RCM in the Public Domain:
An Overview of the
US Naval Air Systems Command's RCM process

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Abstract

The US Navy's Naval Air Systems Command (NAVAIR) has been one of the leading implementers of Reliability-Centered Maintenance (RCM) methodologies in its efforts to improve reliability, safety, and minimize costs associated with the operation and maintenance of the US Navy's aircraft fleet. NAVAIR's RCM methodologies have been updated and refined with over 30 years of RCM experience on a wide variety of complex systems. This paper will present an overview of the NAVAIR process including:

- The NAVAIR RCM process and tools, both of which are openly available to the public
- The relationship between the NAVAIR RCM process and the SAE JA1011 standard
- Clarification of some common misconceptions about the NAVAIR RCM process and RCM in general
- Several case studies of the application of NAVAIR RCM with a focus on various execution methods.
- Examples of applications of NAVAIR RCM on non-aircraft equipment.

Background

The US Navy has been one of the leaders in development and application of RCM analysis. In one of the earliest applications of RCM principles, the US Navy began applying Maintenance Steering Group (MSG) logic developed by the commercial airline industry to the P-3, S-3 and F-4 aircraft in the early 1970's. In 1975, NAVAIR applied an updated version of MSG-2 called the Analytical Maintenance Program to Naval aircraft and engine programs. In 1978 the Department of Defense (DoD) sponsored DoD report AD-A066579, "*Reliability Centered Maintenance*" by Stanley Nowlan and Howard Heap of United Airlines. This report was based on the principles of MSG logic and was the foundation of most modern day RCM processes (reference 1). Throughout the 1980's DoD issued several documents related to RCM analysis; most notably in 1986, DoD issued MIL-STD-2173, "*RCM Requirements for Naval Aircraft, Weapons Systems and Support Equipment*". This document was the basis of the current NAVAIR RCM Process. In 1996, MIL-STD-2173 was superseded by NAVAIR 00-25-403, "*Guidelines for the Naval Aviation Reliability-Centered Maintenance Process*", which contains the current RCM process described in this paper (reference 2).

The objective of this paper is to introduce the NAVAIR RCM process; identify some of the tools and resources available to those interested in using RCM analysis; and demonstrate some of the lessons learned from application of the NAVAIR RCM process. The NAVAIR RCM process is a completely non-proprietary process that is free and openly available to the general public. It is the hope of the authors that exposure to this information will encourage some people to pursue the use of RCM who might not otherwise do so because of the perception that a long term and expensive commitment to a proprietary process and tools is required.

Anyone who has been exposed to any of the public discussion surrounding RCM knows that there are many vendors offering RCM services. Many of the claims about these competing processes seem to be contradictory and confusing. Some of the information being passed around is, at best, unsubstantiated and, at worst, inaccurate. A secondary purpose of this paper is to address some of the known inaccuracies, particularly those directed towards the NAVAIR RCM process and the closely related SAE JA1011 RCM Standard.

It is not the intent of this paper to compare RCM processes, nor is it the intent to suggest that the NAVAIR RCM process is superior to any other RCM process. We will attempt to point out where we believe the NAVAIR process is unique and how it can be effectively used in the public domain. Many RCM vendors provide experience in specific industries, different approaches to executing RCM analysis, and various tools such as software that may be beneficial to a particular user. It is the hope of the authors that this paper can provide potential users with a means to learn more about RCM independently and decide for themselves what type of process best meets their needs, before committing to one particular process or vendor.

NAVAIR RCM and the SAE JA1011 Standard

In the early 1990's the US DoD began a series of initiatives to streamline the acquisition process for military procurements. One of these initiatives was a decision to eliminate, as much as possible, the use of military standards in new acquisitions, and instead, rely on commercial or performance standards. This decision was documented in a memorandum from Secretary of Defense William Perry dated 29 June 1994. The decision was enforced with the systematic canceling of a large number of military standards. One of those cancelled was MIL-STD-2173, which documented the RCM process used by NAVAIR at the time.

In support of this acquisition streamlining effort, a group called the Reliability, Maintainability and Supportability (RMS) Partnership, began coordinating the efforts of various other organizations involved in developing standards related to reliability, maintainability and supportability. Through the RMS Partnership, the Society of Automotive Engineers (SAE) was asked to lead the development of an RCM Standard to replace the various Military RCM standards being cancelled since no equivalent commercial standard existed at the time.

SAE chartered a sub-committee to begin development of an RCM standard under its G-11 Supportability Committee. The RCM subcommittee initially consisted of representatives from the US Navy and various DoD contractors. It was noted that the development of a "commercial" standard was being performed almost exclusively by personnel associated with DoD.

The group started down several different paths in development of this standard, including one directed by "higher-ups" in SAE that the sub-committee develop a "preventive maintenance" standard because they didn't think there would be enough interest in RCM. The actual quote from an email is presented for its humor value: *"We [the SAE Supportability Committee] are not* *interested in an 'RCM spec'. We want a 'scheduled maintenance spec'. An 'RCM spec' would be too narrow in scope. There's not enough general interest in RCM to justify SAE involvement in such a spec."*

The group also found itself, at various times, trying to correct known or perceived deficiencies in current processes but could not always agree on how to correct them. After several of these false starts the group concluded that there was no "standard" RCM process and that a "standard" was not the place to develop new and untried procedures. They also decided to ignore the directive to create a preventive maintenance standard. The group began to settle on the idea of creating a set of criteria with which to compare existing processes to ensure a given process was conforming to the original tenets of RCM as defined by Nowlan and Heap.

The group made further efforts to seek out additional experience from commercial industry. In late 1997, the well-respected John Moubray and a few users of the RCM2™ process became involved. With new participation and a clearer direction in place, despite some lively debate, the group was able to complete the SAE JA1011 Standard in 1999. The group also continued work on SAE JA1012, which was intended to "provide additional clarification and amplification for some of the key concepts and terms in JA1011"[1] (references 3 and 4).

At about the same time the SAE effort was started, NAVAIR started an effort to retain their RCM process information in a format that would not be viewed as objectionable as a "standard". The effort also was intended to capture the many lessons learned and improvements identified from significant RCM efforts performed after the release of MIL-STD-2173 in 1986. The result of this effort was the NAVAIR manual, NAVAIR 00-25-403. Many of the participants in this effort were also participants in the SAE JA1011 development effort including the author of this paper who participated in both efforts.

At this point it is worth discussing how DoD uses standards. In what may be a gross oversimplification, DoD uses standards to ensure it knows what it is getting when it buys a product or process. While there is an assumption that a standard referenced in a procurement satisfies the exact requirements of the procuring activity, solicitations often encourage vendors to provide alternative solutions as long as they can be proven to meet all relevant requirements and are advantageous in some manner. In the opinion of this author, SAE JA1011 was intended to be used the same way; as a reference to ensure a potential user of a particular RCM process understood what they were getting relative to the original RCM concept as proposed by Nowlan and Heap. It was not intended to conclude that this was the only process to determine maintenance requirements or even the best process for every situation. In other words, it is the responsibility of the user of a process to decide whether or not a process complies partially or completely with JA1011 and whether it even matters.

Finally it is also worth noting that there seems to be a notion in some camps that SAE JA1011 was primarily developed from the RCM2™ process. In fact, SAE JA1011 was heavily influenced by users of both the RCM2™ and the NAVAIR RCM processes. However, as noted above, much work was accomplished prior to the involvement of Mr. Moubray. In the opinion of this author, as a participant in its development, SAE JA1011 was an impartial assessment of the original tenets of RCM and was as unbiased by any particular personal or business agenda as was humanly possible. Any of the dozen or more people involved will attest that debate was lively and no one person or group got everything they wanted in the document.

NAVAIR RCM Process Description

The NAVAIR RCM process has been evolving ever since the first applications of MSG-2 logic on US Navy aircraft in the 1970's. The RCM logic, analytical tools, and associated execution and implementation processes have been refined and improved over the years based on the experience and lessons learned from many applications of the process under a variety of circumstances.

The NAVAIR RCM process is fully described in NAVAIR 00-25-403. This manual provides information on the following topics:

- RCM analysis planning and preparation
- RCM Training and certification
- Failure Modes, Effects, and Criticality Analysis (FMECA)
- The RCM analysis decision logic process
- Implementation of analysis results
- Sustaining the maintenance program through RCM analysis
- Assessing RCM effectiveness

Figure 1 shows the overall NAVAIR RCM process, which includes four major steps: planning and preparation, the analysis, implementation of results, and sustaining the program. It can be seen from this process overview that the NAVAIR RCM process provides a comprehensive RCM program that addresses not just the analysis process but also the preliminary effort and follow-on efforts necessary to ensure the RCM effort achieves the desired results.

Figure 2 is the NAVAIR RCM logic diagram. The NAVAIR RCM logic has many similarities and a few noteworthy differences from many of the earlier processes. Like many other logic charts, it differentiates safety and non-safety and hidden and evident failures. It also addresses environmental consequences in the safety branches. Applicable task types and other outcomes depend on which branch of the logic tree the failure mode falls into. One of the most noticeable differences from other logic diagrams is the lack of a preferential order in the review of each task type. Most RCM processes assume a preferred order in the selection of a maintenance task, e.g. on-condition first, time-directed or hard-time second, etc. In these processes, if one of the tasks is deemed to be applicable and effective, it is selected and the analysis continues with the next failure mode. The NAVAIR RCM process encourages consideration of all applicable failure management strategies for a given failure mode and provides comparison methods to help select the most effective of all applicable solutions.

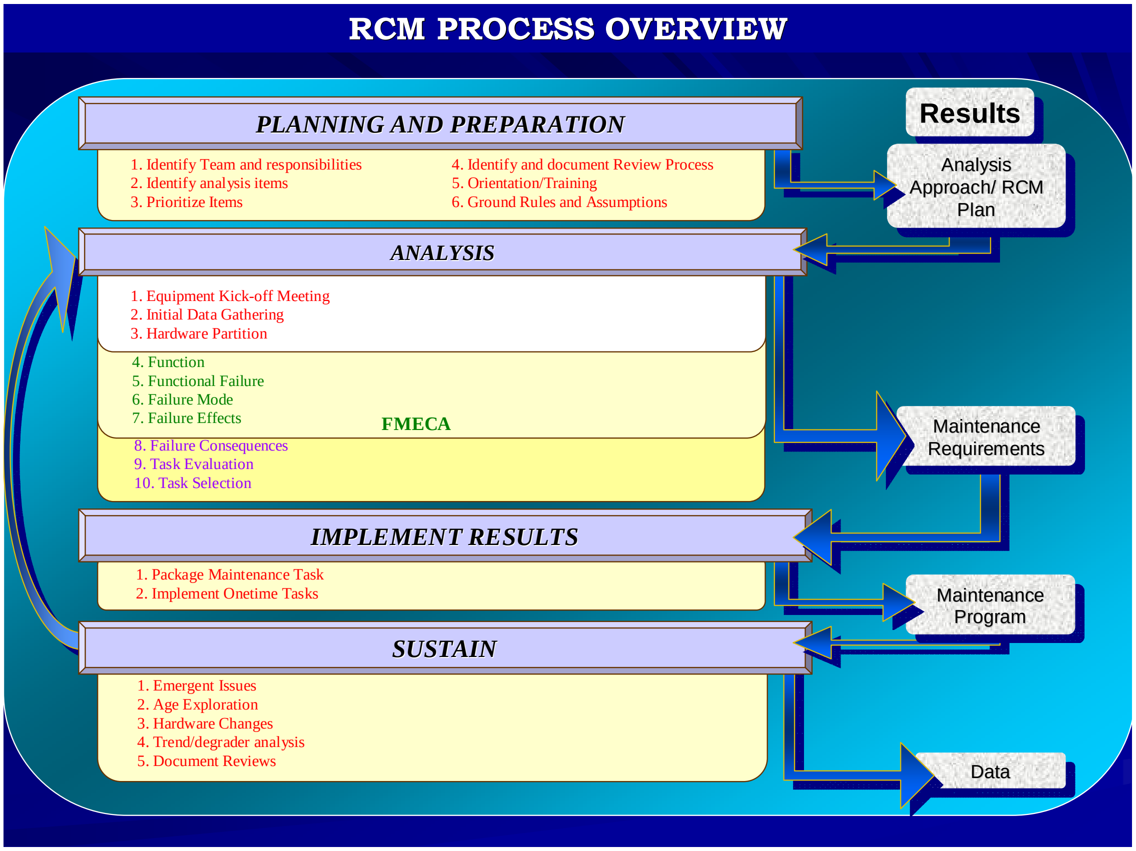

Figure 1.

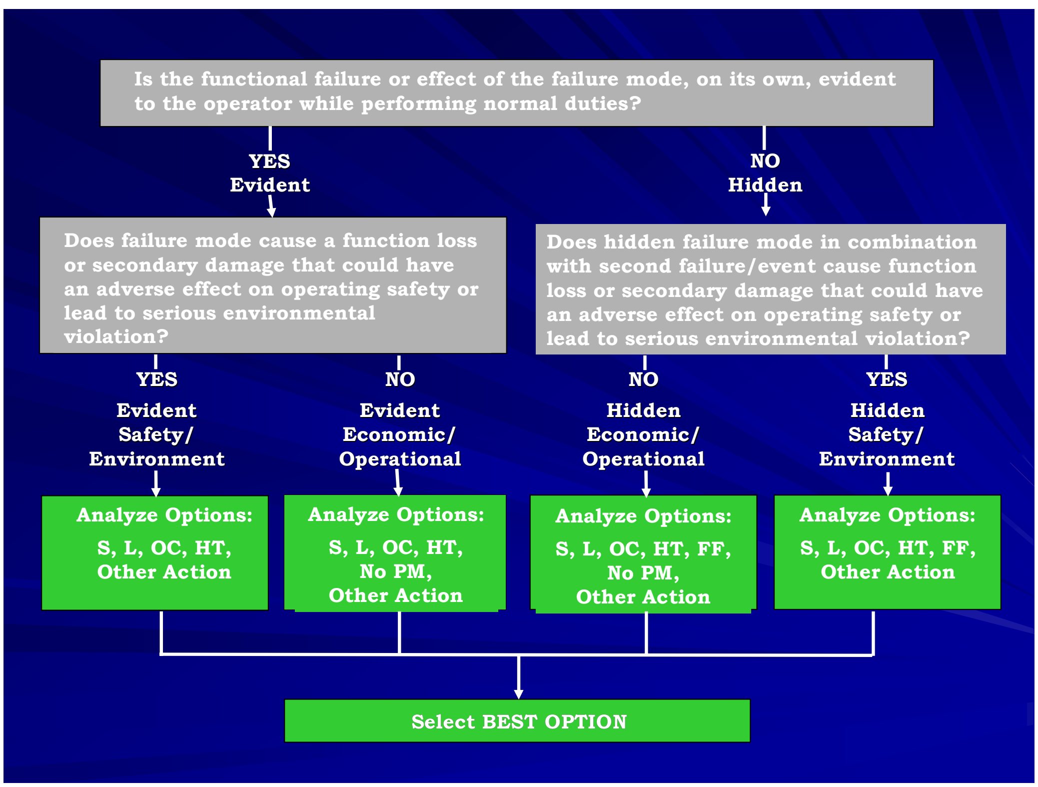

Figure 2.

While it is not the intent of this paper to provide a complete description of the NAVAIR RCM process, there are few additional points about the NAVAIR RCM process worth mentioning:

- The process provides analytical methods for task interval determination. However, the process does not require them to be used. Users are free to use whatever means they choose for task interval determination.
- The process provides specific data collection tasks called Age Exploration tasks for use where the analysis may have been based on assumptions that warrant further analysis when better data is available. The use of these tasks is also optional.
- The process contains provisions to develop specific non-maintenance solutions called "Other Actions" to address failure modes. These Other Actions can include design changes, operating restrictions, operator training, equipment replacement, procedural changes, etc. The analysis contains procedures to assess the relative benefits of these actions compared to other applicable preventive maintenance options and run-to-failure.
- The process does not require any specific execution strategy. It has been used with facilitated teams, as well as by dedicated RCM analysts. Guidance is provided for both methods. Additional discussion on this issue is provided below.
- The process has been applied to many types of equipment including industrial equipment, power generation, and facilities.
- The process provides guidance for application on a limited basis based on user determined priorities when resources do not allow a full application.
- The process provides guidance for developing a living RCM program.
- The process considers both physical and automated inspections to be on-condition maintenance and emphasizes the need to justify implementation of integrated sensing technologies on the same basis as other RCM options.
- The process provides information on grouping maintenance tasks to gain additional efficiencies.

Execution Strategies

Unlike many other RCM processes, the NAVIR process does not promote one particular execution strategy over another. Additionally, users of the NAVAIR process have employed many of the techniques other processes use as reasons to claim their processes are better, faster, or more efficient.

For discussion purposes, we will discuss three main types of execution strategy (with the acknowledgement that there could be any number of others that we are unaware of):

- Formal facilitated groups: One of the most widely accepted methods of performing RCM today is the use of an RCM "facilitator" to lead the analysis of a system in a meeting setting using a group of system experts that include maintainers and operators.
- Dedicated analysts: The analysis is performed by one or more RCM analysts who gather information from all relevant sources including system experts, operators and maintainers. Typically the analyst is an RCM expert with anywhere from some to extensive knowledge of the equipment he or she is analyzing.

- Informal facilitated analysis: Analysis is performed by one or more facilitators using one to a few key subject matter experts in informal settings gathering additional data from other sources as needed. This could be considered a combination of the other two approaches.

Other techniques for expediting the analysis include the use of analysis templates that contain partially completed analysis from similar equipment, limiting the analysis to address only existing preventive maintenance tasks, and limiting either the systems or failure modes addressed in the analysis. The NAVAIR RCM process has been applied using some form of all of these approaches.

Tools and Resources

The NAVAIR RCM process is supported by some excellent tools and resources. These tools are again openly available to the public at no charge. These include technical documentation, software, analytical tools, and process improvement forums.

Software

The primary software tool used by NAVAIR for RCM analysis is the Integrated Reliability-Centered Maintenance System (IRCMS). IRCMS is a stand-alone software tool designed to assist in the analysis process as well as provide a repository for analysis decisions that are easily reviewed as needed. IRCMS is a public domain tool developed for the US Navy and is available via the World Wide Web at the sites listed below. IRCMS has been used on aircraft and related systems as well as industrial equipment and in commercial settings.

The current version available at the time of writing of this paper is version 6.2.5. The current version was written for the military aircraft environment but was easily adaptable to commercial organizations by redefining a few aviation and military terms such as “flight hours” to mean “operating hours. However, version 6.3 is due to be released within the next few weeks and was written to address most of these differences. Version 6.3 also has some new advanced features such as the addition of a pre and post RCM hazard risk index assignment.

IRCMS is relatively easy to use; however experience has shown that a full understanding of its features and capabilities is best accomplished through hands on training via another experienced user, or through readily available formal training. IRCMS was designed to be very open to process changes and therefore does not restrict the analysis with an overly rigid decision logic. As a result, a thorough understanding of an RCM process is required to effectively use IRCMS. Although we are unaware of anyone trying this, there is no reason IRCMS couldn’t be used with any RCM process that closely follows the requirements in SAE JA1011. Software offered by vendors may prove better for a given application, but IRCMS can provide a means to explore the process and provide a frame of reference for available capabilities for those considering an RCM project.

Documentation and other tools

As mentioned throughout this paper, the NAVAIR 00-25-403 manual is the primary guidance document for the NAVAIR process. It is available for download at the websites listed below along with several other guidance and program documents. Also available, although not on the website, is an Excel spreadsheet that provides analytical methods for determining maintenance task intervals based on the methods described in NAVAIR 00-25-403.

Process Improvement

Since the mid 1990's NAVAIR has had an officially chartered committee dedicated to improving the NAVAIR RCM process and tools. The NAVAIR RCM Steering Committee provides a forum to receive feedback on the NAVAIR RCM process and tools. Among other functions, the RCM Steering committee is charged with: coordinating the development, distribution, maintenance, and update of the IRCMS software; coordinating training and certification requirements; and maintaining and disseminating knowledge of advancements in RCM related technologies and processes among other services, industry, and academia. The RCM Steering Committee appreciates feedback from all sources on NAVAIR's RCM processes and tools. This feedback can be provided via the below NAVAIR web site.

Resources

Nearly all of the tools and resources mentioned in this paper are available at no charge from the following websites.

1. NAVAIR RCM website: http://logistics.navair.navy.mil/rcm/index.cfm
2. Anteon website: http://www.anteon-rcm.com

RCM Myths

As mentioned previously, there seems to be a tremendous amount of controversy over what RCM is and what constitutes "proper" RCM analysis. Of course, much of this is driven by competition in the market place and the need for vendors to differentiate their products and services from that of another. Unfortunately some have taken this a bit far by making claims about other processes that cannot be substantiated. Other inaccuracies are misunderstandings or misperceptions that have been perpetuated over time through various forums. In this section of this paper we will attempt to clarify some of the existing misinformation as it applies to NAVAIR, or other military versions of RCM, and the SAE JA1011 Standard. This discussion is intended only to address some of the more often heard inaccuracies. These issues are not universally discussed nor is the discussion here comprehensive.

Myth #1: ***RCM, especially "classical" RCM, is cumbersome, time consuming, and expensive.***

This myth is typically perpetuated by those who use processes that they espouse to be much faster than "traditional" RCM. Early applications of MSG and RCM were very rigorous and highly detailed, and were therefore time consuming. Users began to look for ways to shorten the process. Some looked to change the process itself to make it shorter. For discussion purposes we'll call these "abbreviated" or "derivative" processes. Implied in the "abbreviated process" view is that the "abbreviated processes" will yield the exact same results as a more detailed analysis. Others looked to improve the way they performed the process with only minor changes to the process itself. We'll call these "classical" RCM. In general, the "classical" processes try to abide by the original tenets of Nowlan and Heap's process, and are therefore more likely to be compliant with SAE JA1011. As with any undertaking, people learn how to do things faster and better with experience, so both approaches should yield a faster analysis than the earlier applications of RCM.

Fact #1a: Any RCM process is no more than a set of steps. The basic steps are very simple. The amount of effort put into each step is completely up to the user of the process. The time spent on these steps ultimately depends on the equipment level the analysis is performed at, the amount of information examined and included in the analysis, and how much detailed analytical processing is performed on the data. Basic answers to the process steps can often be completed in a matter of minutes. The only real way to shorten the process is to reduce the information considered or to become more experienced and efficient at processing that information.

As mentioned above, the NAVAIR RCM process not only includes a set of steps very similar to those described in SAE JA1011, but also includes some analytical tools for interval determination, and cost and availability assessment of maintenance tasks. The extent to which these tools are used on each individual failure mode or maintenance task is at the sole discretion of the user. Recent applications of the NAVAIR RCM process range from years for some aircraft applications to days for some commercial plant systems. **Our opinion:** ***Applied appropriately, any SAE JA1011 compliant process (including the NAVAIR RCM process) should require nearly the same effort as an appropriately applied "abbreviated process".***

Fact #1b: There have been no comprehensive independent studies of various RCM processes to determine if any are in fact faster than others. There has been at least one study (reference 5) that compared the results of a "classical" process and an "abbreviated" process on two identical systems at different locations. This study demonstrated that, at least in this one case, the two different analysis processes applied on similar systems, did not produce similar results. The results are summarized as follows:

Output[2]	Classical	Abbreviated
Number of Functions	6	2
Number of Functional Failures	14	2
Number of Components in the System Boundaries	13	3
Number of Failure Modes Analyzed	130	8
Hidden Failure Modes	88	0
Number of Critical Failure Modes	73	5
Number of PM Tasks Specified (incl. RTF)	141	8
Number of "Items of Interest" (IOI's)	49	0

Myth #2: RCM must be performed in facilitated teams to give the best, or even valid, results. Variations: NAVAIR RCM and other processes that use independent RCM analysts do not include proper mechanisms for obtaining maintainer and operator input

The argument goes something like this: Including experts from various elements of an organization in the analysis process will extract as much relevant information from as many sources as possible. In addition, the group analysis process will promote "buy-in" from the participants through development of consensus in the analysis results. It is argued that the RCM results are much more likely to be implemented and therefore the RCM more likely to be successful because affected parties participated in and agreed with the analysis.

The facilitated group method is an excellent method of performing RCM analysis in many cases. However, some proponents of this method would have you believe that using any other method, ever, is inefficient, ineffective, or even dangerous. Reasons cited include:

- Other methods fail to include relevant maintainer, operator, or subject matter expert knowledge
- Other methods are likely to fail because they do not get maintainer buy-in to the requirements generated by the analysis.
- Other methods take longer due to getting bogged down in unnecessary detailed analysis of data
- Other methods do not disseminate the information developed in team meetings as well

Fact #2a: RCM has been successfully and efficiently executed, and the results implemented, using several different execution strategies.

Fact #2b: There are situations where the facilitated team advantages may not apply or where other approaches may be better overall, considering that the facilitated team approach requires participants to all be trained in RCM and away from their regular jobs while participating in the analysis effort. Remember, any valid approach will still be required to obtain necessary information from operators and maintainers.

- Contracted maintenance: Some contract maintenance situations may make it impossible to include relevant maintainers. For example, in some facility maintenance environments, maintenance may be performed on an on-call basis. The same maintenance personnel or even the same company may not perform the same task each time.
- Highly specialized equipment: Equipment such as gas-turbines, aircraft structure subject to fatigue, or other highly complex equipment may require detailed engineering analysis of failure mechanisms and associated task intervals. While maintainer and operator input may still be useful, it may make no sense to subject them to the details of such analysis.
- Highly stressed or lightly manned operations: Some organizations simply cannot afford to remove key players from their primary responsibilities long enough to perform the analysis in meetings over days or weeks. Or, it may be more cost effective to outsource the analysis effort. Again, any outsourced effort should ensure

appropriate means of collecting relevant information from key sources and ensurinfg organizational buy-in to results are employed.

- Highly regulated industries: In cases where maintenance is regulated and closely monitored such as aircraft, nuclear power, etc., the consideration of buy-in from maintainers is likely moot. The tasks get done or someone gets fired or goes to jail.
- New acquisitions or new technology: The majority of available data may be engineering or test data that might be most efficiently analyzed by one or two technical specialists.

The bottom line is that there are more ways to get information into an analysis than by having a group sit in a room and talk about it. There may be times when that is the most effective way and others when it is not.

Myth #3: The Military/aviation environment is so different from the industrial environment that analytical processes for one do not apply to the other

This general myth can be broken down into several similar misperceptions that most likely come from a misunderstanding of military and aviation environments:

Myth #3a: Military and aviation deal mainly with highly critical failures that warrant detailed analysis.

Fact #3a: Military equipment, especially aviation, designers have spent years and invested huge resources designing in redundancy and designing out critical failures. Most failures of aircraft components are economic or operational in nature. Critical failure is simply unacceptable from a design standpoint.

Myth#3b: Military applications are more concerned with safety and operations than cost and have large amounts of money to throw at things like RCM.

Fact #3b: The US Military has been faced with declining budgets and aging equipment since the end of the Cold War. Most of the impetus for RCM in the US Military is to maintain an acceptable state of operational availability while reducing the cost of operations and maintenance.

Myth#3c: Military versions of RCM require large amounts of data including previously performed FMECAs.

Fact #3b: The NAVAIR RCM process contains the same methods for determining failure modes and effects as other RCM processes. Previously or independently performed FMECAs are often used as source data for analysis, but when available, are often performed at lower equipment indenture levels that make them unusable as a direct input to RCM analysis. Other data is used in much the same way it is in other industries.

Myth #4: The RCM process only applies to new designs

This myth, whose origins are unknown, most likely came about because RCM was originally developed from the MSG-2 process, which was developed for new commercial aircraft.

<u>Fact #4:</u> The ***RCM process*** developed by Nowlan and Heap was developed for DoD to apply to new and in-service aircraft. In fact, Nowlan and Heap has a section dedicated specifically to application to in-service aircraft. ***MSG Logic*** was originally developed for new commercial aircraft[3]. Most recent applications of RCM to equipment in DoD by far have been to equipment that has been in-service for a significant portion of its life cycle.

Myth #5: RCM must be a zero based analysis

<u>Fact #5:</u> RCM can be performed as a zero based analysis or using an existing maintenance as a starting point. Many NAVAIR RCM applications have effectively used the existing maintenance program as a starting point as will be demonstrated in examples below. NAVAIR 00-25-403 provides guidance on limiting the scope of analysis by limiting the source of failure modes considered. Analyzing all failure modes would be at one end of the extreme and analyzing only new failure modes as they occur would be at the other. Most NAVAIR applications of RCM fall somewhere in the middle of this range.

Myth #6: NAVAIR RCM is not SAE JA1011 compliant

This is probably the most absurd of the inaccuracies in the public domain, given the histories and relationship of SAE JA1011 and NAVAIR RCM. It probably hasn't been widely distributed, but it seems to persist in certain circles. Most of the claims made in this argument were based on outdated or inaccurate information about the NAVAIR process, for example from NAVAIR training materials that pre-dated SAE JA1011.

<u>Fact #6:</u> The NAVAIR RCM process is fully compliant with the spirit and intent of all provisions of SAE JA1011, as many of the participants in its development were also authors of NAVAIR 00-25-403. Reference (6) explores this issue in great detail. This paper is available on the websites previously listed.

Case Studies

The case studies present in this section will probably be from a slightly different perspective than a traditional case study format. Rather than provide a detailed review of one specific application of the NAVAIR RCM process, we will present higher level overviews of several RCM projects. We believe this will better serve the audience by demonstrating the flexibility of implementing the NAVAIR RCM process rather than showing more examples that claim some quantitative savings in some metric that is only meaningful to the organization performing the analysis. It is also believed that some of these implementation approaches could be used with other RCM processes as well. We will, however, present the results of a study that tries to demonstrate quantitatively, at a high level, the improvements made by RCM in reliability, availability, and maintenance cost across the NAVAIR organization.

A-7 Corsair Aircraft

The A-7 Corsair is a carrier based attack aircraft fielded in the 1960's and retired by the US Navy in 1992. It is discussed here because it is good example of a limited analysis approach. An MSG-2 style analysis was performed early in the aircraft program's life but it was not kept up to date. Changes were made to the maintenance program over time with little documented analysis. As a result, the aircraft maintenance program and its initial analysis diverged significantly. Late in the life of the program a decision was made to re-implement RCM analysis with NAVAIR's newer process. Based on the fact that the existing maintenance program had some basis in analysis, and the late stage of the life of the program, a decision was made to go straight to a living RCM program with no initial analysis. Any changes to the maintenance program from that point on would be through RCM analysis, but no up-front analysis of existing tasks or failure modes would occur. System performance trending was used to identify systems that might benefit from an RCM review and RCM analysis was performed only when a system began to perform poorly. Failures deemed to be "important" were also analyzed as they occurred. The trend monitoring and RCM analysis was performed by full-time RCM experts acting as independent analysts who were also experienced maintainers on the aircraft.

The A-7 RCM Program was thought of as one of the best at the time and demonstrates one possible scenario for application of RCM. If a system has a maintenance program that is thought to be fairly good to start with or there is little life remaining in an existing system it may be worthwhile to start RCM from a sustaining perspective rather than starting with a large initial analysis effort.

E-6 Mercury Aircraft

The E-6 Mercury aircraft is a strategic communications platform operated by the US Navy. It is based on a modified Boeing 707 commercial airframe. The original maintenance program was developed from a review of existing tasks on its predecessor the EC-130, the 707 Boeing recommended maintenance program, and the US Air Force E-3 aircraft that was also based on the Boeing 707 airframe. A sustaining RCM program was put into place much like that on the A-7. Recently an effort was started to update the existing maintenance program with RCM. The aircraft was already very reliable, but it was felt the existing maintenance was negatively impacting the operational availability of the aircraft. The approach taken was to analyze, at least initially, only failure modes being addressed by existing maintenance tasks. A team of dedicated contractor and US Navy analysts were employed. To complicate matters it was decided to perform the analysis by maintenance package (e.g. 56 day requirements, 600 flight hour requirements, etc.) This required the analysis to address each system multiple times and resulted in significant redundancy of effort. It did, however, also allow significant benefits from the analysis to be implemented much more quickly than other approaches. Whole maintenance packages could be extended and modified at once, whereas a system-by-system analysis approach would require the complete analysis to be done before major changes could be incorporated, or individual tasks would have to be updated piece-meal. The RCM effort is still ongoing, but significant savings in maintenance man-hours and increased availability have already been realized.

F/A-18 Hornet Aircraft

The F/A-18 "Hornet" is a carrier-based, supersonic, twin engine, all weather, combined fighter and attack aircraft. The Hornet replaced the F-4 Phantom, A-7 Corsair, and the A-6 Intruder as they were phased out in the in the 1980s and 1990s. Like some other US Navy aircraft, the RCM was performed by the prime contractor during the initial design of the aircraft. Also like many other aircraft, the analysis was maintained sporadically during many years of operation. Similar to our other examples, a decision was made to revisit the RCM program. Because only one year of funding was allotted initially, the decision to pursue a maintenance package analysis strategy like that on the E-6 was made to show return on investment as soon as possible to justify continued funding of the effort. However, unlike the E-6, after one maintenance package was analyzed and the benefit demonstrated, the analysis would return to a more efficient system-by-system approach taking into account all significant failures, not just those covered by existing maintenance tasks. Again, this effort is still ongoing but significant returns on investment have already been realized.

High Pressure Shop and Instrument Air System

RCM analysis was performed on several industrial equipment systems at a large DoD industrial facility. This was one of the first applications of the NAVAIR RCM process on purely industrial equipment. The RCM project was driven by the purchase of some new Predictive Maintenance (PdM) equipment including vibration testers and infrared cameras. The existing maintenance program was informal and largely undocumented. The purpose of the RCM analysis was performed to maximize equipment availability on a production critical asset and ensure longevity of the equipment by developing a comprehensive preventive maintenance program. The RCM approach was to analyze all “significant” failure modes identified through operator and maintainer experience and work

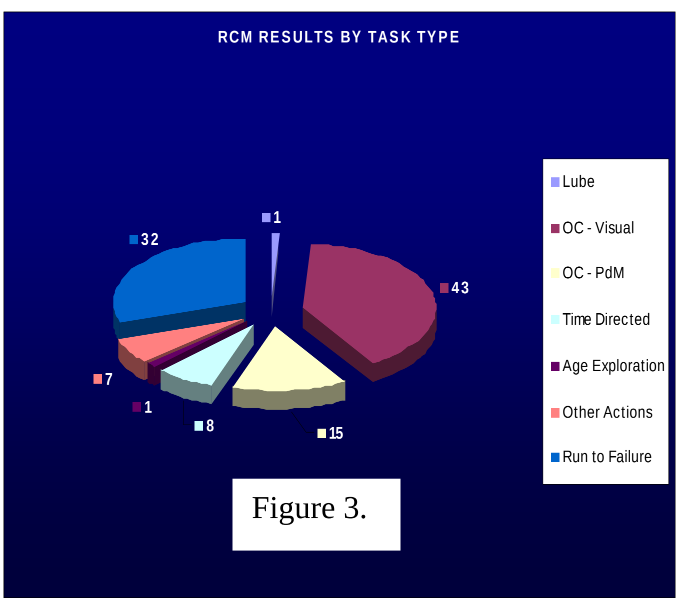

Figure 3.

order data. The analysis was performed by one contractor analyst over a period of a few months. This case study demonstrates a more traditional, complete top-down analysis approach on industrial type equipment. A summary of the outcome is shown in Figure 3. No comparison was made to a previous maintenance program as none was documented.

Impact of RCM

Given that the primary focus of RCM is the prescription of an optimal maintenance program, upon implementation its effects will be first seen in a lean preventive maintenance requirement package. Depending on the state of the previous maintenance approach, the extent of changes in preventive maintenance requirements from application of RCM will vary. Typically on aircraft, maintenance programs that were not initially analytically based are more conservative. When RCM is applied, preventive maintenance is usually, but not always, reduced. The following table summarizes the impact of RCM analysis on 3 recent NAVAIR projects. These numbers represent changes to only the preventive maintenance requirements addressed via RCM.

RCM Effects on PM Man-Hours Required

Project	Pre-RCM	Post-RCM	% PM Change
EA-6B	435,925	160,060	-63%
F/A-18	272,332	88,559	-67%
E-6B	76,810	29,661	-61%

A proper sustainment effort is essential to delivering the full benefits of RCM. An optimal maintenance approach should yield decreases in one or more of the following: failure rates, corrective elapsed maintenance time, and corrective maintenance man-hours due to the application of the correct type of maintenance for each failure mode. A study carried out for NAVAIR on the expected results of such benefits is summarized in the following table[4]:

Project	Percent RCM Improvement per Year			
	Time on Wing	EMT/FH	MMH/FH	MCI
EA-6B Airframe Corrosion	51%	-23%	-24%	9%
P3 Flap Actuator	49%	-14%	-16%	33%
ALQ-99 Ram Air Turbine	3%	5%	3%	-4%
APS 115 Radar Antenna	11%	-7%	-8%	15%
Average All	**28%**	**-10%**	**-11%**	**13%**

Conclusions

RCM is a relatively simple process, but its implementation presents many different issues. RCM is mostly an application of “common sense” using some basic physical and reliability principals. Detailed analytical methods have a place, but not universally. The best approach to executing an RCM program will be based on the goals, resources (time, fiscal, manpower, and technical), and commitment of the organization attempting to perform RCM. The most common trait in successful implementations of RCM is good leadership from those seeking to implement it. Good leadership will result in buy-in from the rest of the organization.

Many of the RCM variations in the market place have strong points and weak points. There is probably no one best process for all situations. Be wary of claims that suggest otherwise. Many of the differences in RCM vendors are as much about style, approach, and personality than technical process. However, these can also be important in the ultimate success of a project. Learn as much as you can before committing to a process and make sure you are comfortable with the approach you select. The NAVAIR process and resources can be a valuable asset to learn more about RCM even if you ultimately settle on another process.

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