kind of, we had fixed intervals, but they were then able to be extended based on a fairly cursory field inspection, what we called ASPA, or aircraft service period adjustment. And what we were finding was, say we had a fixed interval for induction of three years, let's say on a particular platform. Well, just before that induction and then every year thereafter until it was inducted, a team would go out and basically look at the condition of the airplane from available sources and access places and make a determination as to whether the airplane was in immediate need of depot attention. Now what was happening was some of these airplanes were being extended multiple times. And by the time they got to the depot they were in pretty poor shape. And the underlying methodology was somewhat subjective that you can imagine. I don't know how much maintenance background, you've got."

Interviewer: "20 years in the Air Force."

Interviewee: "Well there you go, then you're aware that if you want to keep an airplane, and wanted to put some attention to it, and you could make it look pretty good even though underneath there may be some corrosion or systematic problems and things like that. So having an inspector come out and do a couple days inspection was not necessarily really correcting the underlying condition of the airplane and so that's why we went to the integrated maintenance concept to basically say, you know there's a point in time where these airplanes need attention. We need to figure out what that is, and then execute it, and the methodology that was chosen for that was RCM."

Interviewer: "If I understand that the difference between, for instance, MSG-2 and MSG-3, wasn't MSG-3 more developed to be applied to a new acquisition program to develop the initial maintenance program versus…?"

Interviewee: "That may be true to a certain degree, but I'm not sure that's entirely accurate. MSG-2 was used for development of new acquisitions also. I think the biggest difference was MSG-3 kind of drove you toward more data-based decisions, where MSG-2 was largely dependent on the logic tree, but the decisions themselves were largely subjective. I don't know if you've looked at the old MSG-2 logic, but it would ask you some questions that you answered, and based on those answers you would determine what kind of inspection to do or whether to do an inspection at all. But it gave you almost no guidance on how often to do it. And so MSG-3, actually RCM, was a step even different, slightly, in some respects than MSG-3, but RCM in particular, put some rationale behind, well now that you understand the difference between a hard time task and on condition tasks and those kind of things, there's also some thought process that could go into to determine how often to do those things. And then they also got into some additional, I think RCM and MSG-3 also put much more weight on the trade-off analyses regarding safety and cost and readiness and those kinds of things. More so than MSG-2 did. So I think it was a natural outgrowth of, it wasn't necessarily a difference between acquisition and an in-service thing, I think both could be applied in both cases. But I do think one of the things MSG-3 did bring to the floor and probably oftentimes the most overlooked part of an effective RCM program is that it isn't a one-time event. It should be ongoing, you should be gathering data and it introduced the concept of age exploration, which I don't believe was in the MSG-2. You know you make some conservative assumptions based on the best data available and then you go out and monitor and gather data in overtime and make adjustments. I think that was one of the big things added by RCM and MSG-3 that is still, at least in the military circles, is probably not being executed as well as it should be a lot of times. We still pay people to do something one time and then sit on the shelf and don’t go back and revisit it.”

Interviewer: “If I understand correctly, you're the chairman of the RCM steering group for the Navy is that correct?”

Interviewee: “For NAVAIR, don't say Navy let's make sure you keep that clear. I'm only for NAVAIR, we also have the NAVSEA side, and they will have a slight difference in their approach.”

Interviewer: “But they fundamentally use RCM as well?”

Interviewee: “They use RCM they've got a different MIL SPEC. Their MIL SPEC has a similar logic tree, but they also concentrate much more in their MIL SPEC on how to write the maintenance cards and that kind stuff, whereas for us in NAVAIR that’s handled in other specifications.”

Interviewer: “So what is the primary function, then, of the steering group, and what type of things do you do?”

Interviewee: “Basically develop policy and processes, training courses, assist programs with problematic issues, review programs, executions and plans to make sure what they're doing is both logical and defendable. And you know gets us in the direction that we want to go. We provide advice and assistance in any direction related RCM. We interface with other services as we’re doing now, academia, industry, etc. and just try to stay on the leading edge of the technology.”

Interviewer: “Do you set policy then?”

Interviewee: “Yes we do.”

Interviewer: “As far as the way NAVAIR...”

Interviewee: “Right, there's a NAVAIR Instruction on RCM which we author. We also author the -403.”

Interviewer: “Is that 4790.20A?”

Interviewee: “Yes, that's actually pretty old; we’ve actually been trying to get an update out for a few years. I hope we’ll get one out shortly. If you’d like to see the draft update, I can send that to you.”

Interviewer: “That would be fantastic. So prior to your function on the steering group yourself, have you had experience with NAVAIR as far as RCM analysis and implementation on specific weapons platforms?”

Interviewee: “Yes, you're talking about me personally? Yes my personal background, I started with NAVAIR in 70…October 77. And I was working at that time, the A-7 platform, which is one of the early implementations of RCM. And at that time we were still using, it was kind of pre - we are in the process of, it was before Nowlan and Heap had been published. And so we were doing a kind of the derivation of MSG-2 that was what we call the 400 manual, but it was very similar to MSG-2. Then when Nowlan and Heap came out, there was a MIL Handbook 266 written that captured the processes of the RCM as defined by Nowlan and Heap, and subsequent to that the MIL STD 2173 was issued and MIL Handbook 266 was canceled. So I worked A-7s back then in both the maintenance analysis and RCM arenas. Subsequent to that I did some work on development of the A-12 in the early, and then when the A-12 was canceled, it kind of evolved into what's now JSF and I was on some of those development programs in the early 90s. I then became the E6 TACAMO…I don't know if you're familiar with the E-6, that's basically a 707 derivative airplane similar to 135 or an E-3. I was the integrated program team lead for that. So I had the total program for in-service and modification for that aircraft back through the early and the mid 90s. From there, I moved into the COMPSEA for maintenance planning and design interface, which encompassed RCM for Jacksonville and from that position I was selected as the national lead for RCM. And I think it was about 99."

Interviewer: "Was your experience with the E-6 then, was that an existing set up that you revised to incorporate RCM or was that RCM from the get go?"

Interviewee: "What happened with the E-6 was, the E-6 was bought back in the early 90s back when we were in acquisition reform and streamlining and all that kind of stuff, and it was bought basically with very little analysis and very little data delivered. It was one of these, you know, if we need it we'll buy it later kind of approaches, and they largely built their maintenance program off of existing maintenance programs for the E-3 and 135. So there wasn't a lot of maintenance analysis behind it. And they also did not buy a depot maintenance program. And so what happened with the E-6 was as we got into operations about 4-5 years into operations of the airplane, somebody said, 'Hey, these airplanes are starting to need some depot attention, we're getting some corrosion, we've got some structural inspections that need to take place, etc. etc.' However, we didn't buy enough airplanes, I don't know how familiar are with the E-6 but it's only a sixteen airplane fleet. It was a tactical communication platform that gives, I mean strategic communication platform that provides the command-and-control structure for missile silos and nuclear submarines and that kind of thing. Anyway there wasn't enough pipeline to set up what would be a traditional depot program where every three, four or five years you'd send an airplane and it would stay there for a year-and-a-half and then it comes back fixed. And so we started exploring some innovative ways to get the work done and we said, ‘Hey, let's do some RCM, let’s find out what the underlying intervals of these various tasks are and rather than package them all into a one-stop event at a depot every few years, lets it we can do about spreading them out around the life cycle and what that would do for us and what we came up with was what was called with an enhanced phase maintenance. We basically took all the tasks that were done traditionally within the walls of the depot and spread them throughout the lifecycle of the aircraft. So they could be done in very short packages in combination with a level phase inspections. And basically we were able to take the depot requirements and break them into packages that could be done in 12 day intervals and aligned them with the organizational level maintenance such that the aircraft never left the organizational level site. We brought the ALC technicians at Tinker to the squadrons and had them work side by side with the squadrons to perform the depot level maintenance. So that kind of became a precursor to what the Navy did as a whole in implementing integrated maintenance for all airplanes.”

Interviewer: “What specific challenges did you encounter when you tried to go from the existing preventive maintenance program to one that incorporated the RCM analysis? As far as the implementation went, what kind of roadblocks did you run into?”

Interviewee: “Well, the first thing you get is particularly dealing with maintainers that have been around for long time is the resistance to doing something other than what they've been familiar with doing. So there's a bit of a sales job that you have, if you want the buy-in and from the maintainers. And that’s, ‘Hey, this inspection that you been doing for years is really not adding any value to the airplane. And here's why.’ And so getting them involved in the process to overcome that resistance to, well that's not the way they do things around here kind of approach. I think that's a big one. In general, RCM reduces the overall requirements. So I haven't found at least in my implementations that there's a big issue from a logistics standpoint in terms of getting additional parts and equipment in that kind of thing. Usually you're reducing your maintenance requirements are not increasing them. There is an issue that we've had traditionally though, in terms of sustaining the effort. As I said there's a tendency for many to think of it as a one-time event in funding it and then thinking it's done, rather than retaining a core effort that basically continued to look at the maintenance program, continued to look at the findings, implements a few age exploration programs, gathers data, makes adjustments, and does continuous improvement. So one of the biggest issues we had is getting that funding stream that would keep a set of people focused on that activity, because what happens if you don't keep that as a separated, designated activity, those folks tend to migrate back to doing reactive-type stuff. You know, answering questions responding to emergencies that kind of thing so it almost has to be set aside and say your function in life is to continue to make things better. And if you don't do that, they tend to be absorbed by the overall support structure.”

Interviewer: “Was the Navy's culture and leadership commitment at that time conducive to the move to RCM or were you still?”

Interviewee: “In some places, but I wouldn't say it fully was. Now we did have in the mid-90s, there was a couple back when we are doing the implementation of IMC we were able to get a statement of support out of the Chief of Naval Operations, which was pretty important. That basically said that he wanted to move to IMC for all platforms and IMC would be based on RCM, so that gave us the hammer that we kind of needed to get things rolling. In addition, we had an RCM effort going on the surface side with the ships. So the Navy leadership as a whole had stood behind the RCM as a concept. But that didn't mean that every person in every leadership position was supportive. So we've at times had to go back to some leadership and have that support reemphasized. We got some letters signed by our engineering logistics admirals at times that said that RCM is a core part of our processes and doing business, and reemphasized to the organization that this is something that we do on a continuous basis. And that helps because you can use that to put some emphasis on programs that might be falling by the wayside. The other thing we find is, let me see, you’re in a SPO structure you probably have a similar problem, is we find it very hard to maintain consistent application among all the Navy programs. And there are some that are doing very well that there are others that it's not necessarily a priority and they give it a little bit of a short shifts. That's a big problem because we a lot of independence with the programs, and I think you guys do, too. So trying to maintain consistency across the NAVAIR organization is a difficulty. NAVSEA has kind of fixed that, but in a way that I'm not sure we could adopt. They have a central office a central maintenance office at NAVSEA headquarters. And basically they have put out edicts that say, no preventive maintenance will be implemented on any naval ship or submarine without an RCM analysis to support it. And they manage that through a central clearinghouse so to speak. So if you want to make a change to a PM requirement, you have to submit the RCM analysis in a stepwise fashion. In other words, you submit the FMECA, you get that approved, you submit the next step, you get that approved, and eventually you get the actual PM changed. So that's a bureaucratic approach, but seems to be working for them."

Interviewer: "Do you feel that the autonomy you give to your separate programs would not allow for that kind of set up?"

Interviewer: "Yeah, I don't think our leadership would support that currently, just because of the way we've given the program managers cradle to grave authority."

Interviewer: "Which is kind necessary the way we do business."

Interviewee: "Yes."

Interviewer: "How about the data that went into the analysis, particularly on the E-6. Did you have any concerns with the purity of the data; did it have to be scrubbed?"

Interviewee: "That is always a concern. One of the things we've been trying to emphasize in our training with RCM now is, you're always going to have questions about the accuracy of data. So you've got to make sure that you are not conducting analysis that's dependant upon data alone. Something like the data coming out of the maintenance reporting system. In other words, you've got to get out, and you've got to talk to the maintainers and talk to the operators. You've got to talk to the engineers and you've got to get their perspective on what's actually happening and then compare that to the data to make sure that it makes sense, because I don't care what organization you're in, the data is never perfect. And so you've got to use the best information available to you and make rational judgments on the use of that data. So we don't, our method doesn't say just take data and run it through a formula here's your answer. We basically are trying to get people to recognize that they've got to get out and understand the equipment, understand the maintenance environment, understand the operating environment. Get the best data you can, make adjustments to it based on other information and then make your decisions."

Interviewer: "How helpful do you think it's been for you in NAVAIR having the 00-25-403 and the NAVAIR instruction that describe this is how were going to do business?"

Interviewee: "403 is invaluable, the instruction is more just, the current version of the instruction is not very enforceable, I mean, it's got a couple words in it, and that's what I mean with us trying to get an update, some of the words in the 'a' version or a little soft. But what helps us more is the 403 is pretty specific in terms of methodology. We provide free software, which kind of makes the process consistent because people are more likely to use our software than go out and buy something. So that helps us keep the process consistent from program to program, and then having training that's focused on the 403 itself also. And even in addition to that, working with a relatively few number of contractors that are all familiar with the 403 process, that keeps things somewhat under control."

Interviewer: "I think that maybe a bit of concern with the Air Force right now. There are a number of contractors who are practitioners of what a lot of them are calling RCM, but they are varying degrees of and varying degrees away from what you consider RCM."

Interviewee: “And I think the SAE JA1011 can help you with that. In other words, you can put your contracts out stating that you want them to be compliant with that. Of course, then you've got to be able to know whether they're compliant with that or not, but at least it gives you some consistency. We found that the contractors that promote JA1011 generally are using a process that's fairly at least viable, whereas those that are out promoting ‘hey I can do it faster quicker, cheaper’ are the ones that are more likely to take shortcuts that could be dangerous. I’ve actually had some calls from some of your contractors that, because of the information we make available publicly on our web sites and the like, start to migrate to our process. ARINC is one that was supporting the H-60, I believe is called me personally several times on an Air Force contract they're working saying is it OK to use your information. I said, ‘Sure, I don't care.’ And the Army's done the same thing. The H-47 in the Army is contracted under a company that's actually run by an ex-NAVAIR employee who has taken some RCM-2 training. So it kind of got some cross-service flavor there, too. I think we’re starting to see some migration into some common practices, although there are still some out there that are deviating. One of the other things we're doing, you might just one a make a note of, we've also got a representation currently on the IAC committee that's writing their RCM spec. I don't know how familiar you are with the IAC, but it's an international standards body, and they have a current RCM specification out that's written largely in line with MSG-3. But they're starting to, because they want to apply RCM not just to aviation, but to other types of equipment, and MSG-3 has some things in it that are hard to implement say, in a plant equipment type environment. So we've been able to get a representative on that committee, and it looks like the product is going to come out is going to be very much in line with, at least conceptually, you know, terminology and things like I'll probably be different, but at least conceptually process and logic with the 403 so that helps again to have people merge on a common process."

Interviewer: "Were you in a position where you feel felt like you had to make a business case for the RCM implementation on the E-6 or the A-7, or do you feel you had enough support going in that you had already passed that point and you could pretty much press on?"

Interviewee: "Let me talk the A-7 first. The A-7 wasn't a matter of a business case because the A-7 was in on the ground floor. It was a matter of continuation, and I was in a position at the time where I was responsible for the preventive maintenance requirements, the MRC cards and those kind of things, the depot specs. And so I just made it a practice that we would continue it myself, because one of the questions I ask people when they say, 'Well, we don't have enough resources to do RCM', I ask them the question, 'Well, what are you going to do instead?' So my personal philosophy is RCM doesn't take a lot of additional resources if it's maintained. The issue with RCM is to maintain the discipline in the decision-making and as long is you maintain the discipline in the decision-making, you can make that decision with minimal data or lots of data, so the question then becomes how important is the decision and that drives how much data I gather to make that decision. But RCM itself is more of a matter of just a disciplined approach in decision-making. As far as documenting your rationale, following your logic, using the data in the proper way, avoiding seat of the pants discussions and decisions and those kind of things. Avoiding saying, 'We're going to do it because that's the way we've always done it', rather than finding out what's the underlying cause of the failure and how should we address that. So in the A-7 world it wasn't a difficult because that was my area of responsibility, and I just made it a process that we implemented in and how we executed that area. And it didn't take a lot of additional resources. Certainly we could have used more but we did have enough to maintain it. And my guess is that most programs have enough resources to do RCM to some level. Personally I would rather see a program make a commitment to say, ‘This is the way were going to do business’ and it becomes a business process than to go out and procure a couple million dollars this year to do RCM, do it one time through, and then drop it. It I would rather see them get a consistent level of funding and prioritize their efforts so that they are always working on most important things continuously than to do them all once and then forget about them after that. So that's what we did in the A-7 arena. We came up with what we called in RCM audit process, where basically any decision we made related to preventive maintenance, if we didn't have the time or resources or priority at the time to fully complete a detailed RCM analysis, we would make a decision based on available data that at least used RCM thoughts and processes and logic and identified that as an area that was incomplete, and then we would kind of rack and stack those incomplete areas and prioritize them and the ones with the most potential payback would be the ones that we worked in any given time. In the E-6 arena, it was more of a matter of the program and that we call the APML, which is the assistant program manager for logistics was supportive and behind it, so we had some benefit there of him wanting to do RCM, there was no convincing necessary in that case. But again, I mean business case analysis, in my mind, is really, I mean I know it does come into play. But in reality, if you just make it part of your core way of doing business… My question is if you don't well then we'll are you doing instead? And if the answer is what we're doing undisciplined methods to determine what our maintenance requirements are, I mean that's a scary. To me that's what would have to be defended. You wouldn't do that in any other area of aviation. What if somebody said I'm going to make my structural certification based on the seat of the pants guessing about the structural integrity of aircraft? You know, you have a disciplined process for how you do that. Why wouldn't you have a similar discipline process for maintenance requirements?"

Interviewer: "What about the flip side of the coin when the RCM analysis supports deleting a lot of previous inspection requirements that were maybe, based on design characteristics are what the design engineers thought was a good idea, but haven't been borne out as viable or necessary by the historical data that's been collected. Have you come across that that type of situation?"

Interviewee: "Well, recognize RCM isn't just based on historical data. I mean, if the design features of the item say that this is something that must be maintained, and if it isn't in its raises a potential for safety failure, and you get data to show that then you should not delete requirements, just based on data. I don't think, I think one of the problems we've got is that we've created two worlds. We shouldn't have a world of structural engineering, design engineering, making one set of recommendations and RCM and maintenance analysis making another set of recommendations. We should be in concert with each other. I'm familiar to a fairly a significant degree with the ASIP program at the Air Force has, and AFSIP and MECSIP and all those things. Those fit perfectly with the RCM logic. The ASIP program is built on damage tolerance and crack growth analysis. That is the underlying philosophy for RCM on-condition inspections.

There should be no reason there's a conflict there. Or if there's conflict it's because one side or the other is not making their case, so to speak. So if a design engineer says, 'I want you to do this because I want you to do this' well, that shouldn't be supported. But if he says 'I want you to do this because this thing fails, and it fails at a frequency that's unacceptable,' well that's the same logic that RCM would say you should want to do it. Properly implemented, there shouldn't be any conflict. I think a large part of the conflict is because people have come up through different avenues to get where they are and don't understand that they are, that they shouldn't be in conflict. We've had some discussions with our structures people and once we sat down and talked the process with them and said we need the information that they have from a structural analysis standpoint in terms of strength and fatigue and damage tolerance and corrosion and material selection and all those kinds of things. Those are important elements to making the decisions that RCM asks you to make. Once we leave that out and let them understand the process, they said 'Oh, gosh yes, we certainly want to do that.' So I think the conflict is more lack of understanding the process is themselves.'

Interviewer: "Did you have much interaction with the aircraft manufacturers in your experience? One of the things I spoke with the F-15 SPO about what they're doing. They had not gotten, but they anticipated some flak from Boeing, who owns the F-15s saying hey…"

Interviewee: "We've had mixed results with that, I think to some degree it comes back on where they are all in their responsibilities. We've had pretty good response results with Lockheed. Some of the Boeing areas have been very supportive, others less so. Again, I think it comes from their background, but, what you've got to get into again is a lack of understanding in terms of if they aren't using RCM, what are they using to make the decisions that they're making? And again, once you sit down and say, ‘Here's what we're doing and we want it documented so we have a historical record of why we did what we did’ you begin to see that it does fit together. What they resist is when they see it as additional work. If you see it as I'm going to do all the structural analysis over here and then come over here and do RCM analysis and repeat the activities they did in the structural analysis, well then that's wasteful and they should be resisting it. But if we show that we want maintenance requirements development to be based on good sound engineering and rational logic that looks at cost, safety, and operational impacts, and balances those to come up with a good maintenance program, once somebody understands that there's not too many people that actually resist it. What happens is, they often are contracted as two separate efforts and then it looks like it's redundant.”

Interviewer: “Being pretty new to the concept of RCM analysis and RCM-based preventive maintenance programs are there any other classic or high-frequency roadblock type things that come up during RCM implementations that you think that it would be helpful to be aware of?”

Interviewee: “Well, one of the things that we were just talking about is the use of the FMECA. FMECA is actually looked at fairly differently from the maintenance community as it is in the design community. And what we found is particularly helpful is to sit down with the requiring officers, which often come out of the R&M community and obtain some, we've actually written some memos of agreement, but basically obtain some agreement that you're going to use FMECA results for this purpose. And generally in the design community, it's to identify single point failures, identify protective measures that must be taken for critical failures, those kind of things, input reliability on high-frequency failures and things of that sort. You know, were looking at for more of a design and manufacturing producability aspect. Whereas in the maintenance side, we're generally looking for failures at the on-aircraft maintenance level that cause a need to buy parts, do maintenance tasks, develop testing and training and support equipment and those kind of things. And to reach an agreement that this one document needs to be written in such a way that it can support both of those efforts is really important. Otherwise, you do end up with a lot of redundant activity. We find that FMECAs that are written just for design are almost unusable if they weren't written with at least a maintenance use in mind, maintenance logistics use in mind. They're almost unusable in-service and we actually have to redo them ourselves. Whereas, if we had gotten involved in the development stage, we probably could have helped to guide the development and structure of that information in such a way that it could have been usable. So that's pretty important."

Interviewer: "That's all I have for you sir, I'm sure that I will come up with many more questions, so if you don't mind if we can keep an open an open invitation I'd love to give you a call back and discuss more stuff as I get more breadth of experience."

Interviewee: "Anytime. When you get near your final report I'd certainly like a copy of the report."

Interviewer: "Certainly, thanks very much."

Interviewee: "Goodbye."

Appendix D Interview Three

Interviewer: “I've spoken with XXXX XXXX, who works in Wyle Labs so far. He's working with XXXX XXXX on the F-15 RCM analysis and I have also spoken with Hugh, we spoke for little over an hour yesterday. If I understand correctly, you are in the C-5 shop right now is that correct?”

Interviewee: “Right, C-5 and we do have a few 141s left.”

Interviewer: “Is your experience with reliability-centered maintenance then primarily with the 141s, or with the C-5?”

Interviewee: “Yes, we started with the 141 probably 10 years ago. And what we did was about 3 years ago 141 and C-5 merged, so we brought the reliability process that we had with the 141 over to the C5. So it’s the same process, it's just that we're not as far along with it as far as implementation, because we're having to take it piece by piece.”

Interviewer: “Were you extensively involved in the 141 RCM implementation, then?”

Interviewee: “Yes, we didn't actually call it RCM, but I guess it's similar. What we did was, I don’t know if you’re familiar with the ASIP, the aircraft structural integrity program. What we did, because that’s been around for years, and we took that same philosophy and tried to apply it to components versus structure, trying to look at how long parts were going to last and things like that, versus how long it was going to take for crack to grow or something like that. And that's what we did is we took that and kind of converted over to systems integrity, and that's when we termed the phrase FSIP. And then we went from there. And then helped to get some of the other weapons systems on board.”

Interviewer: “And what was your primary role with both the 141 and the C-5, were you the guy performing some of the analysis, or were you more concerned with the implementation side or…?”

Interviewee: “A little bit of both. I was the FSIP manager, and what happened was we had contractors that we had, like Lockheed, and some other smaller companies that we had on board that would help do the analysis. And I would do some, but I was mainly kind of over the program, I guess, managing the whole reliability program for systems.”

Interviewer: “Did you have to do any kind of a scrub of the raw data, did you get your data from like GO-81?”

Interviewee: “GO-81, right. And GO-81 is the AMC reliability database and it dumps into REMIS like most of the others. And our folks, when they did the analysis, they would go in and scrub it - if there were some anomalies, they would clean it up. If it was something that they could identify, like if a work unit code and the verbiage didn't match up, if they could determine which one was actually the accurate piece, then they would clean it up. And if they couldn't, then they would just throw out that data if they couldn't determine what the real action was.”

Interviewer: “So what was the output, then from the analysis phase, was it pretty much an extensive list of ‘these tasks need to be performed at this interval’ or was it ‘a lot of these tasks are being currently performed and don't need to be performed anymore’ or…?”

Interviewee: “Not necessarily saying we're going to take these processes out. We may change some of the processes a little bit, but the main thing that we would do is we would, we could print out lists of every work unit code, and it would show what the reliability of that part was. That was one piece of the puzzle. We wouldn’t use that and say ‘OK, there's our high one, let’s throw a bunch of money at that part.’ That was only one piece of the puzzle. We’d pull in a lot of other stuff in like field data as far as individual bases, we might go to them and say ‘Hey, is this really a problem?’ Sometimes it would turn out it was a supply problem, not necessarily a reliability problem. And we would scrub it that way and look at DRs, and all the different little parts that tell you, parts of the process that tell you that there's a problem. And then what we did is we came up, and this is something we did on the C-5, that we didn't ever do on the 141, but when they came in with the C-5 there were so many issues that we needed to attack. We determined to come up with a matrix that would actually rank the parts, or the work unit codes in order of what was the most important.”

Interviewer: “As far as failure mode criticality, or…?”

Interviewee: “Well, and there were a lot of different pieces of it that we threw in, like we’d say MTBF was one of them and en route failures was one of them because for cargo aircraft that’s a big issue. When they fly from point A to B to C to D before they go back home, if they break anywhere along the way it's a big problem because they may not have the support there, or the infrastructure to actually replace those parts. And it could get real costly if you have to send a team out and send equipment out and all that stuff to recover the aircraft so en route reliability was a big issue. We would see stuff like -107s, which is what the field submits their requirements through. If we would see a big number of those on a component that would play into it. So we had about five or six different areas that we considered were real critical. And then we weighted those and then something like en route reliability would be one of the higher weightings. And anyway, we spit out a list of any every work unit code and we were able to prioritize it.

Based on that we would go in and say, depending on where that component is, what's the best way to attack it? And in some cases, the part, you know, the reliability was, I guess what you'd expect from a used part. But since you are flying it to fail, you are having them fail at times you didn't want them to fail. So we would come up in a case like that with the time change and say this part will last, based on the data we've got, we know the majority of the parts are gonna last, say, 5000 hours. But if we go from PDM to PDM, that's about say, 6000 or 7000 hours, for example. So what we've got to do is pick a point before that, when the aircraft is at a scheduled downtime and we can replace these parts. So we may come in and say 'OK, every third ISO' or something like that we'd change it. That was one approach. The other approach, depending on what system it was, we would do what we'd call a 'zero time' on the whole system. An example of that would be, say, the flap system. If you came in, and what would normally happen is, you've got a torque tube and a universal joint, and there's a bearing or something like that and you're having problems. So you're going to say 'OK, this bearing is worn, replace it.' Okay now that fixed your problem, but a week later and I got more problems, so you trace it back and say now it's the U-joint. So you go in and replace it. So it's a cumulative type effect. Really all you're doing is your piece-mealing it and by the time he got down to the end, now you're kind of starting over now that first part you replaced, now it's worn again, so we went in and we had a big program on the 141. We came in and we actually redid the whole flap system all at one time. And it was like over 400 parts, and we'd go in and all the wear-type items we would replace with new parts. They would clean up and do NDI on like, say the carriages and the tracks, and stuff like that.

And they came in and we completely redid the whole thing, and zero time the whole system and that worked out really well."

Interviewer: "And that was based on data analysis that said 'Hey, if you start replacing part by part it can cause the other parts to wear quicker?"

Interviewee: "Right. In that case, just from verbal feedback and all that the flaps were continually causing a lot of man-hours in the field. And initially one of the bases actually came up with the idea. They said 'Hey, we've been going in and replacing a lot of these parts, instead of replacing just one or two', and that got us to thinking, 'Hey that's a good idea to do this for the whole system and do it for the whole fleet.' So over several years as the commands get their money budgeted, that's what we ended up doing is every single aircraft that would come through PDM we would do this in conjunction with PDM, so there wasn't any additional downtime, and then we got all that changed out. So it was kind of a feedback from the field. Plus we knew down here at PDM that there was a big workload as it's trying to get out and get off the base were the flap systems. So through experience and feedback and all that. That was the big thing we found that which isyou can't just look at one little piece of the puzzle, because you're not getting a true indication, and in some cases it could be that the folks would say that work unit code is the one I remember the best and start keep dumping them in and then saying, 'We have a big problem with this component."

Interviewer: "Unfortunately, garbage in, garbage out."

Interviewee: "Exactly. So you do have to be careful with it. But we would always look at several different pieces before we launched into some big program like that. And then the third piece of that outside of the time changing, and then what we call the zero time of the complete system is we would go in and there were a lot of components we called original equipment. And that would be something like on these older aircraft that was designed for the life of the aircraft, which at that time was probably 15 or 20 years, and now we are way past that, in some cases may be twice that. The parts have never been looked at. So we determined we're not having a problem now, but it's probably not going to be long before we start having major problems. And if we don't have some kind of infrastructure set up to cover that, then, you may be potentially down an aircraft, the whole fleet, with no solution. So we started attacking those and started identifying areas that we would consider original equipment that had never been looked at."

Interviewer: "Kind of akin to an age exploration analysis in the RCM world."

Interviewee: "Yes, I'm not familiar with that on the RCM, but it probably would be. It can get tricky because there are a lot of areas maybe that you're not aware of that haven't been looked at. But you start with the most critical. And like on the 141, one of those was where the horizontal stab attaches to the vertical stab. There are pivot pins and some big bearings, some massive bearings there, and those bearings had been replaced sparingly over the years. But nothing major, so we considered that original equipment. And we came up with a process to have those replaced during every PDM also. The trick there was the bearing went in on the vertical side. It was a pressed fit on the vertical stab side. So the bearing was larger than the hole, so we had to freeze the bearing to get it in, and the problem was when the bearing would fail, to get it out you had to be real careful because you could score up and damaged the hole in the vertical stab. So we came up with a process that, if that happened, they could go in there and bore it out and come in and we had some oversized bearings manufactured. So they could go in and bore it out to a different, three different sizes, and then put in one of those oversized bearings to take care that. So that worked real well, too."

Interviewer: "Were you able to get any like, cost benefit or cost avoidance data on your flap zero time: before and after kind of thing?"

Interviewee: "Unfortunately, when we started, we just said, 'This is good to do', and we didn't think too much about gathering data like that. But after we started implementing it a lot of people were asking that same question, so we went back and tried to gather as much as we could, and I guess it wasn't as ideal as it would have been had we started getting it at the beginning. Some of that data after the fact was difficult to gather. But what was happening was, as the aircraft would go back to the field, the field guys would call us and say, 'Hey, what did you guys do to our flaps?' because they were used to spending at least half of their time during ISO sitting there and working the flap systems. And now they came back, and they ran so smooth you could hardly hear them running. And they didn't have to do anything to them. So they're kind of jokingly saying, 'Hey, you are going to put us out of business because were used to spending so much time on those.' So I guess any data on those that we would have had probably wasn't real accurate, but I know that feedback from the field was pretty much that we have eliminated their flap problems. We're trying to go to the same program on the C-5. The key here is getting funding for it, and if we go ahead with it, then we'll definitely start to gather the data up front, so we'll have that."

Interviewer: "Did you use anything published as far as like a roadmap for your analysis? In other words, 'Here's the way we're going to look at the data, here's the criteria we're going to use to analyze it, here's the decision tree were going to use to figure out which things are going to be more critical than others?"

Interviewee: "Not really, I mean nothing that was published. Probably the closest thing we got to that was Weibull analysis, which I don't know if you're familiar with that, but essentially what it does is, if you've got, like for on the structural side, if you've got just a small number of data points, what it will do as it will take those data points and extrapolate it out and give you a real high confidence level…"

Interviewer: "Yes, you fit a Weibull curve to it."

Interviewee: "Yes, so we'd used some of that and the key that was that you had to have serially tracked, you had to have serial data. You couldn't use MTBF data, because you had to have individual points. So on the items that we had that were serially tracked, we did use that on. So that was probably about the closest thing we got to something formal. And I know nowadays, everybody says, 'So show me how you did this'...This evolved over about 10 years. And we just kind of did it on-the-fly and we did what made logical sense. And a lot of that's probably fairly in line with some of the stuff that's published now, but we were just kind of doing it on our own. Now one thing that we are doing on the C-5 right now, and we're not to the implementation phase yet, but MSG-3, which is similar to RCM - in fact, some folks call them synonymous with each other; but we're going through MSG-3 analysis on all the inspection work decks for the C-5 and what they're doing is they're going through, and kind of going to like you were asking earlier on. You've got these inspections, and are they necessary, are we need to add more, or do we need to shift them? So a lot of that's happening, where they're taking some out and maybe adding some. They may be shifting some say from ISO to PDM or vice versa and stuff like that."

Interviewer: "And is the vehicle for that analysis a failure modes, effects, and criticality analysis?"

Interviewee: "Yes, and initially the intent was to get that from Lockheed. But they never could pull all that data up without having us pay them a lot for it so the MSG-3 folks just went back and developed it on their own."

Interviewer: "So do you have contractors doing that analysis for you?"

Interviewee: "Yes, we do, and they're getting close to finishing that up, and then they're going to come out with some sample work cards that we can go up and get approval for. But what they did was they had all these folks from the field that would come in and have depot folks come in, the engineers, you know anybody that was involved in whatever component they were looking at, and they would come up and develop all of the FMECA data, and then they would go through all the failure modes and all that stuff."

Interviewer: "Was the intent then with the 141 to use your analysis to revise the preventive maintenance program or essentially just to improve the reliability of systems?"

Interviewee: "Yeah, pretty much just to improve the reliability."

Interviewer: "But now it sound like in the C-5 maybe you were looking with this MSG-3 more towards actually revising the preventive maintenance program and making it more cost-effective."

Interviewee: "Right, and that's exactly what's happening and to be honest, when we came to C-5 we really were not. I mean, we had heard of MSG-3 and we used some of their terminology like in our processes, but we were not real familiar with what MSG-3 did. As we get more involved in it we realized how beneficial it would be in part of that what we're trying to do is extend our PDM intervals out. Right now we've got 7-year and a 5-year, based on which MDS it is. And what we're trying to do is push them both out to an 8- year. So if we can get… Once they finish the analysis if everything looks good on that then we will have some major cost savings over the next, say 10 or 20 years.

Interviewer: "And will that PDM stretch be justified because the ISOs are more effective?"

Interviewee: "Yeah, part of it and what they're going in and determining is what we had was a lot of the, some of the, I guess I'll say the analysis that showing why the initial PDM intervals was set up was mainly for the landing gear. So what they're planning on doing is, unless the analysis tells us something different, is go with an eight-year PDM cycle and what we'll call them maybe a major ISO or mini-PDM at four years and that would mainly be for the landing gear, and whatever ISO tasks were required at that time. So that was the main driver. From what we can tell it was landing gear that pushed it to five or seven. Based on the aircraft. There are some structural things too, but I think most of those, from what we've determined, can be done either stretched out or done at that major ISO, that 4-year."

Interviewer: "So, your analysis on the C-5 being performed now by contractors - is that by two digit work unit code system or how are they breaking that analysis down?"

Interviewee: "Yes, I think that's where they start at is that the two digit, and then they're working down to the five digit also. But I think that's the approach on, with the MSG-3 is that they start at the… And they're also doing some monitoring on that, too, on the two-digit level, which is what we call performance-based planning and logistics, PBPL. I think the philosophy there is if you look at the system-level or the two digit level than you're going to see indications that you get degradation before you actually see failures of components. I think, they say it's kind of an analogy to that would be like healthwise with your body. You start feeling that you feel bad or what ever before, you have, say, an organ or something that goes bad. So it's kind of the same philosophy. If you can read the symptoms right, it's just a little more proactive. So you can catch it before you actually have a failure. I assume that works based on past experience with the commercial airlines that have used MSG-3 and RCM that that is a good approach."

Interviewer: "Well, my thesis research with the F-15 primarily is concerned with the implementation phase. You know, they have a contractor doing the RCM analysis for them as well. And I'm trying to look at what potential hurdles we're going to have with the implementation. Based on your experience with the 141 and your involvement with the analysis now on the C-5, what hurdles do you see with the implementation of the data? Coming up with a revised set of 'here's what you're inspecting, here's when you need to inspect it' is one thing. But unless we can get it implemented correctly and have the field buy off on it and adhere to it and get leadership to buy off on it, all that analysis is for nothing, unfortunately."

Interviewee: "It is, and that's what we're kind of worried about now. We went through I guess about a month ago, and said once we finish with the analysis who all do we have to go through to get approval to implement this? We came up with about a three-page list of different folks, going all the way through our base here at Robins, and then going through AFMC, our command, and then going through AMC, and in a lot of cases going up to the Air Force level to get some of these, because we're going to have to get a waiver or approval if we're going to go out to extend the PDM cycle out. So that's going to be a major hurdle. Another big hurdle is the cards themselves. What they're proposing, the contractors that we have are from the commercial industry. They used to be employed by Northwest and what they're proposing is a commercial style work card. In the current work cards, and I'm not sure that you know what they're like. Let's see, what's the size? Like 8 x 5 or something like that. So what they're proposing is a normal eight-and-a-half by 11 sheet, and in addition to that it's going to have… Normally, in an older work card you'd say OK…Do this task in accordance with so-and-so job guide or so-and-so tech order. This one's actually going to have that procedure in the card step by step on the card itself. Part of the problem with that is, at least on the surface, it violates the tech order reg that says that you need to have all of your procedures in one location, and then any other book that the references needs to reference it and are not respelling out that procedure. You know, that way, if you have changes in one you don't have to find everywhere else that it changes. But what we're trying to push is that now in the digital age, that even if you've got it in several books, it's really easy to link those. If you've got hyperlinks and cross links and stuff like that electronically, and if you have it in the one location, you can have it tied to all the other T.O.s and stuff electronically so when you make one change in either takes you to those areas and it makes a change in every location."

Interviewer: "Would this implementation then involve going exclusively to electronic Tech Data, like a portable maintenance aid that they carry with them, or are you still talking about paper tech data?"

Interviewee: “Yes, for what do they call those they call those things Cruze Pads, they spent…some of the folks use them out there. That would be the long-term. But what I'm looking at is not necessarily when you're using the tech data, but when you're updating. That would be our T.O. folks, our TOMA and those folks -- they update the data, and when you go and make a change in one location need to find out where it is everywhere else that's really just the folks updating the T.O.s, and the field guys don’t really have to be involved in that. So, what I'm looking at short-term, would be, you know that we keep that configuration control, I guess for lack of a better term in the TO area, that whenever a change is made to this procedures that they've got links to all the other places where it's listed, where they can go in there and make the same changes. But then long term would be the Cruze Pads or whatever they use the guys out there. And the maintenance crews would actually have it where, say it is an older work card, when you click that link it takes you to that spot. What we’re trying to get away from is a guy taking a wheelbarrow full of books out there, which they don't do anyway, and technically I guess they should if you follow it to the letter. So we’re trying to avoid that. And we I think it makes it a lot more or a lot less ambiguous if you have everything on that one sheet. That's going to be major. That's going to be a major obstacle. What we're trying, the way were trying to push that is we’re trying to say that we meet the intent of the reg. You know, it says you shouldn't have it in one location. We’re saying we’re meeting the intent by we're able to instantaneously link all those locations, where it is called out.”

Interviewer: “Do you see that revision of the tech data as critical to the success of the change in the inspection?”

Interviewee: “Well, not necessarily. I think if we can get that change in, you know, you implement it to the most effective phase. But if that gets shot down, then worst case we would use the same format and everything that we currently have. But with different verbiage in the work cards.”

Interviewer: “More of a revision of the existing tech data.”

Interviewee: “Right, of what ever tech data. So I don't think it would kill the program, but it wouldn't make it as effective.”

Interviewer: “Do you see any way to streamline that three-page list of people that have to be in the loop if it came, say, from more of a high level down, flowing down instead of having to go up and then back down again?”

Interviewer: “Yeah, it would, and we've talked about that because, what we've talked about is you have to go all the way to the top here at Robins and start the bottom in AFMC and go all the way up to the top there, and all that. So if we can get it up and say our two-star says, ‘This is great, I’m 100% behind it.’ If he pushes it over lateral across to somebody high up at AFMC and it may prevent us from having to do that up-and-down type thing.”

Interviewer: “Do you feel that you have that level of commitment at that level of leadership? Or do think that’s something that you still have to sell?”

Interviewee: “We got to sell it to that level. I know that our colonel, in our colonel level, which is at our group level, he says it's his top priority. So we do have it at I guess you’d call that a mid-management level and, but we haven’t briefed it up to the general yet. I believe that we’ll probably get his buy-in pretty strongly when we get it up there. I know he's going to be looking at it too from how’s it going to impact the PDM? You know, you don’t want that, all of a sudden you go and cut your PDM workload in half or something like that. I don't think that's going to happen, but that's going to be one of his concerns. And the other thing we’re kind of worried about as we go through all of these coordination processes is, if anywhere along the line somebody non-concurs, then it pretty much kills the whole thing. So that's what we’re kind of worried about as so many folks that we've got to get coordination from the anywhere along the line, you know, we could be dead in the water. And that would help like you mentioned, if we could go from high level to high level that would cut out a lot of that because any folks below it that may not agree with it - you know that they’ve been pretty much directed to coordinate on it, so...”

Interviewer: “Any other difficulties you anticipate with the implementation?”

Interviewee: “Let's see. The cards, getting all the folks as far as getting the extension to the PDM. Right now I don't really have a good handle on that. That could be a problem, I don’t really have a good handle on it. I know that I did actually earlier this year went up through the same group and it’s at the Air Force IL-level, that I got their coordination on extending one A-model PDM from 5 years to 7 years, and it was a special case because it's in the mod program. But I went up and got their approval. What I'm not sure is, if you go in and ask for a whole fleet. When you're extending them, in some cases you're extending them out three years. You know, if they're just going to say ‘OK, as long as you your colonel signs off on it we don’t have a problem.’ If it's going to be that easy, or if they're going to say, ‘No, we've gotta go into a test program,’ which they call a CEI or CIE… I forget what they call that. But there's a program when you take a few aircraft and say, we're going to try it with these and see how it works. I think it's a CIE program I can't remember what that stands for. Maybe like a controlled, maybe like an initial evaluation thing, instead of going full bore across the whole fleet, we'll take two or three aircraft let them run through it and then several years from now we'll see if it looks like it's going to be viable."

Interviewer: "Sure, gather up to the lessons learned and see what we can do."

Interviewee: "So that could potentially be a big stumbling block."

Interviewer: "How about the analysis itself? Do you have any concerns with the quality of the analysis, or the quality of the results of the analysis being performed?"

Interviewee: "On the systems I don't. On the structures we've already, and I'm a systems guy by nature, but our structures folks have looked at the analysis (which actually was completed before the systems) and they've been reviewing it and they have recently come up with some concerns. One of them is that Lockheed, they came through and developed what they call an FSMP, a force structure management program. And what it does is essentially outlines all the inspections required at the different intervals that Lockheed recommends. And then we can take that and bump it against what we're currently doing and see what matches up."

Interviewer: "Is Lockheed's recommendation based on design considerations or performance in the field considerations?"

Interviewee: "Probably both initial design and any new data that may change that."

Interviewer: "And would that be data that they collected themselves or the same GO-81 data you're using?"

Interviewee: "They've got their own system. They call it STEFIS, and I'm not sure what that...hold on one second…It actually comes from REMIS, this STEFIS data and it may have more in it because I know that GO-81 dumps into REMIS. But a lot of times REMIS may have more than GO-81 actually will display. But anyway, they developed this out of that data and then what happened was the contractor went through and looked and they went through and said, ‘OK. We've been doing this inspection here and you know, we've never found anything. So we're going to take it out.’ And yet, that was an inspection that Lockheed had recommended still be in there. And as the structure guys went through and they went through Lockheed's FSMP and they started throwing stuff out that they didn't think should be inspected, and they didn't really like that approach. And I can see why. Just because you've gone 20 or 30 years and never had a problem doesn't mean you're not fixing to start having some major problems.”

Interviewer: “But was Lockheed's perspective mainly pride in ownership of the original solution, or did they have some data that would back up why they thought it was a good idea to inspect those things?

Interviewee: “They wouldn't have data, because if they've never had a problem, I guess it wouldn't have data, but I think they were looking at more from a reliability-type thing is hey, if you do have a problem here, you’ve got a major problem may have a mishap.”

Interviewer: “And we can at least tell you that we told you to inspect it!”

Interviewee: “Right, exactly. And from our standpoint, if you don't ever look at it and it's a major area, you know, I mean you may be walking on thin ice here. I guess from the commercial standpoint, which the contractors were, they said, ‘Hey.’ What I found out was with MSG-3 the whole reason it was developed was to save money on the commercial side. The guys were doing inspections, inspections, inspections, and all these things and they said we need to be more efficient. So a lot of things they would say, ‘If we've never had a problem here, we're not going to look at it until we have a problem.' So, I mean, that's great from probably from the commercial side, but we're not as concerned with the dollar amounts associated with running the business as we are with safe and effective missions. So some of that stuff they're saying, 'You don't even need to look at it,' but we were saying, 'I think we do.' So we've got them going back through the FSMP and identifying all the stuff that they took out an that they're going to reevaluate it."

Interviewer: "Well that's a very valid concern, I mean, if you have the manufacturer of the airplane saying, 'We don't think the way you're doing business is safe,' then that's a huge dissenting vote, and it can throw a big monkey wrench in the works."

Interviewee: "Yes, it sure is, and we're hoping that it's not going to come back and say, based on putting that stuff back in, here, we can go to eight years. But we're just going to have to see. They're probably, in about two months, and they'll be through with that. So we're kind of keeping our fingers crossed that they won't have any kind of major changes."

Interviewer: "Well, I think that's about all I have. I greatly appreciate your time, this has been very helpful. You brought up some issues that I'm not sure we've considered on the F-15 side of things. Definitely things like getting the manufacturer's buy-in, that can be huge."

Interviewer: "Yes it could be. And just one thing that between us, say us and the F-15. And you probably already know this, but the F-15, they probably fly their profiles probably a little closer to what a commercial airliner would do in that they may fly out and fly back usually the same day. So they're out and back where it is, you know, the commercials from one location to another and what happens is they are flying to locations that can handle pretty much all the maintenance that’s required. So if you fly from Atlanta to Chicago, they have folks that can handle maintenance issues at both places. And F-15s fly out and back and a lot of times the same location, at least are the same in its capability do maintenance. With our heavy jets, they may get to a place without even a hangar or equipment, cranes or anything and they’ve got some components they have to replace that have failed. Like I said, I’m sure you're aware of that, but that's one thing we always throw out there. You can't put all the weapons systems in the same box. Because the way they fly, they just don’t work. And the reason I bring that up is, that was a huge obstacle we had only for when we started dealing with our MSG-3 folks, because they came from the commercial side, and they couldn't understand why we're doing time changes. ‘Well why are you doing that? That's wasting money, get as much as you can out of it.’ ‘No, you don't understand.’ We finally got them to realize that what's happening is, you know, we may be gone for 2 weeks before we come back to home base. And if that home base is the only place he can handle this issue, then if you fail anywhere along that route you're in big trouble. And costly. So that’s the reason I brought that up, because that's a big issue that folks in the commercial side may not realize the situation. So anyway...”

Interviewer: “Well thanks very much for your time.”

Interviewee: “Okay, you're welcome. Bye-bye.”

Appendix E Interview Four

Interviewer: "All right hey I really appreciate you taking the time to let me interview you for this research. Are you still going to school or you back to work full-time now?"

Interviewee: "Well I'm at work this week, between semesters in college and use or lose leave."

Interviewer: "Oh, gotcha."

Interviewee: "Within the next week or so."

Interviewer: "I had a good conversation with XXXX and he talked about some of what they're doing on the C-5 and C-141 as far as RCM. If I understand correctly you and Dodd worked previously together is that correct?"

Interviewee: "Yes, we did."

Interviewer: "And did you have any RCM analysis or implementation going on at that time, and what was the background of what you were doing?"

Interviewee: "My background is, I've been a 141 guy for 25 or 26 years now. My area of expertise was structures and the aircraft structural integrity program. And as I was doing that job, I was looking around at the other things that are going on with the airplane. This is in the late 80s and early 90s, and we started thinking that the principles we were using for ASIP would work with the systems as well. You know with the functional systems, because the idea, when you boil any integrity program down to its basics, it's: you figure out what can break, you figure out if you can stand it to break, and if you can't stand it to break don't let it. And as my old boss used to say that's farmer talk for what an integrity program is."

Interviewer: "It doesn't have to be complicated to work, right?"

Interviewee: "Exactly. And I started talking with those guys in the systems branch at the time and started trying to convince them that they could do similar things with the systems as we were doing with structure. There were a few little differences, because there is... The main thing that we had to overcome with those guys was they were always of the mindset that they had been drilled into all their lives, that, you know, you use every component until the very last seconds of its life is gone and it breaks and then you have redundant system on airplane to take care of it. And if you get back to land, then you fix it. Well that didn't make a lot of sense me from an operational perspective, because lots of places where 141s went, or C5s, C-17's, lots of airplanes like that go there's nobody to fix it. So when it breaks somewhere out en route. You have to wait and get an MRT generated to find the parts and take those guys away from the work they're supposed to be doing at their home base to go fix the airplane. You take another airplane out of service, you know, out of missions service to carry them to go fix this airplane and a lot of other stuff. That was cost that nobody was tracking it was just considered to be part of doing business. And that didn't make an awful lot of sense to me. So once I finally got them to start thinking about, OK what does it really cost when an airplane's broke in Mogadishu or some of those out of the way places that there's no repair capability, and they started thinking about it, and that was kind of the genesis of the 141 FSIP program, and we started looking at it and those guys started taking off on a couple of different ideas. We had looked at the MECSIP program I'm sure you're familiar with MECSIP?"

Interviewer: "Yes."

Interviewee: "But at the time we're looking at it MECSIP was written basically for new airplanes and airplanes that were under development, because it was talking about all the test data that OEMs were predicting how long their parts would last in function and all that kind of jazz and we started looking at and we didn't have any of that kind of data. But then we started thinking, well, we don't have any of that data, test data, but we have 20 years of operational data, and that's a whole lot better than test data. So where we started going with that was to go back and look at the data that we had from CAMS, GO-81, REMIS and all those different data systems as well as, one of the smartest things we ever did, was we went out and found a couple of old crew chief type guys. In fact, one of the guys that started, helped to start the FSIP program for 141s is a retired Chief Master Sergeant XXXX XXXX, who had worked 141s all his life and really knew the airplane and knew where the data that we were getting from the field was, I won't say wrong, but suspect. And he would go in and put some experience against what the systems were telling us and say well here's probably what really happened and start talking to the guys out there in the field, and getting them involved in that same effort."

Interviewer:"So Chief XXXX would point you in the right direction and the folks in the field would back up what he said?"

Interviewee: "Absolutely. And we got two more guys. We brought them in both of those retired Air Force guys, well, one retired one got out and started working for Lockheed is a service rep. But then we had another guy who had retired from headquarters AMC after being out for a long time and working maintenance and ISO issues. They both knew the airplane really well. They knew the data systems, well, they knew what was really going on well. And their understanding of what was really going on and our understanding of how things are supposed to work, combined, turned out to be a fantastic team. It was a real synergistic type... I hate to use that word, but a real beneficial arrangement for everyone, as far as I was concerned. Because we get the benefit of their knowledge, and they got the benefit of ours. We worked something out that was really helpful to the war fighter. It took, from the time I first broached that idea with those guys until we finally got something workable out in the field, it probably took about three years. So we were, it took me about six months to get them convinced that it would work. And once they finally saw the light, then I kind of had to throttle them back some because they were trying to go at it too fast and trying to make changes to everything overnight and that doesn't work either, in this man's Air Force."

Interviewer: "Was your sell then primarily for the cost avoidance standpoint, or was it primarily from the systems functions standpoint or was it kind of a mix?"

Interviewee: "Cost avoidance was a beneficial, I don't want to say that, say a side benefit. I was more concerned with aircraft availability. You know, having airplanes out and ready to go when they were needed to go. That was something we were all is getting beat up on; you'd see airplanes down in the field. Down in the en routes for things that could easily have been done, you know, somewhere else a lot cheaper and a lot faster. In fact, we did a presentation in Albuquerque, at an aging aircraft conference I think it was in 96 I need to send you that, and let you take a look at that, because we got the engineer at AMC, they have a token engineer on staff. Back during the days when the C5. The first C-5A wing, was in serious trouble with fatigue cracks and the AMC four-star got an engineer and put them on his staff to translate so that he could double-check and make sure that what he was being told, you know wasn't being blown smoke by bunch of engineers."

Interviewer: "Needed somebody who could sprechen zie engineer, huh?"

Interviewee: "Well, sprechen zie engineer and sprechen zie general at the same time, and sometimes that's not really easy to do. The guy that was in that position at the time had grown up in the 141 SPO basically from second lieutenant to captain and he knew what we were trying to do. And he was very, very helpful getting that, I won't say accepted, but selling that concept. At AMC…can you hold on just a second, Chief?"

Interviewer: "Sure."

Interviewee: “Chief, I hate to do this, but I just got preempted by the boss.”

Interviewer: “Understand.”

Interviewee: “I can certainly phone you back later today if that works for you.”

Interviewer: “That's fine with me, probably around two.”

Interviewee: “That sounds perfect. Okay thanks Chief, bye.”

Interview continued that afternoon.

Interviewer: "When we left off last we were talking about the engineer that was on the AMC staff that kind of helped you at the AMC commander level to sell the idea."

Interviewee: "That's something that none of the other commands have right now. We've tried to encourage that as much as we could, you know all the way up through ASC/EN and AFMC/EN. That guy was military, too, which helped a lot in the transfer of moving in and out a lot."

Interviewer: "You think it definitely would have had an impact if the guy had not been gunning for you?"

Interviewee: "It would've made it a lot more difficult, yes."

Interviewer: "What other difficulties did you encounter or do you anticipate if you didn't have him that you would have encountered as far as getting support? Had you not had him on your team, what challenges might you have faced or what challenges did you face even with him helping out?"

Interviewee: "Well, to be honest, we used his influence there at the old LG. I can't even remember what the new symbols, A4, A5, what they use now, but just the old LG staff and basically just amongst the weapon system managers there. We didn't really take the idea up until we had done as much stuff as we could do at the lower levels. One of the things we did is we just went out to the field guys, you know, being the 141, we only had about eight or 10 bases, so it's not like you have 400 bases like the F-15s and those guys. We just went out to the units and just sat down with the maintainers and said, 'OK. Here's some ideas that we think we can help you keep the airplanes flying better and keep your home a lot more. And here's what we need you to do to do that. We need better data in CAMS and we need some cooperation. You know, pick up the phone and call us if you got an issue going on. Let us know.' Just keep open lines of communication, and we started it kind of the grass-roots level, got those guys excited about it and they could see what we were doing and how the information they were giving us was going to help them and only after we got it started good, did we try to go up the chain with it. It seems like the things we were trying to do were completely different than anything people had done before, and it usually works better when it starts in the bottom and bubbles up than if it starts at the top and gets shot down. If you know what I mean."

Interviewer: "Being a maintainer we would be at least skeptical about something that no maintainers were involved and as far as here's a great new way to maintain this airframe."

Interviewee: "And that's where having XXXX and XXXX and XXXX helped an awful lot, too, because they were maintainers all their lives and they went out and spoke the language. We engineering types were there and we took off our ties and would go out to the field, but having those guys there, and a lot of field units knew them already from their time as Lockheed field reps and headquarters and other places. Their reputations kind of preceded them somewhat and that made it a lot easier. I know that you're aware that RCM had... There were RCM regulations in place that we were supposed to be doing in the 70s and 80s. But as I've seen on a couple of other occasions, when the Air Force codified RCM, it didn't do it in the best way it could've been done and it left a bad taste in a lot of people's mouths."

Interviewer: "Do you mean as far as the way it was implemented or the actual way that they wanted the RCM to be done?"

Interviewee: "A little of both. It was put out with the maintenance steering group concept in the ATA and at the time that we first ran against that it was MSG -2; MSG-3 wasn't out at the time. And nobody really understood what that was all about. We just got told get this format, and do this analysis in this way. And of course, you're always behind the power curve on day-to-day problems. So you don't really have time to go digging up a lot of stuff like that. To be real honest sometimes you get things that come down from headquarters AFMC or they come from ASC, people who live their whole lives in an ivory engineering design tower and have not gotten their hands dirty. And like you're talking about; if something comes down from higher up to the maintenance troop and there's been no maintainers involved in it they'll be skeptical. And we were too. The way the reg was written and a lot of other things such as implementation wasn't conducive to success, I guess. So when we started doing FSIP, we realized that all it was was RCM. You have to be real careful not call it RCM because it gives you that... for the same reason we came up with the functional systems integrity program moniker rather than just calling it MECSIP which is what really was because MECSIP had a bad name with people, because it involved talking about new airplanes and a bunch of tests and a lot of calculations and analysis and stuff that we weren't sure that we knew how to do."

Interviewer: "Was your roadmap MSG-2 then, is that what you started out with?"

Interviewee: "In a roundabout way."

Interviewer: "Or was it the Air Force's kind of spin of MSG-2 that they had in the instructions at the time."

Interviewee: "It was the Air Force's spin on MSG 2 that they had in the instructions at the time. And to be honest, the FSIP thing. We didn't really use a lot of that we just tried to do what made good common sense. And really what our program boiled down to was, if you've got a part and you've got historical records that show it can fail every 10,000 hours and scheduled downtime happened before 10,000 hours, change the part. You know, get it as close to 10,000 you can, but change the part because like we were talking about this morning. You can change a part for thousand dollars at home station, where it might cost you $110,000 to change it en route somewhere trying to get everything there to do it with. And we didn't bring the MSG to concept in the Air Force. The RCM concept said you should look at the whole airplane in detail and look at that in a relatively quick manner and we looked at that and we said, well that's not really... I don't think that's what we want to do because it doesn't make a lot of sense to look at every single component from that perspective. You know some things, let it break and it doesn't matter. But what we decided to focus on were things that were on the mission essential list. You know, you've got redundancy while you're flying. But you're supposed to fix everything before you take off. And if one of those components breaks in Mogadishu, you have to get another one out there to replace it before you can leave again. Those are the ones we concentrated on to begin with. We wanted to make sure that those were going to be ready to go when you got ready to leave. You know, wherever you are. Another thing that we looked at - and again I'm not sure if there's any MSG-3 concept in this - I'm not sure if there's anything it but just common sense. There are parts on the airplane that were designed for its original lifetime of, you know 30,000 hours or 20 years, and you're flying at 35 or 40,000 hours and 30 years, and you still have those original parts on the airplane. Things like on the big airplanes, the flap system, you have all kinds of bellcranks and linkages and drives and torque tubes and all that kind of stuff and over the years, you get a little bit of wear on each one of those parts and, while each part may be individually within intolerance, the whole system gets tolerance built up and get so much slack and slop in it that it doesn't work like it's supposed to any more, and you have lots of problems with that. So we went ahead and started just taking those systems as we could get parts together to do it and just going in and replacing everything in that system. You know, at one time to get back to almost like new condition, and then you can go for another 20 years and don't have to worry about it. Instead of fighting it, day after day after day."

Interviewer: "Were you originally a proponent of RCM or was that kind of what you envisioned when you wanted to take the concepts from the ASIP and put them into the FSIP or was that kind of something that came along after the fact, once you started down that road?"

Interviewer: "It's something that came along after the fact. Like I said, my biggest driver, and that was let's keep the airplanes flying. Bring them down once in awhile when you need to bring them down to fix them. And while it's down, everything we can do to it to keep it from coming down again unscheduled; do it. That was our biggest goal was to try to keep them flying. It's a lofty goal. You probably never get there, but try to eliminate unscheduled maintenance."

Interviewer: "Do you think, looking back that RCM kind of served that purpose well or do you think you would've been better off going in a new direction?"

Interviewee: "Hmmm good question. I think looking at RCM, the C-5 has just been going through an MSG-3 analysis. ISO decks and home station decks and the phase decks for the C-5 are basically a kludge. Things have been added to them without any thought as to where they really go. And we just had to say, 'OK, stop and let's look at everything now and put it back in order like it's supposed to be.' I think one of the things that we discovered while we were doing that was that you can't take the literal results of analysis like that without applying a little bit of 'Kentucky windage,' if you will. You know, back off and look at it with a critical eye and get some people who know the airplane and maintain the airplane involved. It's not something you can do from an engineering perspective by yourself. And I think that maybe one of the fallacies of RCM is that you can analyze everything in, you know with the slide rule. There are some things that I've found, some of my best engineering has been done without the benefit of calculation. You know, just looking at it and applying your experience. I think RCM gives you a good framework to begin the process with, but I'm not sure it's the be-all and end-all by itself."

Interviewer: "One tool in the toolkit."

Interviewee: "Absolutely, and there are a bunch of others out there and you need to use all of them."

Interviewer: "Did you... When you performed your RCM analysis for the 141, was it again just mostly from a perspective of how can it increase the reliability of this thing? Or did you actually get to the point where you looked at inspection and time change type items and say, 'Hey, the analysis doesn't support the fact we continue doing this. It’s not cost-effective.' On the F-15 for instance, they've come up with a lot of the 200 and 400 our phase inspection items that the RCM analysis, in conjunction with talking to the maintainers, don't support continuing to do those things."

Interviewee: "There were a few things that we came up with and looked at and said, 'It doesn't make sense to keep doing this.' But we found a lot more things that made sense to start doing than to stop doing when we looked at everything that we are doing from that perspective - does it make sense or does it make sense to not do it?"

Interviewer: "And did you feel comfortable using the RCM analysis as the justification or the basis for either starting those new tasks or discontinuing the tasks that weren't supported? Was the justification there based on that analysis?"

Interviewee: "Yes, yes it was. Nobody needs real justification - maintenance guys don't need a lot of justification to stop doing extra work."

Interviewer: "But what about the aircraft manufacturer. Especially if those are things that their design engineers said would be a good idea and we are saying, 'The data doesn't support continuing to do it.' Did you get any resistance from them?"

Interviewee: "Not really. We were kind of bucking the traditional Lockheed reliability group in all the things that we were doing, because it wasn't the way that they had always done it. But from our perspective, the way things had always been done wasn't working really well. And so it was time to step back and take another look. We had some of the folks at Lockheed, who were very helpful and very encouraging to help us along at about that time. One of the things that we had intended to do all along was to go back in to do some more rigorous statistical work on some of the numbers. But then the airplane retirement kind of caught up to us and didn't give us a chance to go back and do a lot of that - looking at things from a probabilistic perspective instead of just a deterministic perspective. There's a big benefit in doing that in terms of balancing resource expenditure versus risk, you know what you're trying to accomplish. And you have to be careful when you talk about risk. From the ASC and AFMC headquarters in perspective risk is your program cost and schedule. From our perspective risk is that you lose the airplane. And you have to balance those kind of things. There are a lot of good things that can come out of good statistical analysis and I hope that I can convince those guys they need to start doing some of that as they get their hands around the C-5 a little better. The 141 engineering team and the C-5 engineering team were merged about two years ago. The C-5 had not done a lot towards anything like RCM or those kind of deals so that we had to drag them along kicking and screaming. And it has taken the guys awhile to get their arms around the whole beast, because there are about four times as many systems on that thing than there are on the 141. Again, the RCM analysis in and of itself is a good to have in the toolbox. Along with several others it's just a matter of knowing when it's the right tool for the right job."

Interviewer: "Do you think there are any things that, looking back, you think, 'Man I wish we would have done that a different way or we could have saved ourselves a lot of hassle, had we done it this way instead of that way' as far as implementing the changes that the RCM analysis recommended?"

Interviewee: "I can't think of anything right off that we could have done a whole lot different. If we had the data or..."

Interviewer: "Even as far as the change management. You know, how do you sell it up and down, you said you started more at the grassroots level and got the support there."

Interviewee: "Absolutely, I think one of the things that I would have done differently is I would have gone out to the field units as we were going through the changes. I would've gone to the depots that manage those particular items and explained up front the benefits from making a lot of these time change items instead of fly to fail items. And the benefit is they get a steady demand or at least a more steady demand. And they get that predictability in how many they have to fund for repair or purchase. The depots get a lot more stable workload, and they like that a lot better. It just makes life... It eliminates a lot of those up and down sawtooths that we find all the time. You know, you fly along until one unit finds something broke. And then they start looking at all their airplanes and the word gets out to the other bases and everyone starts looking at the same thing and they're all broken and you have to go out and buy 10,000 units to replace them all and then you don't need any of them for another 10 years. Then you go through another whole cycle, and it's really, really ugly. Think if we had gotten those folks more involved upfront, you know as far as change management and changing the supply side we probably would've been better off."

Interviewer: "Well that certainly makes sense, anything that's going to change the amount of parts in the pipeline to the depot or the traffic pattern of the parts flowing through the depot, that's something I hadn't even considered to be honest with you. That's a good point. Sometimes I think the depots, even now to a certain point, are configured to deal with that sawtooth demand, because they'll completely shut down one product line to go work another one, versus just having a steady demand that they can count on and spread their resources. They'll completely jump from one thing at the expense of one item to go work whatever's hot."

Interviewee: "Well it depends on the item, too, sometimes. If it's the, you're working a throwaway item as opposed to a repairable and you've got a year contract delay time to buy the thing, and to find a bidder who can do it, and you're bound by the small business rules to go to small business or disadvantaged business or whatever, and by the time it takes to prove after three times that they can't build the things and you have to go back and pay the OEM six times as much as you wanted to pay him for the part to get right now because you have airplanes are sitting on the ground. That whole thing just doesn't make a lot of sense. If you can keep a steady demand or relatively steady demand. That makes everything a lot easier for everybody."

Interviewer: "Was your education in RCM kind of a practical one, or did you have some formal training?"

Interviewee: "No, I didn't have any formal training at all, and sometimes that's the best education."

Interviewer: "Is there anything that you thought, I wish he would've asked that but I didn't?"

Interviewee: "No not really."

Interviewer: "I think I've pretty much got what I need. Thanks again for being flexible on getting back with me and everything. I do appreciate it."

Interviewee: "No problem."

Appendix F Interview Five

Interviewee: “Now, are you a maintenance person?”

Interviewer: “Yes an aircraft maintenance guy.”

Interviewee: “Oh good. That's totally my background as well. I like to talk to maintenance people.”

Interviewer: “Roger that, we kind of speak the same language, don't we?”

Interviewee: “Sometimes engineers don't quite understand, but okay.”

Interviewer: “Right, I understand you designed it that way, but, here's how we use it.”

Interviewee: “Exactly right.”

Interviewer: “And here's what we wish you would have thought when you designed the thing. Well, as we talked about very briefly before, the basis of what I'm doing is: there are some guys in the F-15 sustainment SPO at Warner Robins led by XXXX XXXX - they've actually got a team of contractors there working for them - that are trying to revise the preventive maintenance program on the F-15 based on reliability-centered maintenance analysis. And they've got what looks to be like a pretty good system for getting the analysis done. And one of the products of that will be ‘perform these tasks at these intervals,’ in a lot of instances actually ‘quit performing these tasks,’ because there's no history of failure, and even if they did fail the criticality is such that we're wasting time and energy inspecting things that really don't need to be looked at. So the basis of my research is, once we've got that analysis performed and we've got that list of ‘perform these tasks at these intervals.’ How do we then implement that into a revised preventive maintenance program? Because I think the Air Force is really starting to strongly espouse the idea of reliability-centered maintenance for new acquisitions, but they haven't really come on as strong in supporting reliability-centered maintenance as far as taking an existing weapon system with an existing preventive maintenance program and revising that based on reliability-centered maintenance analysis. The Navy, I think has a lot more experience with that. I'm talking with some guys who actually have a working group/steering committee kind of thing. Hopefully I'll get some good information from them. But I also wanted to get some different aspects, different perspectives from people who have been involved with reliability-centered maintenance analysis and implementation, and so that's what I was hoping to get - some information from you is with your experience with Northwest."

Interviewee: "And you also know, I assume, that we're doing this on the C-5A - the C-5?"

Interviewer: "Well, I spoke with XXXX XXXX earlier today. And he had some good information, not only on what's going on with the C-5, but he had some history with the C-141 as well as far as the RCM – well, not purely RCM, but the concept of hey let's take some historical data and see which way it leads us."

Interviewee: "Yes, if we go to the full extent we're going to get into a lot of conversation here, because really I think there's so much that you need to know about, what reality is. There's a lot of published stuff, but there's a lot of reality as well. So I would hope to be able to share all of that with you."

Interviewer: "Definitely, that sounds good."

Interviewee: "Because I'm a highly opinionated person, so be prepared, fasten your seatbelt."

Interviewer: “I wouldn't have it any other way. So your current capacity as far as what you're doing right now is that reliability-centered maintenance analysis is that your primary focus right now or?”

Interviewee: “We're doing it all. What we're doing is a complete MSG-3 on the C-5 with working into the process of a maintenance program to support that. And that includes RCM. And those words in themselves, maintenance program, is a very important couple of words in that if you look in the ATA document of the MSG-3 document, I don't know if you've done that ever. You will see in there that it tells you that after you go through all of that analysis and develop the tasks, you have to develop a maintenance program to make it work. And that's all it says. Now it's up to you to figure out how to do that. It’s written loosely in that document, because the maintenance program is a competitive issue with the various airlines. So there are some guidelines that the FAA is in fact, the old advisory circular there was 120-17a. That is now an obsolete one because it refers to MSG-2. They're working on a new one that's been out a few times and has been withdrawn back, because it's too complicated. So I don't know or at the moment where that is. But if you read 120-17a, you want to do that, because even though it uses MSG-2 there’s lots of neat stuff in there. Some neat direction and guidelines on how the airlines are supposed to set up their reliability programs.”

Interviewer: “Can I get that from the FAA a web site?”

Interviewee: “Yes, you can so that's a good starting point. A good starting point is also to get yourself a copy of the ATA document, the MSG-3 document. That's very important stuff, if you got that you… But those are very useful tools to get a good, a fairly good understanding of the whole process. Now several things, and I don't know if I'll remember to do them all, but as we get through this, different things will come into my mind. I've got a sort of a scattered brain. It's all over the place.”

Interviewer: “I tend to talk my way through things.”

Interviewee: “Exactly, a couple of key items is that in order to implement successful RCM. Excuse me reliability. In order to implement a successful reliability program. You have to have several things that we've recognized very early that the C-5 did not have. One of the main things is cleansed data. The C-5, let me back up. The C-141 had a program. But it wasn't with cleansed data. So the data they got was in many cases misleading. Misleading data is worse than no data, and how many people hang their hat on misleading data?”

Interviewer: “Because it's what they have and what's convenient.”

Interviewee: “That's right. So at what we did right from the get go and what we call… We've got two entities that are dealing with reliability. One is called a PBP, performance based planning, and the other one is called RIP, reliability improvement program. They've changed the names from time to time, but that's essentially what they are. RIP is the process of following the systems of the aircraft across the fleet, following their reliability. PBP is the process of following a system on a particular aircraft for its reliability and looking for the bad actor aircraft, or, in this case the bad actor system to a bad actor aircraft. So they’re really both the same thing in reality, they both use their data from the same source as the cleansed data, but they're different in the respect that one looks for the trends across the board in systems and the other looks for a bad actor airplane and a system that's causing that bad actor airplane. So that's very important to me in my world, and we've been quite successful in the initial application with the C-5 on that. In showing the people here how well that works when you do it right. And while I'm on the subject, I'll just give you an example of that. We've got inbound aircraft into the PDM process. And we're looking for trends of systems on those individual aircraft, and one of the things that stood out very very strongly was the slats. Now when you talk to the people in the field, and the people around the whole system, they said flaps were giving us the most problem. But when you cleansed the data down and found that it was actually slats. So we said, we found this aircraft coming into PDM. It was about a month away at this time, and it had terrible slat problems. So one of those things to companion with that is the fact that almost every C-5 that goes out of here, and when they do the functional check they always have slat problems. So we put together a team to work those slat problems on that aircraft and drill that down. And we set out laying up an inspection program, a very in-depth inspection program on the slats, which didn't even exist. Many things in the slat area they had never even dealt with. In fact, what they did for instance, is they if an actuator was bad, they would replace the actuator and that was about it. But what you find, when you have a complicated system like that, a progressive system like the slats on the C-5 with all of the jackscrews that go all the way in and out and you have a tapered wing, well a swept wing, is that the wear is not constant. Number one. So time change doesn't fit with that process, because you're going to have different wear characteristics for every one of those actuators. They just don't deteriorate at the same rate, but what you do find though is that if you have some bad actuators, they will cause deterioration to the other ones, deterioration to the associated ones. So we set up an inspection criteria when it came in to determine degradation. Degradation is the name of the game. If you look for failure only you can not be proactive. You have to be able to determine degradation to be proactive. The difference between MSG-2 and MSG-3. MSG-2 is a parts-based maintenance program and MSG-3 is a systems based maintenance program. MSG-2 looks for multiple failures of parts before the flag waves. You're already reactive. MSG-3 looks at the health of the system as it's starting to deteriorate, very early in the deterioration. So now you're proactive. It doesn't tell you which parts are bad or if it's a system that's bad. But you have to do that investigation. That's how you become proactive. So what we did was set up this inspection, this degradation inspection on the slats. Determined what has degraded to a certain point, a judgment point in our part, because engineering was very little help, actually no help on this, because they didn't have any data to work with. In our judgment, based on the experience we have – we have a lot of experience on this team - and they make judgments as to what was deteriorating and what needed to be handled. Now, for example. Slat tracks, big old tracks on the C-5. Nobody was adjusting those tracks at any time. So we found when they did the inspection that we had a lot of side to side sway in those tracks. Now, once you're tied to the slats you don't notice that as much. But what you have is the fact that in-flight is the wing was flexing, you do get a lot of side to side play. So you're tearing up more actuators and more moving parts. So we had to determine what had to be replaced. We cleaned up that slat totally, that was one of the very first aircraft that went out of here with absolutely no slat write-ups. It's flying today so far, without any problems. Now we've got to watch a long time before we can be sure that we're successful, but I have no doubt in my mind that, if not 100% were darn close to it. So those degradation checks told us that we had to get into that aircraft. That was a PBP thing. That was one aircraft, and we looked at that system degradation, and we addressed it. So anyhow, I wanted to give you that example, so you understand how one needs to measure success. The other part of this equation is that the Air Force has an interesting way of doing business for me is they measure success by availability. Now in the industry, we measure availability, because it's very important, because we fly all of our airplanes every day, and when you launch in the morning if you don't have that airplane the whole day is shot. It's a mess. But the biggest measurement that reliability measures is, and I just said the word. The term reliability, we measure the health of the aircraft, not just on availability. If you have a process, a corrective process that measures reliability, determines the level of where you want the baseline, where you want to be, and tracks that you will get availability. But if you just measure availability, you will very seldom get reliability, because availability, you can get availability by just throwing a lot of parts on the aircraft. That will not necessarily give you reliability. If the system is deteriorated and is bringing the parts down, you will not get reliability, but you can get availability. So the measurement of reliability is very important to a successful program to a successful reliability program to be redundant on the words. But that's exactly the issue that we've been trying to turn them around on. Even though availability is a very important measurement I surely don't deny that. It's not the key measurement that will give you reliability. The same with parts. And there again, I can only speak for the C-5, because I don't know this generally across the board. But in the C-5, if you have parts on the shelf, you don't worry about it. You just keep replacing those parts. As long as you have availability of the parts…in the world I came from the flag waves when the system or the whole fleet system starts to use too many parts for whatever reason. You look at parts usage, and that's one of the very first flag wavers of a problem in reliability. And if you start using too many parts, you've probably been using too many parts, replacing parts left and right, you have to drill it down, drill it down, drill it down to that lowest common denominator and find out what is really the problem. And not all that many times you will find that the system has suffered degradation and the system is bringing down the parts. These aircraft are famous for that."

Interviewer: "Isn't that one of the key problems with the way the Air Force collects its data? Because it only as good as the troubleshooting skills of the technician. I mean, if he just follows the fault isolation guide and changes a part because that's what it tells him to do and doesn't look any further, then the next guy does the same thing, and the next guy does the same thing, we're not finding anything about what is causing a system to fail. It's just change the part and press on."

Interviewee: "That's exactly right."

Interviewer: "That points to the part instead of the system degradation, like you're talking about."

Interviewee: "And he got availability by doing what he did, didn't he? Now here's the key on that. And this is why we set up a PBP and the RIP deal, because especially PBP. You don't want to expect too much of that to happen from the maintainer out at his level or her level. Because their job is to get the airplane out. So what you have to do is set up a process that keeps overseeing all of that data. Pulling the data in, cleansing it, overseeing it, seeing where those problems are and then give them through a process in minimum works go to bring that system back to its inherent reliability. That's the key. If you expect the typical airman out there to do it is not going to happen, but maybe one in 50 times, or some darn thing like that. It's a very hard number, low number really in reality, where airmen aren't really that dedicated and into the maintenance program that they can follow to that degree."

Interviewer: "Or even have the perspective or forethought to do it."

Interviewee: "Exactly, so don't hang your hat on, say, well they should do that. You need to develop a reliability group that has all of those attributes that does that. That brings that data in and cleanses it and determines, drills it down and then gives them the help they need out there. And schedules the tasks. We call that REV, a reliability enhancement visit, and we schedule a visit not maybe at the time we do a regular check, which is preferable, but if the aircraft is severe enough it may even be between the checks. ISO check and like that. But what we do is we do that REV process a lot like we're talking about this slat problem on the C-5 there. And depending on the complexity of it is when you can do it. Now, we will bring that aircraft up to its inherent reliability. And that's the key. Are you familiar with the term inherent reliability?"

Interviewer: "Yes."

Interviewee: "You understand that that's the ultimate reliability you can get out of that system or that aircraft unless you upgraded in some way."

Interviewer: "It's the designed-in reliability."

Interviewee: "That's right, it's as good as it gets. In one of the biggest mistakes that a lot of people make is that they think if they throw enough maintenance at the reliability, it will improve above inherent reliability. You'll never do it. You can only go to inherent reliability until you change something. So throwing maintenance at it will not improve. If the inherent reliability is bad, you have to redesign, and the MSG-3 process uses that. Most of your categories come down to either a recommended redesign or in the case of the safety categories, a mandatory redesign. And so that's part of that process. It's a very good part of that process, and helps to identify when it is practical and required to do an upgrade. You get a lot of supporting information to sell that. The other part of that is what we do here…”

(Telephone line got disconnected, called back.)

Interviewee: “I tell you I don't know what happened. You want me to continue on?”

Interviewer: “Please, please.”

Interviewee: “Okay, the thing I was talking about was the business case. Once you recognize what you identify, a degradation of some sort, whatever it is. The key, of course, is to build a business case to justify that. That's such an important part that I see in the C-5 world anyhow, where the skill did not exist to do that. I see engineers totally frustrated, ‘Well, I tried to convince them to fix this and to fix that and they won't do it.’ Well yeah, because all you bring is costs to them. You never bring benefits, and you've got to do that. You've got to dig in there and show them that in the long run you’re going to save money. The business case we did on the slats showed them over the year saving bunches of money. And I can’t remember the exact number, I don’t have it in front of me, but it came out in millions of dollars. The standard has always been and always will be: it is cheaper to fly a reliable aircraft. And once you recognize that, once you accept that. And you understand you've got to build a business case to prove that. Then you'll get your changes that you need: improvements or whatever it is that you need to get the aircraft reliable. At Northwest, because Northwest is like all of the other airlines, very competitive, we had to justify every penny. Every penny, and at times, that sounded ridiculous to me. But I realized more and more as I was into it that you know, it's absolutely mandatory because it's got to pay for itself. And if you do it right, it will pay for itself. The time element of when it pays for itself is sometimes quite variable. But it will eventually pay for itself if you do it right. If you do the justification. So that's a big part of a properly run reliability program. Another part of a properly run reliability program is you cannot manage a maintenance program from a cubicle. Big problem in many cases, people try to manage from a cubicle. You've got to get in there. You've got to be able to talk to mechanics, you've got to be up to speak their language. You got to know what reality is, and that's a big item that in this case in the C-5. Most of the maintenance program decisions are made by engineers up in the cubicle. And then they wonder why when they apply something out there, it doesn't get done the way they thought it should be done. So being an old maintainer, you can probably associate with that quite well."

Interviewer: "How many beers did it take before this became a good idea?"

Interviewee: "Yeah! But anyhow, one of the other items that's so important to us from the industry is how we deliver. You make a maintenance program change, you do an MSG-3. You come up with a whole revised maintenance program. How do you deliver that to the maintainer? In the C-5 again, that's the only one I can use for comparison, the work cards just say 'do the task.' And then maybe give you a reference and then maybe not, sometimes they do sometimes they don't. But it's very brief, just 'do this task.' In the world that we came from, we found out that we had to go several steps further. And we have what we call the commercial style work cards that were introduced here and we're just doing the prototypes of that, if you will, and that is very in-depth information. So it is actually, right now, technically against military regulations in that we are going to bring T. O. data to the work card. They're sort of against that at this time, we've got to convince them to change their mind on that. We have a tracking system that will allow them to do that. So, you know that if the maintenance manual changes, your work card gets changed automatically that kind of thing. That's been in the industry today, and it's part of the production management database. I don't know if you've heard that term before or not. Any aircraft that gets developed today, since '77 for instance. All the recent aircraft come out with a PMDB, a computer database that has all the attributes of the maintenance program, and everything is linked. So on your work cards, you link all your work cards to that. So when a change comes down, it recognizes that that change has to happen on the work cards or the maintenance manual or whenever you're working with."

Interviewer: "Are they working primarily with electronic tech data in the commercial world, or is it still paper?"

Interviewee: "Absolutely, well actually the 777 is no paper. The 777 was the first aircraft to build a common source database. And what that is, it starts out with the CATIA have you heard of CATIA?"

Interviewer: "No."

Interviewee: "The CATIA is the design system built by the French. You design the aircraft with this CATIA system. And everything is linked from then on every flight manual is linked to any changes that are made to a component or system or whenever it is. It's all lengthening grows like a tree out from the end. It's an excellent excellent system. It was an ATA spec. Air Transport Association spec. I was very familiar with it because I used to represent Northwest on the ATA on the technical data standards committee. And that was one of the things that we worked on was a common source database. That's the key to it. Now granted, an old aircraft like the C-5, you can't get that sophisticated, but we can make, with computer systems, we can make the electronic links today to let us then present that information to the maintenance person as accurate data. And the maintenance manual can be upgraded when it needs to be. But the key there is to make that maintenance person make as few trips to the maintenance manual as possible, giving them the information. The other element to that is that's your opportunity to communicate with them. Engineers, technical writers, what do they call them, whatever level it is. That's your opportunity to make it very clear to them what you expect out of this task. When you do an MSG-3 review you come out some very defined task for instance and systems you look for every failure mode of that component. Or that system or subsystem. Once you've identified all those failure modes. You are in an absolute positioned to say this is exactly what kind of maintenance program we need to maintain that failure condition or to maintain so that failure condition doesn't exist or so it's controlled anyhow. And so once you do this you need to move that to the next level and take advantage of it. Because if you're going to do the MSG-3 review and you want to improve reliability than you have to take it all the way. Don't stop there and say well we got been a good job and that's the key to that. There are so many items in this program that make up the total program, but delivering that work card is so important to that maintainer."

Interviewer: "So are you talking about the difference between something along the lines of inspect hydraulic tubing for wear becoming something along the lines of inspect hydraulic tubing between this fuselage station and this fuselage station for nicks in excess of this radius, and if you find that fault than you do this?”

Interviewee: “Yes, and in the case of hydraulic tubing, and that's probably not the best example but in that case, you may have a specific area where that's concerned. Maybe you've seen a lot of failures, and that information will come out of your MSG-3 review. Extra point I need to add to that is, the MSG-3 review is continuous. It never stops, and that's important. It's important to note. I've talked to a lot of people in the Air Force here, and it's almost a fear of changing something because they fear they're going to be stuck with it for a long, long time. A good MSG-3 program is nothing but a new baseline to start from your reliability system and tells you how successful are you and then you've got to start moving it constantly to get more successful. The tasks, one of the things that we are hoping that we can get incorporated in this work card system is that we have, I talk about this production management database, but we call us are maintenance program database. It's not as verbose is that one, but each one of the tasks has a control number. The best way to handle this is on the work card to put that control number off to either the top rider something like that someplace where it's very obvious and you train to that until the maintainer that's what that is that your maintenance program control number. When they make a right up for that they add that control number to the right of. Now, your reliability stats become extremely effective, don't they? I mean, now you don't have to cleanses much everything leads right to say that is the task that drove me to that write up. Now you can tell the health of your program immediately the immediate results start to come out of that and hopefully that will be encouraged as you can see we've got a lot of things you gotta do to get these work cards that this program, but it's actually important to it. If you want a good reliability program you've got to have that connectivity, those arms and tentacles out there that make it work. I know I'm dwelling out on that but then I apologize, but it's so important.”

Interviewer: “So then we're talking about a lot more than just changing some intervals on some inspection requirements. We’re talking about a culture change in the way we do our preventive maintenance program?”

Interviewee: “Absolutely, absolutely.”

Interviewer: “Did you encounter that challenge when you were at Northwest or was it already an ingrained way of doing things?”

Interviewee: “Oh no it was a big challenge. Northwest essentially was on an MSG-2 program, and in fact, I can draw some parallels that are just amazing. On the new aircraft, when they came out. They always were on MSG-3, and it was not a problem because everything folded right in. But we had a lot of old aircraft. Two of the oldest ones we had were the DC-9 and the DC-10. You're probably familiar with them.”

Interviewer: “I flew on a Northwest DC-10 to England earlier this year.”

Interviewee: “Well they're about to get retired, I don’t know if you know that. Very shortly they’re replacing them. But the bottom line is, when they did the tech reviews on them. I happen to be in the DC-9 Tech review MSG-3 review. I was not on the DC-10, although I did sit in on some of their meetings. And the reason I was set up there I was in Atlanta at the time I was at the DC-9's main base in the DC-10 was Minneapolis. And when they figured out they were going to do the DC-9, they sent me up there to observe the DC-10, they knew they're in trouble already. That's part of why they sent me up there to see if I can identify where the problem was. And it was very obvious right from the start. They did not have a strong facilitator and a strong process in doing their review. They didn't stick to the program. They were just all over the place. And the maintainers who came in to give empirical data were actually running the show. And they came up with a product that was worse than the original and the reliability was equally as bad. When we get the DC-9 that last one I did before I retired, we took from those lessons and in fact a side note here is when the FAA sat in on a lot of these with both the DC-10 in the DC-9. They like to sit in on these things and oversee them when they got dumb at the DC-10, the FAA informed Northwest that they are not going to support any more MSG-3 reviews for Northwest Airlines. They were that disenchanted with them, so we had a meeting up remaining and we talked to the FAA and we said we would like an opportunity to show you that we can do it right. We started the MSG-3 review and within three weeks of one we started, the FAA wrote us a document saying that they are totally for this program and are behind it. Within three weeks of starting, because they saw it was done right. Now, what happened with the DC-10? Well it wasn't long after that that Northwest made the decision to replace the DC-10. It was interesting because I was in a way back before that I was in an RCB meeting that's a reliability control board that's where you want to Minneapolis and sold it to all the vice presidents when you wanted to make a maintenance change that was going to increase costs and they had to buy into it. And I was sitting there and the vice president XXXX XXXX just an excellent MSG-3 person, just excellent. He was talking there about, in fact, that was just before they started doing the DC-10 and he said, you know, we're going to go do this MSG-3 on the DC-10. We're going to review the whole program and that kind of thing, and one of the analysts from the DC-10 raised his hand and said ‘I don't understand.’ He said, ‘we've been flying DC-10's longer than anybody in the business. We know more about this airplane than anybody why are we doing review?’ And XXXX XXXX made this simple statement, he said ‘look, it's real simple. What you say is exactly true, but we have the worst reliability of all the DC-10's in the country in the world. And we have the highest cost. That's why we're going to do an MSG-3 review.’ But that attitude that that guy portrayed just indicated, was portrayed all the way through that MSG-2 process. It was unsuccessful. In other words, we can't change, we know all of what we need to know. We've run into that in the C-5, as you can well imagine. And sometimes he does have to work around that sometimes you have to accept what they say and then go back and do your reliability work and get back to them and say, you know, this is why we need to go in this direction. You don't necessarily win all of those battles sitting down in the MSG-3 review. But you sure identify the battles.”

Interviewer: “Do you have that level of leadership commitment that you had at Northwest with the C-5 project?”

Interviewee: “Excellent leadership, we have had tremendous support right from the start. Is it safe to say names?”

Interviewer: “I don't know whether I'll be able to include them or not, but...”

Interviewee: “You might not want to, but just between me and you. It started back with a tiger team review that they set up for the C-5 because its reliability was so bad in a Colonel XXXX who is a general now I think you may general just recently. Colonel XXXX was the SPO and Colonel XXXX, as he portrayed to us, sat in the final meetings of all the tiger team review in just kept hearing the same things he'd heard for years and years and he was very disenchanted. So he decided he was going to go out and investigate the industry, said he invited me from Northwest and another guy from Delta, because that was local here. Just to oversee what they were saying and give our opinions, will Colonel XXXX must've liked what we're saying because he invited me to come back down on a permanent basis. Fortunately I was retiring at the end of that year so that worked out quite well. So anyhow, Colonel XXXX started this whole thing. The next SPO, we had was Colonel XXXX, who was totally supportive in fact, he just became a general too, I think he's on the 135, where are they, in Oklahoma? I think at Tinker. Now we have Colonel XXXX who's very supportive of us. But also we've got the chief engineer XXXX XXXX in a civilian comparable to one of those higher-ups and that would be Mr. XXXX and those were the people who really pushed this right from the get go and supported us. Because as you know there's going to be a lot of resistance. So we've had that backing we've been very fortunate in having that backing, because I honestly don't believe we'd be here talking today if we would not have had that. There's just no way that we could have continued because I'm sure that they had to really stand tall, and that's important."

Interviewer: "Do you think that that leadership commitment came as a result of their self gained knowledge of what you're doing and why it was a good thing or was it sold to them? I mean with the business case made for each incoming commander. Hey this is why were doing this and this is why to good idea or...?"

Interviewee: "Each new commander, we always give a presentation, but I don't believe by any means that that was the sole driver. I believe that there was a lot of hidden support. An example of that is Colonel XXXX was constantly going to Washington, supporting this program. So for some reason or another, funding always became available. I don't know the intricacies of the government/Air Force and how that works so I couldn't even talk about that, other than to say somehow the support was there. That's all I know. It was there when we needed. So somebody did some selling of it somewhere. And it's such a good deal because as you said it's a culture change. And all culture changes don't come easily. We talked about it at Northwest, too, and I certainly got off on a tangent on that but Northwest had to have a culture change. Northwest was a combination of several airlines, unless you know that but Northwest was a combination of Republic and Republic was a combination of southern North Central and Hughes air West. So there are a lot of cultures mixed into that out of all of those Hughes air West had the best maintenance program the best corrective maintenance program. But ironically, when they first merged everyone ignored that because the powers that be were from different ends, and we lost years and years of valuable experience until we finally got back on track. We got totally on track when the name I mentioned, XXXX XXXX, the VP, came on board. And he was totally supportive of MSG-3, he knows it like the back of his hand. And once we got that things really started to happen. We really got our arms around the program and really started progressing. And we had the good practices and policies in place to make it work. But it was never easy. It was tough, all the time. When we turned on the DC-9 program, because we know it was tough, one of the things we did was we went to a full-court press on training. In fact, we has all parts of maintenance programs and everybody was involved in that we actually went out in the field and visited the stations and talked with those people and said hey this is what's coming and this is why it's coming with video. So we had made up in advance and all kinds of preparatory information that was put together to definitely inform them as to what they had coming. Now an interesting thing happened because of that. Typically the airlines have way in the high 90s of reliability, I don't know if you know that but in very high 90s and 96 or better percent reliability. The DC-9 had about 96.5 or 6, something like that, reliability. Almost immediately, when we turned on the program, within short months, the reliability went up over 98%, 98.3 or something like that. I can't remember the number off the top of my head and you say, ‘Well, wait a minute; the maintenance program really didn't have a chance to take affect. I mean, some of the new checks weren't done yet and nothing's really happened why did that reliability go up?’ And the bit that you have to understand is the airlines. The reason that went up was that the maintainers quit trying to gold plate the airplane at the wrong time. We have a standard statement here: there is a time to find any time to fix and you need to be in control of that. Because if you don't control it it will control you. And there's no better example of that than the C-5 ISO check. We're doing way too much structural repair on ISO, and it's causing days and days 20 or 30 extra days before they can get it back out. And that availability isn't it? And you've lost that aircraft, you need to structure your structures task if I can reuse that word. So that they are at the right time to your advantage. If you don't look for degradation at the right time, you will find it at the wrong time. And that's what happens when you don't have control over a maintenance program. My boss just walked in sorry. So the bottom line is you have to be in control of your maintenance program. You have to have a rational program to do that. And we have a lot of these little bywords that we say, if you don't give the maintainers are rational maintenance program that they can understand and buy into they will design their own. And now you've lost control and the rest is predictable, isn't it? And I know those are simplistic things, but they are so real. For a maintainer, I just know that you can buy into that. A lot of hire people engineers and that they can't quite understand that they don't see it that way, but they don't know how dependent they are on that maintainer to do the right thing. They don't understand that that your bread-and-butter out there. That's the whole thing up there. But anyhow, I get talking too much, sorry about that."

Interviewer: "Did you have the same problem with un-scrubbed data at Northwest as you initially saw with the C-5 or is the data collection in a different way or…?"

Interviewee: "Yes, that's an excellent question, and you have to go back a ways on that. There was a time when we had problems with un-scrubbed data the original people…and I was fortunate to be a part of North Central Airlines and we were the ones who started. We had the IBM system that was built for that purpose. It was called Scepter, and it's still used for that today. We were one of the initial airlines to do that kind of thing, to do that reliability work and build that in a computerized fashion, a reporting system. The old 'red-tail' Northwest is we called it, they had a hard copy system. So they only had key items that something was brought to their attention. It was key. And the rest was impossible. So North Central was doing a fairly good job of getting on that reliability trail. They were totally there yet by any stretch of the imagination, but one emerged when Northwest bought North Central, which was Republic back then. There was a very negative approach to the stuff. So again, the culture change, it took a long time to get that right. So the scrubbed data was well, in fact there was no scrubbing taking place there for awhile. They just took the data and they didn't have any clue to do what with it. So finally we had to get to the point we had people describe that data. That's when the maintenance program specialist position was designed and put in place, and the reliability positions. And they worked closely hand-in-hand. I was a maintenance program specialist. The reliability people did just reliability. But what the reliability people did, once we got our funding on track, was they reviewed every write up every day, every write up to look for its accuracy if they couldn't figure it out, they would get on the phone and talk to mechanics and say, 'what did you mean by this?' Well then, what happens when you've got that type of oversight is it starts to drive accuracy tremendously."

Interviewer: "This was a full-time job for that person?"

Interviewee: "This was a full-time."

Interviewer: "You know in the Air Force, what we did is we take someone who are it has about 12 hours of stuff to do in packed into a 10 hour day and we make that an additional duty for them. We call it the data integrity team. Obviously, you can see what's going to come out of that."

Interviewee: "That's predictable too, isn't it? So then we set up this PBP/RIP saying we had people scrubbing data. Now as we started putting the reports out to the field. They're going to see that this station, Travis for instance, now just pick on Travis. Say your data is worse than everybody else in the system. They'll see that in comparison. We'll have to tell them that we do have to report it. And they're going to start getting on board then aren't they? They're going to see that they are the ones who are keeping the data from being accurate. Will it ever be totally accurate? No. It will get to the point where we don't have near as much scrubbing to do. The RIP tool that we designed, the integrated design for us, does a lot of the scrubbing for us. We found some constant, a lot of constants in the process. If the work unit code says this and how mal says that, I'm trying to think of the term I've just lost it, but whenever you do a task out there that changes the status of the aircraft you make out this work order or something like that? Well, all that gets related and tells you whether an item needs to be scrubbed or not. This software, they built it's really neat if you ever get a chance to come here and look at its nifty, and it's really helped us in scrubbing that data. As I say as that goes around the hornet will get better and better and it keeps improving on itself. So we're really looking forward to that, but we're getting some neat data have already that shows trends that people did not even know that they had here. That's what reliability is all about, if you're going to be proactive. You've got to have that stuff. You've got to have it before it becomes a disaster. Anybody can react to disasters. But if you've got a reliability program that can see it coming. That's the name of the game isn't it? And that's what it's all about in a nutshell."

Interviewer: "Have there been things that have gone other than as planned with the work you're doing on the C-5 now?"

Interviewee: "Oh absolutely, to say the least."

Interviewer: "Any common themes there, or just a smattering of this and that?"

Interviewee: "Well, there's so much that went on. One of the things that happened, as were talking about the 141. When we first started. We're working with strictly C-5 people. Then they decided to retire the 141, and I guess they're still in that process. So they moved all of the 141 people into the C-5 environment. While now all of a sudden everybody wanted to do it like the 141 did."

Interviewer: "Because you're bringing in that culture."

Interviewee: "Yes, and boy that is still tough today, we are still running into a lot of resistance on that. I met with an engineer this morning and went to the whole process with him and went over and over again until finally he caught it. That was labor-intensive this morning, but I've got to do that. I've got to get everybody to understand how it works, and the value of why it works. And that's a tough deal. That happens constantly, and that was a major roadblock that came in our face, but, you indicated before, that the people who knew where we wanted to go stood tall and stayed the course. The chief engineer, especially Colonel XXXX, all those people I talked about they stood tall. And we keep fighting those battles until we when we got to. If you try to change a culture, and you back down because it's going to get difficult, then you should not have gotten into the culture change business. It's the wrong business to be in.

Nothing good is easy, no truer words were said when it comes to change at that level. But it's been tough. There are a lot of things that we predicted in a lot of things we didn't predict that have happened. One of the other items that keeps and you're probably very familiar being an Air Force person at AMC the command people there keep changing. And we first had them on board and everything looked good, and then they changed all kinds of people. And then we're right back where we started again. So it's just constant its constant, but you have to keep fighting it because it's worth it. It is worth the time and effort to get this on the right track. The outcome, the results are just going to be excellent. And you have to work for that."

Interviewer: "Do you feel your experiences at Northwest were for the most part transferable to what you're doing with the C-5 or do you think it's a completely different ballgame?"

Interviewee: "That's yes to both answers. Let me just relate to you when I tell people constantly and not try to simplify that's what I bring to the table is what ATA did, you know, I'm talking about the Air Transport Association, their process, what they should have done. What Northwest did, and what they should have done. Bring that to the table with the complexities of the Air Force and all of the different things, for instance, the best example is you have to forecast out three years in advance to get a budget change. You put that in those complexities and you get a very complex transformation process. Is that somewhat answer your question?"

Interviewer: "It does yes, but the core competencies of RCM analysis and implementation of that analysis. Apart from the Air Force or DOD-isms, do you think for the most part they were transferable? Or because of the culture that we have, do you think it's a completely different process to implement that stuff?"

Interviewee: "No, and it can't be a completely different process. It can't be and still work. There are some norms in this process their stone hard. I mean they have to be there. So you have to figure out how to do it within the system, but you have to have those for the most part, we've got those in place, are they totally successful yet? Of course not, but they're mostly in place. It's interesting, I need to comment on RCM versus MSG-3. I don't know if you've ever made a relationship of the difference between the two. First of all, they both had the same genesis. Nowlan and Heap came up with RCM. I'm sure you've heard of those two gentlemen. Fortunately for me, when we did the MSG-3 back on the 747-400, I met those guys. And I didn't even know who I was meeting at the time. Amazing how astute I am. I only found out years later who they were. But they also wrote MSG-3, the initial MSG-1 was what it was at the time, and then MSG-2. But the point that I'm trying to make here is that because they are the same people, the process is essentially the same."

Interviewer: “Yes, it's just refinements of additions to, correct?”

Interviewee: “The big difference is that RCM was written as a general application so that people could do it on trucks, tanks, whatever. Plant maintenance, whatever. MSG-3 is specifically designed for a new aircraft coming down the assembly line. That's the way it was originally designed to develop a maintenance program for their plan. So it's very conditioned to that. You see a maintenance program developed to the methodology of MSG-3. You don't necessarily see that in RCM. You see tasks developed, and you then have to develop what your needs are to a maintenance program, but other than that they are exactly the same thing. They are in the same world, and you use a lot of the same methodologies.”

Interviewer: “So to do an MSG-3 review on an existing weapons system with an existing maintenance program. How well laid out is that? Is it just kind of a situational thing where you say based on what we're encountering we need to take this part, but we're not going to be able to accomplish this part? Is the roadmap that well laid out?”

Interviewee: “That's the one that takes a little experience. I've just got a document here that I'm going to read. This is in the very first part of the MSG-3 document, the operator/manufacturer schedule development document. And it says right on the very first page. ‘Read before using this document’ and what it does say is, ‘this document contains recommended specification that have been developed for covered topics. ATA does not mandate their use. You must decide whether or not to use the recommendations in this document. You may choose to use than in whole or in part or not at all.’ That sentence says a lot. That phrase is a lot right there, because that's the key on any MSG-3 review. When you do an MSG-3 review with the FAA and the ATA, you write what is called a policy and procedures handbook. That handbook is just those things that you have to change or things you have to adapt, based on previous experience. That tells you what's in this document has been done differently or whatever you always have to develop that document because the ATA document is somewhat vague, intentionally it is intentionally meant that way so that you have room to develop a better process than your partner does our whatever it might be. And again, that's a competitive world. And it also recognizes that every aircraft is different, and every environment is different. So you have to build accordingly. The only difference we did after we got into this, we learned that I started out by writing is a typical PPH. Where it just had the exceptions in there. And I realized that I just had to completely rewrite the document, even if it was plagiarizing right out of the ATA document. Because you couldn't be referencing back and forth, it got too complicated. So in reality, what we have is a revised ATA document now with all that stuff, but there’s so much stuff that you have in there that the ATA document doesn't have for instance, the ATA document says you can do structure analysis and you have to develop a rating system, a structures rating system. Well, it doesn't they have to do that. That takes experience and a lot of plagiarizing. What we did, we plagiarized a lot of ours from what we thought was the best and that was the MD-95, Douglass MD-95, which is now the C-17, 717, 717. Boeing 717. That's right. It's the same airplane, it’s just when Boeing bought it they changed the number. But that airplane, the process that they did was when we look at all the ones that were done without it was the best in the world. So we plagiarized a lot of it and then we modified it to fit the C-5. The ratings are different, the time intervals are different. One of the big things…I may just jump back on this. When you talk about the difference between RCM and MSG-3 is the approach you take in MSG-3. You start out with goals. Goals of where you want to find that time to fix to be. And then you try to adjust and you try to make the maintenance program work to do that. In RCM what you do is you just lay it out. If you look at a matrix that lays out all the different tasks fallout and then you find a median. You bring some of them down you'd bring some of them up. And if you can't bring them up to have to go down to the next lower level."

Interviewer: "Task packaging."

Interviewee: "Exactly, grouping. But in MSG-3 we say, 'no, there's a better way to do that' and use MSG-3 to do that. For instance, the C-5 now is on five-year PDM with the A-models and a seven-year PDM with the B-models. We're shooting for 8 years and all their major maintenance is between about 8 and 10 years today in the industry. Lockheed had done a bit of a study on the C-5 that said 8 years was feasible. So we thought, okay that's the best place to start. That's a good guidepost to start with, what you do is you look at where those tasks fit in in the multiple intervals between that. For instance, ISO's or whatever, that will support the aircraft to get to 8 years. That's the name of the game. You don't just go to 8 years to support the airplane to get there and that methodology that way. MSG-3 does that much better than RCM does. You start with that goal in mind, and it helps you drill back down through and support that to get there. That's a large difference, but it's a whole different approach than pure RCM, and again it was written by the same people, but they knew the industry, and they knew what they had to do. So they wrote it just slightly different and developed it differently. But it's a very important part of that and it's part of what I have a real hard time getting engineering to buy into, because they look at it and say 'oh, we have to do that NDI every six months,' and I say ‘no, we don't have to, you want that NDI done when it's time to find it to fix.’ That's when, even though that crack is not visible. I want to know that. But on the lower levels, I want to keep myself safe and reliable. What makes it safe and reliable? Visual inspections, unless the crack grow so fast that I can't afford to do that with then that's a different ballgame. But if it isn't that fast then I need to depend on that. But does support and inspections to get me where I need to be? Essentially, when you look at the way the Air Force has done it they do a lot of that. But I think in reality, the maintenance program part of it, especially the SPO up here, the engineers don't recognize that that is happening. They don't see how the field has changed things over the years. That's what they're doing, they’re building support to get to that major maintenance, and it's slowly been moving in that direction. The problem is, when it gets to major maintenance today, they don't do the complete aircraft. And that's part of what we're changing; that culture. My statement on that is, when you're going through PDM here you do a limited scope PDM. But when you go out for the functional check you do a total scope functional. Well, that ain't gonna work because you’re going to find stuff that you didn't even check when you're at PDM. So they take 60 or 90 days to get to functional where it should only take four or five days. In the industry on our 747, we were about four days to get to functional, and that was it when you can't find too many unknowns when you know, you only have four days left. You better get your arms around it. And that's where we’re trying to encourage the program here in what we’re developing here. That's a big part of that culture change. Sorry, I got off on a tangent there. It’s not necessary reliability, but in my mind it's all interchangeable.”

Interviewer: “Well I'll tell you what, I think I've probably got about a million more questions, but I think I have enough right now that I need to get my head around. This is probably a good breakpoint. Would it be all right if you have, maybe in a week or so I get a call back with a new line of questioning and went down that road?”

Interviewee: “That would be perfectly alright with me.”

Interviewer: “Great, I really appreciate that. Thank you.”

Interviewee: “Goodbye.”

Appendix G Interview Six

Interviewer: “Just to kind of to refresh you on what I'm doing. My research centers on the reliability centered maintenance analysis that's currently being performed by a contractor for the F-15 sustainment office. Their intent is to rewrite the preventive maintenance program for the F-15 based on that RCM analysis. This is still a relatively new concept for the Air Force. We've started to use RCM in our acquisition process for quite awhile, but we haven't revised many preventive maintenance programs for existing platforms to incorporate RCM analysis. So while they're comfortable and confident in the analysis and the results of the analysis, the concern of that sustainment office is that if this analysis isn't implemented properly and accepted throughout the F-15 maintenance community then all that time and money and energy has been wasted. So what I'm doing is conducting interviews and then comparing responses across those interviews to try to figure out... I've spoken with folks in the Navy, I've spoken with folks with commercial RCM…like for Northwest Airlines…experience and some other Air Force sustainment offices who are just now starting to try to incorporate RCM or variations of RCM into what they do. My hope is to kind of cross that spectrum of backgrounds and experiences to come up with some common themes in common answers that we can use to successfully implement this analysis for the F-15. So you've been with the Coast Guard for quite awhile is that true?”

Interviewee: “Actually, I've been with the Coast Guard since the inception of the program.”

Interviewer: “Fantastic, which was when?”

Interviewee: “Which was February of '90.”

Interviewer: “And when you say the program do mean the inception of RCM with Coast Guard aircraft?”

Interviewee: “Correct.”

Interviewer: “And that's with both fixed wing and rotary?”

Interviewee: “Yes, I'll give you a little bit of a background. In the Coast Guard, until 1989, they had no RCM program. I don't know who introduced them to the idea, but somehow, one of the system managers at the headquarters in DC decided that it was about time to implement such a program. Now I say system manager, I mean the guy who was the officer who was responsible for the entire aircraft type for the entire fleet aircraft type. We still have them, but the responsibilities of changed over the years and they were different from what they were back then. But the system manager, we had one system manager per aircraft type, and we basically had four system managers, and then we had avionics and engine systems and so on and so forth. But I was dealing primarily with, at the very beginning, with the system managers. As I was saying at the end of '89, they decided to start such a program. And they were looking, from what I was told, I don't have any paper trail, but this is what they've told me. They were looking to find somebody who would have ties to the academia, and so I applied for the job and I was hired.”

Interviewer: “And that's as the RCM program manager?”

Interviewee: “Yes, to establish the RCM program and do the RCM analysis. That was February of 90, and I've been with the program since then.”

Interviewer: “So the Coast Guard had a commitment at that time to incorporate RCM, but they hadn't actually begun on that journey yet is that correct?”

Interviewee: “Yes, when I came on board that had nothing. They had absolutely nothing. When I went into my office on Monday morning, that Monday morning 16 or 17 years ago, there was nothing. I had to start creating a paperwork, a paper trail. First of all, I was totally ignorant, I must admit to the Coast Guard structure. So, I mean, that was my greatest difficulty with the program. Finding out who was responsible for what, who these people were the other thing that has happened, which is a little bit strange for contractors. I'm a contractor from day one. And I have been since then. When I was hired, although I have an interview from the company that had the ACMS program affiliation, the computerized maintenance system, where we have all of the maintenance data on the maintenance actions in all the data we collect from the maintenance and that is performed on the aircraft it was a company called TAMSCO back then from Maryland, although I was hired by them I had a token interview by the company. I was referred to the Coast Guard and hardly knew or dealt with other people in the contract. I had a couple of interviews with the Coast Guard officers, and they basically said and what I was told later, they agreed, and I was hired. And I started working with them. At the beginning there was basically nobody on the program for about six months I was the only one. Given the fact that the Coast Guard is very small organization, if you compare to other uniformed services like the Air Force of the Navy there's no comparison as far as people go. The Coast Guard didn't have as many resources, financial, or any resources. So I was the guy for about six or seven months. I think I hired the first person in the last week in August of 90. So from February until August of some unknown, and at that time

I was working to set the program to what needed to be done. Find out about how the Coast Guard works, and at the same time, decide, what I would need to do in order to demonstrate the RCM concept that it was beneficial for the Coast Guard to have such a program. Because I should say that there was some reaction negative reaction to the program from upper echelon management."

Interviewer: "What was the basis of their concern?"

Interviewee: "That was basically a waste of time, they had seen programs come and go like I don't know what they had. Up till that time, but I've seen other program since then, that come in, and I'm sure you have seen them to in the Air Force. It was the same kind of thing out of about 45 or six system managers I recall one specific system manager who was really very enthusiastic about the program and believed in the program and believed in the future of RCM. And this was the only person at the beginning that I had who I was working with to decide what to do. The way to promote the benefits of the program. Once that was done, and I think it was done on around May of 90 so from February to May, towards the end of May. The concept basically was proven to others, and I recall that particular month because of the beginning of man went over to France because of looking at some components that are wanted to change hard time intervals for someone over to France and met with people from the manufacturer, Aerospatiale, and finally I came back and they did change some intervals we saw the benefits we lightened the workload on the field personnel and realized financial benefits immediately. We saw them within the next few months and that was the turning point for this system managers and other managers."

Interviewer: "So the business case made by that initial success turned…?"

Interviewee: “Yes, because that initial success was in the millions, and I remember the item that I looked at. It was the main gearbox of the -65 helicopter. And remember that we had an interval of 1500 hrs according to the manufacture, which we were doing at that time, and I looked at the data. I noticed that the component was a very reliable and it could be extended to talk to the people to the manufacture, and they did have some objections I must admit that they couldn't provide any data that would convince me not to extend the interval to, I think we took it to 2000 hours from 1500 hours, and I remember, we saved probably about 20 overhauls and something a believe about $300,000 a pop times 20, you're talking about a lot of money. Plus the fact that the people in the field didn't have as much they could devote their efforts to other areas where the action needed to devote them to. And this was at the time, the item that really turned a lot of minds and came on board.”

Interviewer: “So was your decision on that gearbox an individual component that you looked at to try to establish a business case, or was that a kind of a stem to stern review of the aircraft, or did that come later?”

Interviewee: “No, what happened was, I sat down, because like I said I was trying to find out. Let me say that my prior experience with helicopters was zero. I did have experience with other aircraft: with the Mirage program in Europe, it was a French aircraft, with the C-130, and the Corsair before that, but no helicopters. However, I sat down with the system manager, who was also a pilot on that aircraft and asked him exactly what I needed and I said ‘give me something steer me in the direction of some components, which will be fertile ground to prove our case,’ and I don't remember how many he gave me but I chose the main gearbox because of completeness of data. It was the easiest one from what I recall. I also recall that because what I suggested in my report, the extension was longer than 500 hours. Even the Coast Guard was taken a little bit aback. I recall that we talked with the AFIT director of reliability. Dr. XXXX. I don't believe he's there anymore, did you ever meet the guy?"

Interviewer: "No, I didn't."

Interviewee: "He agreed with what I had done, with the course that I had recommended. It was a very successful venture, choosing that component."

Interviewee: "So once you had that initial support them from that gearbox success, did you go every aircraft stem to stern then, or how did you proceed from there?"

Interviewee: "Once we had proved our case, we went around and I devoted all my efforts to putting the program together, because it needed to be done. There was no authority, the structure of the program had to be put together. And I think, if I recall correctly, at the beginning of '91, about a year from the moment I came on board, the program was implemented. I'm not going to tire you with the groups I set back then, and we still have, who's going to be responsible for what in the RCM. You can see those in my presentation, which I'm sure you have. There are basically three groups, once I set up those groups. The first two, the RCM Steering Group and the Maintenance Review Board, the MRB, were not very active, I must say. Anyway, those two groups were not very involved at the beginning. Mainly because too many fires to put out, but the working groups were very involved. The working groups were the people who actually did the work. They reviewed the entire maintenance program for every aircraft. Again, I explained in my presentation how that was done through the maintenance tasks that we already had. The Coast Guard being such a small organization, it doesn't have too many people, and it definitely doesn't have the financial resources for a full-scale RCM program. So we decided to compromise, and the plan that I put together was designed to minimize any requirements for official resources: money or human. It was designed to minimize additional workload on existing resources, and what I mean is the people in the field and in the depot, down in Elizabeth City where we do the overhaul, and also minimize the need to include paperwork, because these things, when the program was put together and finally working, we realized that we could do with what ever small number of people we had available. We would put a working group together, experts from different areas, drawn from the field, brought into a central location. Sometimes here in the DC area, sometimes, most of the time, down in Elizabeth City, and we would go through, and whatever time was needed; one week two weeks, whatever, go through all the maintenance actions on all the components that we had maintenance actions for. And using the RCM logic with the people, we reviewed every single action that we have and we replaced, changed, and we saw the benefits early on, basically. Even people from the field, realized, although some of them were coming in negatively disposed toward the program and what they were tasked to do. By lunchtime, after I talked to them the first day, they had converted. So I won't say it was very difficult to convert people. I would say it was rather easy. Another important thing that happened was, after we were able to prove the concept and the benefits. Another thing that we managed to do was standardization, a successful program obviously needs consistency. And I mean keeping one aircraft type the same as another. And we did that. Different things are being taught by different people, and more and more people came aboard."

Interviewer: “The logic that you used was that based on MSG-2, MS-3, or some RCM variant? I see from your presentation that you used Winsmith and Reliasoft software tools, which are based on Weibull analysis, but then how is that incorporated with the RCM decision logic to actually make decisions?”

Interviewee: “Okay, we had people from the field in each working group, which were different depending on which items were decided we had decided to look at with two different personnel from the field. The logic that we used was a variant of the MSG-3. It's basically the same, very close to what the Air Force, at least the one that I had seen from the Air Force, because back in '90 to '92, there was an effort from the different services. I believe it was spearheaded by somebody in the Pentagon to come up with a common RCM manual. I don't know if you're familiar with that. I was part of that group, and we were meeting for about two years and the people in that group, there were about 10 to 12 people: Marines, Navy, NAVAIR, NAVSEA, Army, Air Force. And I remember seeing the Air Force logic, which was very close to ours, but the only difference, I think there was between the Coast Guard logic and the one that was being used by the FAA or the industry rather, which was MSG-3, is we have added an additional branch dealing with the operations. How can I explain that? The effects from the mission, which is basically the same kind of as those from safety, but we had a separate branch. So the original MSG-3 has five branches, and we have six: three for the evident and three for the non-evident. That's about the only major difference. And this is where we used to come up with, to have the appropriate interval or not. Now, the frequency of the interval of the maintenance task was determined by, sometimes by data that we had recorded in our system, because all of the aircraft that the Coast Guard used at that time were mission aircraft and we had plenty of data. At least five or six years and in some cases longer. More than that. So we had plenty of data to make decisions. We knew what kind of failures we would see. So we didn't have to go through FMECAs. We worked with whatever we had already experienced. On some occasions, to shorten the time, if the task that needed to be done was such that the experience of the personnel involved participating was such that it could be decided easily, then we would go with the consensus of the group. So we did not have and we still do not have FMECA as a way that our decisions are derived. And this process, once completed, I would say it took about a year for each aircraft. It has been repeated about three, four times since then. Maybe not 100%, but very close. We have reviewed each and every maintenance task that we have using the logic. The structural and the engine logic about, I'd say about three times for one aircraft, for the helicopter the H-60, four times, I believe for the -65. At least three times for the C-130 and the Falcon [HU-25 Falcon Jet – Coast Guard Reconnaisance/Surveillance Aircraft]. This is how we did it. Now we had this process completed about the late ‘90s. ’99, something like that, 2000, 2001. Since then, we have decided to go with.. another route was just decided looking at the individual maintenance actions and looking at the RCM. We decided to go another way, because we saw some benefits, well, actually huge financial benefits. And that route is marrying the RCM output to the logistics decisions. This is still in its infancy, because logistics people have not bought the idea yet. However, the aircraft managers knew… what I call the system managers, now we have the product line managers. Now all the system managers are here in DC with their responsibilities. The management of the fleet, from the engineering point of view, has transferred onto Elizabeth City, where we have the depot. The system manager has been replaced by the product line manager, the PLM, and he is responsible for whatever maintenance needs to be done on the aircraft and everything. He reports to the engineering chief and so on and so forth. I'm not going through the Coast Guard managerial structure now, but that's how it works, and these people have realized the benefits. I work very closely with them, and I think, what I preached since '94, that this marrying needs to be done, it finally is being done right now. But we have to convert the logistics community. Those people, I don't know what they are, but they're not engineers. They are theorists. It's a little bit hard to convince them."

Interviewer: "I'm not sure I understand what you mean when you say marrying the RCM output with logistics, can you give me an example?"

Interviewee: "Yes, I can give you an example. The reliability analysis on a system can determine, assuming that the operations and everything else remains as it is, the reliability of the system can predict its future demand on the logistics community. Why? Because we believe the mission is number one, and the mission drives everything else. The mission drives maintenance, maintenance drives logistics, logistics drives all the other resources. Then the circle is closed, and it goes from logistics and resources back to the mission, but the mission is number one. And logistics people in general, no matter where I've talked to them or where they come from. I'm not talking specifically for the Coast Guard right now. My experience has been that logistics people believe logistics drives everything else. In engineering, people here in the Coast Guard, we believe that the mission is number one and everything else tries to adapt to whatever the mission is, and the needs of the mission. And we have realized benefits there from getting the output from the reliability studies from the systems, and in putting them into the logistics: future uses, requirements, should I say, we want to know how many we will need and because you know, how many you will need. Then you can plan your budgetary needs much better. And whenever we have applied it, we have had success in excess of… There are two groups of systems and components: systems and components that we share with the Navy, and when they get out of the US Coast Guard inventory we lose track of what is going on with those components and then when they come back than we have different reliability than what we had; and the components we have under our jurisdiction at any time, they never leave the Coast Guard inventory. For those components that never leave our inventory we have successes in excess of 90%. And when you relate that to money, of course, this is big. And some of our system managers, some of our PLM's have seen that. And they're asking more and more. The other components that we share with the Navy, we may have in the in the -60 community, helicopter, they can go down to 55%, and they can go all the way up to 85 or 90% again. On some occasions, even though I have the Navy aircraft out in the desert in Arizona and sometimes we need to reactivate them and for that reason, the Falcon community back in 99 timeframe. I did a study and had to prove future resource requirements using the idea that I just described, marrying the reliability with the logistics. In the first year of this that I did the additional use that calculated at air stations, which are very small. We're down to about three or four aircraft now. But within a year I had successes of 100%. And we were very impressed. I don't think it was luck, because while I thought about it many times, I have had so many successes in this area that I don't believe anymore that it's luck. There is something there. And the better the data, the better the results. The higher the percentage of success. So, this is where we have steered all of our efforts. Now, the difficulty is that we have very few people in the program. Still 16 or 17 years later, we still have four people only on the program: myself and not one for each aircraft, we have both helicopters which have a guy who deals with ad hoc queries and ad hoc problems. And we have another guy for the C-130 and another guy for the Falcon. When it comes down to coming up with projections for resource requirements for the future, because I use something that I have developed. Its not off-the-shelf, all the studies have to go through me because I haven't shared my tool with anybody else. So the amount of systems and components and I have to go through a year is somehow limited. However, we translate that into money, and we have seen successes that have enabled us to…we have enabled the product line managers to have budgets for a couple of years ahead of time. There are some… I know, in particular, of a product line manager who has a known budget for two years ahead now. So they're working on those from my work. So this is where we believe that we should steer quite a lot of our effort from the RCM group."

Interviewer: "When you implement changes from your analysis, are they done as packaged groups of changes or, if one of your working groups comes up with a change on the interval or even a recommendation to stop performing a certain maintenance task, are they implemented as an individual task and then they move on? Or do they view wait until they get a group of changes, or is it done on a calendar basis, or how do you do that?"

Interviewee: "In general, in the Coast Guard, we have the aviation computer maintenance system. We have gone away from phased maintenance. We don't really have phase A, phase B, phase C, whatever, you know we don't have check A, check B, whatever. We've gone away from that, from what I've been told in the early to mid-80s. What we have gone to is a system that is opportunistic maintenance, unless there is need to have intervals packaged. And the need comes from the fact that when we access a difficult area, maintenance needs to be done there on other components. Although they are not directly related to what we do now, if the aircraft is down at night. We do the maintenance or we take the aircraft down one-way access an area that is very difficult. So the intervals are packaged basically, if we take away the life limits and things like that on an opportunistic basis."

Interviewer: "Right. But then how are your changes implemented? Are they implemented one at a time when he recommended changes...?"

Interviewee: "Sometimes they are one at a time, that most of the time I would say, one at a time, yes. Because at the moment, what we have started doing is we're evaluating intervals again. And as they go through five tasks or 10 tasks or whatever, that we do together as a package, an existing package of tasks, I evaluate that and that is the accepted or rejected, modified, how can I say that? As a group and approved as a group. By the PLM for the particular aircraft. So to answer your question, it would be either one at a time or as a group."

Interviewer: "But pretty much as they are recommended?"

Interviewee: "Yes."

Interviewer: "And did you encounter, especially when RCM was just taking hold as a way of doing business in the Coast Guard, did you come up with any recurring problems from the implementation side of things? The analysis was proved to be sound, but once the changes were made were there any specific problems with those implementations? I mean, especially if you're doing one change in the time that requires a change of your Tech Data, correct?”

Interviewee: “Yes.”

Interviewer: “Did you run into any recurring problems with getting that done in an efficient manner, or did you have a pretty good system set up that worked well?”

Interviewee: “No, I can't say that we... we never had any problems. Let's say that I decide to look at, reevaluate one part. The inspection of a 'gizmo A'. When I finish my evaluation, and I realize that it would be better to modify one way or the other, extend or shorten it. Either way, it doesn't matter what it is. If the test needs to be modified, before I recommend it to the Coast Guard officers for approval, uniformed personnel, I get the response from the prime unit. The prime unit is, I don't know how it works in the Air Force but, in the Coast Guard. We have set one air Station, as the expert air Station for the aircraft. So we have one air station per aircraft that we call the prime unit. The prime unit is responsible for, we want to believe that we have expert personnel there, and if something happens if we need to modify something or we need to start a pilot program with a particular aircraft, then the prime unit is involved because we believe we have very expert personnel there. So before I recommend to management, a modification to a maintenance program, whenever that is, I discussed it extensively with the prime unit personnel. The maintenance people there, and I already have them on board or I go back and look at what is done and take their recommendations into account and modify my recommendation to include the expertise of the people who work on the aircraft. Because I don't work on aircraft. I don't get my hands dirty. If somebody doesn't get his hands dirty. I believe they shouldn't be, they shouldn't have the final word. You should definitely have, should include the people who do the maintenance, know the aircraft much better, because they work on it and they also fly. Because in the Coast Guard, the people who work on it and do the maintenance also fly the aircraft. Which is in some cases, a good thing, and in some others, it is not a good thing. They try to err on the conservative side, and of course it makes it more difficult to do away with, they want to keep extra maintenance requirements that would otherwise be wanted for deletion. Or should I say in industry or in the commercial world. The maintenance requirements wouldn't be as often as they are sometimes in the Coast Guard."

Interviewer: "The leadership commitment to RCM as a way of doing business in the Coast Guard, is that captured in any kind of a written directive or instruction?"

Interviewee: "Yes, when I... I'm trying to remember the Commandant's number of the manual...13-0-20, I believe...the series inspection book. There is a section there that talks about RCM and what it's supposed to be. It should be about a quarter of a page or half a page, but it talks a little bit about what the RCM program is. And then it refers to the RCM process guide that I wrote back in the early 90s and is being reviewed and updated every so often. I believe the last time is reviewed was in the late 90s. And I don't have the number but it's called the Aeronautical Engineering Process Guide for the Reliability-Centered Maintenance Process. And the Coast Guard T.O. is number 85-00-30, I believe. I can find out the number and send it to you."

Interviewer: "If you could, electronically, that would be great."

Interviewee: "Yes, I don't have a current copy. I have one, but it's very old, but I can get a current copy of it to you if you want one."

Interviewer: “Yes, I would appreciate that. Well, I think we've covered all the questions I had, again, I really take appreciate you taking the time to answer my questions. I will be more than happy to send you a draft copy of my report once again approved by my thesis advisor.”

Interviewee: “I was going to ask you if you could oblige me in sending a copy of your thesis. I would very much appreciate it.”

Interviewer: “No problem.”

Bibliography

Creswell, John W. *Research Design: Qualitative & Quantitative Approaches*. Thousand Oaks, CA: Sage Publications, Inc., 1994.

Dai, Shu-Ho, and Ming-O Wang. *Reliability Analysis in Engineering Applications*. New York: Van Nostrand Reinhold, 1992.

Denzin, Norman K., and Yvonna S. Lincoln. *Handbook of Qualitative Research*. Thousand Oaks, CA: Sage Publications, Inc., 2000.

Department of Defense. *Maintenance of Military Materiel*. Department of Defense Directive 4151.18. Washington, D.C.: Department of Defense, 2004.

Department of the Air Force. *Aerospace Equipment Maintenance Inspection, Documentation, Policies, and Procedures*. AFTO 00-20-1. Washington, D.C.: Department of the Air Force, 2003a.

----. *Aerospace Equipment Maintenance Management*. AFI 21-101. Washington, D.C.: Department of the Air Force, 2004.

----. *Improving Air and Space Equipment Reliability and Maintainability*. AFI 21-118. Washington, D.C.: Department of the Air Force, 2003b.

----. *Air and Space Maintenance*. AFPD 21-1. Washington, D.C.: Department of the Air Force, 2003c.

Director, Policy Processes and Program Health Naval Air Systems Command. *Reliability Centered Maintenance Steering Committee Charter*. Patuxent River MD: Naval Air Systems Command, 2004.

Ebeling, Charles E. *An Introduction to Reliability and Maintainability Engineering*. New Delhi, India: Tate McGraw-Hill, 2000.

Heintzelman, John E. *The Complete Handbook of Maintenance Management*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1979.

Ireson, W. Grant, Coombs, Jr., Clyde F., and Richard Y. Moss. *Handbook of Reliability Engineering and Management*. 2nd ed. New York: McGraw-Hill, 1995.

Kelly, Anthony. *Maintenance Strategy*. Oxford, England: Butterworth-Heinemann, 1997.

Leedy, Paul D., and Jeann E. Ormrod. *Practical Research Planning and Design*. Upper Saddle River, NJ: Merrill Prentice Hall, 2001.

Levitt, Joel. *The Handbook of Maintenance Management*. New York: Industrial Press Inc., 1997.

Maintenance Management. Ed. Edward Hartmann. Norcross GA: Industrial Engineering and Management Press, 1987.

Mann, Lawrence, Jr. *Maintenance Management*. Lexington MA: D.C. Heath and Company, 1976.

Marshall, Catherine, and Gretchen B. Rossman. *Designing Qualitative Research*. Thousand Oaks, CA: Sage Publications, Inc., 1989.

Merriam-Webster. "Definition of efficient - Merriam-Webster Online." .13 October 2005. http://www.m-w.com/dictionary/efficient.

Mobley, R. Keith. *An Introduction to Predictive Maintenance*. New York: Van Nostrand Reinhold, 1990.

Moubray, John. *Reliability-Centered Maintenance*. 2nd ed. New York: Industrial Press Inc., 1997.

Naval Air Systems Command. *Guidelines for the Naval Aviation Reliability-Centered Maintenance Process*. NAVAIR 00-25-403. Patuxent River MD: Naval Air Systems Command, 2003.

----. *Reliability Centered Maintenance Program*. NAVAIR Instruction 4790.20A. Patuxent River, MD: Naval Air Systems Command, 1999.

Nowlan, F. Stanley, and Howard F. Heap. *Reliability-Centered Maintenance*. Vol. A066-579. Springfield, VA: National Technical Information Service, 1978.

Pham, Hoang. *Recent Advances in Reliability and Quality Engineering*. Singapore: World Scientific, 2001.

Reese, Charles D. *Accident/Incident Prevention Techniques*. London: Taylor & Francis, 2001.

Salyer, Patricia. *Reliability-Centered Maintenance (RCM) Programs*. AFMCI 21-103. Wright Patterson AFB, OH: Air Force Material Command, 1994.

Smith, Anthony M. *Reliability-Centered Maintenance*. New York, NY: McGraw-Hill, Inc., 1993.

Society of Automotive Engineers. *Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes*. Vol. JA1011. Warrendale, PA: Society of Automotive Engineers, 1999.

Wyle Laboratories. *F-15 Environmental Control System (ECS) VRCM Analysis Report*. Warner Robins AFB, GA: Wyle Laboratories, 2004.

Wyle Laboratories. *F-15 Flight Control System VRCM Analysis Report*. Warner Robins AFB, GA: Wyle Laboratories, 2005a.

Wyle Laboratories. *F-15 Fuel System VRCM Analysis Report*. Warner Robins AFB, GA: Wyle Laboratories, 2005b.

Wyle Laboratories. *F-15 Landing Gear System VRCM Analysis Report*. Warner Robins AFB, GA: Wyle Laboratories, 2005c.

Yin, Robert K. *Case Study Research: Design and Methods*. Thousand Oaks, CA: Sage Publications, Inc., 2003.

Vita

Chief Master Sergeant Michael H. Martin graduated from Columbus North High School in Columbus, Indiana. He entered undergraduate studies at Purdue University in West Lafayette, Indiana. He enlisted in 1985 and graduated Basic Military Training and Technical School as an Honor Graduate. Chief Martin earned a Bachelor's Degree of Science in Computer and Information Systems Management from Colorado Christian University in 1999.

His assignments include Royal Air Force Upper Heyford, England; Clovis Air Force Base, New Mexico; Eglin Air Force Base, Florida; the United States Air Force Academy, Colorado; Kunsan Air Base, Republic of Korea and Royal Air Force Lakenheath, England. In August 2004, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the Presidential Logistics Squadron at Andrews Air Force Base, Maryland.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. REPORT DATE (*DD-MM-YYYY*)	2. REPORT TYPE	3. DATES COVERED (*From – To*)
03-09-2006	**Master's Thesis**	September 2004 – March 2006

4. TITLE AND SUBTITLE

IMPLEMENTING RELIABILITY-CENTERED MAINTENANCE ANALYSIS IN A REVISED PREVENTIVE MAINTENANCE PROGRAM FOR THE F-15

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Martin, Michael H., Chief Master Sergeant, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Street, Building 642
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GLM/ENS/06-08

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

330th Fighter Sustainment Group/LFEF
Attn: Mr. Hugh Darsey
235 Byron Street, Suite 19A DSN: 468-6207
Robins AFB GA 31098-1670 E-mail: hugh.darsey@robins.af..mil

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Reliability-centered maintenance is an approach to analyzing how and when equipment fails in order to maintain a desired level of performance or functionality. It employs the use of failure modes, effects and criticality analysis to rank order potential failures, and combines this rank order with the use of a prescribed decision logic process to determine what preventive maintenance tasks should be performed and when. Reliability-centered maintenance analysis has been used by the United States Navy, the United States Coast Guard, and commercial airlines to develop and update preventive maintenance programs for their aircraft for many years. While the United States Air Force has prescribed the use of reliability-centered maintenance analysis to develop preventive maintenance programs for new acquisitions, the use of this analysis to revise and update preventive maintenance programs on existing aircraft is relatively new. Once the analysis yields maintenance tasks and intervals, this analysis must be successfully implemented in a revised preventive maintenance program in order to be effective. This research proposes a solution to successfully implement reliability-centered maintenance analysis results in a revised preventive maintenance program for the F-15 weapons system.

15. SUBJECT TERMS

Reliability-Centered Maintenance, Preventive Maintenance, Aircraft Maintenance, Maintenance Management

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			William A. Cunningham, PhD (AFIT/ENS)
					19b. TELEPHONE NUMBER (*Include area code*)
U	U	U	UU	231	(937) 255-6565, ext 4283; e-mail: William.Cunningham@afit.edu