NAVAIR 00-25-403
31 October 1996

MANAGEMENT MANUAL

GUIDELINES FOR THE NAVAL AVIATION RELIABILITY-CENTERED MAINTENANCE PROCESS

SUPERSEDURE NOTICE - This manual supersedes NAVAIR 00-25-403 dated 31 July 1990.

DISTRIBUTION STATEMENT C. Distribution authorized to U.S. Government agencies and their contractors to protect publications required for official use or for administrative or operational purposes only determined 31 July 1990. Other requests for this document shall be referred to Commanding Officer, Naval Air Technical Services Facility, 700 Robbins Avenue, Philadelphia, PA 19111-5097.

DESTRUCTION NOTICE - For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

PUBLISHED BY DIRECTION OF COMMANDER, NAVAL AIR SYSTEMS COMMAND

LIST OF EFFECTIVE PAGES

Insert latest changed pages: Dispose of superseded pages in accordance with applicable regulations.

NOTE: On a changed page, the portion of the text affected by the latest change is indicated be a vertical line, or other change symbol, in the outer margin of the page. Changes to illustrations are indicated by miniature pointing hands.

Dates of issue for original and changed pages are:

Original 0 . . . 31 October 1996

Page No.	*Change No.
Title	0
A	0
i-v	0
1-1 - 1-2	0
2-1 - 2-13	0
3-1 - 3-24	0
4-1 - 4-15	0
5-1 - 5-6	0
A-1 - A-7	0
B-1 - B-6	0
C-1 - C-6	0
D-1	0
E-1 - E-10	0

*Zero in this column indicates an original page.

NAVAIR 00-25-403
TABLE OF CONTENTS

List of Acronyms

AD	Accidental Damage
ADP	Automated Data Processing
AE	AGE Exploration
AEB	Age Exploration Bulletin
AFC	Air Frames Change
AIR	Naval Air
APML	Assistant Program Manager for Logistics
APMS&E	Assistant Program Manager, Systems and Engineering
ASO	Aviation Supply Office
ASPA	Aircraft Service Period Adjustment
ATTN	Attention
AVDLR	Aviation Depot Level Repair
AYC	Accessory Change
BCS	Baseline Comparison System
BIT	Built-in-Test
BUNO	Bureau Number
CA	Criticality Analysis
CAO	Competency Aligned Organization
CBR	Cost Benefit ratio
CCL	Critical Crack Life
CNPM	Cost of Not Doing Preventive Maintenance
COMNAVAIRPAC	Commander, Naval Air Pacific
CPL	Crack Propagation Life
CPM	Cost of Preventive Maintenance
D - level	Depot Level Maintenance
DAWIA	Defense Acquisition Workforce Improvement Act
DIM	Dimension
DPL	Deterioration Propagation Life
DMMH	Direct Maintenance Man-hours
DOD	Department of Defense
DTWA	Dual Trailing Wire Antenna System
DWG	Drawing
ECA	Equipment Condition Analysis
ECIFR	Engine Component Improvement Feedback Report
ECP	Engineering Change Proposal
ED	Environmental Damage
EDL	End Item’s Design Life
EFM	Engineering Failure Mode
EHR	Explosive Hazard Report
EI	Engineering Investigation
EM&D	Engineering, Manufacturing and Development
FH	Flight Hour
FLT	Flight
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects, and Criticality Analysis
FSI	Functionally Significant Item
FY	Fiscal Year
GFE	Government Furnished Equipment
HMR	Hazardous Material Report
hr	Hour

HR	Hazard Report

HT	Hard Time
I-level	Intermediate Level Maintenance
IDL	Item Design Life
INST	Instruction
IPT	Integrated Program Team
IRCMS	Integrated Reliability-Centered Maintenance System
ISST	In-service Support Team
L/H	Left Hand
LCL	Lower Control Limit
LDC	Life to Detectable Crack
LDD	Life to Detectable Deterioration
LMDSS	Logistics Management Decision Support System
LOC	Location
LORA	Level of Repair Analysis
LSA	Logistic Support Analysis
LSAP	Logistic Support Analysis Plan
LSAR	Logistic Support Analysis Record
LTWA	Long Trailing Wire Assembly
MA/FH	Maintenance Action per Flight Hour
MAL	Malfunction
MER	Maintenance Engineering Report
MIL-STD	Military Standard
MIM	Maintenance Instruction Manual
MMH/FH	Maintenance Man-Hours per Flight Hour
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MRC	Maintenance Requirement Card
MTBF	Mean Time Between Failures
MTBMA	Mean Time Between Maintenance Actions
n/a	Not Applicable
NA	Naval Air
NADEP	Naval Aviation Depot
NALDA	Naval Aviation Logistics Data Analysis
NAMP	Naval Aviation Maintenance Program
NAMSO	Naval Aviation Maintenance Support Office
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command
NAVWAG	Naval Aerospace Vehicle Wiring Action Group
NDI	Non-destructive Inspection
NHA	Next Higher Assembly
NLG	Nose Landing Gear
NMC	Non-mission Capable
N	No
n	Number
O - level	Organizational Level Maintenance
O/I/D	Organizational/Intermediate/Depot maintenance levels
OC	On-condition
OJT	On-the-job Training
OPNAV	Office of the Chief of Naval Operations
Pacc	Acceptable Probability of Failure

Pact	Actual Probability of Failure
Pmf	Probability of Multiple Failure
PC	Personal Computer
PCA	Physical Configuration Audit
PM	Preventive Maintenance
PMA	Program Manager, Air
POA&M	Plan of Action and Milestones
PROC LIFEREG	Life Regression
PROC LIFETEST	Life Test
QECA	Quick Engine Change Assembly
QDR	Quality Deficiency Report
qtr	Quarter
R & M	Reliability & Maintainability
R/H	Right hand
RAMEC	Rapid Action Minor Engineering Change
RCM	Reliability-Centered Maintenance
ROI	Return On Investment
RS	Residual Strength
SAS	Statistical Analysis Software
SC	Severity Classification
SDLM	Standard Depot Level Maintenance
SE	Support Equipment
SERV	Service
SI	Significant Item
3-M	Maintenance Material Management System
SN	Serial Number
SOW	Statement of Work
SRA	Shop Replaceable Assembly
SRC	Scheduled Removal Component
SRF	Structural Rating Factor
SS/FL	Structural Sampling/Fleet Leader
SSI	Structurally Significant Item
SSIR	Structurally Significant Item Report
STWA	Short Trailing Wire Assembly
TD	Technical Directive
TEC	Type Equipment Code
TPDR	Technical Publications Discrepancy Report
UCL	Upper Control Limit
VF/FH	Failures per Flight Hour
VMA	Marine Attack Squadron
WRA	Weapons Replaceable Assembly
WUC	Work Unit Code
Y	Yes

1.0 INTRODUCTION

1.1 Definition of Reliability-Centered Maintenance (RCM). RCM is a life cycle process for establishing and adjusting preventive maintenance (PM) requirements for all levels of maintenance. RCM ensures that the PM requirements are based on the failure characteristics of the equipment and allow it to realize its inherent reliability. Only applicable and effective tasks are used to prevent failures. If an appropriate task does not exist, no PM will be performed. The equipment will be redesigned to eliminate the failure mode if the failure is of a safety consequence. As the equipment experiences changes (changes in mission, modifications, etc.), RCM will adjust all of its PM requirements.

1.2 Purpose of Document. As directed by NAVAIRINST 4790.20 series, PM requirements shall be identified by conducting a RCM analysis, based on results of the failure modes, effects and criticality analysis (FMECA). This manual has been written to provide a single source guidance document for Program Managers for Logistics (PMAs), Assistant Program Managers for Logistics (APMLs), In-service Support Team (ISST) Leaders, and anyone tasked with performing a RCM analysis. It covers (1) planning for RCM, (2) RCM analysis theory and specific guidance, (3) documenting the analysis, (4) implementing the results of the analysis, and (5) sustaining the RCM analysis through Age Exploration (AE), including guidance on documenting the cost savings obtained by using RCM. This manual explains RCM requirements as implemented by Naval Air Systems Command’s (NAVAIR's) current RCM software (see section 1.3). MIL-STD-2173, Reliability-Centered Maintenance Requirements for Naval Aircraft, Weapons Systems and Equipment, is for guidance only.

1.3 RCM Software. NAVAIR’s current RCM software is the Integrated Reliability-Centered Maintenance System (IRCMS). This software shall be used to perform all RCM analyses for NAVAIR. For more information and current version contact the RCM program manager:

Commanding Officer
Naval Air Systems Command
Attn: AIR-3.2B (RCM Program Manager), Bldg 446
47056 McLeod Road, Unit 8
Patuxent River, MD 20670-1626
(301) 342-3838 extension 176

Use of equivalent standard commercial software shall be approved by AIR-3.2B.

1.4 RCM Training. The following is a list of RCM related courses. All prospective RCM analysts, either government or contractor, should be formally trained to perform RCM.

1.4.1 Naval Air Systems Command RCM Analyst Course. NAVAIR offers the RCM Analyst course. This course covers NAVAIR's RCM methodology and provides training on NAVAIR's current RCM software. Local On-the-Job Training (OJT) can also be provided by experienced RCM analysts who can provide "real world" RCM analysis techniques. For more information contact the RCM program manager:

Commanding Officer
Naval Air Systems Command
Attn: AIR-3.2B (RCM Program Manager), Bldg 446
47056 McLeod Road, Unit 8
Patuxent River, MD 20670-1626
(301) 342-3838 extension 176

1.4.2 Air Force Institute of Technology RCM Analysis Course. The Air Force Institute of Technology offers RCM Analysis course. This course is a Defense Acquisition Workforce Improvement Act (DAWIA) ACE course. For more information contact:

Air Force Institute of Technology
School of Systems and Logistics,
Professional Continuing Education
Wright-Patterson Air Force Base, Ohio 45433-7765
(937) 255-7777 extension 3164 or DSN: 785-7777 ext 3164

1.5 RCM Working Group. The RCM Working Group is an AIR-3.0 chartered working group of ISST/Integrated Project Team (IPT) RCM experts. It provides a formal forum for the regular and timely exchange of technical RCM information in order to standardize RCM concepts, philosophies, and techniques. The working group meets periodically and is available for technical RCM support to programs (as required). AIR-3.2B is the Chairman of the RCM Working Group and should be contacted for any information.

2.0 RCM PLANNING

2.1 Introduction. Development of a RCM program plan is the first of many steps in initiating and maintaining a program that maximizes safety and operational availability, reduces overall cost of ownership, achieves equipment inherent reliability, and provides an audit trail for PM requirements. The RCM program plan should describe all processes and procedures that will be implemented and performed within the RCM/AE programs, and identify all resources necessary to execute these processes and procedures. The purpose of this plan is to ensure that issues that have impeded prior RCM efforts are identified and removed prior to becoming problems again. The RCM program plan should address, as a minimum, the following elements that are each presented in detail in this chapter:

a. RCM analysis ground rules and assumptions

b. Scope of initial analysis

c. Sustaining task procedures

d. Available resources/data identification

e. Responsibilities definition

f. Effectiveness metrics

g. Training requirements

h. Contractor support/interface

i. RCM/Logistic Support Analysis Record (LSAR) interface

j. Reporting requirements

k. Funding requirements

l. RCM program plan of action and milestones (POA&M)

2.2 RCM Program Development (Planning) Team. The PMA, APML, Assistant Program Manager, Systems and Engineering (APMS&E), and ISST leader should collectively identify the team of government and/or contractor personnel which will be responsible for the development of the RCM plan. The RCM planning team composition may include, but is not limited to, the following personnel (and associated competencies) and organizations:

a. APML, APMS&E, ISST/IPT Team Leader, ISST/IPT Sub-Team Leaders. This includes competencies 3.1, 3.2, 3.6, 4.1, 4.3, and 4.4.

b. ISST/IPT engineers, logisticians, technicians, data and cost analysts. This includes competencies 3.2, 3.6, 4.1, 4.2, 4.3, and 4.4.

c. Contractor engineers, logisticians, technicians

d. Automated Data Processing (ADP) personnel (competency 7.2)

e. Budget personnel (competency 1.2)

f. Contracts personnel (competency 2.0)

g. NAVAIR RCM training personnel (competency 3.2)

2.2.1 RCM Planning Team. RCM planning team members, either individually or collectively, should possess the following knowledge in order to effectively develop the RCM Program Plan:

a. RCM decision logic

b. R&M data analysis

c. Logistic Support Analysis (LSA)/LSAR

d. Competency Aligned Organization (CAO)/ISST issues

e. Naval Aviation Maintenance Program (NAMP) policy and procedures

f. Maintenance requirements of the subject program

g. Basic personal computer (PC) skills (project management, database development/management)

h. Statistical techniques (sampling procedures, Weibull, actuarial analysis, etc.)

i. Structural analysis techniques

j. Statement of work (SOW) development

k. Contracting

l. Financial issues

m. Required databases/access requirements

n. PC training availability and requirements

o. Knowledge of the equipment functions and functional failures

2.3 RCM Program Plan Elements. The following paragraphs provide additional information on RCM Program Plan elements listed in paragraph 2.1.

2.3.1 RCM Analysis Ground Rules & Assumptions. This element of the plan should provide for definition of (or reference to) agreements as to how the RCM analysis will be performed (initially and throughout sustainment), standard operating procedures (i.e. software, data, specifications, etc.), data sources, analytical methods, cost benefit analysis methods, specific analysis approach information, default values, system safety identified acceptable probabilities of failure, and any other appropriate information that is required for a consistent and efficient RCM analysis effort. Specific examples, and lessons learned that have been utilized and developed by various programs, are contained in Appendix A.

2.3.1.1 Failure Mode Effects Critically Analysis (FMECA). The FMECA is one of the major data inputs to, and is the starting point of, the RCM process. As such, ground rules & assumptions should also be included for the FMECA unless previously documented elsewhere such as in a FMECA Plan or LSA Plan (LSAP) on new acquisitions. Although this document is not intended to be a FMECA guidance document, criticality analysis is one area of FMECA that is consistently misunderstood and has a major impact on RCM analysis.

a. Criticality Analysis (CA). To correctly integrate the RCM and failure modes and effects analysis (FMEA)/FMECA efforts, a clear understanding of the difference between FMEA and FMECA is necessary. The design FMEA is used to identify and eliminate unacceptable failure modes early in the design process. Later a CA is performed (either formally or informally) to prioritize those failure modes for analysis through RCM, LSA, etc. Therefore, CA is not adding information to the FMEA, it is limiting the scope of the FMECA from what is in the FMEA. It is essential that this process be well thought out in advance to preclude focusing on extremely remote failure modes in the RCM. For additional information on the FMEA/FMECA process and its relationship to RCM see MIL-STD-785, MIL-STD-1388, MIL-STD-1629, and MIL-STD-2173.

(1) In simple terms, CA is the process of selecting which failure modes require RCM out of all theoretical failure

modes identified in the design FMEA. CA may be a detailed quantitative methodology as identified in MIL-STD-1629 or it may be a simple qualitative method such as using a system safety criticality type matrix of severity class versus probability of failure or mean time between failure (MTBF).

(2) Typically the CA method will be specified in a FMECA plan (new acquisitions). However, if a separate or specific method is solely for RCM analysis, it should be provided as part of the RCM Ground Rules and Assumptions.

b. Analysis Approach. The analysis approach to be used during the performance of the RCM analysis is a critical element in the planning and executing process. The analysis approach is primarily applicable to the FMECA, which in turn influences the RCM analysis. There are two primary approaches for accomplishing the FMECA/RCM analysis. One is the hardware approach and the other is the functional approach. The plan should clearly define and describe which approach is to be utilized, to what indenture level, and all associated ground rules and assumptions for the approach. Refer to MIL-STD-1629A for more information on performing the FMECA. The following provides a brief description of each approach.

(1) Hardware Approach. The hardware approach is normally used when hardware items can be uniquely identified from schematics, drawings, maintenance manuals, and other engineering design data. The hardware approach is normally utilized in a part level up fashion (increasing indenture levels/bottom-up approach); however, it can be initiated at any level of indenture and progress in either direction. Each identified failure mode is assigned a severity classification which is utilized to establish priorities for PM task development or redesign.

(2) Functional Approach. The functional approach is normally used when hardware items cannot be uniquely identified or when system complexity requires analysis from the initial indenture level downward through succeeding indenture levels. The functional approach is normally utilized in an initial indenture level down fashion (top-down approach); however, it can be initiated at any level of indenture and progress in either direction. Each identified failure mode is assigned a severity classification which is utilized to establish priorities for PM task development or redesign.

2.3.1.2 Significant Item (SI) Selection Criteria. Definitions of what constitutes a high failure rate or expenditure of resources for the SI selection logic should be included.

2.3.1.3 Flight Assumptions. List any required usage related assumptions such as, when a flight begins and ends; number of flight hours per month; and default conversions such as catapults per flight hour, flight hours per flight, etc.

2.3.1.4 Analysis of Systems Interfaces. A consistent analysis approach to systems interfaces such as wiring, tubing, and hoses should be developed.

2.3.1.5 Default Values. Pre-determined default values (for numerical data inputs) should be defined and listed in the plan to avoid confusion and provide for consistent data entry. Default values can be developed for any or all numerical data elements within the IRCMS software.

2.3.1.6 Government Furnished Equipment (GFE). In any new aircraft program there will likely be some equipment which another activity has cognizance over. Any PM requirements for the subject equipment itself should be developed from RCM analysis by the cognizant Government activity. Any factors which may give reason to believe that the current PM requirements need to be updated or adjusted should be relayed to the cognizant Government activity. Also, even though a part of a system may be GFE (for example an ejection seat), interface components of that system may still require analysis. Identifying system boundaries prior to beginning the RCM analysis will assist in identifying these components. Procedures for identifying items such as functional block diagrams should be provided.

2.3.1.7 Directed PM Requirements. Most programs will encounter PM requirements that are mandated from a variety of sources. There are basically two ways to handle this type of requirement:

(1) Document the mandated requirement in the RCM program with appropriate justification, or,

(2) Perform the RCM analysis as if the requirement did not exist and document differences along with the source of the mandated requirement. The ground rules and assumptions should identify how directed PM requirements are handled.

2.3.1.8 RCM Process Tailoring. Include any tailoring of the RCM process for the specific program. Some examples might include limiting AE tasks on Daily/Turnaround inspections, alternate structural rating factor tables, alternate methods of determining task intervals, etc.

2.3.1.9 Standard Equations. MIL-STD-2173 contains “controversial” formulas that, through experience, have been modified or deleted. Each program should review the formulas, determine their applicability, identify substitutes, and document those decisions in the ground rules & assumptions. Equations used for probability of failure, task interval calculation, and cost benefit analysis should be documented. If these formulas and equations are contained in documents external to the IRCMS, then reference to them should be listed in the memo fields within IRCMS.

2.3.2 Scope of Initial Analysis. This element of the plan should define the scope of the initial analysis. The scope is the amount of initial analysis to be performed and will determine the resources required to execute the tasks and estimated duration of the tasks. This scope of the analysis will differ according to the phase of the program (new acquisition or in-service), and the extent and currency of any prior RCM analysis.

2.3.2.1 Acquisition Programs. RCM in acquisition programs is interdependent with a number of other efforts including FMEA/FMECA, LSA, system safety, etc. Acquisition programs, which may include major modification programs, should initiate RCM efforts concurrent with the FMEA and LSA/LSAR process as early as possible in the acquisition process. During acquisition, the FMEA and RCM should influence the design and any associated supportable requirements which will be reflected in the LSAR. The scope of the RCM analysis should be at a level with the LSA. RCM should not be performed on every item (weapons replaceable assembly (WRA) or shop replaceable assembly (SRA)) of a weapon system. However, initial LSA candidates should also be considered as initial RCM candidates, as should any system or component in a baseline comparative system or a similar system that has an existing, effective PM task. No PM should be identified without proper RCM justification.

a. <u>RCM in Concept Exploration and Demonstration/Validation Phases</u>. RCM should be performed concurrently with the FMEA effort as it progresses through the various program phases. During Concept Exploration and Demonstration/Validation, FMEAs are started at a high level and worked to progressively lower levels as the design proceeds, primarily to identify failure modes which should be designed out. Likewise, preliminary RCM analysis should be performed to ensure PM is optimized via the design process. This preliminary RCM may, or may not, include actual formal RCM analysis. The following should be goals of this preliminary RCM:

(1) Elimination of PM
(2) Early indication of impending failures (design for on-condition maintenance and damage tolerance)
(3) Elimination of support equipment required for PM
(4) Elimination of hidden failures

(5) Facilitation of required PM by ensuring the incorporation and adequacy of: access, Built-in Test (BIT), test points, sampling valves, etc.

b. RCM in Engineering and Manufacturing Development Phase. The formal RCM analysis begins during the Engineering, Manufacturing, and Development (EM&D) phase as hardware is being further defined. The RCM analysis should be performed concurrently with the design of the aircraft and completion of sub-system and WRA level FMECAs, ensuring maximum potential for impacting the design. The initial RCM is considered completed after the Physical Configuration Audit (PCA). Although the initial RCM analysis is complete at this point, it is never really finished as updates for Engineering Change Proposals (ECPs) and operational experience are required. These updates are the sustaining phase of RCM. Additional information on the acquisition process and the relationship of RCM can be found in MIL-STD-1388-1A, MIL-STD-2173, and DODINST 5000.2-R.

c. Initial Packaging (Organizational/Intermediate/Depot (O/I/D)) Process/Philosophy. Identifies the philosophies and processes that will be used to package the RCM justified tasks into the most logical and cost effective maintenance program. Some factors which influence development/identification of packaging philosophies may include, but are not limited to: fleet size, operational requirements, task constraints, and minimal I-level capabilities.

d. Level of Analysis. A listing of the systems, subsystems, and/or components that will be subject to significant item determination should be developed. RCM should be performed at as high a level as possible. Experience has shown that the system or subsystem level is usually a good place to initiate the RCM analysis.

2.3.2.2 In-service Programs - Factors. Many factors are involved in defining the scope for in-service programs. These factors include, but are not limited to, the following:

a. Age of aircraft (life cycle phase)

b. Prior or existing RCM analysis

c. Current maintenance philosophies

d. Number and complexity of aircraft systems

2.3.2.3 In-service Programs - Plan Steps. The plan should include the following steps for consideration during the scope definition for in-service programs:

a. Current PM Program Baseline. Defines the existing PM tasks and available RCM analysis (version of maintenance requirement card (MRC) deck, standard depot level maintenance (SDLM) spec., etc.).

b. RCM Candidate Identification and Prioritization. Identifies functions, items, and/or PM tasks to determine which will be subject to RCM analysis. Prioritizes those that are subject to RCM analysis based on safety, operational availability, and expected return on investment considerations. Some examples of limiting the scope of the initial analysis include:

(1) "Stake-in-the-ground method". This is a minimum initial effort method. It assumes most current PM tasks are reasonably justified, and will immediately go into the sustaining phase. Any benefits from RCM will be via proactive sustaining efforts.

(2) High profile analysis. This is similar to analysis method one above which consists of jumping into proactive efforts of the sustaining phase, such as analyzing high cost drivers except that a higher initial effort may be warranted.

(3) "Back-fill method". This is a medium level effort for the initial analysis. It assumes that the current PM program adequately covers all potential failure modes, but that there may be some PM being performed that may not be required. A list of items and/or functions is developed for analysis from existing PM tasks.

(4) Complete analysis. This requires the highest initial effort and should be only considered when potential returns are high, i.e. programs with significant life remaining, and/or high current maintenance costs, and/or very low reliability.

c. Initial Packaging (O/I/D) Process/Philosophy. Identifies the philosophies and processes that will be used to package the RCM justified tasks into the most logical and cost effective maintenance program. Some factors which influence development/ identification of packaging philosophies may include, but are not limited to: fleet size, operational requirements, task constraints, and minimal I-level capabilities.

d. Level of Analysis. A listing of the systems, subsystems, and/or components that will be subject to significant item determination should be developed. RCM should be performed at as high a level as possible. Experience has shown that for a complete RCM analysis, the system or subsystem level is usually a good place to initiate the RCM analysis. If only selected items are analyzed, the WRA level may be more appropriate.

2.3.3 Sustaining Task Procedures. This element of the plan should provide for identification and description of the procedures, and process, that will be used to sustain, monitor, update, and refine the RCM analyses. These procedures can be categorized as either proactive or reactive. The plan should include, but not be limited to, the following analysis procedures and processes which are presented in more detail in Chapter 4.0.

2.3.3.1 Proactive. The objective of the proactive analysis is to optimize current PM requirements, delete unnecessary requirements, predict adverse failure trends, predict previously unforeseen failure modes, and improve the overall efficiency and effectiveness of the RCM/PM program. A number of analysis processes are used to meet these objectives:

a. Age Exploration (AE) Tasks. Specific AE tasks (or inspections) are implemented where default answers are used in the initial or updated RCM analysis. These inspections are intended to be of limited duration to provide data which will verify or correct the default answers. The RCM analysis will provide the requirements for specific AE inspections. The RCM/AE Plan provides guidance for the implementation of these AE inspections. Note: Although referred to as AE "inspections", they may not actually be inspections; they could be a review of a database, etc.

b. Top Degrader Analysis. Top degrader ranking indicates which systems or items are having the highest operational or cost impact on the aircraft. Degrader measurement factors could include: maintenance man-hours per flight hour (MMH/FH), non-mission capable (NMC) rates, maintenance actions per flight hour (MA/FH), failure rates per flight hour, failure aborts per flight hour, engine caused aborts per flight hour, etc.

c. Trend Analysis. Trend analysis provides an indication of systems or components which may become problems in the future. Measurement factors used for trending are the same as those used for top degraders; however, changes in the values are important rather than the values themselves.

d. Preventive Maintenance (PM) Requirements Document Reviews. PM documents include MRCs, depot level maintenance specifications, and any other technical manuals or data which contain PM requirements. Periodic review of these documents will reveal outdated maintenance processes, techniques, tools, or supplies, allowing updating to increase effectiveness or lower cost, and requirement updates that should have previously been incorporated but have not. Fleet representation should be included to addresses current or emergent issues/problems that have been identified.

e. Task Packaging Reviews. Task packaging is the process of incorporating a number of maintenance requirements with discrete engineering intervals into optimum uniform intervals such as a 550 hour phase inspection or 56 day corrosion cycle. As requirements are updated they continue to be placed into these packaged intervals. Due to changes over time, the original packaged interval may no longer be optimal. Task packaging reviews should periodically evaluate the packaged maintenance intervals to ensure that as maintenance tasks are added, deleted, or modified, optimum packaged intervals are maintained.

f. Fleet Leader Programs. The fleet leader program is used to predict the onset of failures of systems or components not meeting original reliability expectations. The objective of this program is to identify specific suspected problem areas and periodically review these areas on one or more of the highest usage aircraft, engines, or components. This program may include structural sampling tasks identified through the Structurally Significant Item (SSI) logic. The fleet leader program may also include specific AE inspections.

2.3.3.2 Reactive. The objective of Reactive Analysis is to determine the appropriate response and/or any corrective action to any reported problem or failure. Results from the review of a RCM analysis will be one of the factors considered in determining a response to that problem. The RCM review (and update if necessary) will determine if changes in PM requirements are necessary, and will indirectly aid in determining if one-time inspections (Bulletins), re-designs (ECPs), maintenance process changes, or other corrective actions are necessary. Reactive analysis will also address non-RCM driven design changes, incorporation of test results, etc.

a. Failure Related Reviews. This process historically has been the primary activity of maintenance engineering activities. In addition to the RCM analysis, other analyses and investigations must be performed. While not formally part of the RCM/AE process, these other analysis and investigations and investigations are related to the RCM/AE process.

Failures and other problems are reported through various means. Each requires a specific type of response. Some examples are requests for Engineering Investigations (EIs), Hazardous Material Reports (HMRs), Quality Deficiency Reports (QDRs), Technical Publications Deficiency Reports (TPDRs), or mishap investigations. The specific requirements for each are provided in OPNAVINST 4790.2 series. In addition, each failure or incident should be addressed though the RCM/AE process to determine requirements for changes in scheduled maintenance requirements, or assist in determining the need for one-time inspections, design changes, process changes, or other corrective action.

b. Updates for Design Changes. Design changes may be driven by a variety of factors including a redesign decision from the RCM logic. Whether or not a design change is driven by RCM analysis, a review and/or update of the RCM analysis may be required. Design changes are implemented through the ECP process, or other major modification programs. An assessment of the impact on supportability is a part of any proposed design change. RCM analysis reviews or updates should be accomplished prior to completion of the design change in order to completely assess any impact on maintainability. Design changes driven by a re-design decision from the RCM analysis require a RCM update on the new design. Design changes driven by other factors require a review of the applicable RCM analysis to determine if an update is required.

c. Test or Other Data Inputs. Results from tests or other sources of data may require RCM review and/or update in much the same manner as failures. Test data may be also used in the course of a RCM review or update caused by some other event.

Tests may be performed to verify a fix for a failure or to identify the true cause of a failure. In these cases the test data would actually be part of the solution for a failure related analysis and should flow directly into the resulting RCM review or update.

Tests may also be performed to verify the integrity or function of non-failure related design changes. In this case the test data should also flow directly into the corresponding RCM review or update.

2.3.4 Available Resources/Data Identification. This element of the plan should provide for identification of existing source data for the RCM process (i.e. FMECA, engineering analyses, databases, field data, etc.). It also should identify resources available to perform the RCM analysis (i.e. personnel, available training, computer software/hardware, etc.). Details on data sources are presented in Chapter 5.0.

2.3.5 Responsibilities Definition. This element of the plan should provide for identification and definition of the organizations and personnel responsible for each task in the RCM process. NAVAIRINST 4790.20 series provides for the overall

NAVAIR RCM program responsibilities. The following is provided as an example of identification of responsibilities:

a. Assistant Program Manager, Logistics (APML). The APML is responsible for ensuring that AE program requirements are based on RCM in accordance with applicable instructions, and that RCM is correctly integrated into the maintenance planning process. The APML is the approving official for the RCM/AE plan.

b. Assistant Program Manager, Systems & Engineering (APMS&E). The APMS&E is responsible for ensuring engineering data, analyses and testing to support RCM and AE efforts is made available. The APMS&E will ensure engineering requirements in support of RCM are performed and funded during the redesign process. The APMS&E will utilize RCM philosophy for determining maintenance requirements resulting from engineering investigations and supporting analyses.

c. Design Interface and Maintenance Planning Department (AIR-3.2). AIR-3.2 is responsible for the overall program management of RCM and AE policy and procedures for NAVAIR.

d. In-Service Support Team (ISST)/Integrated Program Team (IPT). The ISST/IPT is responsible for development and implementation of the RCM/AE program in accordance with the RCM/AE plan and direction provided by the APML.

e. Contractors. Contractors may be responsible for performance of RCM/AE analysis as required by modifications or other programs as described in applicable contracts. Any required ISST/IPT memorandums of understanding/agreement (MOUs/MOAs) should also be developed and referenced in the plan.

2.3.6 Effectiveness Metrics. This element of the plan should identify metrics of effectiveness for the RCM program. Some metrics may be cost avoidances, PM man-hours relative to corrective maintenance man-hours, end item availability, etc. The method of measuring these metrics should also be provided.

2.3.7 Training Requirements. This element of the plan should identify the training requirements of the RCM team personnel (numbers and type) (i.e. management training, RCM analyst training, Naval Aviation Logistics Data Analysis (NALDA)/Engineering Change Proposal (ECA)/Logistics Management Decision Support System (LMDSS), etc.). This should also include contractor personnel, if applicable.

2.3.8 Contractor Support/Interface. This element of the plan should identify and list (or reference) SOWs, partnership agreements, data analysis/transfer agreements, data formats and other recommend contractual vehicles necessary to execute/implement the RCM program. Any other interface requirements not covered by the above mentioned documents should also be listed.

2.3.9 RCM/LSAR Interface. This element of the plan should provide a description of (or reference to) the procedures for which the RCM process will interface with the LSA process. Any scheduled maintenance requirements or other maintenance procedures or requirements added, deleted, or modified through the RCM/AE process by the government or contractor should be incorporated into the LSAR for programs which utilize the LSAR for documenting, developing, and implementing an integrated ILS maintenance program. Depending upon the aircraft program, this process may vary quite substantially. One possible process may include a database program which exports FMECA data from IRCMS, creates and populates the associated LSAR data tables (BF, BG(A), BG(B), BG(C), BG(D), BG(E), BG(F), BG(H), BI, and BJ(B), and then exports the tables as text files for input to the LSAR database.

2.3.10 Reporting Requirements. This element of the plan should provide for definition and listing of the RCM program reports which will be compiled and submitted on a periodic basis to the ISST/IPT Leader, APML, PMA, or any other designated recipient. These reports may include, but are not limited to:

a. RCM Status: Summary of RCM analyses performed during the reporting period.

b. RCM Cost Avoidances: Summary of cost avoidance calculations associated with the RCM analyses performed.

c. AE Status: Summary of AE inspections and data which was collected and analyzed during the reporting period and the RCM results of those inspections.

d. Effectiveness/metrics: Status of metrics performance during the reporting period.

2.3.11 Funding Requirements. This element of the plan should provide for definition of funding requirements for ISST/IPT and contractor tasks. It also should define annual sustaining and non-recurring requirements and statement of estimated return on investment for the RCM program. The following example is provided:

a. ISST/IPT

(1) Labor estimates could be provided in this format for identification of both initial RCM analysis requirements (as required) and maintaining/sustaining requirements once the analysis is performed. Actual fiscal year (FY) requirements will obviously be dependent upon the scope of the initial analysis and sustaining efforts. Evaluation of other programs should be performed in order to develop realistic estimates.

	1stFY	2ndFY	3rdFY	4thFY
FY (Total)				
(Performing RCM)				
(Sustaining RCM)				
PM Program Management				
Material				
Training				
Meetings				

(2) Performing RCM could be contracted as part of a partnership agreement. However, maintaining of the RCM analyses and the overall PM program should remain within the ISST/IPT.

(3) Funding requirements for material should include any hardware or software.

(4) Funding requirements for training should include funding for NAVAIR RCM Analyst Training (on-site at the Naval Aviation Depot (NADEP)) and other associated Reliability & Maintainability training, workshops, symposiums, etc.

(5) Funding requirements for meetings should include continued ISST/Contractor partnership meetings and other RCM Working Group meetings.

b. Contractor(s). Funding requirements for contractor efforts will be dependent upon the approved MOAs, SOWs, partnership agreements, etc. These documents will contain the detailed responsibilities and specific tasking. Redundant efforts should be avoided as much as possible. However, as a worst case, the ISST/IPT funding estimates could be used for contractor estimates.

2.3.12 RCM Program POA&M. This element of the plan should provide the RCM Program POA&M for the execution/implementation duration of each of the plan elements/tasks and its associated resource requirements. The POA&M should identify the next 5 out-years of sustaining efforts.

3.0 RCM ANALYSIS PROCESS DETAILED DESCRIPTION AND GUIDANCE

3.1 RCM Analysis Overview. The RCM analysis process is summarized by the steps listed below and shown in FIGURE 3-1:

a. Functional Failure Analysis. Defines equipment functions, functional failure, and EFMs to which RCM analysis may be applied. This is usually accomplished through a FMECA.

b. RCM SI Selection. Determines which items and/or functions will be analyzed and categorizes the item as either functionally significant or structurally significant.

c. RCM Decision Logic (includes analysis of Functionally Significant Items (FSIs) and Structurally Significant Items (SI)). Determines failure consequences and PM and potential redesign requirements for SIs.

d. AE Analysis. Determines data gathering tasks needed to support the RCM analysis and possibly refine the PM program.

e. Packaging of PM Requirements. Determines the optimum grouping of PM requirements at all levels of maintenance based on economical, operational or logistically feasible considerations.

3.2 FMECA. The FMECA identifies (1) the equipment item (or system/sub-system), (2) its functions, (3) functional failures, (4) EFMs, (5) effects of the failure on the item, system, and end item, and (6) failure detection method. RCM analysis is then used to determine if there is some type of PM task which will reduce or prevent these consequences of failure for each failure mode. MIL-STD-1629A provides instructions for performing a FMECA.

RCM PROCESS/IRCMS GUIDANCE

MIL-STD-1629A provides a detailed description of FMECA data elements. The IRCMS software can be used to actually perform the MIL-STD-1629A FMECA (Task 103) or a previously performed FMECA can be entered into IRCMS for the purposes of RCM analysis. Paragraph 2.3.1 provides additional information on FMEA/FMECA and development of associated ground rules & assumptions.

3.3 RCM SI Selection. SI selection is the process of determining which systems, subsystems, WRAs, and/or functions will be subject to RCM analysis based on safety, operational and economic considerations.

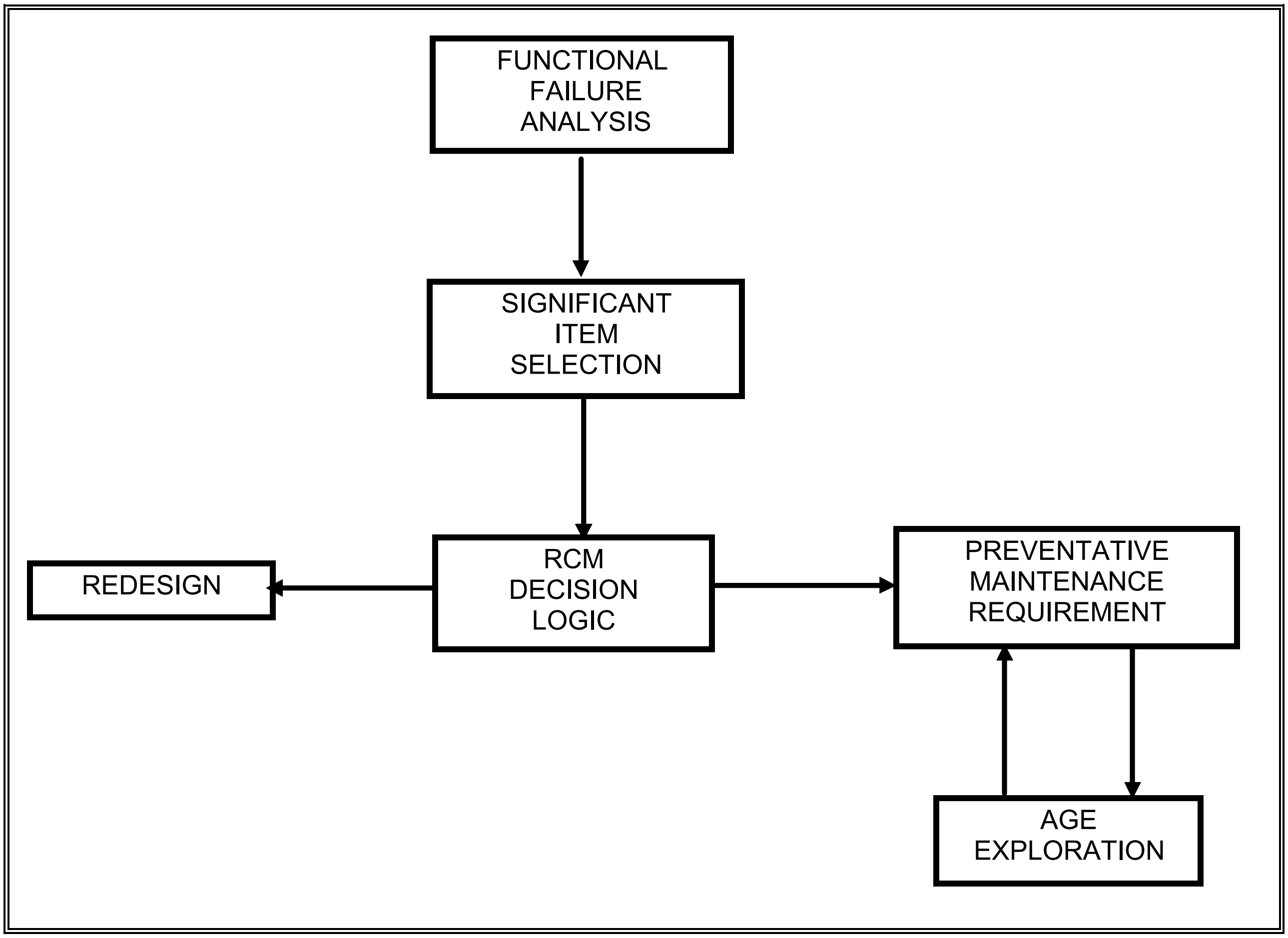


FIGURE 3-1. RCM Analysis Process

3.3.1 New Versus In-Service Programs. It should be noted that SI selection can be performed before, after, or concurrently with performing the FMECA. For new acquisition programs, a FMECA is typically performed prior to the RCM analysis because the FMECA has many uses besides just the RCM analysis. In this case the SI selection logic is used to limit the application of RCM on items already in the FMECA. For in-service programs, the FMECA is likely to only be performed for the RCM analysis and may be done during or after SI selection. In this case, the SI selection process is applied to functions or functional failures, identified from a functional block diagram (see paragraph 3.3.2) or other list of functions or functional failures and the FMECA is performed only on significant items. An LSA candidate list can be used as starting point for SI selection. MIL-STD-1388-2A provides additional information on the LSA process. Ground rules and assumptions should be developed in the RCM Implementation Plan to clarify the order of these steps for a particular program.

3.3.2 Functional Block Diagrams. Functional block diagrams (or functional breakdowns) are excellent tools for selecting significant items. A functional block diagram is constructed by dividing equipment into functional systems, similar to the two digit work unit code (WUC) systems for aircraft. Each of these systems is then further broken down into progressively lower levels of indenture (subsystems, WRA, or SRA), see FIGURE 3-2. This breakdown is useful to visualize the functional relationship of the various components to each other, to the higher levels of indenture, and to the end item. Every attempt should be made to accomplish the RCM analysis at the highest level of indenture possible, typically the system or subsystem level. A RCM

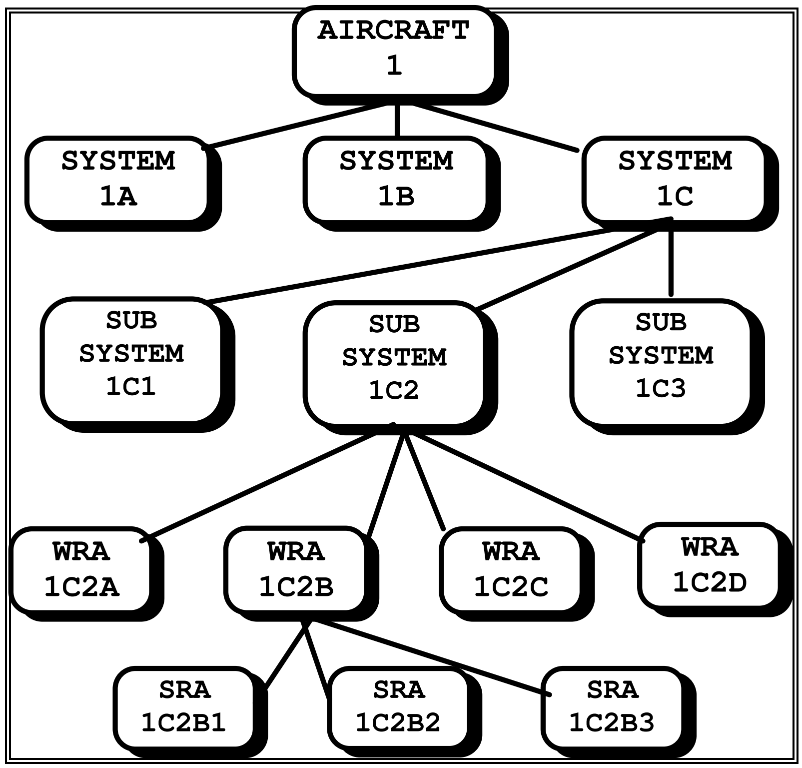


FIGURE 3-2. Functional Breakdown

analysis should be performed at the level necessary to ensure a complete analysis, but should not be performed on too large of a scale in order not to complicate the overall analysis process. (SSIs should be analyzed below the subsystem level.)

3.3.3 RCM SI Selection Logic. FIGURE 3-3 is the logic process used to determine if an item/function requires RCM analysis by evaluating the functions that the item provides to the end item. It divides items into three groups: structurally significant, functionally significant, and non-significant based on answers to the SI selection logic questions described below.

RCM PROCESS/IRCMS GUIDANCE

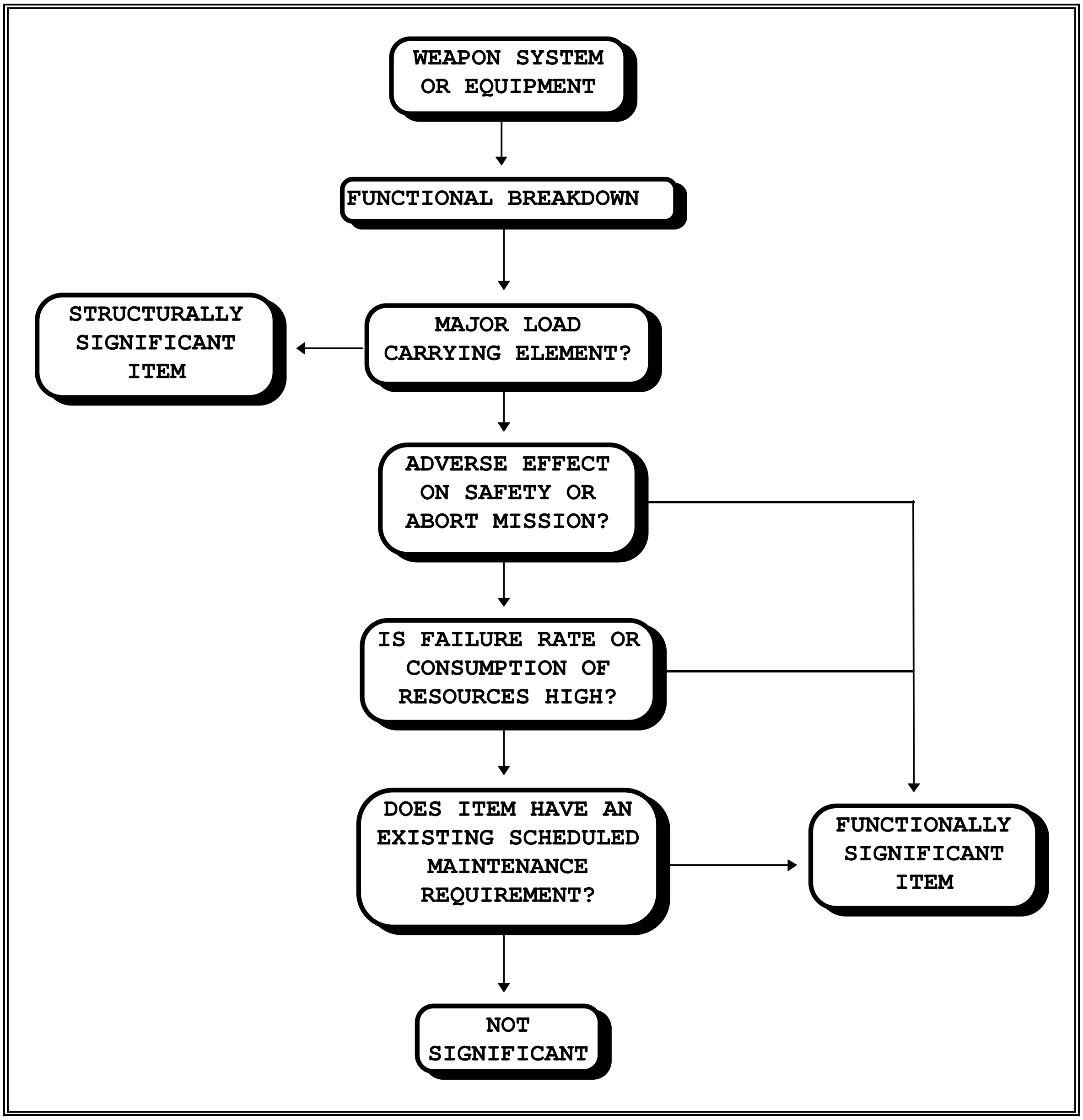
SI selection is accomplished in IRCMS by answering four questions on the FMECA function screen. These questions may be answered at the time functions are entered or later; however, they must be answered prior to beginning the RCM analysis.

a. Question 1: Does the function of the structural element carry major ground or aerodynamic loads? The intent of this question is to evaluate all item functions subjectively with regard to ground or aerodynamic loads. This includes system components with structural functions such as actuator housings, pistons, rod ends, connectors, hinges, bellcranks, etc.

SSIs are identified to analyze structure (load carrying elements) whose failure, if left undetected, would have an adverse effect on safety. Safety is affected if surrounding structure or backup elements can not carry the remaining load for the design life of the aircraft after the element in question fails (residual strength reduced to less than design limits). Structural items, including equipment with structural functions, for which functional failure will not affect safety are treated as FSIs. SSIs should be chosen carefully because once designated as an SSI, some PM task or redesign will be required.

SSIs which also have non-structural functions such as actuator housings, pistons, rod ends, connectors, hinges, etc. should be analyzed as both an SSI and FSI. To accomplish this in IRCMS, add structural and non-structural functions for each item as required.

b. Question 2: Does loss of the function cause an adverse affect on operating safety or abort the mission? If question 1 was answered "No", this question must be answered. Analyze functional failures to determine whether they have safety consequences or would cause mission abort. Answer this question for each functional failure (resulting from the failure cause which is the EFM) of a given function. If the function has a Severity Classification (SC) of I, it shall be identified as safety. If the function has a SC of II, it will be identified as either safety or mission abort. In either case, a yes answer will be given and the item shall be listed as a FSI. Secondary damage must also be considered in answering this question. If a function/failure is hidden, the condition that causes the failure to become evident shall be assumed to have occurred.



c. <u>Question 3</u>: Is the actual or predicted failure rate of the item or consumption of resources high? Thresholds for high failure rates and consumption of resources should be provided in Analysis Ground Rules and Assumptions. Determination of what constitutes a high failure rate may be different for different safety hazard severity classifications.

FIGURE 3-3. FSI/SSI Selection Diagram

"Consumption of resources high", implies that the failure is of a high cost item (cost of the item or manpower used to replace it) which may or may not fail frequently, or of an item which fails often but may not be a high cost item (repair or manpower). Failures which cause significant loss of equipment availability would also be considered a "high consumption of resources". Finally, if the functional failure results in any primary or secondary damage that causes high repair costs or out of service time then consumption of resources would also be high.

d. Question 4: Does the item have an existing PM requirement? For in-service equipment review the current scheduled maintenance requirements. For new acquisitions, the Baseline Comparison System (BCS) should be used as a primary

DECISION QUESTION	DEFAULT ANSWER IF UNCERTAIN	POSSIBLE ADVERSE EFFECTS OF DEFAULT
SI Identification		
Is the item significant?	Yes - Classify item as significant	Unnecessary analysis
Failure Consequence Evaluation		
FSI Decision Logic Question 1	No - Classify failure as hidden	Unnecessary maintenance or redesign
FSI Decision Logic Question 2	Yes - Classify item as safety critical	Unnecessary redesign or maintenance that is not cost effective
FSI Decision Logic Question 3	Yes - Classify item as safety hidden failure	Unnecessary redesign or maintenance that is not cost effective
EVALUATION OF PROPOSED PM TASKS		
Is a servicing or lubrication task applicable/effective	Yes - Include task at default interval	Unnecessary maintenance
Is an OC task applicable/effective	Yes - Use short enough intervals to make task effective	Maintenance that is not cost effective
Is HT task applicable/effective	Yes - Use real and	Maintenance that is

Is a combination of tasks applicable/ effective	applicable data to establish life limit Yes - Include on OC task with a HT task	not cost effective Maintenance that is not cost effective

FIGURE 3-4. Default Decision Logic Chart

determinant. This does not necessarily imply that the FMECA and RCM analyses from like equipment are applicable, but does indicate that this item is significant from a maintenance perspective and should be subject to analysis. If the answer to any of these questions is unknown, use FIGURE 3-4 to provide conservative default answers to the logic questions.

3.4 RCM Analysis of Functionally Significant Items. After an item is determined to be functionally significant through the FSI/SSI Selection Logic (see FIGURE 3-3), appropriate PM tasks are evaluated for applicability and effectiveness (see FIGURE 3-6).

RCM PROCESS/IRCMS GUIDANCE

Applicability determines if the type of task is appropriate for preventing the failure mode, and depends on the failure characteristics of an item. Effectiveness determines if the task can be performed at a reasonable interval that will (1) reduce the probability of failure to an acceptable level (when safety is a concern), or (2) be more cost effective than allowing the failure to occur (when safety is not a concern). The RCM logic (and IRCMS software) will determine task applicability based on data provided by the analyst. If a task is applicable, the RCM logic allows the analyst to develop an "effective" PM task. It is then up to the analyst to decide if the calculated PM task interval is actually effective (practical).

The order of task evaluations for each logic path represents an assumption that the first task evaluated would be the most desirable from a cost-effectiveness perspective and each subsequent task would be increasingly less cost-effective. This assumption does not always hold true and additional tasks should be given at least a cursory evaluation for cost-effectiveness even if one task is found applicable and effective. Unlike previous versions of RCM software, IRCMS 5.3.1 now allows the consideration of more than one PM task.

The criteria for determining applicability and effectiveness are summarized in FIGURE 3-6. Information from the FMECA, along with data from any available source, should be used to evaluate each task. If the answer to any of the task evaluation questions is unknown, use FIGURE 3-4 to provide a conservative route through the logic.

3.4.1 Failure Consequences. After the SI's failure modes have been properly identified through the FMECA, the first three RCM decision diagram questions can be answered (see FIGURE 3-4) for each failure mode. These answers determine the consequence for each failure and identify which branch of the decision diagram to follow during task evaluation. In answering these three questions, use the data provided in the FMECA.

RCM PROCESS/IRCMS GUIDANCE

a. Question 1: "Is the functional failure occurrence evident to the crew or operator while performing normal duties?" To help determine if the functional failure is evident, refer to the item description, compensating provisions, and failure detection method on the FMECA. The FMECA should identify design features, instruments, operational characteristics, or warning lights which make a failure evident to the operator. The functional failure of an item is considered not evident to the operator if either of the following situations exist:

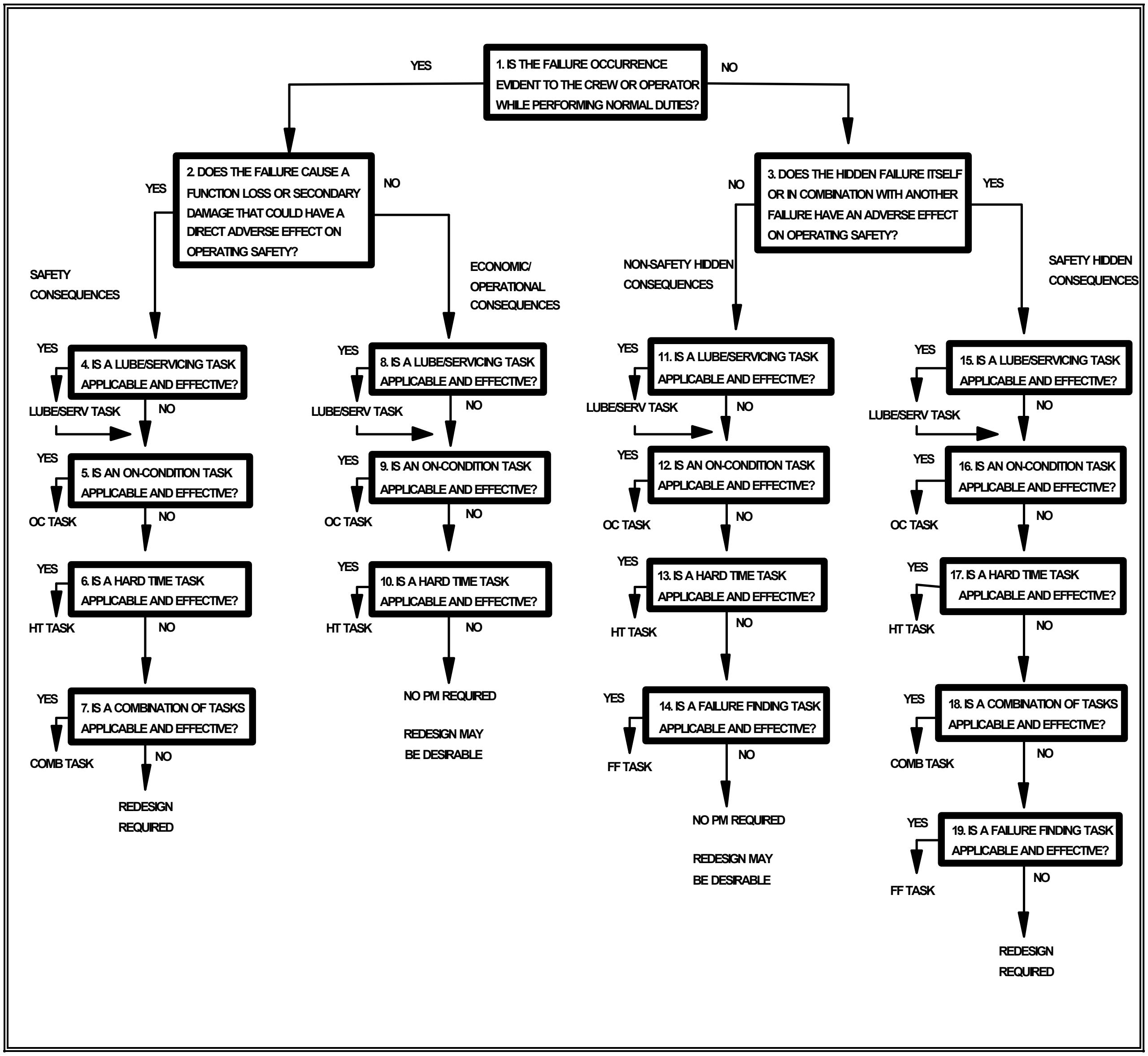


FIGURE 3-5. RCM Decision Diagram For FSIs

(1) The function is normally active whenever the system is used, but there is no indication to the operator when the function ceases to perform.

(2) The function is normally inactive and there is no prior indication to the operator that the function will not perform when called upon. The demand for the inactive function will usually follow another failure and the demand may be activated automatically or manually.

A functional failure is evident only if it can be detected by the crew/operator (not the maintenance technician) that is responsible for the phase of the mission in which the function is

<table>
<tr><td rowspan="4"></td><td colspan="4">FAILURE CONSEQUENCES</td></tr>
<tr><td>SAFETY</td><td>OPERATIONAL /ECONOMICS</td><td>NON-SAFETY HIDDEN FAILURE</td><td>SAFETY HIDDEN FAILURE</td></tr>
<tr><td colspan="4">EFFECTIVENESS CRITERIA FOR ALL TASKS</td></tr>
<tr><td>Must reduce risk of failure to an acceptable level</td><td colspan="2">Must be cost effective; Cost of preventive maintenance must be less than cost of operational loss and/or cost of repair</td><td>Must reduce risk of multiple failures to an acceptable level</td></tr>
<tr><td>TASK</td><td colspan="4">APPLICABILITY CRITERIA</td></tr>
<tr><td>SERVICING/ LUBRICATION</td><td colspan="4">The replenishment of the consumable or lubricant must be due to normal operation and called for by the design</td></tr>
<tr><td>ON-CONDITION (OC)</td><td colspan="4">1. Must be possible to detect reduced failure resistance
2. Must have a definable, detectable potential failure condition
3. Must have a consistent age from potential failure to functional failure</td></tr>
<tr><td>HARD TIME (HT)</td><td>1. Must have minimum age below which no failures will occur

2. REWORK ONLY) Must be possible to restore to an acceptable level of failure resistance</td><td colspan="2">1. Must have age where conditional probability of failure shows a rapid increase

2. A large percentage of items must survive to this age

3. (REWORK ONLY) Must be possible to restore to an acceptable level of failure resistance</td><td>1. Must have minimum age below which no failures will occur

2. (REWORK ONLY) Must be possible to restore to an acceptable level of failure resistance</td></tr>
<tr><td>FAILURE FINDING</td><td colspan="2"></td><td colspan="2">No other task is applicable and effective</td></tr>
</table>

FIGURE 3-6. Applicability and Effectiveness Criteria Summary

used. For some items, particularly certain support equipment and some electronics racks, the maintenance technician is the operator, and the RCM analysis for such items should reflect this.

For a functional failure to be evident, failure indications (i.e. gauges, warning lights, fault codes, crew sensing, etc.) must be obvious to the operator while performing normal duties, without special monitoring. Normal duties for the crew are those procedures typically performed to complete a mission. For the air crew, these duties do not include pre-operation, post-operation, or walk around inspections since the inspections do not ensure operational capability of the equipment while performing its mission. However, operational checks of systems during operation are considered valid methods of detecting failures if the checks are part of normal procedures.

Some systems are operated full time, others once or twice per mission, and some less frequently. All of these duties, providing they are done at some reasonable interval, qualify as "normal". On the other hand, most emergency operations are done at very infrequent periods. Therefore, they cannot be classified as "normal" duties. Justification for this question should include the means the operator has of detecting the failure. In the case where no data is available or the answer is uncertain, the default logic answer is used (see FIGURE 3-4).

b. Question 2: “Does the engineering failure mode cause a function loss or secondary damage that could have an adverse effect on operating safety?” To determine the effect on operating safety for non-hidden failures, consider this question in parts: first, the loss of the function (functional failure) and second, the effects of secondary damage.

If question 1 was answered “Yes”, the failure is evident (non-hidden). Refer to the severity classification, failure effects and compensating provisions provided on the FMECA, and consider the following when answering this question for evident failures:

(1) The EFM (mechanism of failure as defined in MIL-STD-1629A) must achieve its effect, by itself, and not in combination with other EFMs. In other words, the EFM must independently be able to cause the adverse effect on operating safety. However, possible secondary damage caused by the EFM should be considered.

(2) The direct consequence of an EFM is an extremely serious or possibly catastrophic condition (Category I or Category II).

(3) "Operating safety" refers to normal operations during the period of time when the unit is powered-up with the intent to perform its mission. For support equipment the "operating safety" regime is performance of a servicing action until the unit is secured at its designated place and power is off.

(4) The EFM must affect a function that is not protected by redundant items or protective devices. That is, if the function is protected by a redundant item or by a protective device, its failure does not have a direct adverse effect on operating safety. An example of a protective device is a delta pressure bypass valve in an engine oil supply line filter. When the bypass valve activates, the filtering function is lost, but the function of oil flow is protected. Therefore, a clogged oil filter, if protected by a bypass valve, will not cause bearing or engine seizure. In this case, it does not have a direct adverse effect on operating safety.

A "Yes" answer to this question will require some task to prevent the safety consequence or redesign of the item to get rid of the failure mode. A "No" answer indicates there are economic or operational consequences. If the answer to any of the task evaluation questions is unknown, use FIGURE 3-4 to provide a conservative route through the logic.

If question 1 is answered “No”, the failure mode is hidden and effect on safety must be considered differently. Safety effects are similar to evident failures, except that the effect of the failure is not immediate.

For hidden failures, refer to the FMECA severity classification, failure effects and compensating provisions when answering question 2, and consider two areas:

(1) First, analyze the hidden failure to determine if it has an adverse effect on operating safety. This adverse effect on safety can result when the function is called upon, not when the EFM occurs. If the adverse effect on safety occurs when the EFM occurs, the functional failure is not really hidden.

(2) Second, if the hidden failure by itself, does not have an adverse effect on safety, evaluate a combination of failures. In this case, the hidden failure adversely affects safety only when it occurs in combination with one additional failure. This additional failure occurs after, and may be precipitated by the hidden failure. The second failure must be in a related system, a back-up to the system in which the hidden failure occurs, or the failure of a primary system for which the hidden failure is a back-up.

A "Yes" answer indicates there are safety hidden failure consequences. If a combination of failures is identified, include a description of the additional condition in the justification. A "No" answer indicates the failure has non-safety hidden failure consequences, which only involve economic or operational effects. If the answer to any of the task evaluation questions is unknown, use FIGURE 3-4 to provide a conservative route through the logic.

3.4.2 Serv/Lubrication Tasks. As shown in FIGURE 3-5, servicing and lubrication tasks must be evaluated for each EFM. These tasks, by themselves, do not necessarily satisfy the complete requirement for PM; other tasks must also be evaluated.

a. Applicability. Servicing tasks are applicable if replenishment of a consumable (such as oil, gas, oxygen, etc.) is required due to normal operation to avoid the failure mode. A lubrication task is applicable if the design of the item requires periodic application of non-permanent lubricant to avoid the failure mode.

b. Effectiveness. When an applicable task is found, its effectiveness must be evaluated. A servicing or lubrication task is effective if it fulfills a design requirement and can be performed at a reasonable interval. Justification must be provided to substantiate the identified task interval. The servicing interval is based upon the rate at which the item is consumed. Lubrication intervals are generally based on the design of the lubricant. Lubricant military specifications or design specifications should provide the required information for lubricant life under various conditions.

3.4.3 On-Condition (OC) Tasks. OC tasks are evaluated for all FSI EFMs. An OC task is a scheduled inspection for a potential failure condition (symptom of failure). OC tasks call for corrective action to be performed "on the condition" that the item in question does not meet a required standard. By repairing or removing from service only those items that are about to fail, OC tasks maximize the useful life of individual items. DOD Report AD-A085450, "Designing On-condition Tasks for Naval Aircraft" contains additional information on OC tasks.

RCM PROCESS/IRCMS GUIDANCE

a. Applicability. The criteria for OC task applicability is determined by answering three question in IRCMS:

(1) It must be possible to detect reduced failure resistance for a specified EFM. Reduced failure resistance is when the failure mode has begun to occur and can be detected, but the component is still performing its function. Question 1 refers to this condition. Answer "Y" or "N". If "Y", provide the specific means such as "Visual inspection for cracks". Be as specific as possible.

(2) It must be possible to define a potential failure condition that can be detected by an explicit task. Question 2 refers to this criterion. Answer "Y" or "N" and provide numerical values for the potential and functional failures when possible such as ".01 inches" and ".25 inches" for cracks. The potential failure condition may indicate a maximum condition allowed to remain in service such as " wear of .100 inches.", or a minimum detectable condition such as a ".01 inch crack".

(3) There must be a reasonably consistent age interval between the time of potential failure and the time of functional failure. Question 3 refers to this criterion. Answer "Y", "N", or "D". Answer "D" if you have determined a value based on default data or methods. This will require the evaluation of an AE task to verify the default data. If answering "Y" or "D", provide the interval and units for the interval.

If all three of the above criteria are met, describe the applicable task. The task should identify what is being performed, the condition being detected, and as specifically as possible, the location of the potential failure, for example, "Inspect rear wing spar lower flange for cracks at Wing Station 123.4".

Potential to functional failure intervals are typically one of the most difficult values to determine in RCM analyses. Fracture mechanics and fatigue test data, which provide detectable to critical crack life, are useful for crack failure modes. Examples of other available sources of this interval include component tests, data from Aircraft Data Recorders/Engine Monitoring Systems which measure data such as vibration over time, etc. Unfortunately, most other failure modes rarely have simple analytical solutions or available data and require default methods. Default methods include using a current PM task that has proven to be effective and working backwards from the current task interval, or using intervals from like and similar equipment on other aircraft. Chapter 5 provides additional information on the determination of potential to functional failure intervals.

b. Effectiveness. By definition, if an OC task is applicable, there is a task that can be performed at some interval to preclude the failure. Determining effectiveness essentially amounts to determining the longest task interval that still meets the applicability criteria and deciding whether performing the task at this interval is "practical".

The preliminary (engineering) task interval is the interval from potential to functional failure divided by some number. For safety failure modes, this number of inspections "n" is determined by calculating the minimum number of inspections within the interval from potential to functional failure that reduces the actual probability of failure to less than or equal to the acceptable probability of failure. Safety hidden failure modes are similar except that the actual probability of failure times the probability of the condition that make the failure become evident (probability of multiple failures) must be less than or equal to the acceptable probability of failure.

The number of inspections "n" is calculated in IRCMS by $n = \ln(Pacc)/\ln(1-\Theta)$ where $Pacc$ is the acceptable probability of failure and Θ is the probability of detecting a potential failure in one inspection (i.e. 90% implies Θ = .9) assuming that a potential failure exists. This is only one method of calculating task intervals; any other analytically justifiable method could also be used.
For economic/operational and non-safety hidden failure consequences, the effectiveness criteria is cost related. For purely economic consequences, a task is effective if it costs less than the cost of the failure it prevents. For operational consequences, a task is effective if its cost is less than the combined cost of operational loss and the failure it prevents. Whenever practical, a cost benefit analysis, whether formal or informal, should be performed to determine whether a certain task is cost effective and identify the optimum interval at which to perform the task. Paragraph 4.3.4 provides detailed information on RCM cost benefit analysis.

3.4.4 Hard Time (HT) Tasks. HT tasks are evaluated for all failure modes which do not have applicable and effective OC tasks. A HT task is simply a scheduled removal of an item or safe life limit of an item. There are two types of HT tasks: rework and discard. If an item can have an acceptable level of failure resistance restored by rework or remanufacture, a rework task is evaluated. If the item cannot be reworked or remanufactured, a discard task is evaluated.

<u>RCM PROCESS/IRCMS GUIDANCE</u>

a. <u>Applicability</u>. The applicability criteria for HT tasks is determined by answering three questions in IRCMS:

(1) For a rework task, the item must be capable of having an acceptable level of failure resistance restored for the specific EFM under analysis. Question 1 determines whether a rework task or discard task will be considered. "Y" will result in the evaluation of a rework task; "N" will result in the evaluation of a discard task .

(2) The item must exhibit wearout characteristics identified by a rapid increase in the conditional probability of failure (see FIGURE 3-7). Question 2 will ask whether this wearout age exists and its value. If a "D" was entered in the first part of the question, the wearout age is a default value that should be resolved through an AE task.

(3) A large percentage (100% when safety is involved) of the items must survive to the wearout age for the task to be applicable (see FIGURE 3-7). Question 3 asks for the percentage surviving to this wearout age. The definition of "large

percentage" is left to the analyst; however, the definition should be included in the IRCMS or ground rules and assumptions.

If all three of the above criteria are met, describe the applicable task. The task should identify what is being performed and the item being removed as specifically as possible, for example, "Remove NLG shock strut for rework".

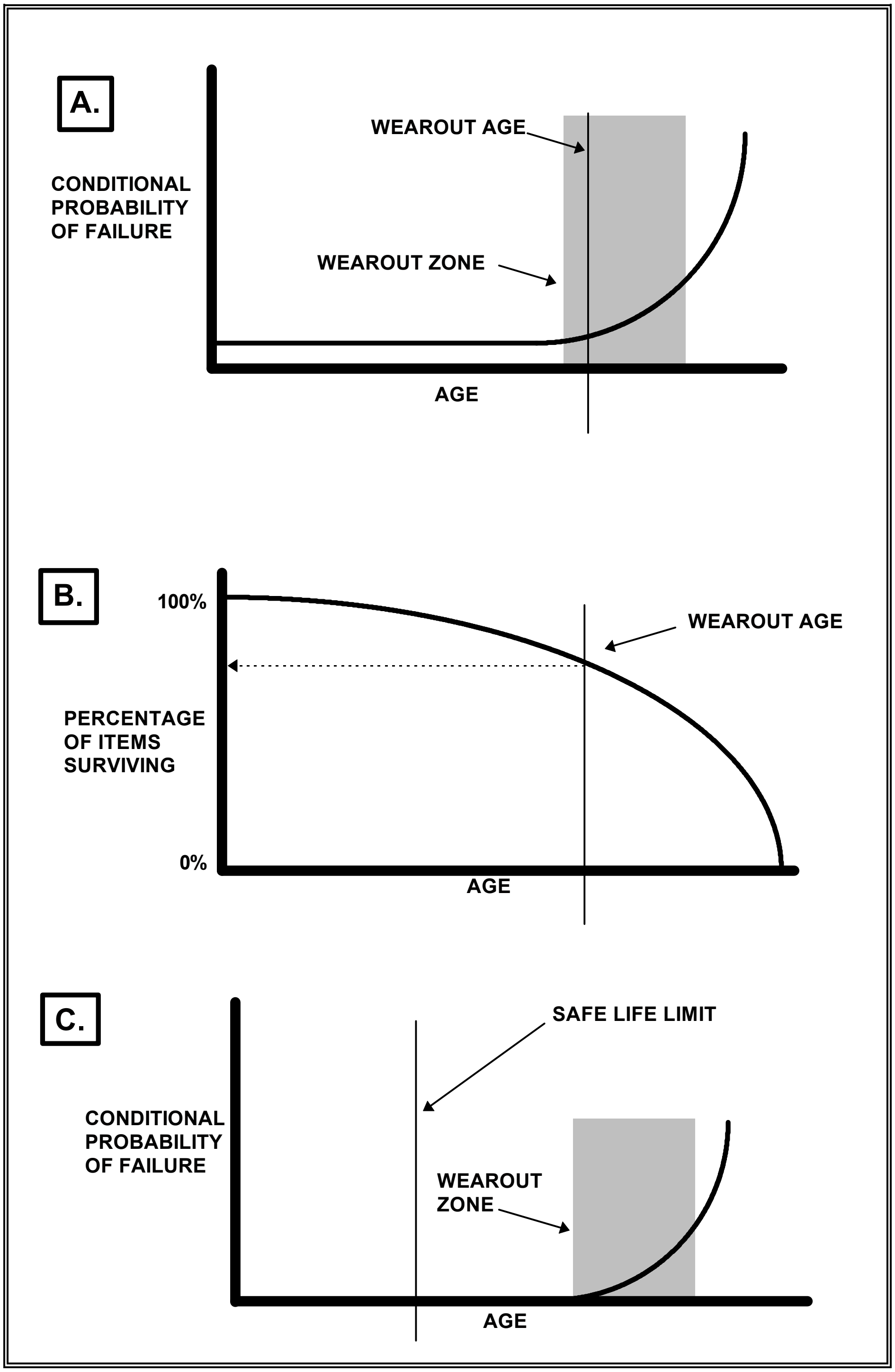


FIGURE 3-7. Applicability Criteria For Hard Time Tasks

b. Effectiveness. Like the OC task, if a HT task is applicable, it can be performed at some interval to preclude the failure. Determining effectiveness means finding the longest task interval that still meets the applicability criteria and deciding whether performing the task at this interval is "practical".

The HT task removal interval is based on the wearout age. When safety is a concern, the removal interval must be well before the wearout age in order to ensure that none of the items will fail in service (actual probability of failure must be less than or equal to acceptability of failure). For non-safety failure modes, a cost benefit analysis should be performed to determine the optimal interval. Whenever practical, a cost benefit analysis, whether formal or informal, should be performed to determine whether a certain task is cost effective. Paragraph 4.3.4 provides detailed information on RCM cost benefit analysis.

HT intervals are usually calculated from statistical analysis of failure or test data. Statistical techniques such as Weibull or Log-normal are very useful as are other analysis techniques such as actuarial analysis in the development of HT task intervals. See chapter 5 for additional information regarding analysis tools and techniques.

3.4.5 Failure Finding Tasks. The failure finding task is used only if OC or HT tasks are not applicable and effective for hidden failure (safety and non-safety) modes (see FIGURE 3-5). Because this task is used to detect failures that have already occurred, only combinations of failures are evaluated for safety hidden failure consequences. Failure finding tasks are usually functional or operational checks to verify proper operation of emergency or backup equipment, or indicating systems. Built-in-tests (BIT) can also be a type of failure finding task. If the hidden failure can be discovered by the failure finding task and corrected before the additional failure occurs, the consequences of the combination of failures is averted. When a BIT or maintenance panel readout detects a latent failure that has no detectable interval from potential to functional failure, the failure finding task will be directly analyzed and the HT task may be omitted.

RCM PROCESS/IRCMS GUIDANCE

a. Applicability. The item must be subject to a functional failure that is not evident to the crew or operator during performance of normal duties. For example, the nitrogen has leaked from the landing gear emergency extension system.

b. Effectiveness. As with OC and HT tasks, if the failure finding task is applicable, there is a task that can be performed at some interval to preclude the failure. Determining effectiveness is finding the longest task interval that still meets the applicability criteria and deciding whether performing the task at this interval is “practical”.

A failure finding task interval should be the longest possible interval that will reduce the actual probability of occurrence of the hidden failure, and the failure or condition which makes the failure evident, to an acceptable level. Mathematically, $Pact \times Pmf \leq Pacc$, where Pact is the actual probability of failure, Pmf is the probability of the multiple failure or condition which makes the first failure evident, and Pacc is the acceptable probability of failure. One method of calculating failure finding task intervals, applicable for random failures, is to use the formula $Pf = (1 - e^{-(t/MTBF)})$ for each of the unknown probabilities in the above equation and solve for t. Note: If more than one probability is unknown, the resulting equation will be indeterminate and will require an iterative solution.

3.4.6 Age Exploration (AE) Tasks. AE tasks are developed to collect data to refine default decisions or data included in the initial RCM analysis. AE tasks may be actual inspections or tests, or simply reviews of usage or failure data such as 3-M. AE tasks are intended to be of limited duration so that when sufficient data is collected, the RCM analysis will be updated and the AE task deleted. Additionally, the RCM logic provides for assessment of the potential cost-effectiveness and for prioritization of AE tasks. Paragraph 4.3.3 provides detailed information on AE tasks implementation.

RCM PROCESS/IRCMS GUIDANCE

In the evaluation of AE tasks, IRCMS first asks questions relative to the cost and resources required for the task and whether potential benefits out-weigh any additional costs. These questions are usually subjective. Rationale for the answers should be provided where possible. The intent is to ensure that only those tasks which will provide a clear benefit are performed and prioritized.

The second part of the AE task evaluation is the development of the task itself. Some of the information required for development of tasks is further described below:

a. Sample size. Sample size is the number of aircraft, engines, or components that will be subject to the AE task. Sample size will vary depending on the type of task and what information is required. For example, if the task is a test to failure, the sample size will likely be very small (often one test specimen). Statistical techniques should be used to determine the minimum sample size required for a given situation. Chapter 5 provides additional information on the determination of sample sizes.

b. Study period. Study period is the length of time the AE task will continue for the entire sample, usually in years or flight hours.

c. Initial interval. Initial interval is the time when the first inspection, data collection, etc. will be performed on an individual item.

d. Repeating interval. Repeating interval is the length of time between inspections, data collection, etc. on an individual item.

3.4.7 Redesign Decisions. In cases where redesign is required and cannot be immediately implemented, PM tasks deemed "not practical" in the analysis may have to be implemented on a temporary basis until a design change can be incorporated. In other cases where an applicable and effective PM was identified, a redesign may still be cost or operationally beneficial and should be evaluated whenever possible.

3.5 RCM Analysis of SSIs. The SSI analysis logic is used to determine PM requirements for items identified as SSIs by the significant item selection process. SSIs are analyzed differently than FSIs because, by definition, all SSI EFMs can potentially affect safety and usually fall into one of three general categories; fatigue damage, environmental damage, and accidental damage. The SSI analysis logic is shown in FIGURE 3-8.

3.5.1 Classification of SSI Failure Modes. The first step in the analysis of SSIs is determining whether a given failure mode should be analyzed as a fatigue damage failure mode or an environmental/accidental damage failure mode. Fatigue damage failure modes can include normal fatigue crack growth, stress corrosion cracking, fretting, thermal fatigue, composite deterioration, or delamination growth, etc. Environmental damage failure modes can include corrosion, erosion, stress corrosion cracking, etc. Accidental damage failure modes can include induced damage, wear, loose/missing structural fasteners, etc. Note that some failure modes such as stress corrosion cracking could fit into more than one category. The decision of which category to include the failure mode will affect what types of preventive tasks are applicable, how the effectiveness criteria for each task is evaluated, and how task intervals are developed.

RCM PROCESS/IRCMS GUIDANCE

The first question in the IRCMS SSI section will determine the SSI failure mode classification. In many cases the answer will be obvious, but each of the following factors should be carefully considered prior to making the decision on which category to use.

a. Fatigue Failure Modes. Fatigue damage is usually related to usage cycles, typically some type of loading. Therefore, the resulting PM tasks are developed to prevent progressive damage due to normal operating cycles from reaching some critical point. Fatigue damage PM tasks will consider factors such as residual strength (RS), life to detectable crack(LDC), item design life (IDL), end item design life (EDL), crack propagation life (CPL), and detectable deterioration (composites).

b. Environmental Failure Modes. Environmental damage is usually related to exposure time, or to conditional events such as exposure to fire fighting agents. The resulting PM tasks for environmental damage will be based on the time and/or level of exposure to some environmental condition and the item's susceptibility to damage from that condition.

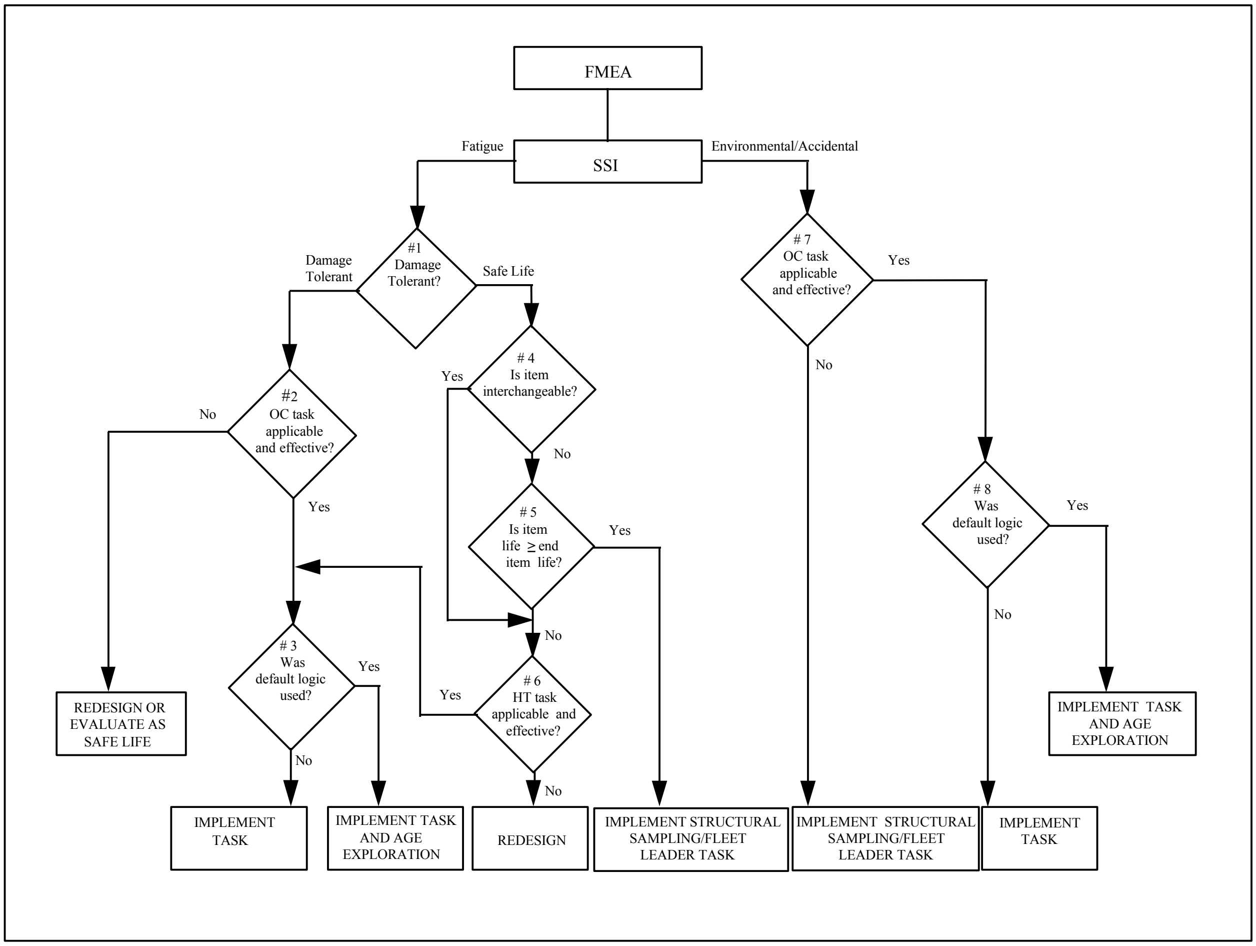


FIGURE 3-8. RCM Decision Diagram For SSIs

c. Accidental Failure Modes. Accidental damage failure modes are usually random events related to level of usage and susceptibility to damage. While not related to age, the probability of accidental damage occurring at a given time increases as the usage increases. The resulting PM tasks will be based on factors such as the location of the SSI, manufacturing quality control, and operating environment.

3.5.2 Classification of Structure Type (Damage Tolerant/Safe-Life). For fatigue failure modes, structure is classified by type (damage tolerant or safe-life) to determine which PM tasks are applicable to the item. For fatigue failure modes of safe life structures, a HT task is usually applicable and will be evaluated for effectiveness. For fatigue failure modes of damage tolerant items, an OC inspection is usually applicable and will be evaluated for effectiveness.

The second question in the SSI section of IRCMS, “Is the item damage tolerant?”, determines structure type. If the item is not damage tolerant, it will be identified as Safe Life. Damage tolerant structure is characterized by either slow crack growth or redundant load paths capable of fully sustaining design loads for some period of time with one or more elements no longer carrying any load. Safe-life structure is characterized by a long life to crack initiation. Damage tolerant and safe-life are design characteristics, however, structure designed to be safe-life may have some failure modes that can be managed as damage tolerant and vice-versa. If a "Yes" response is given to this question, further analysis must be done on the damage tolerant branch of FIGURE 3-8. A "No" response prompts further analysis on the safe life branch of the diagram.

3.5.3 On-Condition (OC) Tasks. OC tasks are evaluated for applicability and effectiveness for damage tolerant fatigue, environmental, and accidental failure modes.

RCM PROCESS/IRCMS GUIDANCE

a. Applicability. Generally, applicability criteria for FSIs applies to SSIs. By definition, if an item is classified as damage tolerant, an OC task should be applicable. Slow crack growth and/or failure of redundant items represent an ideal interval from potential to functional failure. Applicability criteria for SSI OC tasks for accidental/environmental failure modes is exactly the same as for FSI OC tasks.

b. Effectiveness. A damage tolerant SSI should usually have an effective OC task. If not, the SSI should probably be designated as safe-life. OC task intervals for damage tolerant fatigue and environmental/accidental damage SSI failure modes can be developed using the methods described in the FSI logic section for OC tasks or using SRFs which are further described in paragraph 3.5.7.

FIGURE 3-9 provides an example of how rating factors can be used in determination of task intervals. Ground rules & assumptions can be developed for utilization of rating factors in determining task applicability and effectiveness.

Fatigue Failure Modes

CPL SRF	Inspection Interval
1	1/4 CPL
2	1/3 CPL
3	1/3 CPL
4	1/2 CPL

FIGURE 3-9. Rating Factor Based Inspection Intervals.

3.5.4 Hard Time (HT) Tasks. Safe-life structure is designed to be used for a certain number of "cycles", and then removed from service prior to failure. Therefore, HT tasks are evaluated for applicability and effectiveness for safe-life SSIs.

RCM PROCESS/IRCMS GUIDANCE

a. Applicability. Applicability criteria for FSI HT tasks also applies to SSI HT tasks. In addition, one of the two following criteria, which is determined by answering questions 4 and 5 of FIGURE 3-8, must be met for SSI hard-time tasks:

(1) The item is interchangeable. Interchangeability would allow an individual item to accrue more cycles than the design life of the end item by changing from one end item to another. Therefore, some means of tracking time against the SSI to ensure it is removed from service prior to failure must be implemented.

(2) The design life of the SSI is less than the design life of the end item. Obviously, whether or not an item is interchangeable, if its life is less than that of the end item and it is safe-life, a task must be in place to remove the item prior to failure.

If a HT task is not applicable and effective, then redesign or a fleet leader/structural sampling task is required.

b. Effectiveness. Effectiveness criteria for FSI HT task applies. However, the intervals for SSI HT tasks are developed using the results of fatigue tests and/or fatigue analysis. Ground rules & assumptions can be developed for utilization of rating factors in determining task applicability and effectiveness.

3.5.5 Structural Sampling (SS)/Fleet Leader (FL) Tasks. SS/FL tasks are inspections of limited numbers of SSIs vice the entire population to monitor the aging process of the item and ensure structural integrity is maintained. SS/FL tasks differ from AE tasks in that an AE task is intended to verify default information used to develop a PM task, while SS/FL tasks are meant to verify that no PM is required for critical structural items. Like an AE task, when sufficient data is collected to determine that the failure mode is not realistic, or the item should be reclassified as an FSI, than the RCM should be updated and the task eliminated.

RCM PROCESS/IRCMS GUIDANCE

a. Applicability. A SS/FL task is applicable if one of the following applies:

(1) The failure mode is a fatigue failure of safe-life structure, the SSI is not interchangeable, and it has a design life at least as long as the design life of the end item.

(2) The failure mode is an accidental or environmental damage failure mode and an OC task is not applicable and effective.

b. Effectiveness. To be effective, an SS/FL tasks must provide sufficient data to ensure structural integrity is maintained. As with AE tasks, statistical techniques should be used to determine adequate sample sizes and intervals.

3.5.6 Age Exploration Tasks. Paragraph 3.4.6 applies to the evaluation of SSI AE tasks as well as FSI AE tasks.

3.5.7 Structural Rating Factors (SRFs). SRFs are one method of determining a SSI's relative importance to other SSIs based on susceptibility to fatigue, environmental, and accidental damage. Structural rating factors can be used to assess applicability of tasks and to determine default inspection intervals. The ratings range from 1 (most susceptible) to 4 (least susceptible). Susceptibility to each type of damage can be broken down into several sub-categories. After this is done, an average rating factor is calculated for each type of damage which can then be used for determining default task intervals. FIGURE 3-10 provides a structural rating factors table for metallic structures. FIGURE 3-11 provides a structural rating factors table for composite materials. Any rating factor table used should be included in the Ground rules and assumptions section of the RCM Implementation Plan for a given program.

FATIGUE RATING FACTORS	1	2	3	4
A) RESIDUAL STRENGTH (RS), percent	Less than 100 %	100 % - 125 %	126 % - 150 %	Greater than 150 %

of damage tolerant load				
B) LIFE TO DETECTABLE CRACK (LDC), percent of EDL	Less than 100 %	100 % - 110 %	111 % - 120 %	Greater than 120 %
C) CRACK PROPAGATION LIFE (CPL), percent of IDL	Less than 20 %	21 % - 40 %	41 % - 60 %	Greater than 60 %

ENVIRONMENTAL RATING FACTORS	1	2	3	4
A) MATERIAL TYPE	Magnesium	Forged Al, dissimilar metals	Clad Al, Steel, Titanium	Stainless steel
B) SURFACE PROTECTION	Bare	Primer	Anodized, painted	Coated, plated
C) EXPOSURE Internal item	Human waste	Trapped fluid	Vented	Sealed
External item	Salt water	Air pollutants ground water	Rain	Dry air

ACCIDENTAL RATING FACTORS	1	2	3	4
A) DESIGN, MANUFACTURER ERRORS	Complex assembly, difficult fabrication	Complex assembly, simple fabrication	Simple assembly, difficult fabrication	Not susceptible
B) OPERATIONS (consider both ground and flight operations)	Carrier	Ashore, training, high sortie rate	Ashore, low sortie rate	Not susceptible
C) LOCATION	External, ground access	External, special access	Internal, accessible	Internal, covered, heavy surface protection

FIGURE 3-10. Structural Rating Factors (Metallic Structures)

FATIGUE RATING FACTORS	1	2	3	4
A) RESIDUAL STRENGTH (RS), percent of damage tolerant load	Less than 100 %	100 % - 125 %	126 % - 150 %	Greater than 150 %
B) LIFE TO DETECTABLE DETERIORATION (LDD), % of EDL	Less than 100 %	100 % - 110 %	111 % - 120 %	Greater than 120 %
C) DETERIORATION PROPAGATION LIFE (DPL), % of IDL	Less than 20 %	21 % - 40 %	41 % - 60 %	Greater than 60 %

ENVIRONMENTAL RATING FACTORS	1	2	3	4
A) MOISTURE	Item is honeycomb with two of the following: a) external b) regionally low c) enclosed area	Item is honeycomb with one of the characteristics listed in category 1	All honeycomb not covered by the first two categories, cored, or adhesive bonds cured at 200E F or less	Non-honeycomb, Not cored
B) HEAT	Near heat source (external or internal)	External	Internal cockpit area, sunlight	Internal away from heat source
C) EROSION/ ABRASION	Leading edges and external bottom surfaces	Exposed cabin surfaces	External walkways	Not susceptible
D) CORROSION	Carbon/Magnesium or similar	Carbon/Aluminum or similar	Carbon/Steel/Titanium, or similar	Carbon/Carbon or no effect

ACCIDENTAL RATING FACTORS	1	2	3	4
A) DESIGN, MANUFACTURER ERRORS	Enter average value as determined from Fabrication and Assembly Evaluation below			
(Fabrication and Assembly)				
* Process Type	Any process not involving co-curing or lamination	Co-cured, not automated	Co-cured, automated; or Laminate, not automated	Laminate, automated
* Complexity	Complex assembly, difficult fabrication	Complex assembly, simple fabrication	Simple assembly difficult fabrication	Simple assembly, simple fabrication
* Accessibility	None	One side	Two sides	Complete
* Material Inspectability	Sound attenuating X-ray opaque	Sound attenuating X-ray transparent	Sound transmitting X-ray opaque	Sound transmitting X-ray transparent
B) OPERATIONS	Carrier	Ashore, training, high sortie rate	Ashore, low sortie rate	Not susceptible
C) LOCATION	External, ground access	External, special access	Internal, accessible	Internal, covered, heavy surface protection

FIGURE 3-11. Structural Rating Factors (Composite Materials)

4.0 RCM IMPLEMENTATION

4.1 Initial Analysis. Results of the initial RCM analysis should be implemented and sustained according to the RCM plan and the following additional procedures and processes within this chapter.

4.2 Task packaging. The task requirements that result from the RCM analysis may have varying intervals. It would be extremely cumbersome and difficult to manage a maintenance program based entirely on engineering interval(s) resulting from the RCM analysis. Therefore, the tasks must be packaged together in groups so that a number of tasks can be accomplished each time the aircraft is down for PM.

Packaging of tasks is accomplished by considering level of maintenance, engineering interval, and task requirements (i.e., support equipment (SE), work areas). Fleet maintenance personnel inputs are extremely important and should be solicited prior to initiating the packaging process. Only PM task requirements determined through RCM and/or dictated by other sources are packaged. AE tasks that collect information while the equipment is in service are done at the packaged interval of the preventive task they were developed for.

4.2.1 The Packaging Process. First convert all task intervals to a common measurement base (usually calendar time). All tasks are then displayed on a time line to see if there are natural groupings. The goal is to adjust task intervals up or down so that groups of tasks are formed. These groupings should not reflect any predetermined intervals. Non-safety intervals can be adjusted either up or down. Safety intervals on the other hand can only be adjusted down.

Since safety intervals are limited in their ability to be adjusted, use these tasks to determine the groupings, then adjust non-safety tasks to the resulting groups. Some tasks will not be able to be adjusted to fit into any of the groups. These tasks will be included at the engineering interval, in a special maintenance package.

After completion of the packaging process, the "packaged" intervals are recorded along with the engineering intervals. By recording both "engineering" and "packaged" intervals, essential data for future revisions and updates to the PM requirements is recorded. The record of packaged intervals allows comparison with engineering intervals to determine the thought processes used to arrive at the scheduled maintenance intervals.

4.2.2 Packaging Considerations. The following list should be considered when packaging PM requirements:

a. Grouping all the requirements in a specific work area has its advantages, especially if access is time consuming. However, overloading a work area with too many maintenance personnel is poor procedure. Attempt to evenly distribute the personnel in the different work areas.

b. Tasks which use the same SE should also be grouped together.

c. The packaging of PM tasks affects such things as the man-hours consumed to schedule and perform maintenance, aircraft availability, and, in some cases, the structure of the maintenance organization. Therefore, it is of utmost importance that the PM program be as simple and straightforward as possible, and that fleet operator and maintenance personnel inputs are considered. This will also increase the probability of faithful implementation by maintenance personnel.

4.3 Sustaining RCM

4.3.1 RCM Review/Update

4.3.1.1Proactive Analysis. Proactive analysis data is primarily acquired through the Maintenance, Material, Management (3-M) system. The NALDA and ECA systems are used to provide the required data. LMDSS will also be utilized upon complete implementation. Other data sources can be used to gain additional data (locally developed data collection programs, contractor developed data collection programs, etc.).

a. Top Degrader Analysis. Top degraders are “flag s” of potential bad actors to be further analyzed in detail to determine the actual causes of failure. NALDA/ECA data retrieval is initially performed to the sub-system (WUC 4) level. Degrader measurement factors which can be ranked include: MMH/FH, NMC rates, MA/FH, and failures per flight hour (VF/FH). Top degraders are analyzed to determine the causes of failure for the highest ranked items. The RCM analysis for these items should be reviewed, and updated if necessary. Other corrective action should also be considered, if necessary, to alleviate the failures.

b. Trend Analysis. Trend analysis is normally performed as follows: Means and standard deviations are calculated for each parameter for a pre-determined baseline period. Upper and lower control limits of two standard deviations from the mean are calculated. Parameters (such as VF/FH, MMH/FH, etc.) are then monitored for items which exceed the control limits. The RCM analysis for these items should be reviewed, and updated if necessary, after trend analysis and problem characterization. Other corrective action should also be considered, if necessary, to alleviate the failures. Additional statistical processes may also have to be utilized. Appendix B is a trend analysis example.

c. PM Requirements Document Reviews. A review of documents which contain PM requirements should be accomplished periodically. Fleet input on ineffective maintenance tasks or new problem areas should be solicited.

The following type of documents should be reviewed:

(1) Maintenance Requirement Cards (MRCs)
(2) Depot Level Maintenance Specification(s)
(3) Any other Maintenance information Manuals (MIMs) which may contain PM procedures that accompany corrective maintenance tasks.

The subject documents should be reviewed for the following:

(1) Processes or materials which have become obsolete or outdated. This would include taking advantage of new technologies, such as incorporating a new Non -Destructive Inspection (NDI) technique which may detect smaller flaws allowing a longer inspection interval, or replacing older materials such as paints or sealants with less environmentally hazardous or less expensive ones. These reviews should be coordinated and supported with local Materials Laboratory personnel.

(2) The number of RCM history log entries documented against the document. This will provide an indication of the number of tasks that have been identified through RCM as requiring addition, deletion, or modification. The RCM history log is discussed in detail in paragraph 4.3.2.

(3) All documents should be reviewed by each RCM analyst for items under his/her cognizance. Any changes resulting from the document reviews should be documented in the RCM history log. The results of any RCM updates resulting from the document reviews should also be documented in the RCM history log.

d. Task Packaging Reviews. Task packaging reviews should be conducted at two year intervals, as a minimum, following establishment of a task package baseline. Task packaging reviews should evaluate phase intervals, special inspection calendar and event intervals. The cumulative effect of any packaging changes on the maintenance program and maintenance activities should be evaluated prior to implementation of those changes.

e. Fleet Leader Programs. The specific requirements for this program should be developed after the initial RCM analyses are completed. Fleet leader inspections for the aircraft should consist of "opportunity" inspections by ISST/IPT personnel. For example, ISST/IPT engineer(s) would participate on a not to interfere basis with the first phase inspection of the first one or two aircraft to reach multiples of 1000 flight hours (or other multiple). Prior to the inspection, inspection areas and documentation methods would be identified. In the event that a depot maintenance program is established, these inspections would be supplemented by regular visits to the depot line by ISST/IPT personnel.

Proactive analysis results should be periodically reviewed by each cognizant RCM analyst for his/her assigned systems. Reports should be prepared to summarize the results of the periodic condition monitoring analyses and provided to the APML, APMS&E, PMA, and other ISST/IPT members (as required). The results of any RCM reviews or updates resulting from condition monitoring should be documented in the RCM history log whether or not a change to PM requirements is necessary.

4.3.1.2 Reactive Analysis.

a. Failure Related Reviews. The process for responding to reported problems will vary depending on the type of failure, means of reporting, and whether a vendor or organic activity must perform the failure analysis. However, certain basic steps apply to all processes. The interface of these processes with the RCM/AE program are described in the following paragraphs and shown in FIGURE 4-1.

The following paragraphs are intended to be a general description and should not be considered comprehensive. There may be additional actions required, such as stress analysis, testing, etc. Coordination with other activities such as NAVAIR, fleet maintenance personnel, or contractors, etc. may also be required. Some actions may be directed by higher authority. All of these steps are not necessarily a direct part of the RCM/AE process or performed by RCM personnel; however, RCM personnel should be aware of all actions taken during the process and will be involved in recommendations for corrective action through interface with other personnel and activities. Although this process shows a specific logical order, in some cases the steps may be performed concurrently or in a different order.

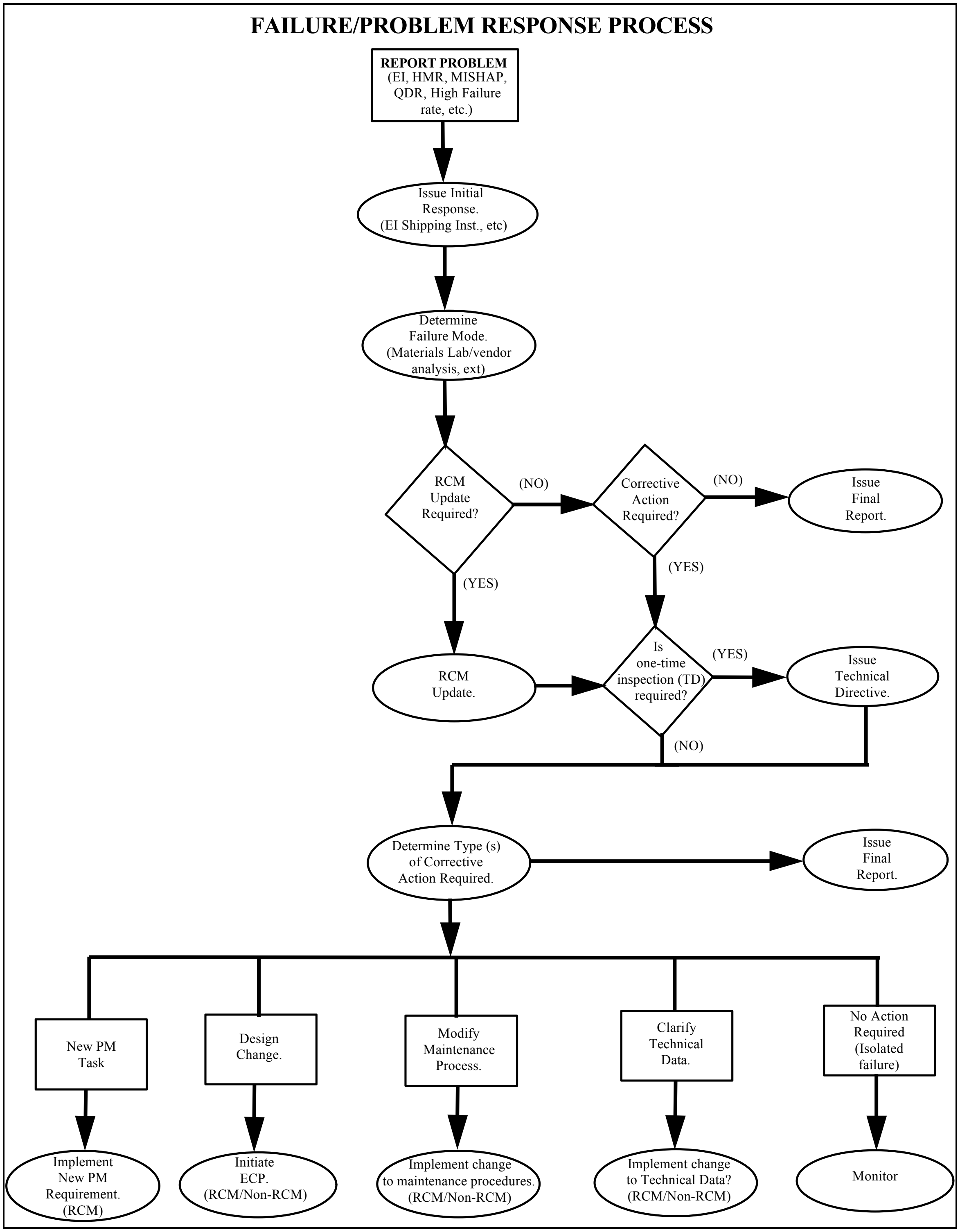


FIGURE 4-1. Failure/Problem Response Process

(1) Step 1: Problem reported. The process is started upon receipt of a report of the problem. The problem could be reported formally through an EI request, HMR, QDR, TPDR, mishap report, etc. or informally such as through a phone call from squadron maintenance personnel. Depending upon the type of report, an initial response, such as a preliminary EI report with shipping instructions for the EI exhibit, may be required. The RCM lead engineer should be provided an information copy of the problem report or a conversation record copy if the report was verbal. Primary responsibility for the investigation and resolution of the problem may be assigned to a RCM, systems, structures, or avionics engineer as appropriate. If the assigned engineer is not a RCM analyst, then a RCM analyst should work with the assigned engineer to address RCM and PM issues.

(2) Step 2: Failure mode determination. This step is the primary research and analysis part of the process. This step will include failure analysis by a vendor or materials lab, background data collection from squadron or maintenance personnel, etc. It will also include actions such as fatigue, stress, fracture mechanics, and statistical analyses to determine PM task intervals, or probability of future occurrences of this failure mode. Although a specific failure mode should be determined prior to any corrective action being imposed, certain responses will often be required prior to this step being complete. For instance, an inspection bulletin may be required immediately if a specific failure mode is suspected for safety of flight concerns. The assigned engineer should be responsible for ISST/IPT involvement in this step, although other individuals or organizations may also be involved, such as the materials lab, NAVAIR, contractors, vendors, etc. If the cognizant RCM analyst is not the assigned engineer, he/she should be provided with data as the investigation progresses.

(3) Step 3: RCM Review. At this step the beginning of the decisions on corrective action begin. If the assigned engineer is not the cognizant RCM analyst, the RCM analyst should provide recommendations on corrective action to the assigned engineer, with regard to changes in the PM program. Any decisions on scheduled maintenance requirements must be based on the results of a RCM analysis.

(a) If this is a completely new failure mode a RCM analysis will be performed.

(b) If there is a current RCM analysis, it should be reviewed to ensure that the failure does not change any of the data in the analysis. If so, a RCM update should be performed.

(c) If the RCM is current, a determination should be made as to whether the effects of the failure require corrective action. If not, a final report stating this fact may be issued, if required. If the effects do require corrective action, step 4. is performed.

(4) Step 4: One -time Inspection. If not accomplished previously, the need to issue an inspection bulletin (technical directive) is determined. If the possibility of additional failures exist prior to the implementation of other corrective actions, and failure effects are unacceptable, a bulletin must be issued. NAVAIR

00-25-300 provides direction for preparing and issuing technical directives. If the inspection bulletin will not permanently mitigate the effects of the subject failure mode, continue with step 5.

(5) Step 5: Corrective Action. The corrective actions necessary for final resolution of the problem are determined. This may be a single action or a combination of solutions. Corrective actions should be agreed upon by the assigned engineer, cognizant RCM analyst, and others as applicable, or may be directed by higher authority.

(a) A PM requirement may be added or modified that would preclude the failure or detect an impending failure before it occurs. Any change to PM requirements should be determined through RCM analysis. Changes to PM requirements directed by higher authority which disagree with RCM recommendations will be documented as such in the RCM history log.

(b) Design changes may be implemented to preclude additional failures. Design changes are implemented through the Rapid Action Minor Engineering Change (RAMEC)/ECP process. Recommendations to incorporate RAMECs/ECPs may or may not be a result of the RCM analysis.

(c) A change to maintenance procedures or processes may be used to preclude additional failures. Some examples are: changing a type of sealant used in an assembly process, changing torque requirements for fasteners, or adding quality assurance steps to a maintenance requirement. These types of actions are usually not directly based on RCM results, but may be used to make a current requirement more effective.

(d) Clarification of an ambiguous current requirement may be necessary, when failures are the result of improper interpretation of that requirement, or failure of the requirement to perform as intended. Clarifications can be accomplished by changes to the appropriate documentation (MRC, MIM, etc.) or through Maintenance Engineering Reports (MER). If the change affects a PM requirement, it should be documented in the RCM history log, even if the RCM is not affected.

The results of the RCM review and/or update, as well as any recommendations for corrective action should be documented in the RCM history log.

b. Updates for Design C hanges. RCM analysis should be reviewed or updated to assess supportability during any modification processes. When a formal change; Air Frames Change (AFC), Accessory Change (AYC), ECP, etc. is received for review or generated by the ISST/IPT, the RCM update, if applicable, should also be available for review. The cognizant RCM analyst should ensure that action is being taken to update the RCM analysis, if required, and that the RCM analysis is acceptable.

4.3.2 RCM History Log. In addition to the IRCMS database which stores only current requirements and the analysis decisions that led to them, a method of providing an audit trail for changes to RCM/PM requirements over time is also required. This audit trail not only identifies factors which led to changes in the PM program, but also identifies when reviews were performed that did not lead to any changes.

The RCM history log provides a means to review the decisions that led to a RCM update. It also helps identify the level of effort expended for RCM related efforts in the RCM/AE program, and provides a method of evaluating the effectiveness of the RCM/AE program.

The RCM history log can be an automated database or document. A RCM history log entry should be completed any time one of the reactive or proactive tasks described above causes a review of the RCM analysis, whether or not a RCM update is performed. Various parts of the log are completed at the time the process is initiated, at completion of the RCM review/update, and when updated requirements are incorporated. An example of information which should be contained in the RCM history log includes, but is not limited to, the following:

a. Previous/current PM task, document, card, task no., etc.

b. Previous RCM Analysis? (Y/N)

c. Man-hours required to perform RCM analysis

d. RCM analysis recommendations

e. Packaged interval (if applicable)

f. New/modified PM task, document, card, task no., etc.

g. Cost or savings of new requirement

4.3.3 Age Exploration (AE). AE is the process used to sustain and optimize a PM program. The RCM analysis furnishes conservative PM requirements when insufficient information exists to create preventive requirements based on real data. AE provides a systematic procedure for collecting the information necessary to reduce or eliminate this gap in knowledge. AE procedures supply information to determine the applicability of some PM tasks and to evaluate the effectiveness of others. For new equipment, AE provides information necessary to adjust the initial inspection interval or assess the applicability and effectiveness of a task. For mature equipment, AE provides information to evaluate existing tasks, thereby optimizing the PM program.

Specific AE tasks will be developed through the RCM analysis process to update default answers used in the analysis process. Specific AE inspections must be evaluated to determine whether each inspection is necessary and cost -effective.

4.3.3.1 Selection Of Candidates. The identification of those ite ms which may require AE is a direct output of a RCM analysis. When applying RCM, a "default strategy" is used if insufficient information exists to make a definitive answer to the logic tree questions. This strategy ensures a conservative, safe answer which can be evaluated through AE. New items added as a result of modifications, ECPs, or changes in operating environment or utilization may warrant AE to determine the effect on the PM program, but these changes must first be analyzed through RCM to determine if AE is required. While AE candidates may result from output of the RCM analysis they can also result from other sources such as PMA or NAVAIR mandates. Available AE resources and fleet impact should always be considered when selecting AE candidates.

4.3.3.2 Design Of AE Tasks. An AE requirement is developed for each AE candidate, and like RCM requirements, is directed at a single failure mode. To fully define the requirement, the following need to be known:

a. Sample size. AE is a sampling pro gram to collect data from a sample just large enough to produce the required confidence in the results, not from the entire inventory.

b. Study period. AE tasks are implemented for only as long as it takes to get sufficient data to resolve the requirement which drove them in the first place.

c. Initial interval. Some failure modes do not develop for some time. The initial interval is the age at which the AE task will be initiated. There must be data to show that the failure mode is not expected to appear before the initial interval.

d. Repeating interval. The repeating interval is the interval at which the AE task will be repeated once it has been initiated.

e. Precision required for measurements. Any measurements that will be made according to the AE task should only require the degree of precision necessary to determine the unknown data. Requiring greater precision than necessary can be more expensive, difficult, and provide more opportunity for mistakes.

f. Task description. A ge neral statement of what action is required needs to be described. Usually the task description will include inspection for the failure mode and recording of it's condition.

g. Analysis Type. Two main analysis types for AE are Degradation or Actuarial analysis. Selection of which type of analysis to use is dependent on the failure mode. These analyses are discussed in detail in paragraphs 5.2 and 5.3.4 respectfully.

4.3.3.3 Prioritizing AE Tasks. In many cases, there is insufficient funding available to implement all AE requirements on all candidates. Thus, we must prioritize the AE efforts to concentrate on those tasks which will benefit the organization the most, in terms of safety and economics. AE inspections can be classified according to the following criteria:

a. Priority 1. AE inspections for SSIs which have crack failure modes, AE inspections developed to validate maintenance requirements which are safety related, or have high cost savings benefits.

b. Priority 2. AE inspections which require no additional resources and are developed to validate maintenance requirements which do use significant maintenance resources (time, equipment, spares) or affect operational availability of the aircraft.

c. Priority 3. AE inspections which require additional resources and are developed to validate maintenance requirements which use significant maintenance resources (time, equipment, spares) or affect operational availability of the aircraft.

d. Priority 4. AE inspections which do not meet any of the above criteria.

Priority 1 and 2 AE inspections should be implemented unless there is justification for not doing so. Priority 3 inspections should be evaluated to determine whether the benefits of implementing the task would exceed the costs. Priority 4 AE inspections should not be implemented unless AE decision logic diagram. some justification is provided. Figure 4-2 provides the AE decision logic diagram.

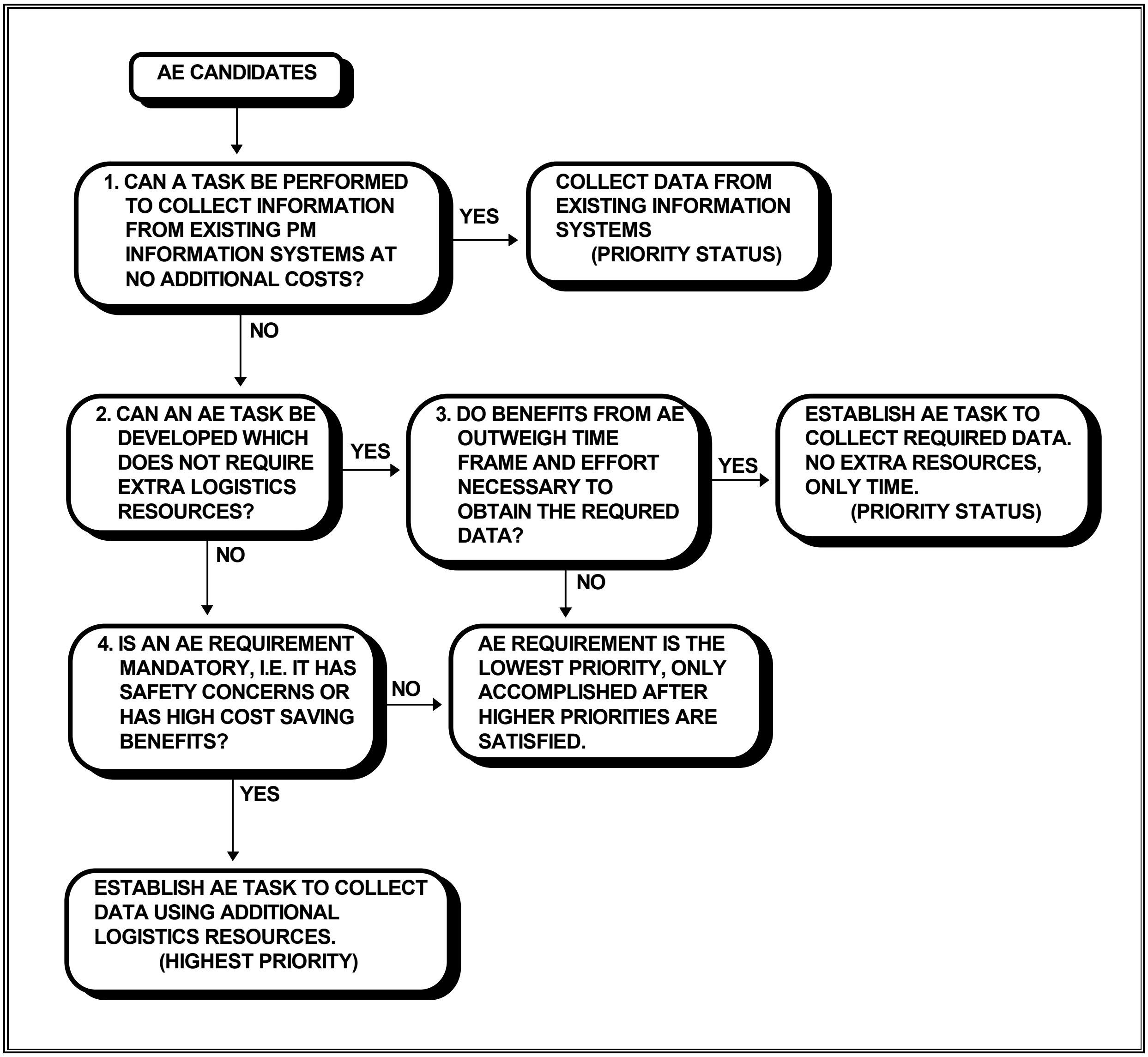


FIGURE 4-2. Age Exploration Decision Diagram

4.3.3.4 AE Inspection Implementation. The following are some acceptable methods of implementing AE inspections:

a. Data collection by the cognizant RCM analyst from available sources such as 3-M, or local depot/overhaul databases.

b. Depot level sampling tasks, carried out in conjunction with depot level maintenance. This method is usually the most effective for SSI AE inspections.

c. Age Exploration Bulletins (AEB). Specific direction for AEBs is given in NAVAIR 00 -25-300. This method is us ed for direct data collection from O-level or contractor maintenance locations, if required. Data should be provided via AE Data Sheet, or other means, to the ISST/IPT. Appendix C provides sample AE data sheets.

d. Equipment History Records (EHR). EHRs are useful for tracking serialized components. Direction on the use of EHRs is provided in OPNAVINST 4790.2F and NAVAIRINST 4790.3B.

e. Fleet leader inspections. Fleet leader inspections sample those items which have accumulated the most operational time and exposure. This method is usually is most effective for SSI tasks.

Sample sizes are normally determined through statistical analysis to determine the minimum required number of samples and inspections to adequately gather the required data. As the RCM is completed, and specific requirements are determined, additional guidance on sample sizes may be required.

For any RCM analysis performed or updated, the cognizant RCM analyst should be responsible for development of an applicable AE inspection (if required) in accordance with applicable instructions, and determining if that task should be implemented. If so, the cognizant RCM analyst should implement the inspection, incorporate the results into the RCM analysis upon completion of the inspection, and delete the requirement for the inspection when complete. Upon completion of the AE inspection when complete, a summary of the results will be documented in the RCM history log whether or not a change to PM requirements is made.

The status of all AE candidates (those items subject to specific AE inspections, and results of data) should be provided on a periodic basis to the APML and PMA in an AE Status Report.

4.3.3.5 Applying Results of AE Analysis. The last requirement of the AE process is applying the results of the analyses to the PM program. AE can not change the PM requirement without going through RCM. It is important for personnel working in the AE program to remember that the NAVAIRSYSCOM AE program is firmly tied to RCM. The information gained during an AE analysis for resolving defaulted RCM decisions must be fed back to update the RCM analysis in order to determine the best PM task and interval. The following paragraphs of this chapter will address specific areas where AE results are used to make changes within a PM program.

a. Adjusting Maintenance Intervals. As a result of an AE task, it may be found that the existing maintenance interval is not the most effective interval. The results of the AE task will provide the potential failure to functional failure interval or HT interval for the particular piece of equipment under analysis. By entering the new engineering interval into the RCM analysis a revised PM requirement will be developed.

b. Adjusting Maintenance Tasks. At the completion of an AE analysis, one of the results may be the adjustment of the existing scheduled maintenance task. The task adjustment may require such things as changing the inspection method, adding more requirements, deleting requirements, or changing the PM task altogether (i.e. going from an OC inspection to a HT removal). AE results are used to update the RCM to accomplish these changes.

c. Modifying Age Exploration Sampling/Programs. Another output of an AE task may be the recommendation of modifying the present AE task to obtain the required results. The task modification may be as simple as changing the number of samples which will undergo analysis or as complex as rewriting the inspection task and data recording process. An effective AE program will undergo constant modifications, such as adding new AE candidates, deleting completed or unsuccessful tasks, changing sample sizes, or adjusting task intervals. A good program will require a continuous system of tracking all tasks and recording the information collected.

d. Design Changes. A redesign requirement for an item is considered the least favorable result from an AE task. However, it is perfectly reasonable and valid when the results of AE does not justify a preventive requirement. Redesign must be considered as an alternative to a PM requirement in some cases, and may be required in other cases (i.e. safety or high costs).

4.3.4 RCM Cost Benefits. One of the basic principles of RCM is that PM is accomplished at the least expenditure of resources. Costs and benefits must be documented to allow us to answer the question "Is the program providing a return on investment?" In order to assess the cost avoidances/savings, a baseline must first be established with which RCM developed PM requirements can be compared. For existing equipment, this baseline will be the existing PM and AE program. For new acquisition programs, there will not be a PM program to collect data from. Therefore, the aircraft being replaced should be used to determine the baseline to compare to the current PM program. Next, the cost of performing the RCM analysis must be determined. After the analysis is performed, the new PM requirements along with their associated costs should be recorded. Changes in requirements for all levels of maintenance should be documented. With all of this information documented, the change in cost (or avoidances) due to these changes (intervals which have been extended/shortened and tasks which have been eliminated/added) can be determined and supported.

4.3.4.1 Calculating RCM Cost Avoidances/Savings. To determine benefits of RCM, we must perform a comparison of the cost of RCM with our baseline PM costs.

$$\mathbf{C_{BL} = C_{OPR}}$$

C_{BL} = Baseline PM costs

C_{OPR} = Operating Costs - Cost of performing PM and AE tasks (see 4.3.4.3)

$$C_{RCM} = C_{INV} + C_{OPR}$$

C_{RCM} = RCM costs as determined from application of RCM and the revised tasks

C_{INV} = Investment costs to develop and maintain PM program (see 4.3.4.2)

C_{OPR} = Operating Costs - Cost of performing PM and AE tasks (see 4.3.4.3)

Cost avoidances/savings of RCM are determined by comparison of C_{BL} with C_{RCM}. This can be applied at the significant item level, system level, or at the end item, to determine the overall benefits of the RCM program. Appendix D provides a detailed example of a RCM cost avoidance calculation.

A significant RCM cost avoidances/savings can be realized in the elimination or extension of HT task intervals. This allows for equipment to achieve its inherent reliability, continue in operation longer, and decrease Aviation Depot Level Repair (AVDLR) costs.

These cost calculations can be automated utilizing spreadsheets, or other software programs. This allows for timely accounting of all associated RCM cost avoidances/savings.

4.3.4.2 Investment Costs. Investment costs are those which must be made to develop and maintain the PM and AE processes. The investment costs include analysis and documentation, but do not include actually accomplishing the PM requirements. To determine investment costs of the RCM developed program, record those costs associated with the analysis (man-hours, and cost per man-hour). Training and other data costs (if incurred) can be pro-rated and also included as an investment cost.

4.3.4.3 Operating Costs. Operating costs are those which are required to actually accomplish PM and AE requirements at whatever maintenance level is necessary. Operating costs need to be determined for both the baseline and the RCM developed program. To determine PM and AE operating costs, record those costs associated with each PM or AE requirement (material costs to do inspections, direct maintenance man-hours (DMMH), cost/DMMH, cost to repair functional failures). When calculating the cost of the new PM program, determined through a RCM analysis, it is important to use the same factors used to determine the cost of the baseline (see paragraph 4.3.4.1). Using different factors will not allow a valid comparison between the pre-RCM PM program and the post-RCM PM program.

4.3.5 Other Benefits of RCM. In addition to cost savings, other important benefits result from the application of RCM. Improvements in safety and operational availability can be partially attributed to the PM program improvements caused by RCM. These and any other benefits associated with the application of RCM should be documented as they occur.

5.0 RCM/AE DATA SOURCES, ANALYSIS & TOOLS

There are several data analysis techniques which are useful for RCM purposes; from the typical statistical processes found in an academic text like regression analysis, to special techniques developed for use in specific circumstances like the Weibull analysis. Personnel responsible for the development, management, and implementation of PM tasks must have an understanding of the various techniques and know when each is appropriate.

The analysis processes and data sources that an analyst should be most familiar with, and are most commonly used, are discussed within this section.

5.1 Data sources. Following are several sources for obtaining data required for RCM analysis or AE. This list is not all-inclusive.

5.1.1 Aviation 3-M Data. Navy 3-M data will probably be the most widely used data source for RCM analysis and contains various maintenance and flight data. Following are several methods of accessing 3-M data.

a. NALDA

b. ECA reports

c. LMDSS

d Naval Aviation Maintenance Support Office (NAMSO) Maintenance/Flight Hour Reports

e. SRC database

f. Engine Component Improvement Feedback Reports (ECIFR)

5.1.2 ISST/IPT In-Service Engineering Data. The following data should be collected, archived, and made available for analysis. Some programs have automated databases which contain various “logs” which track the data and allow for timely automated retrieval of historical data.

a. Technical Directives (TDs)

b. EIs

c. Hazard Reports (HRs)

d. HMRs

e. Depot Maintenance Data Sheets

f. Structurally Significant Item Reports (SSIRs)

g. Aircraft Service Period Adjustment (ASPA) Reports

h. MERs

i. RCM History Logs

j. TPDRs

k. Aircraft Bureau Number (BUNO) Data

l. Miscellaneous History Data

5.1.3 Contractor Analyses/Reports. Through contract requirements, contractor data should be delivered to the government. This data contains various analysis reports which are essential inputs for RCM analysis such as:

a. Fracture Mechanics Analysis Reports

b. Stress Analysis Reports

c. Loads Analysis

d. AE Analysis Reports

5.1.4 Default Data. In the absence of cost/logistical data the NAVAIR Level of Repair Analysis (LORA) Default Data Guide should be reviewed and utilized as applicable.

5.2 Degradation Analysis. Degradation analysis uses evidence of physical or functional degradation as a basis for the design of a PM task. A specific degradation analysis focuses on the single EFM which drove the PM requirement, not upon the general equipment deterioration. The analysis uses measurements to determine the onset and rate of progression of a condition that is expected to be highly correlated to the specific EFM. There are many kinds of degradation. Some of the most common are:

a. Wear (material loss due to abrasion or erosion)

b. Corrosion (material loss due to chemical reactions)

c. Hardening/Softening (particularly characteristic of non-metals)

d. Cracking (often associated with fatigue)

Degradation analysis is most appropriately performed in association with OC PM tasks. Its primary purpose is to either verify the effectiveness of an existing OC task interval, or adjust the interval to the optimal frequency. This is done by developing degradation curves (wear versus time, area of corrosion versus time, etc.), defining a potential failure condition, then determining the interval between potential and functional failure. From the interval between potential and functional failure, task intervals can be developed which will avoid functional failures.

5.3 Survival Analysis. Survival analysis is a generic term that describes the analysis of censored data. Different computer programs have different techniques for handling and analyzing these data. Several examples of survival analysis are provided below.

5.3.1 Life Regression. Statistical Analysis Software (SAS) uses Life Regression (PROC LIFEREG) for data with right-, left-, and interval-censored data; and PROC LIFETEST for data that are right-censored. LIFETEST computes nonparametric estimates of the survival distribution and computes rank test for association of the response variable with other variables. The survival estimates are computed within defined strata levels, and the rank tests are pooled over the strata and are therefore adjusted for strata differences. The Weibull distribution is one of several distributions that can be allowed in the LIFEREG procedure. Other distributions include exponential, gamma, and lognormal. (Reference, SAS manual chapters 15, 25, 26 - LIFEREG, LIFETEST)

5.3.2 Weibull Analysis. A Weibull Analysis is a statistical technique useful for various aspects of failure analysis which provides accurate failure predictions for an entire population based on limited failure data. The Weibull Analysis Handbook (AFWAL-TR-83-2079) provides instructions in the use of Weibull Analysis. The Weibull-Based Parts Failure Analysis Computer Program User's Manual (NADC-89089-60), provides the background and describes the usage of computer codes used to analyze failure characteristics using the Weibull distribution. Weibullsmith™ software is a useful tool for performing Weibull analysis. Weibull Analysis can provide information such as the following:

a. The conditional probability of failure of a part at a given age

b. The expected number of failures over any future time period (Values of the Weibull slope can be compared with historical trends of other equipment in order to fit the type of failure characteristics)

c. The type of failure mode, i.e. infant mortality, wear-out, batch problems, combinations of failure modes, etc.

d. The percentage of items expected to fail by a given age

e. The impact of design changes on failure risk

f. The number of samples required for specific AE inspections

The advantages of the Weibull analysis methodology are that it provides the following:

a. A graphical solution by analysis of plotted curves

b. The type of analysis relating to slope of possible failure modes can be expanded by inspecting libraries of past Weibull curves

c. It is useful even with inadequate data such as small samples, mixtures of failure modes, chart origin being other than zero, use of alternate scales other than time; nonserialized parts or components where the time accumulated on the part cannot be clearly identified, and the construction of a Weibull curve when there is not failures at all, only success data

d. Little difficulty making graphic comparisons to determine best distributions fit to the data because there are only a few alternatives in the Weibull distribution

e. Weibull analysis can be performed by new engineers after training provided by the manual

f. The manual contains all of the above curves and background for operating the methodology, including two computer programs for estimating Weibull distribution for both complete and censored samples

5.3.3 Monte Carlo Analysis. Monte Carlo techniques give you a way of simulating variations in complex non-linear models without running every possible condition. The entire system (weapon system) having various failure modes can be analyzed using this technique. A Monte Carlo simulation can forecast future risk and is necessary when validating a risk analysis. You must know what the underlying equations are before applying some type of random distribution of variables in your equation.

5.3.4 Actuarial Analysis. Actuarial analysis is the process of using life data from an appropriate sample to determine the effect of aging on the conditional probability of failure. The primary use of actuarial analyses is to determine wear-out times for either a rework tasks or life-limits. EHR cards are an excellent method for acquiring the life data required for performing an actuarial analysis. Note that actuarial analysis requires life data, meaning the ages at which all failures occur, not simply a count of failures during some particular time period. The usual objective of an actuarial analysis is to determine the applicability and effectiveness of a scheduled rework or discard task. These analyses can also be used to establish effective intervals for such tasks, or to identify, by separate examination, the impact of the dominant EFMs on the overall age reliability relationship. For application of actuarial analysis to hardware, there are two products of interest; the conditional probability of failure curve and the survival curve.

The conditional probability curve (examples in FIGURE 5-1), sometimes called the hazard curve, shows the influence of age on the probability of failure in a continuous series of time intervals. This probability is called a conditional probability, because it presumes that the item survives to enter each successive interval. The shape of the conditional probability curve determines whether a HT task can be applicable. A scheduled rework task is applicable only if there is some age at which an item shows a rapid increase in the conditional probability of failure. This age is not related to the MTBF.

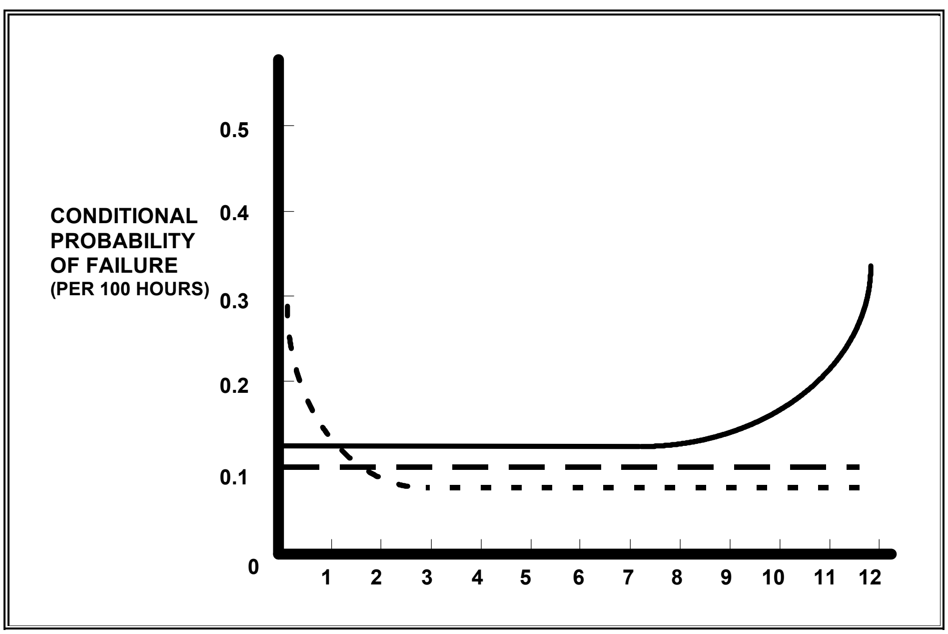


FIGURE 5-1. Conditional Probability of Failure Curves

The survival curve shows the probability of an item surviving to a particular age (examples in FIGURE 5-2). The Survival Curve is used to determine the percentage of items that will survive to the wearout age. The percentage of units that survive determine, in part, the applicability of the HT task. See Appendix E for an example of an actuarial analysis.

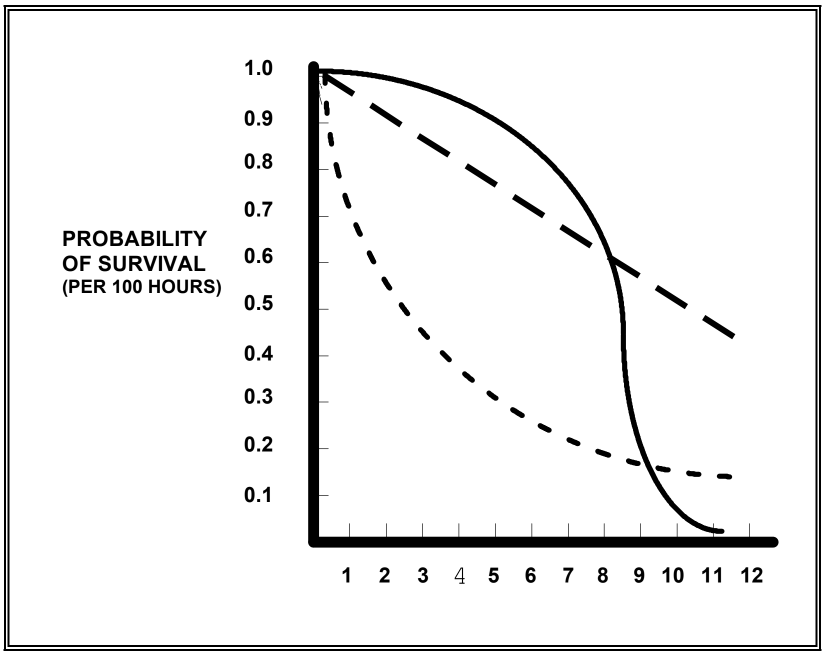


FIGURE 5-2. Survival Curves

5.4 Fracture Mechanics. Fracture mechanics is an analytical method for determining crack growth rates. Fracture mechanics analysis predicts the number of cycles of some applied load required to "grow" a crack from detectable size to critical size at which complete fracture of the part occurs. Its primary input into the RCM analysis is the detectable and critical crack life (interval from potential to functional failure) for SSI items subject to cracks.

APPENDIX A

GROUND RULES & ASSUMPTIONS

AND

LESSONS LEARNED

The following are specific examples of types of ground rules & assumptions, and lessons learned that have been previously utilized and developed by various programs. They have been developed to address various RCM program factors such as minimizing cost of performing the RCM, ensuring a consistent analysis approach, assisting in future reviews of the analysis, etc. They are provided for general consideration and may be used verbatim or modified as required for each program. The examples are by no means a complete list of issues to be addressed.

1. Ground Rules & Assumptions

A. FMECA/RCM

(1) Combining Failure Modes. Similar failure modes for different components may be combined in instances where more than one component failure results in the same Local Effects, Next Higher Effects, End Effects, detection method, and failure consequences. The affected components shall be listed in the memo field with the EFM listing a reference to the memo field. Likewise, different failure modes for one component may be combined if Local Effects, Next Higher Effects, End Effects, detection method, failure consequences, and any resulting PM tasks are the same.

(2) Theoretical Failure Modes. For certain components, EFMs that are determined not credible (i.e. due to system design, materials or other factors, no failure of a device can be established) the EFM shall be noted as “Theoretical EFM”. However, normally non-credible failure modes are not listed on the FMECA. The only reason to list them is to show that an obvious failure mode was considered and found to be not credible. It may not be necessary to list all failure modes.

(3) Hidden Failures. Effects for hidden failures should assume that the failure which causes the hidden failure to become evident has occurred. For example, the normal function of “landing gear extension” has failed which then in turn makes the failure of the “emergency landing gear extension” function evident.

(4) Secondary damage. When performing the FMECA, the effects of secondary damage should be considered. For example, a bleed air duct ruptures and the resulting hot air damages surrounding structure, hydraulic lines, fuel lines, etc.

(5) Normal Duties. The programs definition of “normal duties” must be clear. For example, determine whether the Naval Air Training and Operating Procedures Standardization (NATOPS) procedures are considered aircrew normal duties for failure detection and evidence questions. (Note: The T-45 program elects to consider NATOPS procedures not a part of aircrew normal duties.)

(6) Prioritization of the Failure Modes. The AV-8B program uses the following table, TABLE 1, to assist in the prioritization of their RCM effort. RCM typically is not performed on failure modes that fall under the acceptable risk category.

RCM HAZARD RISK ASSESSMENT

FREQUENCY / CRITICALITY	***FREQUENT (A)*** $> 1 \times 10^{-3}$ > 1 per 1,000 hours	***PROBABLE (B)*** $> 1 \times 10^{-4}$ > 1 per 10,000 hours	***OCCASIONAL (C)*** $> 1 \times 10^{-5}$ > 1 per 100,000 hours	***REMOTE (D)*** $> 1 \times 10^{-6}$ > 1 per 1,000,000 hours	***IMPROBABLE (E)*** $< 1 \times 10^{-6}$ < 1 per 1,000,000 hours
CATASTROPHIC (I) DEATH; LOSS OF A/C OR SYSTEM; SYSTEM OR PROPERTY DAMAGE > $1,000,000	1 HIGH	2 HIGH	4 HIGH	8 MED	12 ACCEPT
CRITICAL (II) SEVERE INJURY / PARTIAL DISABILITY; IMMEDIATE PILOT ACTION REQUIRED TO PREVENT CAT I RESULTING IN SAFETY MISSION ABORT; SYSTEM OR PROPERTY DAMAGE > $200,000	3 HIGH	5 HIGH	6 MED	10 LOW	15 ACCEPT
MARGINAL (III) MINOR INJURY/ 5 OR MORE LOST WORK DAYS; MISSION LOSS OR DEGRADATION; SYSTEM OR PROPERTY DAMAGE > $10,000	7 MED	9 MED	11 LOW	14 ACCEPT	17 ACCEPT
NEGLIGIBLE (IV) LESS THAN MINOR INJURY; CONTINUE MISSION WITH MINIMAL RISK; SYSTEM OR PROPERTY DAMAGE < $10,000	13 ACCEPT	16 ACCEPT	18 ACCEPT	19 ACCEPT	20 ACCEPT

RISK LEVELS:

HIGH	MANDATORY CORRECTION FOR HAZARD ELIMIINATION OR CONTROL. REQUIRES PROGRAM MANAGEMENT APPROVAL FOR RISK ACCEPTANCE.
LOW	INFORM HARRIER PROGRAM MANAGEMENT AND SSWG OF RISK.
MED	REQUIRES MANAGEMENT REVIEW FOR RISK ACCEPTANCE. HARRIER PROGRAM MANAGEMENT AND SSWG CONCURRENCE.
ACCEPT	ACCEPTABLE RISK. REVIEW AS DESIGN MATURES.

TABLE 1. RCM Hazard Risk Assessment

B. SI Selection

(1) Definition of "High Failure Rate or Consumption of Resources". The following are examples of specific criteria related to failure mode SC and MTBFs used when answering the question "Is failure rate or consumption of resources high?" of the FSI/SSI selection logic diagram:

T-45		AV-8B	
SC III	MTBF < 100,000 FHs	SC III	MTBF < 6,000 FHs
SC IV	MTBF < 10,000 FHs	SC IV	MTBF < 3,000 FHs

C. Flight Assumptions

(1) Definition of flight phases: T-45 uses from take-off roll to engine shutdown as the flight phase. E-6 uses from wheels off the ground to wheels on the ground as the flight phase. AV-8B uses from engine start to engine shutdown as the flight phase.

(2) Definition of mission phases: The following are examples of mission phases that various programs use when performing a FMECA:

(a) Taxi

(b) Take-Off

(c) Landing

(d) Climb

(e) Cruise

(f) Flight

(g) Descent

(h) Maintenance

(I) Emergency

(j) Mission

(k) In-flight refueling

D. Systems Interface - Analysis of wiring, tubing, etc.: One method, as is being done on the E-2 program, of analyzing wiring, tubing, etc. is to divide the aircraft into zones and identify functions, functional failures, and engineering failure modes for each zone. Another consideration is whether wiring, tubing, etc. should be analyzed as separate systems or components of another system. The Naval Aerospace Vehicle Wiring Action Group (NAVWAG) RCM implementation guide provides further guidance.

E. Default Values

(1) Acceptable probability of failure. The following is an example of values the T-45 and E-6 program are using.

Severity Classification	Pacc
I	.000001
II	.0001
III	.01
IV	.1

(2) Cost benefit analysis factors. The following are several cost benefit analysis factors that should have default values assigned. Some may vary from program to program.

Labor rate:	O or I organic - $25/hr D organic - $50-$100/hr
Aircraft cost:	Varies with program
Fleet size:	Varies with program
Service life:	Varies with program

Utilization rates: Varies with each program, however the following are example values (Flight-hour per month (FH/month)):

T-45 - 60FH/month
AV-8B - 30FH/month
E-6 - 100FH/month

(3) Potential to functional failure intervals:

T-45 - One aircraft lifetime (14,400FH) for crack EFMs due to contractual requirements.

AV-8B - One aircraft lifetime (6000FH) for crack EFMs due to contractual requirements where no crack growth analysis nor actual failure data exists.

(4) Structural inspection intervals: The following tables, TABLES 2, 3, and 4 are examples of rating factors which may be used to help establish structural inspection intervals for fatigue, environmental, and accidental damage failure modes.

CPL SRF	Inspection Interval

1	1/4 CPL
2	1/3 CPL
3	1/3 CPL
4	1/2 CPL

TABLE 2. Fatigue Damage.

ED Average SRF	On-Condition Task Interval
1.0 - 2.0	7 Day
2.1 - 3.7	14 Day
3.8 - 4.0	56 Day

TABLE 3. Environmental Damage

AD Average SRF	On-Condition Task Interval
1.0 - 1.5	Daily/Turnaround
1.6 - 3.0	Phase/Zonal
3.1 - 4.0	Opportunity

TABLE 4. Accidental Damage

(5) Default On-Condition task intervals. The T-45 program uses, where a current effective PM task and no other data existed, the following method:

(a) Calculate the number of inspections, **n**, according to the methods presented in chapter 3 (paragraph 3.4.3).

(b) Multiply the existing task interval by **n** to determine the interval from potential to functional failure.

(c) The existing task interval is then documented in the analysis.

The following variation of this method, to refine the existing task interval, could be used if the probability of detecting a failure in one inspection, Θ, for the new task is expected to be different from the Θ for the existing task.

(a) Calculate n according to the methods presented in chapter 3 (paragraph 3.4.3) using Θ for the existing task.

(b) Multiply the existing task interval by n to determine the interval from potential to functional failure.

(c) Recalculate n using the expected Θ for the proposed task.

(d) Calculate a new task interval by dividing the interval from step 2 by the value of **n** from step 3.

(5) Default Beta (β) values for Weibull failure distribution analyses for the F-402 - Low cycle fatigue: β = 7.4

(6) Crack growth analysis variables:

AV-8B & T-45 - Initial flaw = 0.01 inch

AV-8B - Initial flaw for welds = 0.05 inch

<u>AV-8B</u> - Initial flaw for bolts = 0.005 inch

F. GFE/Common Equipment

(1) <u>GFE/Common PM Requirements</u>. The T-45 program used existing PM program requirements for GFE/Common equipment. The RCM analysis was performed only to the system interface for GFE/Common equipment. The E-6 program makes a value judgment as to whether the government or contractor would perform RCM analysis on GFE/Common equipment where no analysis exists.

(2) For components that are common among aircraft, an RCM analysis is sent to the directing authority for evaluation of wider application.

G. Directed PM

The T-45 program evaluates directed PM requirements on a case-by-case basis as to whether the PM tasks would be documented in the RCM analysis as is or re-analyzed. Differences resulting from the re-analysis are sent back to the directing authority for resolution.

H. RCM Process Tailoring

(1) Prior RCM logic required the analyst to stop after a task is determined to be applicable and effective. The T-45 program required a cursory review to determine if other applicable and effective tasks were more cost effective. The current RCM logic allows the analyst to continue the analysis and review additional tasks for applicability and effectiveness.

(2) The T-45 program did not require completion of AE task analysis if the RCM developed PM task was a Daily or Turnaround defaulted task.

(3) The AV-8B program identified strength and fatigue crack life and margin of safety cutoff values, based on testing and/or analyses, to limit the number of SSI Fleet Leader Sampling candidates.

I. Data Sources

(1) The T-45 program used two years of 3-M data for like equipment on AV-8B, A-4 and F-18 aircraft to calculate MTBFs.

(2) The E-6 program used ten years of 3-M data for the same equipment used on the EC-130Q for actuarial analysis.

(3) The P-3 program used 3-M data and I-level shop supplied data for RCM analysis of the oxygen panel mounted regulators.

(4) The AV-8B program used subcontractor/vendor environmental, strength and operational test-to-failure data for actuarial and degradation analyses on numerous components.

2. Lessons Learned

A. Leaking is defined as an effect and not a failure mode. A leak is the result of a crack or worn seal or some other mechanical failure. The mechanical failure is the failure mode.

B. Be specific when describing failure modes by identifying the specific hardware, part on/in the hardware as well as the mode description (e.g. fractured forward clevis).

C. Be specific on failure detection methods, identifying specific functions and location versus generic methods – e.g. cockpit fuel pressure warning lights vs. cockpit indications. Refer to the NATOPS manual for specific caution, warning, and advisory descriptions as well as other examples.

D. If a failure is noticeable in the normal course of flight or ground operations, then it is considered detectable for that associated phase of observation. The corresponding "Method of detection" will then be described in the FMECA. The method of detection can therefore in some cases involve observation of the "effects" of such a failure.

E. Experience has shown that failure modes are combined inappropriately when the consequences or effects of failure have not been properly considered.

F. Experience has shown that analysts, on occasion, combine functions inappropriately. For example, a landing gear actuator provides the functions of extending and retracting the landing gear. Failure of the actuator to extend has different consequences than failure to retract. Therefore, the two functions (extend and retract) of the landing gear actuator should not be combined.

G. Avoid use of "turnaround", "daily", "phase", etc. in describing an inspection. Just describe the task and let the packaging determine the interval.

H. Minimize use of words "potential" and "eventual" when describing failure effects. These should only be used when the effect of the failure is not certain or immediate.

I. Task descriptions involving inspection for wear, free play, or other quantifiable limits shall state the limits or state where the quantifiable limits are documented.

APPENDIX B

TREND ANALYSIS EXAMPLE

The following is an example of an A-7 trend analysis that was developed by NADEP Jacksonville as part of their proactive RCM/AE program. The parameters which were analyzed are not the only ones to be considered. Other programs may choose to analyze other parameters, however, the basic trend analysis data plotting processes can be applied to any parameter.

THIS PACKAGE CONSISTS OF THE FOLLOWING WUCs:

29A7320 - Exhaust pipe
29Q2R - Old WUC for exhaust pipe

1. <u>OUT OF LIMIT CONDITION</u>: (as of quarter (qtr) ending 12/83)

<u>PARAMETER HISTORY</u>	<u>REMARKS</u>
FH/VF	Below lower control limit (LCL) 5 consecutive quarters Downward trend since last quarter of 1982

2. <u>INVESTIGATION RESULTS</u>:

a. The following are the scheduled maintenance requirements for the exhaust pipe.

(1) Turnaround: Inspect for cracks and distortion (installed).
(2) Forty-day: Inspect for corrosion (installed).
(3) QECA (quick engine change assembly): Fluorescent penetrant inspect exhaust duct weld beads.(500 hr interval) X-Ray inspect repair welds in forward half of exhaust pipe. Visually inspect for damage (cracks, dents, warps, nicks, etc.).
(4) Conditional: Fluorescent penetrant/visually inspect each exhaust pipe prior to installation. Refer to NA 01-45AAA-3-1.1, Section XII.

b. The increase in VF's was due to increases in Malfunction (MAL) codes 170 (corrosion) and 190 (cracked). Increases in When Discovered codes for inspection (K, L, M) indicate a probable increase in inspections and depth of inspection. Emphasis was placed on proper inspections following investigations of in-flight failures.

c. A review of past EI reports indicated a failure mode resulting in sections of the exhaust pipe being lost in flight. The recommended corrective action to preclude exhaust pipe failure was to comply with existing maintenance requirements.

d. The primary failure mode of the exhaust pipe is cracking. The majority of failures reported at "O" level are MAL code 190. Related "I" level repairs are reported as C or B Action Taken codes, probably indicating weld repairs of the cracks. As the exhaust pipes age and repairs accumulate, an increasing cracking failure rate can be expected.

e. No life limit is currently imposed on the exhaust pipe although COMNAVAIRPAC recommended one in July 1982. (COMNAVAIRPAC 281809Z July 82).

f. It was noted that, due to limited access, only partial visual inspection of the exhaust pipe is possible during the turnaround and 40-day corrosion inspections. The only complete exhaust pipe inspections are during the 500-hour engine hot section inspection and prior to installation (conditional inspection).

g. Cannibalization actions were high during 1982 but were reduced in 1983 due to improved logistic support.

3. <u>RECOMMENDATIONS</u>:

a. Continue to monitor data.

b. Review RCM analysis to determine adequate maintenance requirements including investigating the possibility of establishing a service life limit for exhaust pipes.

4. <u>ACTION REQUIRED</u>:

a. Monitor data for problem areas. (Code 353).

b. Review and update RCM analysis. (Code 353).

5. <u>STATUS</u>:

a. (As of qtr ending 12/84) Status remains open with the following update:

(1) Continued monitoring of data for exhaust pipes revealed a continued high failure rate due to cracked pipes.

Corrosion reporting (Z-170) also remains high. Corrosion as a functional failure mode is very remote due to corrosion resistant metals used to manufacture pipes. The increasing incidence of exhaust pipe cracks appears to be related to the increasing age of the pipes.

(2) The RCM analysis was reviewed and current inspections are deemed appropriate for detection of potential failures. Most verified failures documented are considered potential failures.

(3) Exhaust pipes exceeding maximum repair limits are being condemned and surveyed. Replacement pipes are being provided through coordination with the Aviation Supply Office (ASO). As new pipes are introduced into the system, potential failures should decrease.

(4) Recommend continued monitoring of the data for expected improvement. Ensure appropriate criteria are utilized for rejection of nonserviceable exhaust pipes.

b. (As of qtr ending 12/85) Status remains open with the following update:

(1) FIGURES 1, 2 and 3 show below LCL for all 4 qtrs of 1985. The first qtr of 1985 appears to be a bottoming point.

(2) Expected improvement is apparently being realized. As the old tail pipes are being replaced continued improvement is expected.

(3) Continue to monitor, if system returns to within baselines, closure may be appropriate.

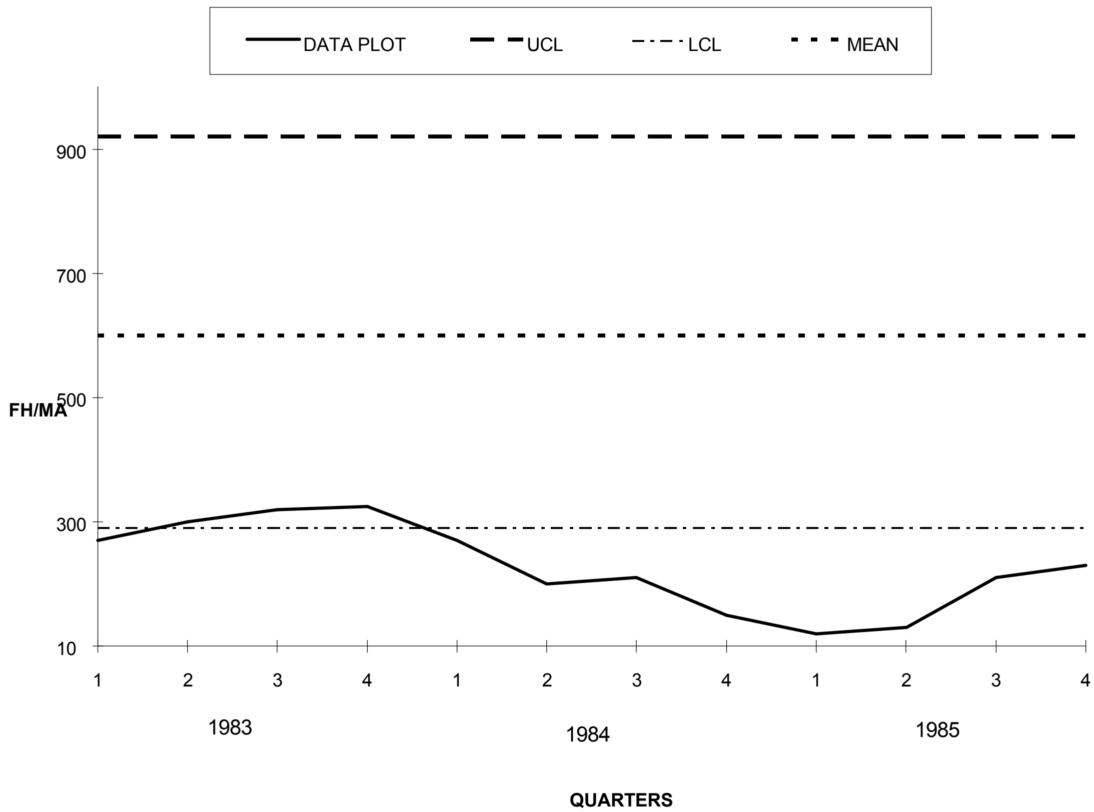


FIGURE 1. Performance Trend - 29Q2R FH/MA TEC AAFF

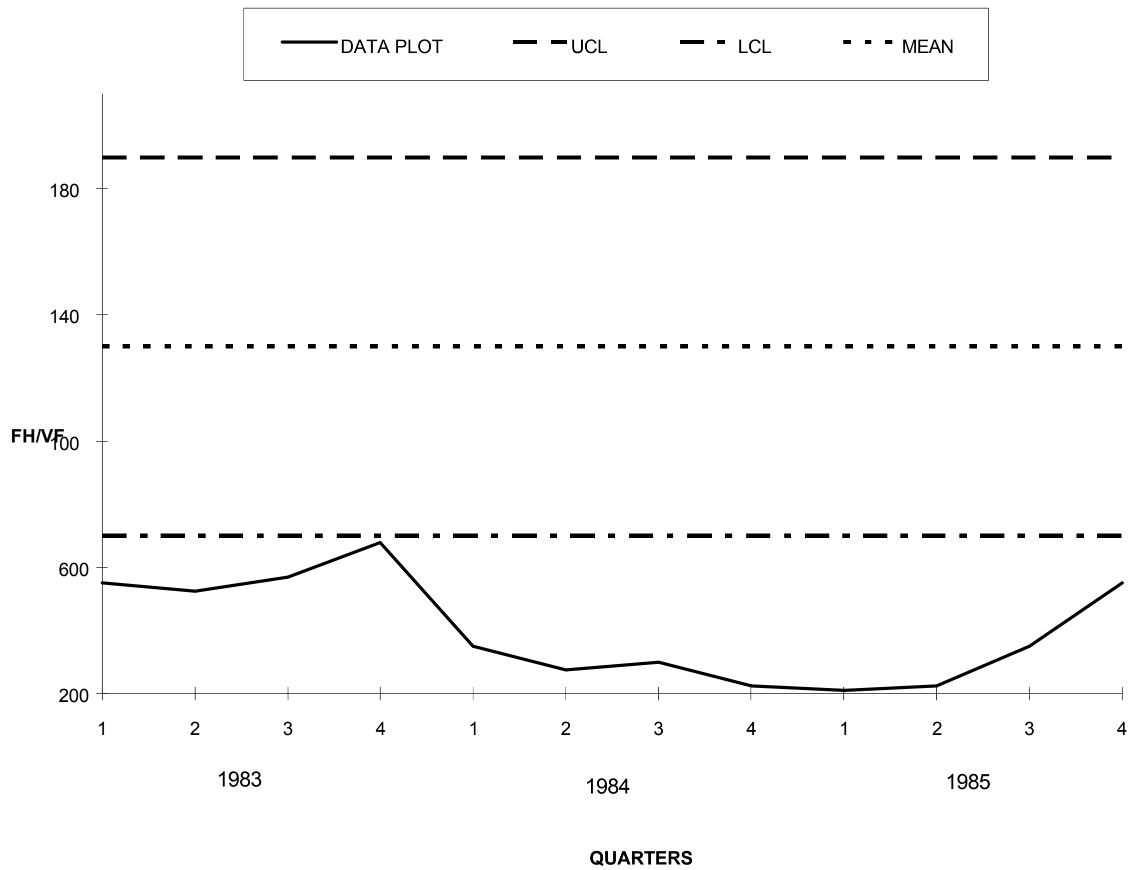


FIGURE 2. Performance Trend - 29Q2R FH/VF TEC AAFF

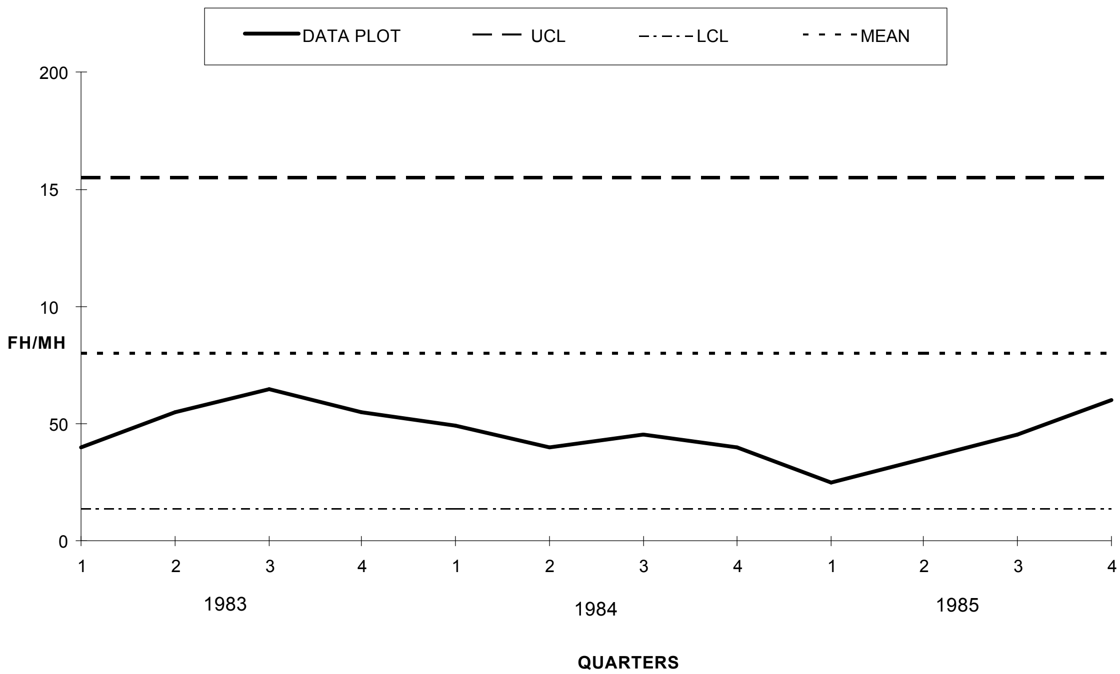


FIGURE 3. Performance Trend - 29Q2R FH/MH TEC AAFF

APPENDIX C

AGE EXPLORATION (AE) DATA SHEET EXAMPLES

As part of the AE program, the requirement exists for the recording of detailed information from the AE sampling inspections. The recommended method of feedback reporting consists of using AE data sheets. These data sheets ask for the recording of detailed information which will be used for the RCM analysis. The data should contain, or accompanying documents, guidelines instructing the maintenance personnel or artisan in a step-by-step manner through the entire data collection procedure for each AE inspection task, ensuring a continuous and uniform flow of information on all items. The data sheet should contain a pictorial view of the area to be inspected for the AE task. A great deal of care should be taken when designing the AE data sheet. Any necessary information left unrecorded could render the entire analysis useless. The AE data sheet should be tailored to each individual AE task, so that only the necessary information is recorded for that particular task.

The following are examples of AE data sheets that have been developed and implemented by various programs. These data sheets have been implemented for O, I, and D level maintenance inspections and component overhaul/repair.

LOC	DWG TOLERANCE	ALLOWABLE WEAR	MEASURED DIMENSION	
			L/H SIDE	R/H SIDE
A1	.1285 - .1305	0.14		
A2	.1285 - .1305	0.14		
B1	.128 - .135	0.145		
B2	.128 - .135	0.145		
B3	.128 - .135	0.145		
B4	.128 - .135	0.145		
C1	.128 - .135	0.15		
C2	.128 - .135	0.15		
C3	.128 - .135	0.15		
C4	.128 - .135	0.15		
D	.128 - .138	0.145		
E1	.1285 - .1305	0.14		
E2	.1285 - .1305	0.14		
F1	.128 - .135	0.145		
F2	.128 - .135	0.145		
F3	.128 - .135	0.145		
G1	.128 - .135	0.15		
G2	.128 - .135	0.15		
H	.128 - .138	0.145		

BUNO:______________________________

DATE:______________________________

FLT. HOURS:_______________________

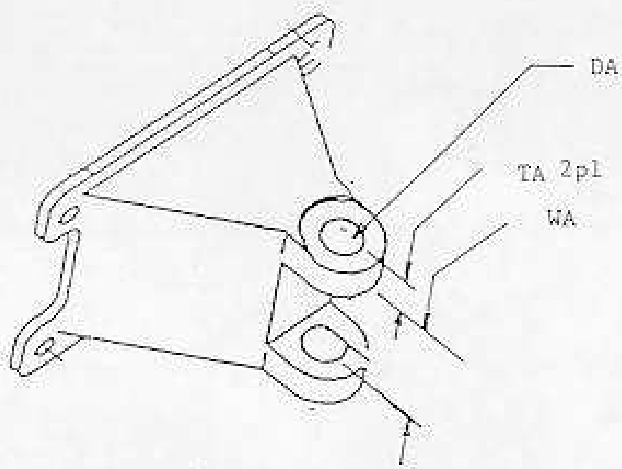
E-6 LE Spring Door
Measured Dimension Data Recording Sheet

Acronym Definitions for pages C-2 and C-3:

DWG - drawing   R/H - right hand L/H - left hand
LOC - location   FLT - flight   DIM - dimension

ATTACHMENT C
DETAIL I

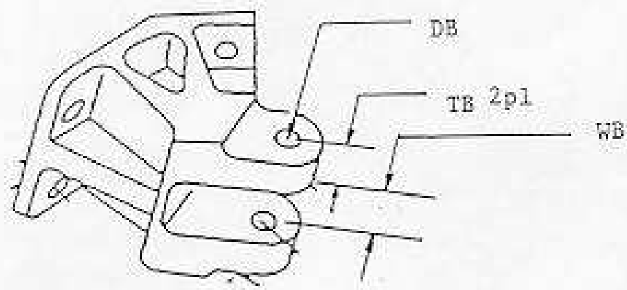
item A



P/N: 65-8703-2

DIM	DWG TOLERANCE	ACTUAL MEASURED DIMENSION
DA	.5611 - .5626	
TA	.21 (ref)	
WA	1.687 - 1.692	

item B



P/N: 9-65146-2001

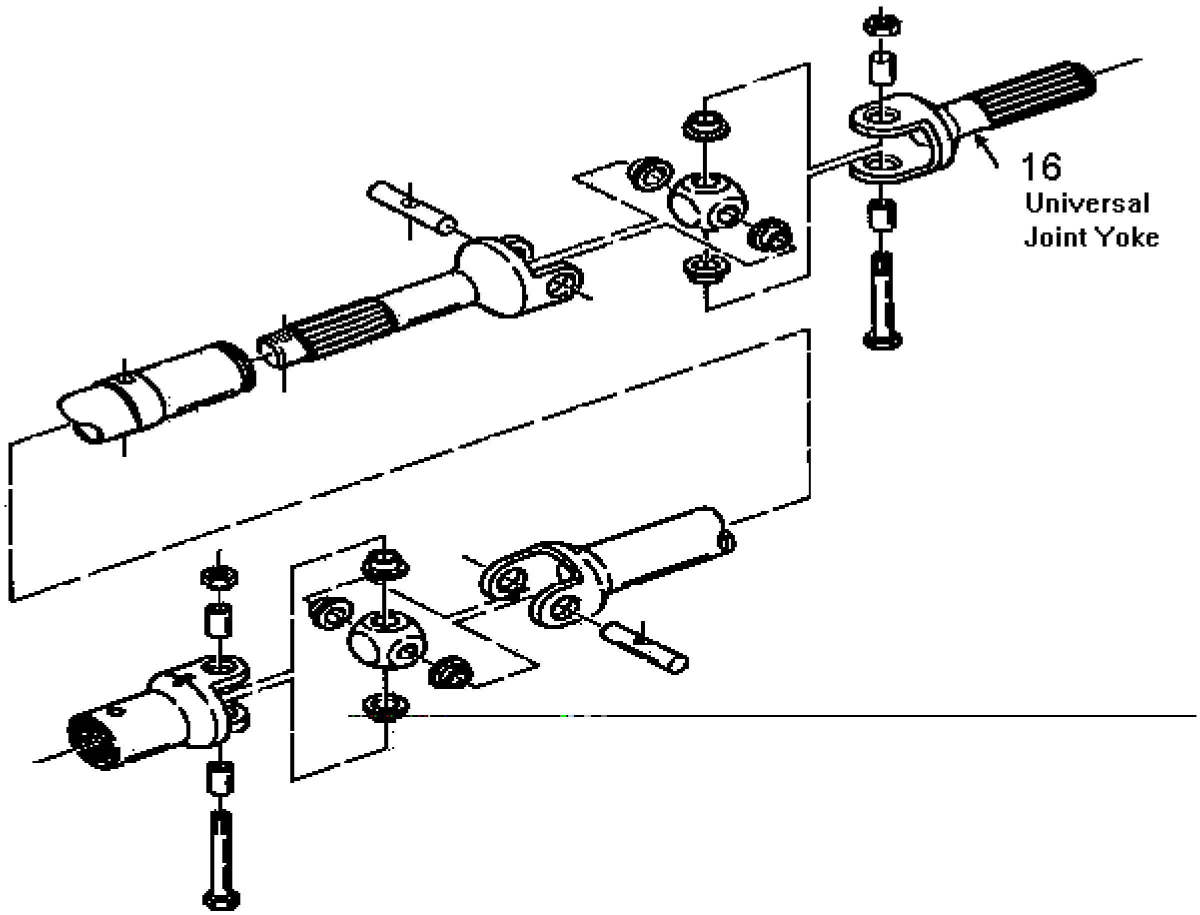
DIM	DWG TOLERANCE	ACTUAL MEASURED DIMENSION
DB	.3112 - .3122	
TB	.44 - .47	
WB	.812 - .817	

STAMP OR SIGNATURE HERE:

RUDDER SN:

BUNO#:

AV-8B AGE EXPLORATION PROGRAM



DATE 19-Sep-95	BUREAU NUMBER 164124	FLIGHT HOURS 1401.1	LANDINGS 2128	ROUNDS FIRED	SQUADRON VMA-214

Report By : OLIVER/Markward   Record Number : 6   Discrepancy Number :

Part Name : TRANSVERSE DRIVE SHAFT, RH

Part Number : 75A607128-1001   NHA Part Number : 75A607105-1007

Serial Number :   WUC : 29E5L   MAL Code : 20

Publication : A1-AV8BB-290-310   Work Package : 07100   Page : 7
Index : 16

Detected : ZONAL

Discrepancy : TEETH ON YOKE ARE EXTREMELY WORN. ALL SPLINES(TEETH) SHOW WEAR, MOST HAVE WORN TO KNIFE EDGE CONDITION. ITEM WAS INSTALLED WITH A -408 ENGINE. WEAR COVERS OUTBOARD 2/3 OF SPLINES, INBOARD 1/3 IS UNTOUCHED.

Action : REPLACED

Action Details : REPLACED RH TRANSVERSE SHAFT

<u>Acronym Definitions for pages C-5 and C-6</u>:

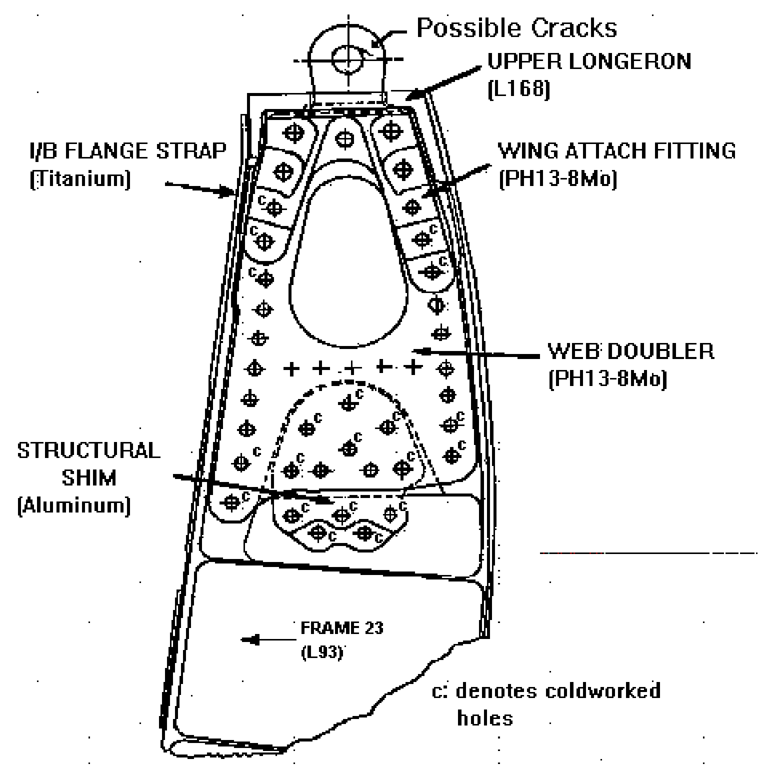
n/a - not applicable
NDI - non-destructive inspection
NHA - next higher assembly

AGE SAMPLING QUESTIONNAIRE

1. General Information		
(a) Work Unit Code 111A0	(b) BUNO	(c) Job Control Number
(d) Part Name Wing Attach Fitting, Frame 23	(e) Part Number 75A327204	(f) Component Serial Number n/a

2. AIRCRAFT DATA n/a		
3. INSPECTION		
(a) Frequency	(b) Damage Found ? YES NO	(c) Damage Length
(d) Other Damage	(e) How Was Damage Detected? NDI Visual	(f) Probable Cause

(g) Indicate Damage



APPENDIX D

RCM COST AVOIDANCE CALCULATIONS EXAMPLE

The following provides an example RCM cost avoidance for the extension of an on-condition inspection from 6,000 FH’s to 8,958 FH’s for the E-6A aircraft.

Variable	Number	Units	Description
AL	24000	Specify	Remaining aircraft life
MHO	20.2	Man-Hrs	O-Level manhours required to perform task
MHD	37.2	Man-Hrs	Depot level manhours required to perform task
MH$O	25	$	Cost of 1 O-level manhour
MH$D	85	$	Cost of 1 depot manhour
N	16	A/C	Number of affected aircraft
RCMMH	160	Man-Hrs	Number of manhours to perform RCM analysis
RCMMH$	85	$	Cost of 1 manhour for RCM analyst
TPC$	0	$	Cost of changing technical manuals
NAE	0	Num	Number of age exploration tasks performed
MHAEO	0	Man-Hrs	O-Level manhours required to perform task
MHAED	0	Man-Hrs	Depot level manhours required to perform task
BII	6000	Specify	Inspection interval before RCM
AII	8958	Specify	Inspection interval after RCM analysis/update
BMHO	20.2	Man-Hrs	O-level manhours before RCM
BMHD	37.2	Man-Hrs	Depot manhours before RCM

Calculations

Before RCM			
BCI	3667	$	Cost of performing inspection before RCM
BNI	64	Num	Number of inspections for remaining life
CB	234688	$	Cost of performing task before RCM

After RCM			
ACI	3667	$	Cost of performing inspection after RCM
ANI	32	Num	Number of inspections performed after RCM
CIA	117344.00	$	Cost of performing inspections after RCM
RCM$	13600.00	$	Cost of performing RCM analysis/update
AE$	0.00	$	Cost of performing associated age exploration
CA	130944.00	$	Cost of performing task after RCM

COST AVOIDANCE 103744.00 $

APPENDIX E

ACTUARIAL ANALYSIS EXAMPLE

1.0 INTRODUCTION

The E-6 aircraft is a Boeing 707 airframe modified for the Navy for strategic communications. In this role, the aircraft is fitted with a dual trailing wire antenna (DTWA) system. The DTWA is a hydro-mechanical driven antenna and reel system. The DTWA consists of two separate antenna reeling assemblies, the short trailing wire assembly (STWA) and the long trailing wire assembly (LTWA). Each assembly was analyzed separately. The LTWA is presented in this example.

2.0 PROBLEM IDENTIFICATION

When the Navy procured the E-6 aircraft, the LTWA system was removed from Navy EC-130Q aircraft, overhauled, and installed in the E-6. While on the EC-130Q, the LTWA was overhauled every 4 years, coincident with the aircraft's SDLM cycle. The E-6 was expected to have a 5 to 7 year SDLM cycle so the question was raised, "Can the LTWA overhaul be extended to 5 to 7 years?" To answer that question the actuarial analysis presented in this example was performed.

It is noted in passing that the one asking the question is presupposing the need for an overhaul. This, at first may seem to be a valid presupposition since the system is currently being overhauled. The better question, however, is "Does the LTWA need to be overhauled and if so when?" This example will answer the latter question.

To answer the question at hand it is necessary to determine if the LTWA exhibits a wear out age. This is evaluated in accordance with the RCM philosophy adopted by the Navy. For the system to exhibit a wear out age it must be possible to identify a point in time where the conditional probability of failure curve shows a rapid increase. The actuarial analysis process used to determine this is documented in MIL-STD-2173 and NAVAIR 00-25-403. FIGURE 1 provides a graphical representation of this process.

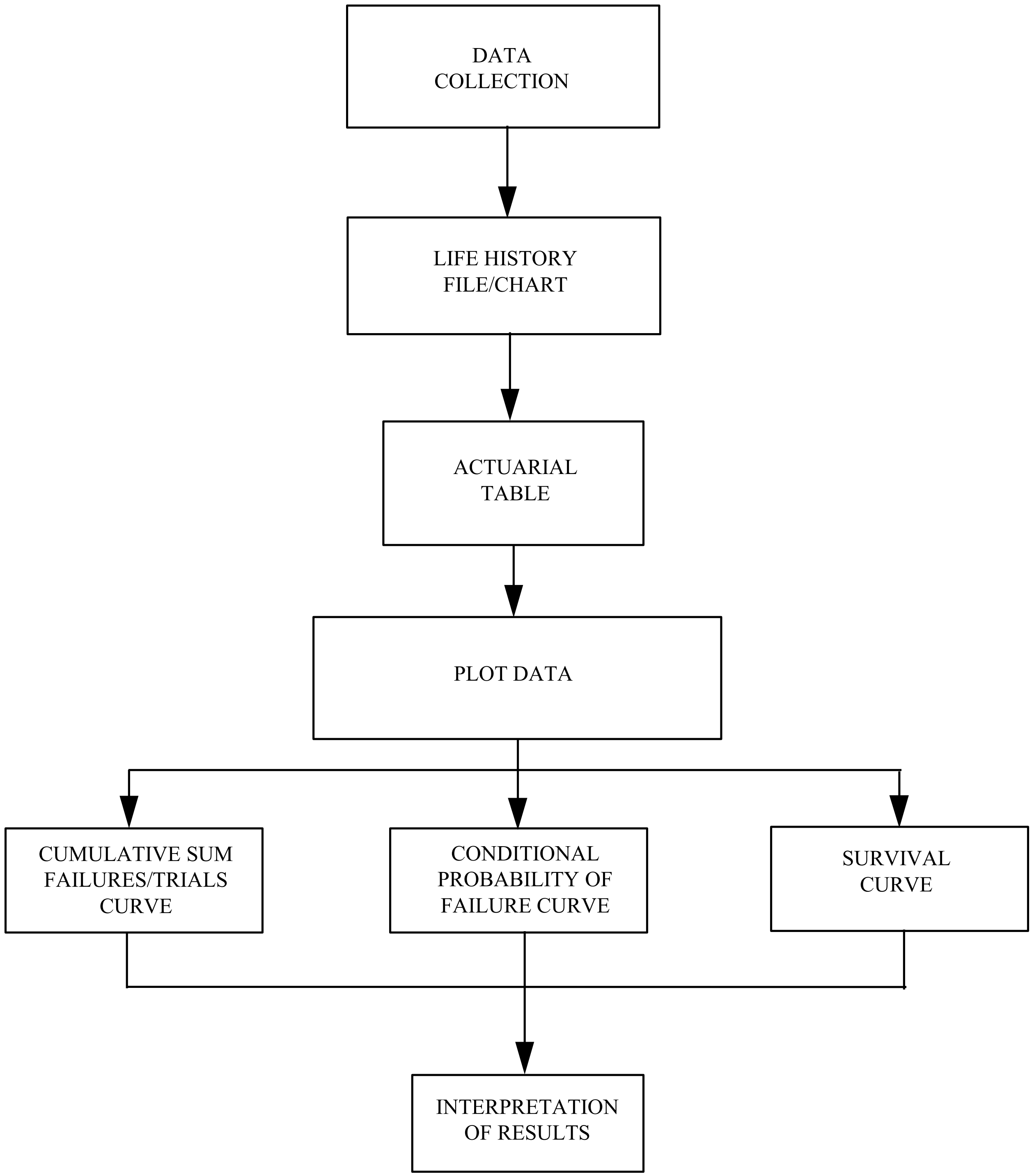


FIGURE 1. Actuarial Analysis

3.0 METHODOLOGY

Actuarial analysis is the processing of life data to determine, from an appropriate sample, the effect of aging on the probability of failure. The usual objective of the analysis is the determination of the effectiveness of a scheduled rework or discard task. Actuarial analysis can be performed in two basically different ways; either from life test data in which a selected group of units all start at zero age and are operated until all have failed, or from a larger group of in-service life data segments bounded by two calendar dates. The second method was used for the analysis presented in this example.

3.1 ACTUARIAL ANALYSIS

The actuarial analysis begins with the collection of failure data for the system or a similar system. For this analysis, failure data for the LTWA system was available since the system had been operating on the EC-130Q for a number of years. A ten year period (1 January 1980 through 31 December 1989) was chosen for analysis. These dates were chosen for 2 primary reasons.

(1) the data was available and relatively consistent. Data consistency prior to 1980 was more questionable.

(2) The LTWA is only expected to operate for 10 years before being replaced with a newer system. The failure data was extracted from the 3-M system.

After collecting the data the maintenance actions were categorized into failures and non-failures. The 3-M data is reported with a number of codes that identify when the defect was found, the type of defect, and the repair action. Also an ECA software package was available that defines the appropriate combinations of these codes for a verified failure. Therefore, the data could be categorized as those maintenance actions that were verified as failures and those that were not.

The next step is to group the data into time blocks. For this analysis the data was originally grouped into 3 month blocks. The failures and non-failures documented against each aircraft were plotted. Figure 2 and Figure 3 provide the Life History Chart data for the LTWA analysis. The X's signify maintenance actions that were verified as failures and the O's signify those that were not. It is noted that in some quarters a single aircraft may have multiple maintenance actions with or without failures. This is a complication that will be considered later. It is also noted that the entire assemblies were not routinely removed from an aircraft until they were overhauled. When an assembly was removed for overhaul, a new or newly overhauled assembly was put in its place. This made tracking by aircraft a good measure of the effectiveness of overhaul and made data collection and analysis easier. Each aircraft would receive 2 new or newly overhauled assemblies during the 10 year period of study.

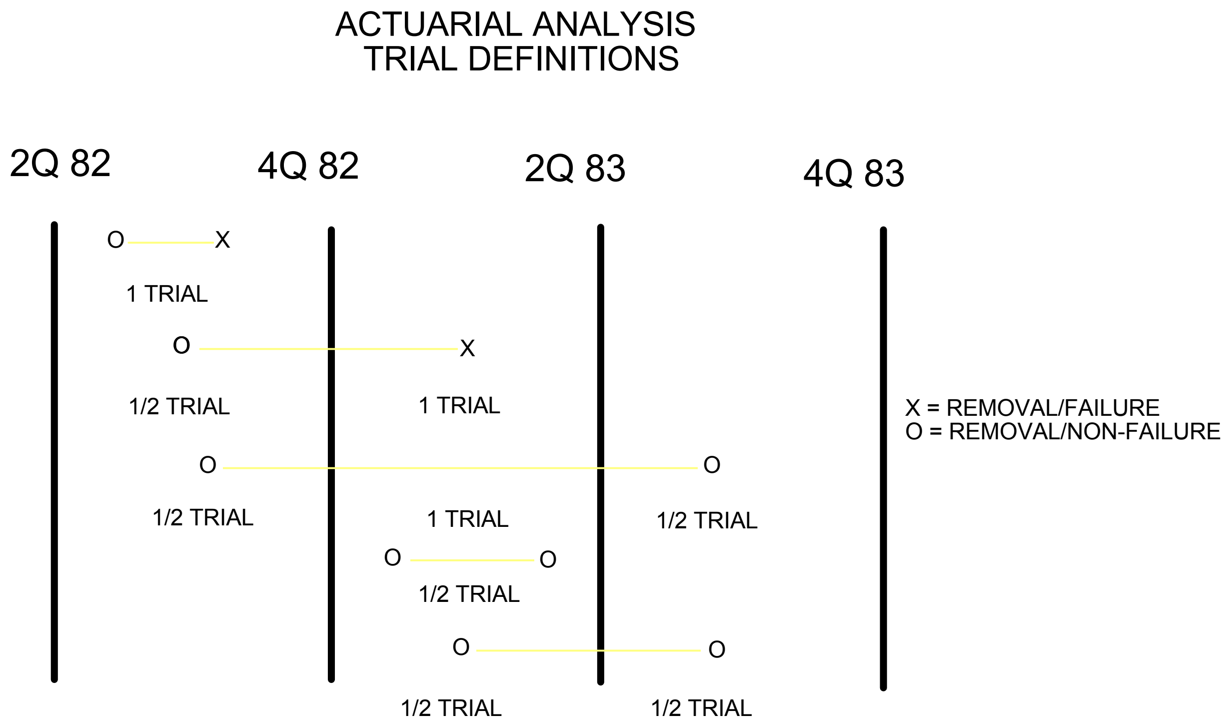


FIGURE 2. Actuarial Analysis Trial Definitions

3.2 CALCULATIONS

The Actuarial Table contained in Table 1 provides the results of the calculations described in this section.

AGE INTERVALS	# FAILURES	WHOLE TRIALS	TOTAL TRIALS	FAILURES/ TRIALS	CUMULATIVE SUM FAILURES/TRIALS	FARED CURVE	MID CELL	SURVIVAL PLOT
2Q 80	3	12	19.5	0.1538462	0.153846	-0.431		1.431
4Q 80	10	21	28	0.3571429	0.5109889	0.103	0.534	0.666846
2Q 81	9	20	22	0.4090909	0.9200798	0.637	0.534	0.3107502
4Q 81	6	20	22.5	0.2666667	1.1867464	1.172	0.535	0.1444989
2Q 82	9	20	23	0.3913043	1.5780508	1.706	0.534	0.0673365
4Q 82	9	19	23.5	0.3829787	1.9610295	2.241	0.535	0.0313115
2Q 83	15	24	30	0.5	2.4610295	2.775	0.534	0.0145911
4Q 83	15	27	30.5	0.4918033	2.9528328	3.31	0.535	0.0067849
2Q 84	10	17	25.5	0.3921569	3.3449896	3.844	0.534	0.0031618
4Q 84	18	26	29.5	0.6101695	3.9551591	4.378	0.534	0.0014734
2Q 85	28	33	39	0.7179487	4.6731079	4.913	0.535	0.0006851
4Q 85	38	41	50	0.76	5.4331079	5.447	0.534	0.0003193
2Q 86	21	28	34	0.6176471	6.0507549	5.982	0.535	0.0001485
4Q 86	10	17	21	0.4761905	6.5269454	6.516	0.534	0
2Q 87	19	28	32.5	0.5846154	7.1115608	7.051	0.535	0
4Q 87	20	29	32.5	0.6153846	7.7269454	7.585	0.534	0
2Q 88	20	27	31	0.6451613	8.3721067	8.119	0.534	0
4Q 88	13	24	32	0.40625	8.7783567	8.654	0.535	0
2Q 89	22	29	34.5	0.6376812	9.4160378	9.188	0.534	0
4Q 89	10	26	27.5	0.3636364	9.7796742	9.723	0.535	0
2Q 90	23	35	41.5	0.5542169	10.333891	10.257	0.534	0
4Q 90	10	22	25	0.4	10.733891	10.791	0.534	0

Table 1. Actuarial Table

The actuarial analysis process now requires that the number of "trials" be calculated. FIGURE 2 is provided to help visualize trials and half trials. If the system operates through the time period without a failure or non-failure maintenance action a full trial is counted. Entering or leaving during the time period without failure counts as a half trial. Finally, a failure during the time period is a full trial. This is where the multiple failures and non-failures maintenance actions within a time period became a challenge. How should these be counted? Should each failure be counted as a trial or should all of the failures be counted as one trial? Similarly, should each non-failure be counted as a half trial or should all non-failures be counted as one half trial? To test the effect of each combination, all possible combinations were analyzed. It turned out that the conclusions of the analysis were the same for all combinations. The rest of this example will use each failure as a full trial and each non-failure as a half trial. Finally, to simplify the analysis the number of trials were calculated for 6 month time blocks.

The next step is to count the total number of failures. Again all of the failures in the time block were counted. After obtaining the total number of failures and the total trials the probability of failing in each time block is calculated by dividing the total number of failures by the total trials. Finally, the time block probability of failures are cumulated and plotted as shown on FIGURE 3.

It is now necessary to fair a curve through the plotted points to smooth the line. Faring the curve can be manually drawn or calculated with curve fitting equations. Since the plot appeared to be linear, linear regression analysis techniques were used. The resulting fared curve equation is Y = 0.534X - 0.431, with a Correlation Coefficient of 0.997. The smoothed data points are now added to Table 1.

3.2.1 WEAROUT AGE

The question of how one knows when an overhaul task is applicable is now addressed. An overhaul task is applicable when the system or component exhibits a wear out age. In statistical terms, the wear out age is determined by a point at which the conditional probability of failure curve shows a rapid increase. The data has been prepared to develop the conditional probability of failure curve.

The conditional probability of failure curve is developed from the smoothed data points. The conditional probability of failure for each time block is calculated by subtracting it's smooth data point from the previous time blocks. Mathematically:

$$MC_{n+1}=FC_{n+1}-FC_n$$

The conditional probability of failure is interpreted as the probability that the system or component will fail during the time block given that it survived until that time. The conditional probability of failure curve for the LTWA is shown on FIGURE 3. Finally, a survivability curve is calculated using the following equation:

$$S_{n+1}=(1-MC_{n+1})*S_n$$

The survivability curve is used to evaluate the effectiveness of the overhaul interval. The overhaul interval is only effective if an adequate percentage of the population survives to the wear out age.

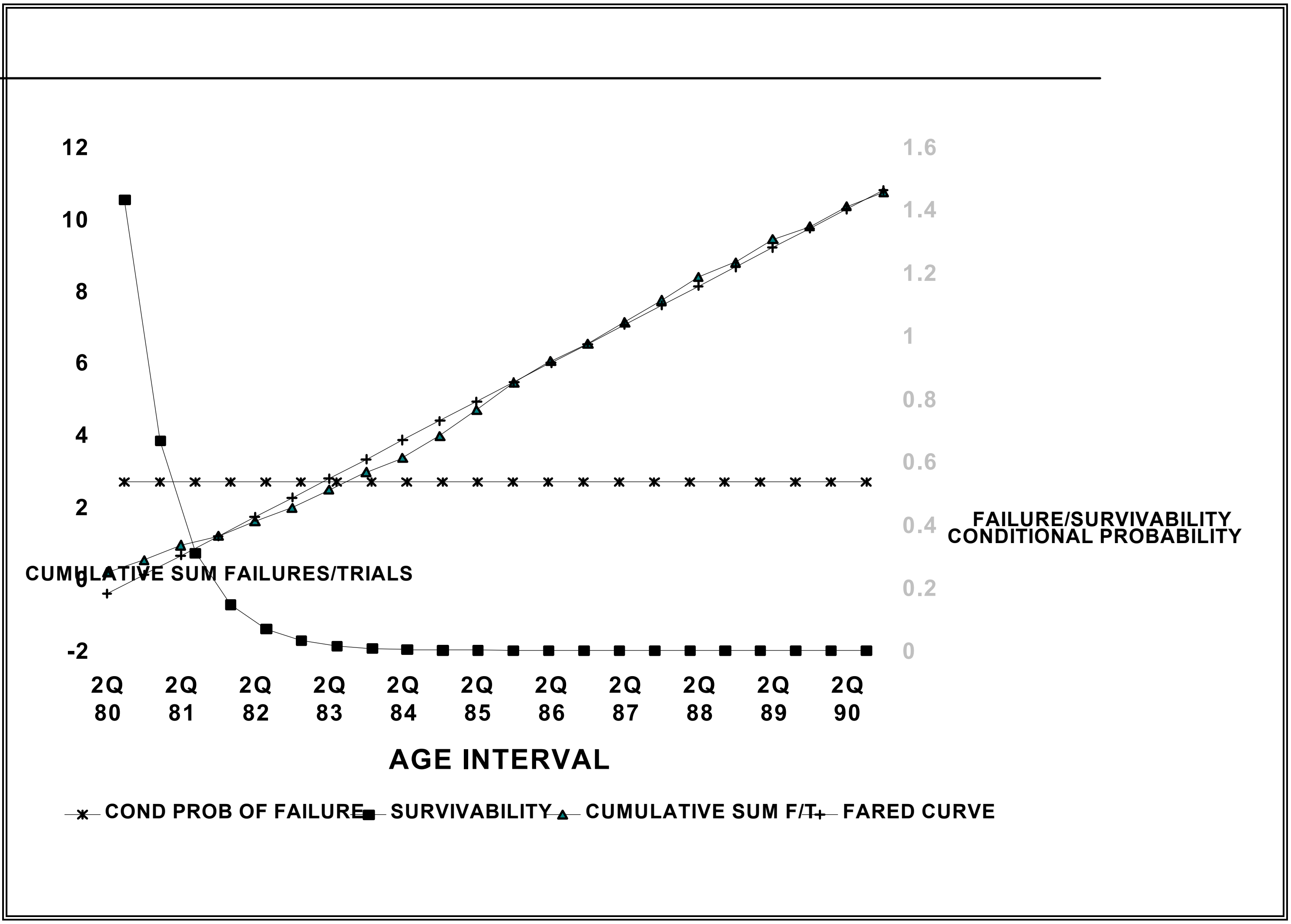


FIGURE 3. Actuarial Graph

4.0 INTERPRETATION OF THE DATA

The heart of the actuarial analysis is in the conditional probability of failure curve. In this case the conditional probability of failure curve is a horizontal line. This is interpreted to say that the probability of failure of the system the day after overhaul is exactly the same as the probability of failure the day before overhaul. Since there is no point at which the probability of failure curve shows a rapid increase, a wear out age is not found.

5.0 CONCLUSION

Recall that the original question was "Can the overhaul be extended from 4 to 5 or 7 years?" The question was modified to "Is an overhaul applicable?" Since a wearout age is not exhibited (at least in 10 years) an overhaul is not applicable.

It is noted that a wear out age might be found at a time greater than 10 years but the expectation is that the horizontal line will continue for many years. In any case the equipment will be replaced before a wear out age is reached.

6.0 RESULT

Since an overhaul was not found to be applicable for either the LTWA or STWA, it was recommended that a complete RCM analysis be performed on the DTWA to determine the appropriate preventive maintenance tasks to maintain the system. The RCM analysis was performed and implemented. Upon implementation of the RCM analysis, it was calculated that replacing the overhaul with other appropriate field level preventive maintenance saved approximately $35-40 Million over 7 years.

REFERENCES

STANDARDS

MILITARY

MIL-STD-2173 (AS) Reliability-Centered Maintenance Requirements For Naval Aircraft, Weapons Systems and Support Equipment

OTHER GOVERNMENT DOCUMENTS, DRAWINGS, AND PUBLICATIONS

NAVAIR 00-25-403 Management Manual, Guidelines for the Naval Aviation Age Exploration Program

DEFINITIONS

The terms and acronyms listed in this example are defined as follows:

1. DTWA: Dual Trailing Wire Antenna

2. LTWA: Long Trailing Wire Antenna

3. STWA: Short Trailing Wire Antenna

4. SDLM: Standard Depot Level Maintenance

5. RCM: Reliability Centered Maintenance

6. 3-M: Maintenance Material Management System

7. ECA: Equipment Condition Analysis

8. Cell: Segment of a Life History Chart

9. Trial: An attempt of the system/unit to cross a life segment boundary

10. Whole Trial

A. A system/unit enters a cell at the lower boundary and makes a successful traverse through the whole cell and continues into the next cell.

B. A system/unit enters a cell at the lower boundary and fails within the cell.

C. A system/unit starts within a cell and fails within that cell.

11. Half Trial

A. A system/unit enters a cell at the lower boundary and is removed from the data set without failure while in that cell.

B. A system/unit starts within a cell and either makes a successful traverse or is removed from the data set without failure while in that cell.

12. Verified Failure (ECA): An action for which:

A. The action taken code is:

1). Repair or replace of items, such as attaching units, seals, gaskets, packing, tubing, hose and fittings, things that are not integral parts of the system/unit.

or

2). Repair, which includes, cleaning, disassembly, inspection, reassembly, lubrication, and replacement of integral parts.

or

3). Corrosion treatment, which includes cleaning, treatment, priming, and painting of corroded items that require no other repair.

and

B. The malfunction code is unconditional, meaning a fault (failure or not) occurred requiring removal of the system/unit.

13. Cumulative Sum Failures/Trials Curve: A graph of the cumulative sum of total failures/trials as a function of age depicting the relationship between failures and age.

14. Conditional Probability of Failure Curve: A graph of the probability that an item will fail during a particular age interval, given that it survives to enter that interval.

15. Survival Curve: A graph of the probability of survival of an item as a function of age, derived by actuarial analysis of its service history. The area under the curve can be used to measure the average realized age of the item.