JAP(D) 100C-22
August 2009
(Superseding DAP 100C-22
dated September 2006)

Ministry of Defence

MILITARY AVIATION ENGINEERING

GUIDE TO DEVELOPING AND SUSTAINING PREVENTIVE MAINTENANCE PROGRAMMES

Sponsored for use within
UK Military Aviation
by
►MAA Reg Dep Hd◄

Publication Organization:
►Military Aviation Authority◄

AMENDMENT RECORD

Amdt No.	Date Incorporated
1	September 2010
2	February 2011
3	August 2012
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	

CONTENTS

PRELIMINARY MATERIAL

Page

GUIDE TO DEVELOPING AND SUSTAINING PREVENTIVE MAINTENANCE PROGRAMMES

Chapter

PREFACE

1. This publication is intended to provide guidance on the RCM principles and processes that are to be applied whenever an RCM study is done, as mandated in the requirements described in Def Stan 00-45 Part 1. This publication is to be considered as the military aviation equivalent of Def Stan 00-45 Part 3.

2. This publication is approved for use by the nominated sponsor detailed on the front cover of this publication as specified in ►MAP-01◄. The publication is available for use in CD-ROM form, through the ►Forms & Publications Logistics Commodities & Services (FPLCS)◄, Bicester. The nominated Publication Organization (PO) identified on the front cover of this publication is responsible for the management and maintenance of this publication on behalf of the sponsor.

3. Recommendations for amendment to this publication are to be made on MoD Form 765 in accordance with the instructions provided in ►MAP-01 Chap 8◄.

4. New or amended material will be identified by ►red text◄ to show the amendment.

5. The terminology used throughout this publication is, where appropriate, in accordance with ►MAP-01◄ and additional terminology has been defined herein. Readers should be aware of possible differences in terminology when comparing this publication to other technical documents or air publications.

Related publications

►MRP RA	MAA Regulatory Publication Regulatory Articles◄
Def Stan 00-45	Using reliability centred maintenance to manage engineering failures. Part 1 Requirements for the application of reliability centred maintenance. Part 2 Developing an RCM project plan.
Def Stan 00-600	Integrated logistic support. Requirements for MoD projects.
JSP 817	Condition monitoring and condition based maintenance policy.
JSP 886 Vol 07	Policy and procedures for the application of Integrated Logistic Support (ILS).
JAP(D) 100C-20	Preparation and amendment of maintenance schedules.

Associated publications

Reliability-centered maintenance,	F Stanley Nowlan and Howard F Heap.
Reliability-centred maintenance II,	John Moubray.
ATA MSG-3	Airline/manufacturer maintenance planning document, Air Transport Association.
BS 5760	Reliability of systems, equipment and components.

Glossary

Age exploration. The process of determining age-reliability relationships through controlled testing and analysis of chance or unintentional events for safety-critical items; and from operating experience for non-safety items.

Age-reliability characteristics. The characteristics exhibited by the relationship between the operating age of an item and its conditional probability of failure.

Calibration standard. A support equipment system or device of known accuracy with traceability to national standards.

Conditional probability of failure. The probability that an item will fail during a particular age interval, given that it survives to enter that interval.

Consequences of failure. The results of a given functional failure at the equipment level and for the operating organization, classified in RCM analysis as safety consequences, operational/economic consequences, safety hidden failure consequences and non-safety hidden failure consequences.

Crack detection threshold. The minimum life, measured in the most suitable lifing parameter, to the first detectable appearance of a fatigue crack in an item subject to a predictable loading spectrum. The life would usually be based on visual detection except where directed NDT examinations are specified.

Crack propagation life. The period it takes a crack to grow from the crack detection threshold to the critical crack length.

Crew. Personnel normally assigned to operate equipment.

Critical crack length. The crack length at which the residual strength of the item is no longer sufficient to withstand 80% of the Design Ultimate Load (DUL).

Damage tolerant structure. Refer to ►MRP RA5720◄.

Effectiveness criteria. The criteria for judging whether a specific task is capable of reducing the failure rate or probability of failure to the required level.

End Item. An aircraft or major item of equipment to which an RCM study is directed.

Failure effects. The impact a failure mode has on the operation, function, or status of an item. Failure effects are classified as local effect, next higher level, and end effect.

Failure finding task. Scheduled maintenance of a hidden function item to find functional failures that have already occurred but were not evident to the operating crew.

Failure mode. The specific engineering mechanism of failure that leads to a particular functional failure.

Failure rate. The total number of failures within an item population, divided by the total number of life units expended by that population, during a particular measurement interval under stated conditions.

Failure symptom. An identifiable physical condition by which a potential failure can be recognized.

Fatigue. Reduction in resistance to failure of a material over time, as a result of repeated or cyclic applied loads.

Fatigue life. For an item subject to fatigue, the total time to functional failure of the item.

Fleet leader concept. The concentration of sample maintenance tasks on the pieces of equipment that have the highest operating ages to identify the first evidence of changes in their condition with increasing age.

Flight cycles. A measure of exposure to the stresses due to individual flights, expressed as the number of ground-air cycles.

Function. The normal, characteristic actions of an item, sometimes defined in terms of performance capabilities.

Functional failure. The failure of an item to do its normal or characteristic actions within specified limits.

Functional Failure Mode Code (FFMC) or Failure Mode Indicator (FMI). A code allocated to functional failures as part of a Failure Mode and Effects Analysis (FMEA). The code identifies the associated functions, functional failures and engineering failure modes.

Functionally Significant Item (FSI). A system or part thereof, other than structure, which is selected for RCM analysis; or any item within a system, or part thereof, that is allocated a preventive maintenance task(s) as a result of RCM analysis, because in either case any of the following criteria apply:

a. Its failure would be undetectable during operations, or would have significant consequences in terms of safety (on the ground or in flight), the environment, operational capability or cost of repair.

b. Its functional failure rate is high.

c. There are OEM maintenance recommendations or existing maintenance tasks associated with it.

Note: This definition reflects the term Maintenance Significant Item (MSI), which is contained in ATA MSG-3, but has been expanded to emphasize that it excludes elements of structure and that the additional criteria at (b) and (c) are directed mainly to retrospective RCM studies of legacy maintenance programmes.

Hard time task. A task to restore a condition or replace an item before some specified maximum age limit to prevent or reduce the probability of a functional failure.

Hidden failure consequences (Safety and Non-safety). The risk of a multiple failure resulting from undetected earlier failure of a hidden function item; two of the four consequence branches of the RCM decision diagram.

Hidden failure. A failure not evident to the crew or operator during the performance of normal duties.

Infant mortality. The relatively high conditional probability of failure during the period immediately after an item enters service. Such failures are due to defects in manufacturing not detected by quality control.

Maintenance package. A group of maintenance tasks scheduled at the same time.

Mean time between failures. A basic measure of reliability for repairable items. The mean number of life units during which all parts of the item operate within their specified limits, during a particular measurement interval under stated conditions.

MSG-1. A working paper prepared by the 747 Maintenance Steering Group, published in July 1968 under the title Handbook: Maintenance Evaluation and Program Development (MSG-1); the first use of decision-diagram techniques to develop an initial scheduled maintenance program.

MSG-2. A refinement of the decision-diagram procedures in MSG-1, published in March 1970 under the title, MSG-2: Airline/Manufacturer Maintenance Program Planning Document; the immediate precursor of RCM methods.

MSG-3. Further refinement of MSG-2, developed for the 757, 767 series aircraft, published in October 1980 under the title, MSG-3: Airline/Manufacturer Maintenance Program Planning Document.

Multiple failure. A failure event consisting of the sequential occurrence of two or more independent failures, which may have consequences that would not be produced by any of the failures occurring separately.

Non-significant Item. An item whose failure (Or a hidden function whose part in a multiple failure) has no direct effect on safety or on the operational capability of the equipment, and involves no exceptionally expensive failure modes.

Operational/economic consequences. The effect of a failure that does not have safety consequences, but which causes a loss of mission essential equipment or results in high repair costs, one of the four consequence branches of the RCM decision diagram.

Potential failure. A quantifiable failure symptom that indicates that a functional failure is imminent.

Preliminary interval. For each PM task, the preliminary interval is that period between tasks derived as a direct result of RCM analysis and expressed in terms of units of operation or usage (e.g. flying hours, calendar time, landings, rounds fired, number of starts etc).

Preventive maintenance. Refer to ►MAP-01 Chapter 5.3◄.

Probability density of failure. The probability that an item will fail in a defined age interval; the difference between the probability of survival to the start of the interval and the probability of survival to the end of the interval.

Probability of survival. The probability that an item will survive to a specified operating age, under specified operation conditions, without failure.

Reliability. The ability of an item to do a required function under stated conditions for a stated period of time (BS 3811).

Reliability Centred Maintenance. A disciplined methodology used to determine the most cost effective maintenance tasks or other actions necessary to realize the inherent reliability, optimum availability and safe operation of an aircraft or equipment.

Safe fatigue life. A life limit imposed on an item that is subject to a critical failure. Established as some fraction of the average age, or fatigue life, at which test data shows that failures will occur.

Safe life structure. Refer to ►MRP RA5720◄.

Safety consequence. The consequence caused by a loss of a function or secondary damage resulting from a given failure mode which produces a direct adverse effect on safety. One of the four consequence branches of the RCM decision diagram.

Significant item. A generic term for both Structurally Significant Items and Functionally Significant Items, which are items whose failure has safety, environmental, operational or economic consequences. A Significant Item may be classified as both a Structurally Significant Item and a Functionally Significant Item.

Structural rating factors. Criteria based on fatigue, environmental damage, and accidental damage - used to rate structurally significant items for the determination of examination frequencies.

Structurally Significant Item (SSI). Refer to ►MRP RA5720◄.

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 (expected life) of the item under consideration.

Teardown examination (mechanical components). The complete disassembly of a serviceable item that has survived to a specified age limit to examine the condition of each of its parts as a basis for judging whether it would have survived to a proposed higher age limit.

Teardown examination (structure). The disassembly of structural items to identify any significant damage that is present either at the completion of a fatigue test, or on structure which is being used for destructive sampling that has not been detected during the test, or its life, respectively.

Use Study. The Use Study details the system description, its mission profile, operating requirements and the existing logistics support available (Def Stan 00-600).

Zonal survey. A general visual examination of a specified zone to detect damage, deterioration and discrepancies, and assess the general condition of the zone. The zone is to be cleaned making sure that all dirt, oils and other foreign materials are removed. Examine the zone prior to and following any cleaning. The task is to be done using enhanced lighting and/or with the aid of a mirror, as necessary, and sufficiently close to the zone as to permit all features of the zone to be seen clearly. Care is to be taken not to cause damage through disturbance of installed items (JAP(D) 100C-20 Chap 1-4 Annex A).

List of abbreviations

AD	Accidental Damage
AE	Age Exploration
ALARP	As Low as Reasonably Practicable
AMM	Aircraft Maintenance Manual
BITE	Built in Test Equipment
CBM	Condition Based Maintenance
CCMM	Continuous Charge Mandatory Maintenance
CM	Condition Monitoring
CMM	Component Maintenance Manual
CPL	Crack Propagation Life
CRL	Component Replacement List
CTM	See Cty
Cty	Contingency Maintenance
DDP	Declaration of Design and Performance
DO	Design Organization
DMML	Draft Master Maintenance List
DRACAS	Data Reporting and Corrective Action System
DUL	Design Ultimate Load
ECU	Engine Change Unit
ED	Environmental Damage
EMI	Electro-Magnetic Interference
EO	Evident Operational/Economic
ERC	Engineering Record Card
ES	Evident Safety
ESA	External Surface Area
ETI	Elapsed Time Indicator
FF	Failure Finding
FFI	Failure Finding Interval
FFMC	Functional Failure Mode Code
FLC	Front Line Command
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FMI	Failure Mode Indicator
FOD	Foreign Object Damage
►FPLCS	Forms & Publications Logistics Commodities & Services (formerly Joint Support Chain Services (JSCS)) ◄
FR	Fault Report
FSI	Functionally Significant Item
FW	Fixed Wing
Fwd	Forward
HN	Hidden Non-safety
HS	Hidden Safety
HT	Hard Time
HUMS	Health and Usage Monitoring System
ILS	Integrated Logistic Support
JAP(D)	Joint Air Publication (Digital)
LCN	Logistics Support Analysis Control Number
LDC	Life to Detectable Crack
L/HIRF	Lightning/High Intensity Radiated Field
LIS	Logistic Information System
LITS	Logistics Information Technology Strategy
LORA	Level of Repair Analysis
LRI	Line Replaceable Item
LSA	Logistics Support Analysis
►MAA	Military Aviation Authority◄
MAE	Military Air Environment
MART	Mean Active Repair Time
MC	Maintenance Comparator
MDS	Maintenance Data System
MML	Master Maintenance List

MP	Maintenance Procedure
►MRP	MAA Regulatory Publications◄
MSG	Maintenance Steering Group
MTBF	Mean Time Between Failure
NDT	Non-destructive Testing
OC	On-condition
OEM	Original Equipment Manufacturer
ORS	Operational Readiness Servicing
PM	Preventive Maintenance
PoC	Point of Contact
Prop	Propulsion
PT	Project Team
►RA	Regulatory Articles◄
RCM	Reliability Centred Maintenance
RCMPP	Reliability Centred Maintenance Project Plan
RFI	Radio Frequency Interference
RS	Residual Strength
RVA	Remote Visual Aid
RW	Rotary Wing
SI	Structural Integrity
SIN	Schedules Identification Number
SNS	Standard Numbering System
SOIU	Statement of Operating Intent and Usage
SPD	Schedules Production Database
SRD	System Requirements Document
SRF	Structural Rating Factor
SSE	Support Solutions Envelope
SSI	Structurally Significant Item
TI	Technical Instruction
TLMP	Through Life Management Plan
UFR	Unsatisfactory Feature Report
URD	User Requirements Document
WBS	Work Breakdown Structure
WFD	Widespread Fatigue Damage
WFSMM	Waived Flight Servicing Mandatory Maintenance
WRAM	Work Recording and Asset Management

RECORD OF CHANGES

Amendment 1 Dated September 2010

Preliminary pages

1. The sponsor detailed on the front cover and in the preface is changed from DE&S SE MAEI to MAA Tech Reg.

2. The term ‘Significant Item’ is defined in the glossary.

3. The definition in the glossary of the term ‘Functionally Significant Item (FSI)’ is expanded.

4. The definitions of the terms ‘damage tolerant structure’, safe life structure’ and ‘Structurally Significant Item’ within the glossary are referred out to JAP 100A-01.

5. The definition in the glossary of the term ‘Zonal survey’ is expanded.

6. A record of changes is introduced to describe the changes incorporated as a result of amendment action.

7. The Contents page and List of Related Publications is updated.

8. The List of Abbreviations is expanded to include additional items.

Chapter 4

9. The term Functionally Significant Item (FSI) is introduced to describe the end-item top-level systems/functions that are non-structural and selected for further RCM analysis.

10. Figure 2, Significant Item Selection shows a revised process.

Chapter 6

11. The FR_{HS} for a Hazard Severity Category of Catastrophic in Table 3 is changed to a value of 2.

Chapter 8

12. The criteria for determining HT task intervals in Para 25 is amended to match the criteria stipulated in the RCM decision logic algorithm.

13. The terminology used to describe the types of On-condition tasks in Paras 15 to 18 is changed to comply with the glossary of JAP(D) 100C-20.

14. Additional guidance is provided in Para 28 on how to do FF tasks on systems that cannot be operationally tested, because they utilize one-shot devices such as explosive initiators.

Chapter 9

15. In the context of the SSI definition in Para 2, the terms ‘detail’, ‘element’ and ‘assembly’ are explained.

16. References to the term ‘inspection’ in Paras 35 and 36 are changed to the term ‘examination’ in compliance with the glossary of JAP(D) 100C-20.

Chapter 10

17. References to the term ‘inspection’ throughout the chapter are changed to the term ‘examination’ in compliance with the glossary of JAP(D) 100C-20.

18. ED and AD sources in Tables 1 and 2 properly reflected in example Zonal and ESA Worksheets.

Chapter 11

19. An L/HIRF protection analysis process flowchart is introduced with additional guidance notes.

Chapter 16

20. References to CREST and RAMIT trend analysis software tools are removed.

Amendment 2 Dated February 2011

Preliminary pages

21. The term ‘Functionally Significant Item (FSI)’ in the glossary is redefined.

22. The term ‘significant item’ in the glossary is redefined.

23. Reference to Def Stan 00-60 in the glossary definition of ‘Use Study’ is changed to Def Stan 00-600.

24. The reference to BS 5760 is removed from the List of Related Publications and inserted into the List of Associated Publications.

25. The reference to AP 100C-20 in the List of Related Publications is changed to JAP(D) 100C-20.

Chapter 1

26. The references to Def Stan 00-60 in Para 12 are changed to Def Stan 00-600.

Chapter 4

27. The reference to Def Stan 00-60 in Para 8 is changed to Def Stan 00-600.

28. The process to select significant items detailed in Para 9 is revised to be described as a process to select system indenture levels and items for RCM analysis.

29. The term ‘Functional Level’ in Figure 1 is replaced with the term ‘Indenture Level’.

30. The term ‘significant item’ is replaced throughout the chapter with the term ‘selected function(s) or item(s)’.

Chapter 6

31. The references to Def Stan 00-60 in Para 33 and Para 36 are changed to Def Stan 00-600.

Amendment 3 Dated August 2012

All pages

32. The publication has been updated to reflect the MAA Operating Model.

CHAPTER 1

BACKGROUND TO RELIABILITY CENTRED MAINTENANCE

CONTENTS

Para

HISTORY OF RCM

1 It has been a traditional belief that all engineering equipment will wear out at some stage. Because of this, early approaches to the development of Preventive Maintenance (PM) programmes were based on the concept that all components could be subjected to periodic overhaul to ensure reliability and, therefore, operating safety. However, tests by commercial airlines in the mid-1960s showed that scheduled overhauls of complex equipment have little or no effect on the reliability of equipment. These tests, the increasing complexity of modern aircraft and increasing cost of maintenance inspired a new concept for PM, known as Reliability Centred Maintenance (RCM).

Civilian aerospace

2 During the 1960s PM was imposing an unacceptable burden on the operating costs of 'modern' aircraft. Aircraft like the DC-8 were incurring millions of man-hours for major structural inspections alone and this was likely to increase with the increasing complexity of new aircraft types that were being planned. To combat this unacceptable situation, representatives of the commercial airlines and aircraft/engine manufacturers formed a 'Maintenance Steering Group (MSG)' with the intent of developing procedures for deriving the initial PM programme for the Boeing 747 aircraft. The decision logic and procedures which were developed was entitled: 'Handbook: Maintenance Evaluation and Program Development'; however, this is now more usually referred to as MSG-1. MSG-1 had a profound influence on the design of the Boeing 747 and resulted in a PM programme that was significantly less expensive both in terms of man-hours and aircraft downtime.

3 MSG-1 was published in 1968 but this was soon updated from the experiences of the Boeing 747 programme. Detailed procedural information for the Boeing 747 was removed to create a revised document, known as 'MSG-2, Airline/ Manufacturer Maintenance Program Planning Document'. MSG-2, published in 1970, was intended for general application to aircraft. However, in 1979, an Air Transport Association task force reviewed MSG-2 to take account of further developments in PM philosophy; see Military Developments. The resulting document was 'MSG-3, Airline/Manufacturer Maintenance Program Planning Document'. MSG-3 has undergone several revisions since the original document was published in 1980 and continues to be reviewed on a regular basis.

4 The widespread use of the term ‘RCM’ has led to the emergence of a number of processes that differ significantly from the original, but that their proponents also call ‘RCM’. Many of these other processes fail to achieve some of the fundamental objectives of RCM and some are actively counterproductive. As a result, a standard was produced that sets out the minimum criteria that any process must comply with to be called ‘RCM’. This standard is known as SAE JA 1011 and was produced in 1999 by The International Engineering Society for Advancing Mobility, Land, Sea, Air and Space. The document does not define a specific RCM process; however, in 2002 a guide to the standard was produced as SAE JA 1012.

Military aerospace

5 The United States Navy (USN) was the first military service to utilize the logic principles developed by the civilian aerospace industry. In 1972, using MSG-2 techniques, the USN revised its PM programmes for the P-3A and S-3A; the success of these revisions later led to the use of the techniques to the F-4J programme.

6 Later, using a series of its own MSG-2 derived manuals; the USN revised the PM requirements for most of its in-service aircraft. However, much of the underlying philosophy of PM was left unsaid in both this document, and MSG-2; to remedy this, the US Department of Defence Air Force Department sponsored United Airlines to write a comprehensive thesis on the relationship between maintenance, reliability and safety. The subsequent report, written by F Stanley Nowlan and Howard F Heap, was entitled 'Reliability-centred Maintenance' and was published in December 1978. This document was to form the cornerstone for modern maintenance philosophy, not only for civilian and military aircraft, but also for wide ranging applications throughout engineering. Nowlan and Heap recognised that RCM would make its greatest impact during the design stage of a project where there is considerable scope to amend the design to eliminate poor maintenance situations. However, they recognised that RCM could also be applied very successfully to in-service equipment, albeit with lesser benefits.

7 Using Nowlan and Heap's thesis, the USN produced a new 'RCM' handbook; however, this was superseded in 1986 by Mil Std 2173(AS). The thesis also formed the basis of the MSG-3 document, from which the United States Air Force developed its own maintenance planning manual - Mil Std 1843.

8 In 1986, the RAF used MSG-3 as the basis for the first issue of AP 100C-22, which replaced the Datum Servicing List (DSL) - published as AP 100C-21. The DSL specified the preferred maintenance for parts and components considered to be common to most aircraft types; this was an inadequate and outdated maintenance concept and it was shown that the DSL led to unnecessary and expensive PM programmes. The next issue of AP 100C-22 was produced to take account of the requirements of Logistics Support Analysis (LSA), introduce methodologies for Failure Modes and Effects Analysis (FMEA) and Age Exploration (AE) Analysis and provide improved procedures for other aspects of RCM - based on Mil Std 2173, RCM by Nowlan and Heap and RCM II by John Moubray.

9 Further developments in military RCM standards include the introduction of NAVAIR 00-25-403, which is the RCM standard used by the United States Navy (Aviation).

10 JAP(D) 100C-22 has been produced to capture the recent developments of current military and civil standards considered as good practice amongst the RCM fraternity at large and to be compliant with current regulatory airworthiness requirements.

BENEFITS OF RCM

11 Examples of some benefits that will accrue with the introduction of RCM are:

11.1 A maintenance programme that is directly related to the operating context of an asset and its anticipated modes of failure.

11.2 Greater safety and environmental integrity.

11.3 The use of condition monitoring techniques to detect critical potential failures.

11.4 Auditable documentary evidence for the derivation of maintenance programmes.

11.5 An increased awareness of the risks of deferring preventive maintenance or changing the maintenance programme.

11.6 The precise and objective reporting of In-service performance, enabling rapid review of asset reliability and maintenance.

11.7 Cost savings.

INTERACTION WITH INTEGRATED LOGISTIC SUPPORT

12 The process of Integrated Logistic Support (ILS) is defined in Def Stan 00-600, and is clarified for RAF use in AP100C-70. ILS is the process for determining and acquiring the logistics support requirements for an acquisition programme and the 'tool' for determining these requirements is Logistic Support Analysis (LSA). A representation of the ILS process is shown schematically in Figure 1. RCM is described by Def Stan 00-60 as forming a key element of the ILS process and is the method used to derive PM requirements. ILS identifies separately the Failure Modes and Effects Analysis (FMEA) and combines this with Criticality Analysis to form the Failure Modes, Effects and Criticality Analysis (FMECA) that is used for many other applications within LSA. However, the FMEA is a fundamental component of RCM and this publication provides specific procedures for performing an FMEA, with the option of including a criticality analysis if required.

13 An RCM analysis will produce data needed to support significant activities required by the ILS process. These will include the ranging and scaling of spares, Level of Repair Analysis (LORA), the requirement for tools and test equipment, manpower skill levels and the requirement for facilities necessary to support the derived maintenance programme.

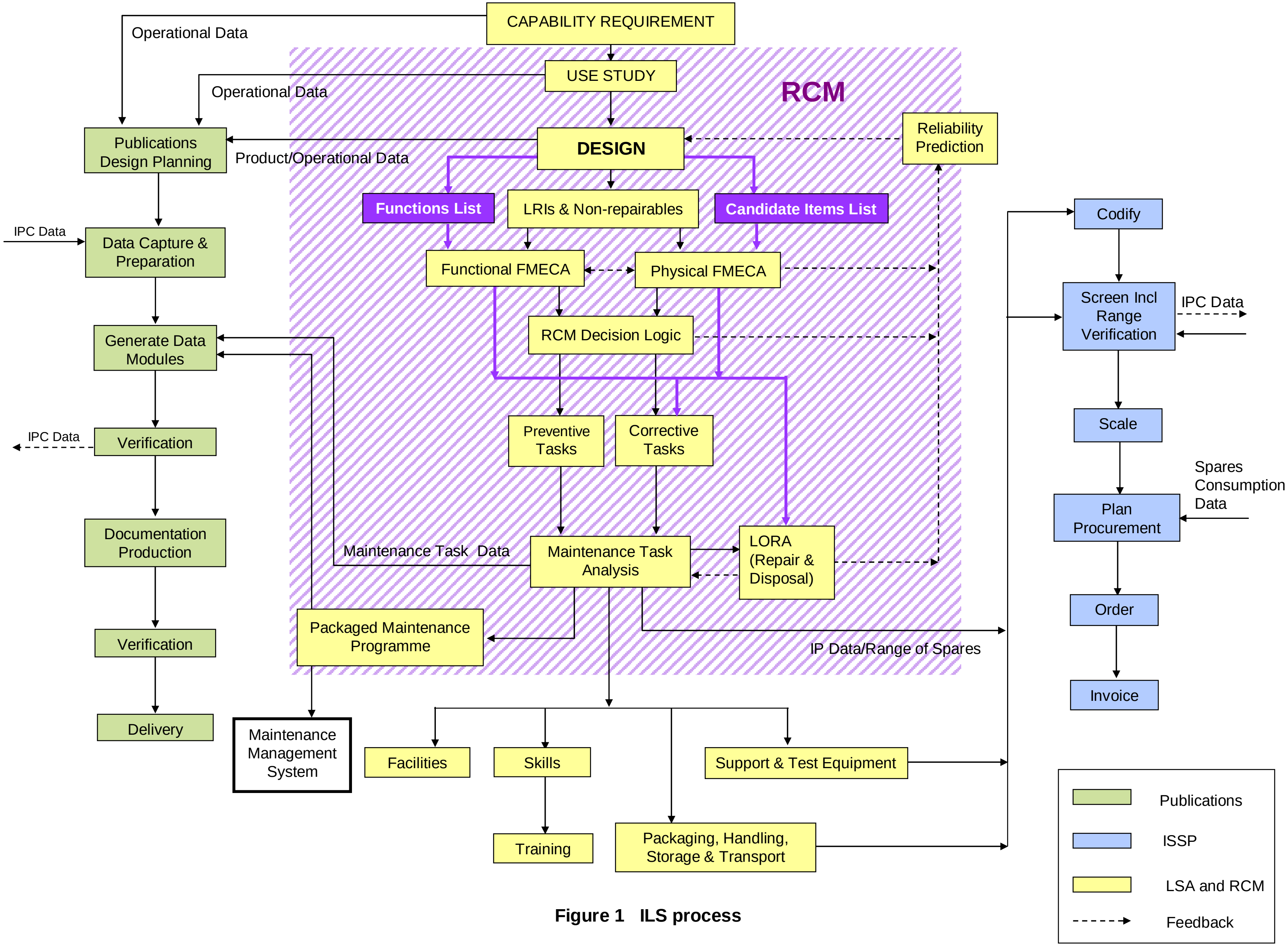


Figure 1 ILS process

CHAPTER 2

APPLYING RCM TO AN END ITEM

CONTENTS

Para

INTRODUCTION

1 To maximise the benefits of RCM, it should be applied to whole End Items to enable comprehensive maintenance programmes to be determined. Within the context of this publication the term ‘End Item’ refers to an aircraft or major item of equipment to which an RCM study is directed. This chapter provides an overview of the various stages pertinent to an RCM study within the MoD Military Air Environment.

PREPARATORY WORK

2 The success of an RCM study, like most enterprises, depends on good preparation, adequate planning and the identification of specific requirements (including deliverables), that is understood and agreed to by all the stakeholders concerned. The preparation process for an RCM programme includes the following activities:

2.1 Planning the complete programme in accordance with an RCM Project Plan (RCMPP).

2.2 Establishing the scope of the RCM programme.

2.3 Establishing the End Item operating context.

2.4 Identifying RCM study contributing authorities and stakeholders.

2.5 Constructing and verifying the functional model.

2.6 Allocating analysis identification/control numbers.

2.7 Determining the functional and physical analysis boundaries.

2.8 Producing a Zonal Plan.

2.9 Identifying Structurally Significant Items together with their recommended maintenance tasks and associated task intervals.

2.10 Interrogating existing RCM database(s) for suitable templates.

2.11 Collecting supporting documentation and data.

2.12 Forming and training of an analysis team.

2.13 Identifying assumptions and ground rules for the study.

RCM project plan

3 An RCMPP should be formulated to record the exact requirements of the RCM programme. The RCMPP is designed to act as an agenda for RCM planning meetings and to stipulate those requirements, assumptions, responsibilities and data sources that are specific to an RCM programme. The RCMPP will subsequently provide the basis of a binding agreement between the RCM Analysis Stakeholders and formalized during the steering group preliminary meeting. Any subsequent changes to this plan may therefore necessitate a task re-appraisal and further meetings of the steering group. An example template for an RCMPP is provided in Def Stan 00-45, Part 2.

Scope of the RCM programme

4 The scoping of an RCM programme formally identifies the End Item to be analyzed, including any of its variations. It will also identify any ancillary items that are to be excluded from the study. A scoping report containing details such as timescales, resources and training requirements should be produced before commencing the study and may form part of the RCMPP.

End item operating context

5 The End Item operating context is a high level statement of the required capabilities of the End Item, together with an overall description of its constituent systems. It also states the designed environmental operating limitations for each mode of usage. It should be generic and represent the type of End Item for which it has been written, with caveats to show differences between variants. It is to relate to and be developed from the scenarios in which the End Item capability is required. Furthermore, it should identify the maintenance organizations that are available to support the derived maintenance programme. For acquisition projects using ILS, the Use Study should contain the information relevant to the Operating Context.

Identification of RCM study contributing authorities and stakeholders

6 The stakeholders of an RCM study must be identified and recorded in the RCMPP and should include the following:

6.1 End Item specific Project Team (PT).

6.2 Associated Equipment PTs.

6.3 Design Organizations and advisors.

6.4 Specialist support groups.

6.5 Front Line Commands (FLCs).

6.6 Members of the RCM study team.

Any other authorities likely to have a legitimate interest in the subsequent analyses are to be identified and recorded in the RCMPP.

Construction of a functional model

7 The primary functions of the End Item shall be broken down and functional boundaries identified to enable discrete analyses to be conducted. The primary functions of an aircraft are usually represented by its constituent systems as described in the Topic 1 series of Aircraft Maintenance Manuals. Where these manuals do not exist, as in the case of new build projects or the introduction of new equipment, then guidance can be sought from a recognized standard numbering system such as those contained in ASD Specification S1000D.

Allocation of RCM analysis identification/control numbers

8 Each system or asset subject to analysis should be uniquely identified to enable the End Item to be managed effectively. The identification numbers for aircraft systems are derived from the standard numbering system assigned to the system chapter numbers of the Topic 1 Aircraft Maintenance Manuals.

Determination of the RCM analysis functional and physical boundaries

9 The limits of each discrete analysis should be defined with regard to the relevant functional inputs, outputs and interface boundaries (see Chapter 4).

Construction of an end item zonal plan

10 A zonal plan is required to assist in the location of assets and identifying areas where maintenance tasks should be done. It is also used to develop a zonal survey programme. The source of these plans or the parties responsible for producing them shall be detailed in the RCMPP. Guidance on the derivation of a zonal plan is contained in ASD Specification S1000D.

Identification of structurally significant items and their preventive maintenance requirements

11 Structural examinations of an End Item are based on its physical configuration; however, scheduled examinations of an entire End Item’s structure are often impractical due to the complexity of construction. Consequently, the identification of Structurally Significant Items (SSIs) will permit economic tailoring of the maintenance applied to structure.

12 Before an RCM analysis of structure can be done it is necessary to identify all the SSIs within the End Item. Requests for SSI listings, together with their recommended maintenance tasks and associated task intervals, should be made to the Designer through the associated PT. The analysis of structure is considered further in Chapter 9.

Interrogation of existing RCM databases for suitable templates

13 The RCM analysis of common or similar assets may already exist within completed studies of other End Items. The RCM records of such studies may be used as templates and read across, either wholly or partially, to new RCM studies. This approach must, however, be treated with caution and must never be used without proper consideration of the associated operating contexts and failure consequences. When these differ, existing RCM studies can only be used as an aid to identify equipment functions and failure modes.

Collection of supporting documentation and data

14 During the course of an RCM programme, information is required to enable the RCM analyses to be satisfactorily completed. The principal sources of data are described in Table 1, although other sources may also be available.

TABLE 1 SOURCES OF SUPPORTING DATA

DATA	SOURCE
End Item and Analysis Level Operating Contexts	Use Studies.
	Statements of Operating Intent and Usage (SOIU).
	Policy Documents.
	User and System Requirements Documents.
	Technical manuals.
	Manufacturers’ Handbooks.
Functional Partitioning	Equipment operating manuals and procedures.
	Schematic system diagrams.
	Technical manuals.
	Specifications (S1000D, AvP 70, ATA 100 etc).
Failure Reporting	In-service databases such as LITS and WRAM.
	Incident reports.
	Commercial databases.
	Survey reports.
	Maintenance bulletins.
	Equipment users and operators.

Formation of an RCM study team

15 RCM should be conducted on a team basis. The composition of the analysis team should bring together subject matter experts with the following attributes:

15.1 Knowledge and experience of RCM.

15.2 Detailed knowledge of the appropriate End Item design features, installation and where applicable, commissioning.

15.3 Knowledge of how the system or equipment is, or will be, used, operated, maintained and supported.

15.4 Knowledge of the condition of the End Item at overhaul, including an understanding of the actual failure modes, and their effects.

15.5 Specialist knowledge including ordnance, Health and Safety, environmental legislation, regulatory bodies and engineering policy.

15.6 The composition of the team will vary dependent on the specific requirements of each study being done. In particular, detailed knowledge of construction and fatigue theory will be required for the application of RCM to structures. The RCM team should consist of an RCM Programme Manager, an RCM Team Leader and other specialist members who will do individual studies, or provide advice and assistance relative to their specializations as required.

16 The composition of the RCM team and the identity of individuals nominated to provide advice and assistance during the course of the analysis should be identified within the RCMPP.

Assumptions, constraints and ground rules for an RCM study

17 It is necessary during any RCM study to establish, within the RCMPP, those conditions, parameters and constraints that may impact on the results of the study. The following list provides some typical examples of issues that should be considered:

17.1 Current and/or anticipated End Item usage.

17.2 Acceptable levels of reliability and availability.

17.3 Existing and proposed maintenance regimes.

17.4 Required maintenance skill levels.

18 The full list of considerations applicable to a study should be recorded in the RCMPP.

RCM ANALYSIS

19 The analysis process begins with the rational selection of those End Item systems/functions and elements of structure that, potentially, would benefit most from some form of preventive maintenance. The criteria for selecting and prioritizing these systems/functions are based on an assessment of the impact of function loss in terms of safety or environmental issues, operational capability and the cost of repair. Current maintenance and Designer recommendations may also be considered during an analysis. Each selected system/function is then subjected to a Failure Modes and Effects Analysis (FMEA) to determine how it might fail; what the possible causes of failure (failure modes) might be, and the effect that such failures may incur. The FMEA may be supplemented with a criticality analysis to provide the measure of risk associated with each failure mode. The causes of failure, or failure modes, are then subjected to an RCM decision logic process to determine the most suitable maintenance task or tasks. If none are found to be suitable, then redesign or change action will have to be considered. When there is insufficient data available to determine whether a task might be reasonably effective, a conservative approach should be adopted to define the task. The task should then be reviewed at a later date as part of an age exploration programme.

MAINTENANCE TASK CONSOLIDATION AND PACKAGING

20 When all the maintenance tasks for an End Item have been identified, it will be necessary to consolidate and group them into scheduled work packages to form a complete maintenance programme so that optimum availability can be achieved and maintenance costs minimized.

ZONAL AND EXTERNAL SURFACE AREAS ANALYSIS

21 A Zonal and External Surface Area (ESA) analysis is done to develop an area based series of supplementary examinations to monitor the general condition of non-significant structure and those system components that are not addressed by the RCM analysis process. It is also used to determine the detailed examination tasks necessary to assure the integrity of aircraft wiring installations and to address the potential presence of combustible materials in those zones that contain electrical wiring. Zonal and ESA analysis is explained more fully in Chapter 10.

INDEPENDENT AUDITS

22 The purpose of auditing an RCM programme is to verify the following:

22.1 The RCM process complies with the fundamental requirements stipulated in Def Stan 00-45 Part 1.

22.2 The RCM programme recommendations are technically correct.

22.3 The technical descriptions of the recommended maintenance tasks are in accordance with a recognized authoring standard.

23 Auditing an RCM programme is explained more fully in Chapter 14.

PRODUCTION OF MAINTENANCE SCHEDULES

24 When the RCM analysis is complete, the rationalized and packaged tasks are converted into useable maintenance schedules and work cards. They may also be produced as electronic data modules and stored on a maintenance management database, such as LITS or WRAM. The production and maintenance of aircraft Topics 5 maintenance schedules are detailed in JAP(D) 100C-20, Preparation and Amendment of Maintenance Schedules.

MAINTENANCE PROGRAMME IMPLEMENTATION

25 The maintenance schedules derived from the RCM programme should be authorised for use by the responsible PT at the earliest opportunity.

SUSTAINING THE MAINTENANCE PROGRAMME

26 Once a maintenance programme is in use, it will be necessary to monitor and sustain its effectiveness throughout the working life of the End Item.

27 RCM analysis should have virtually eliminated the probability of safety or environmentally related failures. However, there will still be other reported In-service failures that need to be periodically or continuously monitored to make sure that failure rates do not exceed acceptable limits. Indicators of maintenance programme effectiveness are the achieved levels of asset availability and reliability, which should be measured and compared against set targets.

28 There will be occasions during the life of an End Item when the content of its maintenance schedule will need to be re-assessed. The circumstances for such reviews are as follows:

28.1 After a specified initial In-service period when accumulated failure data can be analysed and used to confirm initial predictions.

28.2 When there are changes to the life parameters of items that are replaced or modified at a specified measure of usage.

28.3 On completion of major modification or upgrade programmes.

28.4 When there is a radical change to the operating context.

28.5 When there is the potential to achieve significant savings.

29 The frequency and manner in which a maintenance programme is monitored and reviewed should be defined in the Through Life Management Plan (TLMP). There is no requirement to include the policy for this activity in the RCMPP, although reference to its source should be recorded. Guidance on sustaining a maintenance programme is contained in Chapter 16.

SEQUENCE OF RCM PROGRAMME ACTIVITIES

30 The RCM programme activities essential to the derivation and sustainment of an optimum preventive maintenance programme are schematically illustrated in Figure 1.

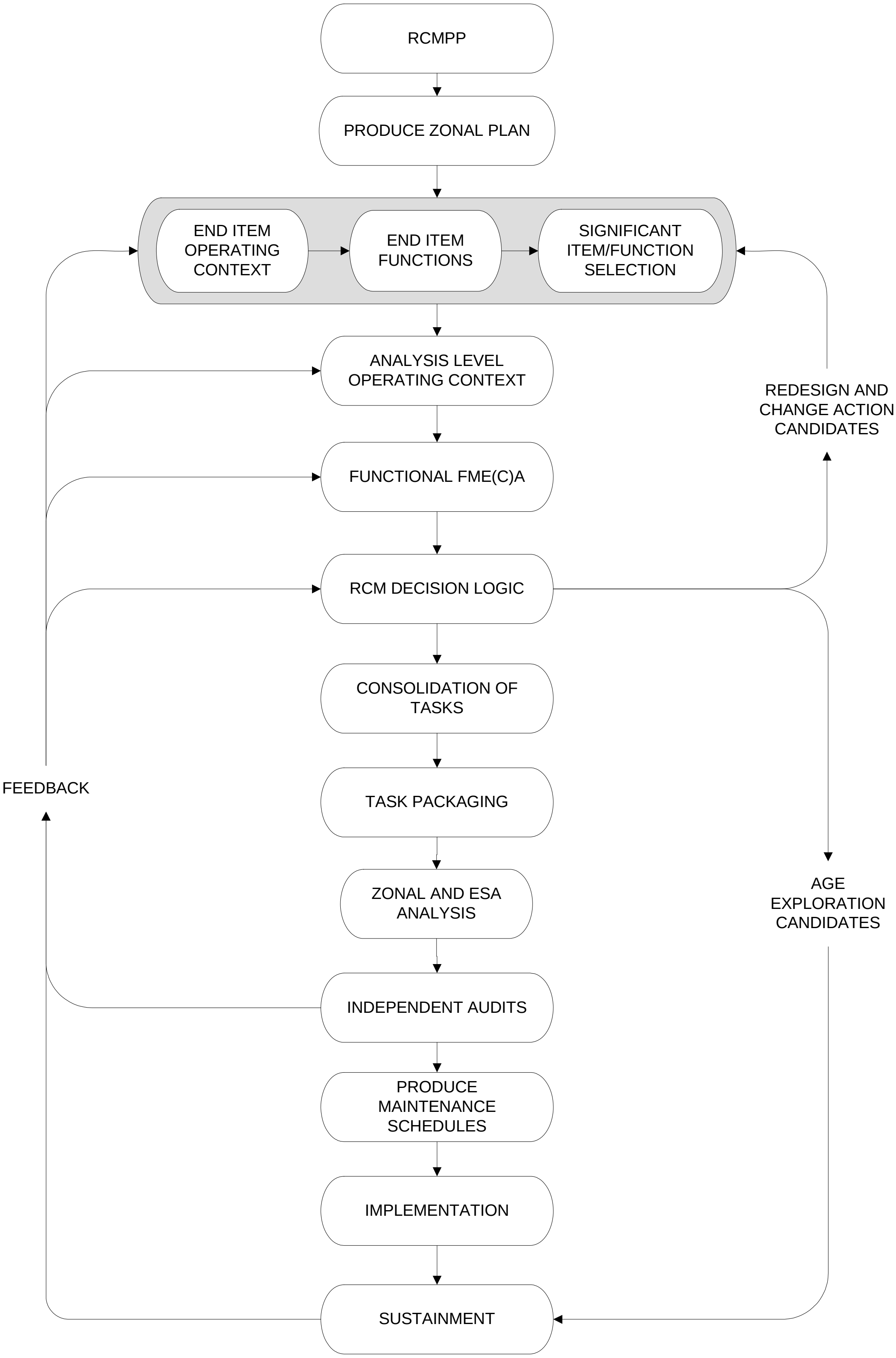


Figure 1 Sequence of RCM programme activities

CHAPTER 3

END ITEM OPERATING CONTEXTS

CONTENTS

Para

PURPOSE

1 The operating context describes the pertinent factors related to the use of an End Item, including a summary of its performance requirements and each of its major embedded systems. The modes of operation should be identified and recorded, together with the organisations available to support the proposed maintenance programme.

DESCRIPTION

2 The operating contexts for an End Item and its major systems will be fundamental to the Functional Partitioning process. More specific and detailed operating context statements will be required to conduct the FME(C)As for individual functions. The operating contexts for the analysis of an End Item's functions must therefore be written in a cascading hierarchy to correspond with the levels under consideration as the study proceeds.

2.1 Operating context statements should identify any system availability requirements associated with prolonged periods of inactivity. Whether these occur during operational or non-operational periods, they must be identified and documented.

2.2 Operating context statements should be regarded as "living" documents and should therefore be sustained throughout an End Item's life. When generating or modifying operating context statements as part of an analysis, type variant, modification state or role changes should be considered and recorded. RCM analyses must take account of these variations as they may cause the results of an analysis to differ. The End Item PT should regularly review and update operating context statements as configuration changes or usage policy and tactical doctrines evolve.

Capability requirements and construction

3 The End Item operating context statement is based on its capability requirements as a whole. It is used to describe the basic construction of the End Item and to define the following operating parameters:

3.1 The physical environment in which the End Item is to operate.

3.2 The specific performance capabilities of the End Item.

3.3 Any variations in End Item type which would affect its capability.

3.4 The primary and any secondary roles that the End Item is required to do.

3.5 Training mission profiles.

3.6 Systems availability requirements.

Engineering disciplines

4 The ability to do forward maintenance on an asset will depend on the resources available, including the capability of its operators and maintainers. For existing End Items this will be determined by the available forward support arrangements. For new projects, the complement of forward personnel may be predetermined, although the maintenance skills that they will require may not be determined until a full RCM analysis has been

completed. Furthermore, forward maintenance may be restricted by operational constraints, such as time limits or facilities. Details of the forward maintenance complement and any constraints should form part of an End Item's operating context statements. These details and the capabilities available at other levels of maintenance should be recorded in the RCMPP.

End item operating context data sources

5 The sources of information required to define the End Item operating context statements may include any of the following:

5.1 Policy Documents.

5.2 End Item Use Study.

5.3 User Requirements Document (URD).

5.4 System Requirements Document (SRD).

5.5 Statement of Operating Intent and Usage (SOIU).

5.6 End Item operating manuals or procedures.

CHAPTER 4

FUNCTIONAL AND STRUCTURAL MODELLING

CONTENTS

Para

Figure Page

INTRODUCTION

1 RCM requires the functional hierarchy and inter-relationships of the systems, sub-systems and elements of structure that constitute an End Item to be modelled and identified at various levels of indenture.

LEVEL OF RESOLUTION

2 The functional model may be resolved to sub-system or sub-sub-system level. For example, a flying controls system may comprise a number of sub-systems such as ailerons, flaps, rudder, elevator and airbrakes. The flaps sub-system may then be resolved to the sub-sub-system level of 'Normal' and 'Emergency'.

3 The overall End Item functionality should be determined using this 'top-down' approach and each of the major systems modelled. The system/functions may include some or all of the following:

3.1 Specific mission and role capabilities.

3.2 Defence measures.

3.3 Motive capability.

3.4 Directional control and manoeuvrability.

3.5 The supply of primary utility services such as fuel, air, electrical power and hydraulics.

3.6 Communication and navigation capability.

3.7 Protection and survivability.

3.8 Control of the operating environment.

3.9 Furnishings essential for safe and effective operation.

3.10 Structure that contributes to airworthiness integrity.

3.11 Accommodation and miscellaneous utility services.

4 The functional model should show a level of resolution suitable for RCM analysis and indicate the boundaries of each discrete system, sub-system or sub-sub-system. A schematic representation of the functional model is shown in Figure 1.

5 The systems breakdown of an end item is normally reflected in the standard numbering system, such as that described in ASD Specification S1000D, which is assigned to the various chapters contained in the Topic 1 maintenance manuals of the end item. For new acquisitions, reference should be made to the systems requirements documents.

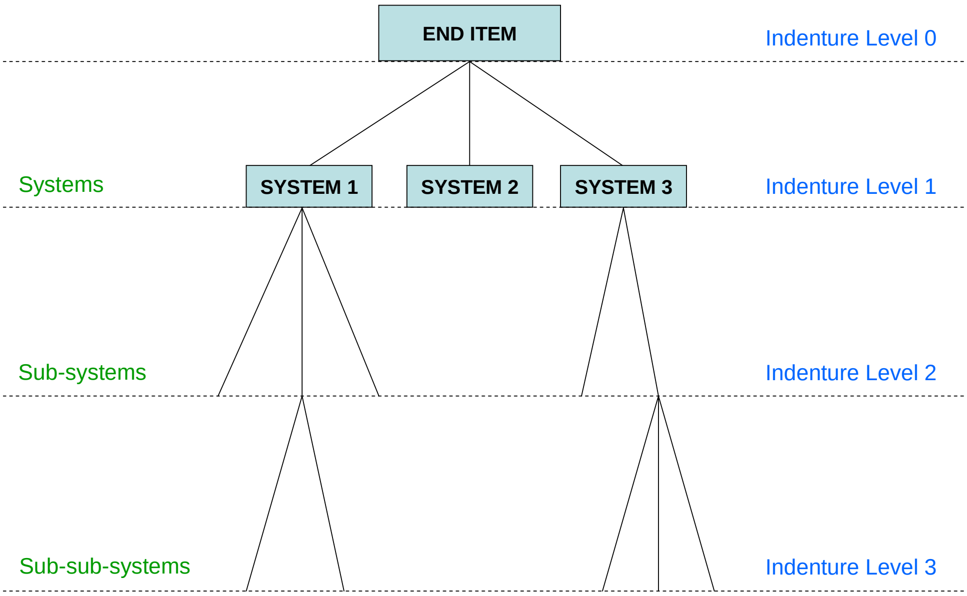


Fig 1 End item functional model

FUNCTIONAL MODEL VERIFICATION

6 Once produced, the model should be verified to make sure that it is complete. This should comprise a check that all the systems and associated sub-systems have been included, by comparison with any suitable configuration documents. For new acquisitions, generic descriptions of system requirements should be used until the design has been finalised.

ALLOCATION OF ANALYSIS IDENTIFICATION OR CONTROL NUMBERS

7 Each discrete system/function identified during the modelling process is to be allocated a unique number, that:

7.1 Identifies it as a higher or subordinate level function.

7.2 Identifies it as belonging to a specific system.

8 These numbers should be assigned in accordance with a standard numbering system, such as that described in ASD Specification S1000D, and may form the basis of a Schedules Identification Numbers (SIN) or a Logistics Support Analysis Control Numbers (LCN) allocated in accordance with Def Stan 00-600.

SELECTING SYSTEM INDENTURE LEVELS AND ITEMS FOR RCM ANALYSIS

9 The advantages, benefits and expediency of an RCM analysis are best realised if the analysis is limited to those systems/functions and areas of structure that are considered significant in terms of their failure consequences: in other words, how much does the loss of a system/function or area of structural integrity matter? A process is therefore needed to determine which systems/functions and areas of structure should be selected for further analysis. Each end item system, sub-system or function is subjected to the selection process shown in Figure 2. A top-down approach is used to select system functions or items for further analysis at the highest possible functional or indenture level, whilst making sure that all the possible functions of the item can be readily identified. Those systems/functions that contribute to the structural integrity of the end item will consist of the major areas of structure that are defined by the end item's standard numbering system. For example and using the numbering system of ASD Specification ASD S1000D, the major areas of structure would be identified as 53-10 Front Fuselage, 55-30 Vertical Stabilizer, 57-10 Centre Wing, etc. Each of these major structural areas will essentially qualify for further structural analysis, which is to be done as described in Chapter 9. Any non-structural function or item that is selected for further analysis, at whatever indenture level, is identified as a Functionally Significant Item (FSI) and analysed in accordance with Chapter 8. The term FSI is also used to identify those non-structural items within a system, or part thereof, which are allocated a maintenance task as a result of RCM analysis.

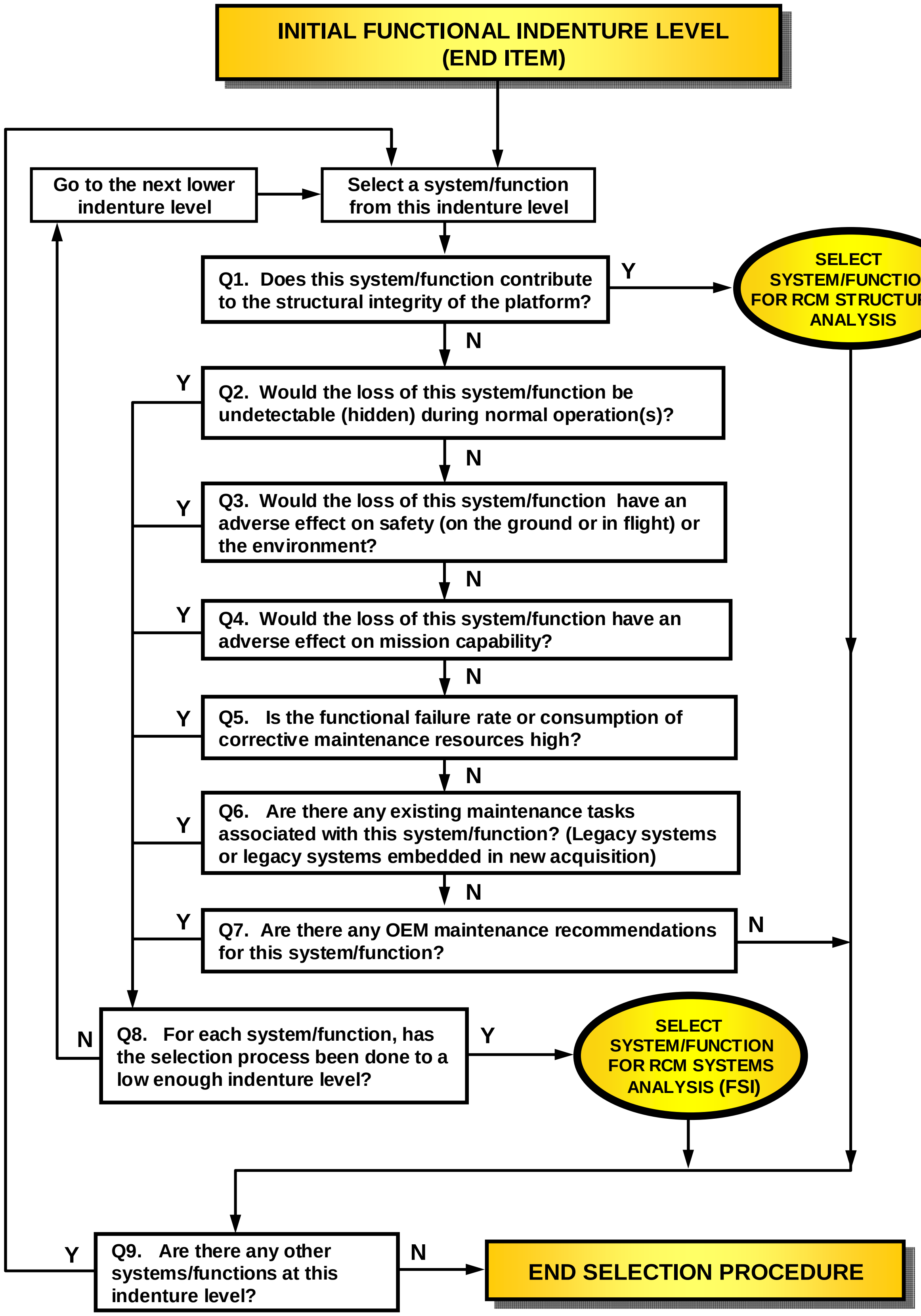


Fig 2 Selecting system indenture levels and items for RCM analysis

10 On completion of functional modelling, each function or item selected for further analysis should be listed in order of importance to prioritise subsequent analyses. The prioritisation activity should consider the following factors:

10.1 Safety.

10.2 Environmental impact.

10.3 Operational necessity.

10.4 Historical upkeep costs.

10.5 Reliability.

10.6 Operational life remaining.

10.7 Maintenance cycle drivers.

11 It should be noted that there are very few systems fitted to an aircraft that would not be selected for further analysis, since most of the systems installed are essential to operational or mission capability. However, limited resources may constrain an RCM programme to those systems which have the greatest impact on safety, availability or cost, should they fail.

12 Initial studies should be done on those selected functions or items identified as most likely to drive the maintenance cycle. These usually relate to major structural examinations or renovations that require the use of deep level maintenance facilities.

OUTPUT

13 The output from this activity should be a verified hierarchical model of selected functions or items, together with their unique identifiers. Each non-structural function or item should be resolved to an indenture level of detail that will enable discrete RCM analyses to be sufficiently thorough.

CHAPTER 5

ANALYSIS LEVEL OPERATING CONTEXTS

CONTENTS

Para

INTRODUCTION

1 RCM analysis requires an understanding of the complete functionality of each of the End Item's systems and how and why those systems can fail. This is best achieved if analysis is targeted at manageable levels. An RCM analysis begins at system level; however, to make sure that all primary and secondary functions are considered, the analysis may need to be done at lower levels of functionality.

2 The analysis level operating context statements are written to precisely define the significant parameters of the functions under review. Every further level of functional breakdown requires an additional operating context statement, amplifying the associated parameters. Specific performance parameters are necessary to clearly determine what constitutes a failure and what effects it will have locally, at system level and on the End Item's capability.

DESCRIPTION

3 Analysis level operating context statements should describe in detail the manner in which each system or level of functionality contributes to the End Item operating context.

4 An analysis level operating context statement should describe the following features and attributes at the level of functionality to be analyzed:

4.1 A brief physical description that includes details of any indication, protection or control mechanisms.

4.2 The micro and macro environmental conditions under which a system or sub-system is operated.

4.3 The availability of any design or operator compensating provisions that will mitigate the consequences of a functional failure; e.g. the existence of any standby systems, built in redundancy or emergency operating procedures.

4.4 The specific performance requirements of each function.

4.5 All modes of operation.

4.6 Any variations in system capability due to type variants or modification states.

4.7 Required system availability.

4.8 Periods of inactivity.

4.9 The requirement for support activities, including the recording of usage or performance data.

4.10 The existence of any operator before or after use checks.

4.11 The presence of any hazardous materials contained in or produced by the system.

4.12 Analysis boundaries.

5 The description of an analysis level operating context will be greatly enhanced if it includes a system diagram. A system diagram may be produced in schematic form as shown in Figure 1 or as a system 'map' that illustrates the interrelationship of system components as shown in Figure 2.

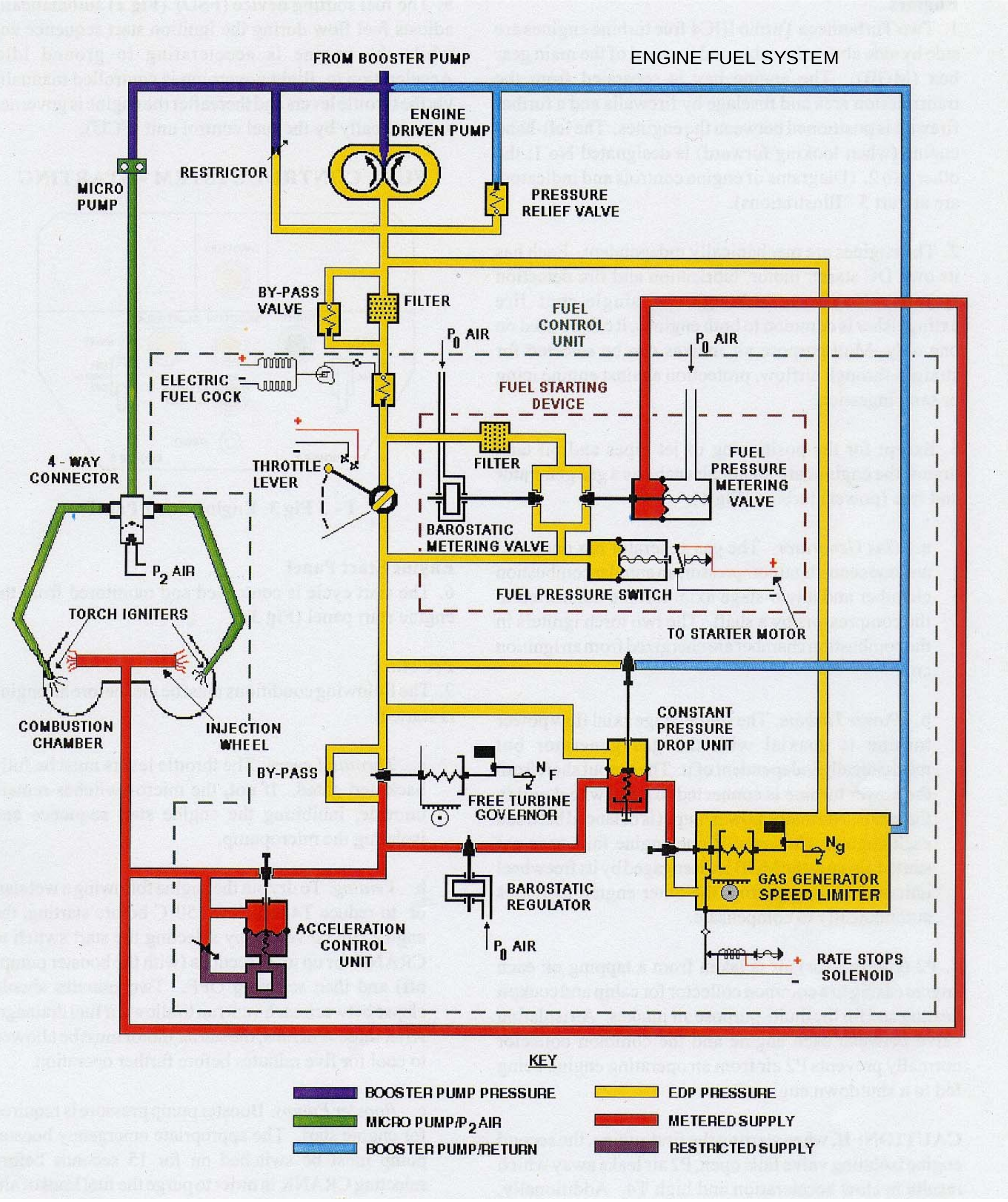


Figure 1 Example of a schematic diagram

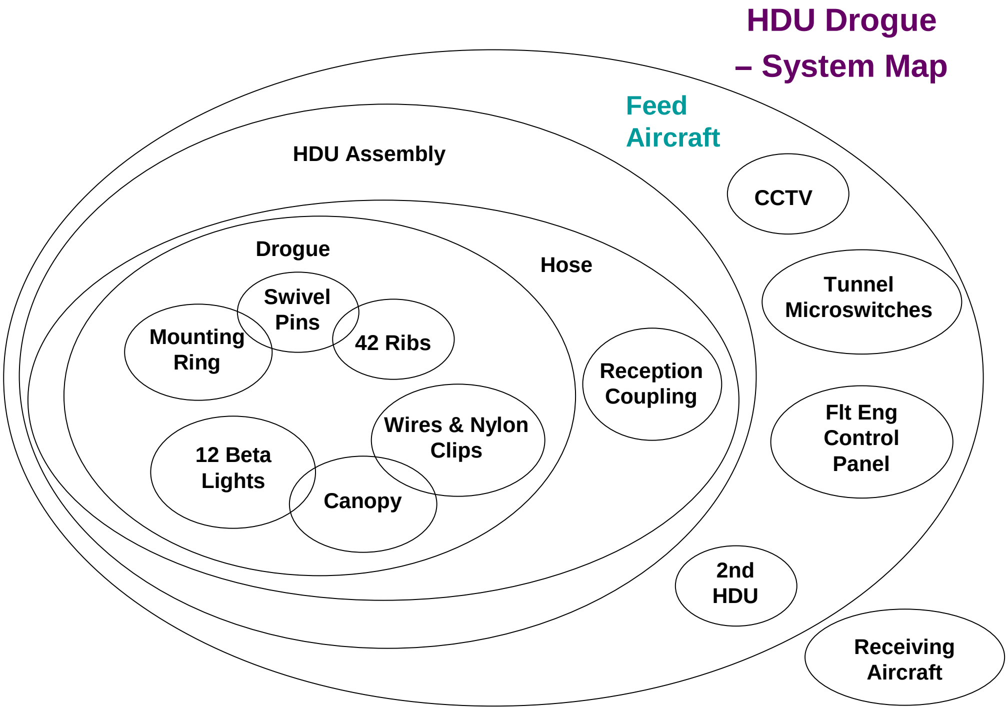


Figure 2 Example of a system map

6 The System Map is a basic Systems Engineering diagram that provides the following benefits during an RCM analysis:

6.1 It assists the RCM analyst to acquire system knowledge (ie, an understanding of the physical 'make-up' of the system).

6.2 It aids production of the system description statement.

6.3 It defines the System Boundary.

6.4 It assists in identifying an appropriate analysis indenture level and in defining Functional statements.

6.5 It prompts the analyst to consider whether failure modes exist for each element of the system.

6.6 It can be used by the RCM analyst to communicate system understanding when inter-acting with the stakeholder community.

ANALYSIS BOUNDARIES

7 The boundaries of each RCM analysis should be defined in the following terms:

7.1 Inputs from other functional elements (these are assumed to be available as required and hence should be analysed separately).

7.2 Outputs that are supplied to other functional elements, which might be analysed elsewhere.

7.3 The physical boundaries of the functional element under consideration (usually shown on a schematic diagram or system map).

SOURCES OF INFORMATION

8 The sources of information used to collate analysis level operating context statements include SRDs, technical publications, users and maintainers. Operating context statements for End Item structures must include details of the design philosophy and any assumptions detailed in the RCMPP.

STANDARD NUMBERING SYSTEMS

9 As already stated, operating context statements cascade down from the End Item to levels of increasing detail that are required to do RCM analysis. Consequently, there needs to be traceability between the End Item, its systems and the levels of functionality to be analysed. The use of a Standard Numbering System (SNS) that uniquely identifies each system and its corresponding subordinate levels of functionality provide this link. A typical SNS for aircraft systems and sub-systems is detailed in ASD Specification S1000D. This numbering system is capable of identifying End Item functionality down to sub-system (three) level; however, lower levels of functionality may be identified by extending the SNS in a manner that is acceptable to the Analysis Sponsor.

CHAPTER 6

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS (FMECA OR FMEA)

CONTENTS

Para

THE FMECA PROCESS

1 A Failure Modes, Effects and Criticality Analysis (FMECA) is used to identify and document the functions, functional failures, failure causes (modes) and failure effects of each level of analysis. Within this process the potential effects of each failure mode are rated according to risk criteria, so that actions to manage the effects of failure can be determined. Furthermore, the manner in which a failure is detected and the existence of any design or operator compensating provisions that could mitigate the effects of a failure should be recorded. If there is insufficient data available to do a criticality assessment, then analysis will be limited to a Failure Modes and Effects Analysis (FMEA).

FUNCTIONS

2 The primary functions described in an operating context provide information on the intended purpose and performance standards of a particular system or sub-system. Functions should not be combined because their consequences of failure and the subsequent selected actions for managing failure may differ. It is essential to clearly define the required performance parameters of each function to establish what constitutes the failed

state. In addition to the analysis operating contexts, information for determining functions may be found in sources such as a System Requirements Document (SRD), maintenance manuals, operating procedures, drawings and discussions with operating crews, maintainers and designers.

Most systems and sub-systems also have secondary functions, which may not always be obvious. Due regard should therefore be given to the following possible requirements:

2.1 Containment.

2.2 Environmental integrity.

2.3 Alarms and warnings.

2.4 Indication.

2.5 Protection.

2.6 Safety.

2.7 Appearance.

2.8 Comfort.

2.9 Control mechanisms.

2.10 Structural Integrity.

2.11 Security of attachment.

2.12 Efficiency/Economy.

Containment

3 Containment is a function of any asset that is used in the storage, transfer, delivery or enclosure of gases, fluids or particles.

Environmental integrity

4 Environmental integrity must be considered if there is a requirement for an asset to operate without breaching any known environmental standards or legislation.

Alarms and warnings

5 Alarms and warnings are used to alert the operator to abnormal conditions and thus allow some form of compensating action to be done. Warnings may also be provided by notices to make individuals aware of potentially dangerous substances, hazards or conditions which exist by design and not as a result of failure.

Indication

6 A means of indication may be required to provide the operating crew with information regarding the performance, condition, status or usage of a system or part thereof.

Protection

7 Protective devices are designed to mitigate the consequences of a failure in one of the following ways:

7.1 By stopping an operation in the event of a failure.

7.2 By eliminating or relieving abnormal conditions that follow a failure.

7.3 By providing an alternative means of operation when a failure occurs (active or stand-by redundancy).

Safety

8 Safety features should make sure that assets function without causing harm to any individual. Protection against injury, contamination or the presence of hazardous substances must be considered.

Appearance

9 Sometimes it is important for assets to be visibly conspicuous, as in the case of those used for display, rescue or survival. Conversely, there are instances when an asset must be inconspicuous and some form of camouflage or concealment is required.

Comfort

10 Lack of comfort for an operator or user can be demoralizing and cause fatigue or distraction, which may diminish operational effectiveness.

Control mechanisms

11 Control mechanisms provide the means by which a function can be governed, including its rate, range or degree of delivery.

Structural integrity

12 Structural integrity is required to sustain defined levels of load bearing capability, including the support provided to any associated assets.

Security of attachment

13 The requirement of an asset to be firmly fixed in position should be considered. For example, the mounting brackets to which a gearbox is attached may be considered as the support function provided by the host structure, whereas the security provided by the gearbox attachment bolts would be considered as a secondary function of the gearbox.

Efficiency/economy

14 The efficiency of an asset must be considered if there is a need to operate within defined cost limitations or performance requirements. Examples of efficiency and economy measures are fuel or oil consumption.

FUNCTIONAL FAILURES

15 A functional failure is defined as the inability of an asset to do a specific function within specified limits. A functional failure may not necessarily cause a complete loss of the function. Partial failures, which lead to a reduced level of performance, should be considered as separate functional failures. Unwanted events such as inadvertent, spurious or undemanded system operations should also be considered as functional failures.

COMPENSATING PROVISIONS

16 Compensating provisions are design features or operator actions that circumvent or mitigate the effects of a functional failure. The FMEA or FMECA should include a detailed description of any compensating provisions associated with each functional failure. These assist in determining the failure effects, severity and consequences in the event of a functional failure.

FAILURE DETECTION

17 Failure detection describes the manner in which the operator is made aware that a functional failure has occurred. Failure detection methods may be provided by design, such as visual or audible warning devices and sensing instrumentation. Operating crews may also sense abnormal phenomena that indicate the occurrence of a functional failure, or provide a warning that failure is imminent. These might include unusual noises, vibration, smoke, or diminished response to demands.

FAILURE MODES

18 A failure mode is the root cause (including human error) of a functional failure. Each plausible failure mode must be recorded in sufficient detail that the most appropriate failure management action can be

identified. For example, root causes of bearing failure such as ‘bearing fatigue’ or ‘lack of lubrication’ are far more useful than ‘bearing failure’, to identify an appropriate maintenance task.

19 It may be sufficient to identify the failure of an asset as being the result of a single failure mode, even though it may have a number of internal failure modes at lower levels of functionality. This is generally recognized as the black box approach and should only be used for Line Replaceable Items (LRIs), which are not subject to a diagnostic procedure on failure, that have no dominant failure modes or do not possess an identifiable wear-out life.

20 Consideration should also be given to potential failure modes that have not yet occurred; those that have not occurred because they are prevented by an existing maintenance activity and those that have occurred, but under normal circumstances would not be evident to the operating crew.

21 Failure modes for assets with an existing service history may be determined from information stored on work recording databases. Test reports; engineering investigation reports, hazardous material reports, and depot estimator and evaluator write-ups are also useful for determining the failure modes. Maintainers and operators with first hand experience of the asset are an essential source of failure information.

22 Failure mode identification on new designs is more difficult. They have to be inferred from the hardware design, general knowledge of how things fail and experience from legacy systems in similar applications. The context in which an asset is operated must be carefully considered when determining the applicability of generic reliability data derived from historic information. The results of fatigue, reliability and qualification tests are extremely useful for assets with or without a service history.

FAILURE MODE INDICATOR

23 At the analysis level, each identified function must be sequentially numbered, which forms the first in a series of characters known as the Failure Mode Indicator (FMI). This links each failure mode to its associated function and level of system functionality. Second in the series is an alpha character, which identifies each functional failure. The last in the series is a number that sequentially identifies each failure mode associated with the functional failure. Typical FMIs might be 1A4, 3B6 or 12D1.

FAILURE EFFECTS

24 Failure effects describe what happens at the following levels of operation when a failure mode occurs:

24.1 Locally at the point of occurrence.

24.2 At the next higher level of functionality (system or sub-system).

24.3 At End Item level.

25 Local effects concentrate specifically on what happens functionally and physically in the location where the failure mode occurs.

26 The next higher level of failure effects will usually concentrate on what happens to the associated system or sub-system and should include an account of any likely secondary damage to adjacent assets. Consideration should also be given to the way in which a failure is detected and to any available compensating provisions. Methods of failure detection and the availability of any compensating provisions may have a significant bearing on the ultimate consequences of failure. For example, flight crew may be given sufficient warning prior to a loss of function and allow evasive action to be taken; or a back-up system may be available to sustain a required function.

27 The end effects evaluate the impact that a failure mode might have on the operational or mission capability of the End Item, including the manner in which safety or the environment might be threatened.

28 Failure effects are based on the occurrence of a single failure mode, only if the resulting functional failure becomes evident to the operating crew. There are occasions, however, when a failure mode remains undetected or hidden, until a second failure occurs. Hidden failure modes can occur in normally dormant protective devices, emergency equipment and systems that provide a back-up or standby capability. The analysis of a hidden failure mode must be extended to include the effects of a second failure, which combine to create a significant multiple failure condition.

29 The failure effects are recorded and used to determine the consequences of failure, so that an appropriate failure management strategy can be developed. Failure effects must be described as if no PM task is in place to prevent or find the failure and that no temporary or improvised action is taken to eliminate or reduce the consequences of failure. This is known as the zero based approach.

30 When compiling failure effect narratives, the use of the Consequence words: Hidden, Evident, Safety, Environmental, Operational or Non-operational should be avoided. Sufficient information should be given to allow individuals not involved in the analysis to form an appropriate conclusion.

31 The recording of effects should not be used to anticipate the outcome of the task analysis. It should only contain information sufficient to allow the consequences of failure and the cost effectiveness of any PM task to be assessed.

EVALUATION OF CORRECTIVE ACTION

32 When recording the end effects of a failure mode within an RCM analysis, an evaluation of the actions required to recover an asset to its normal operating condition should be included. An evaluation should provide the following details:

32.1 A summary of what must be done to restore functionality and repair secondary damage.

32.2 The time taken to restore functionality, assuming all spares, tools, etc. are available. This is known as the Mean Active Repair Time (MART). In cases involving considerable damage, estimates in terms of days /weeks/months will suffice.

32.3 The spares required to restore functionality.

32.4 An estimate of the financial cost of failure, including secondary damage.

32.5 The skill set best suited to do the corrective action and at what depth and line of repair?

32.6 Whether any action can be taken to mitigate the effects of failure, such as imposing limitations on operation, de-rating or doing a temporary repair that allows deferment of full repair to a suitable opportunity.

FAILURE PROBABILITY LEVEL

33 Each failure mode identified in a FMECA is assessed in terms of its probability of occurrence. The RCM process adopts a qualitative approach, whereby failure mode probabilities are grouped into distinct, logically defined levels, as shown in Table 1. These are provided as examples only, since values will vary with the End Item. The actual values adopted by the RCM programme shall be recorded in the RCMPP in accordance with Def Stan 00-45, Part 2. Analysis Managers must, however, be mindful of the probabilities of occurrence defined in safety management plans and of those prescribed in Def Stan 00-600.

TABLE 1 EXAMPLE OF FAILURE PROBABILITY LEVELS

Level	Definition	Probability of Occurrence
A	Frequent	> 1 per 500 measures of operation
B	Probable	< 1 per 500, but > 1 per 5,000 measures of operation
C	Occasional	< 1 per 5,000, but > 1 per 50,000 measures of operation
D	Remote	< 1 per 50,000, but > 1 per 1,000,000 measures of operation
E	Extremely Unlikely	< 1 per 1,000,000 measures of operation

HAZARD SEVERITY CLASSIFICATION

34 Each failure mode should be categorised according to the severity of the hazard that it presents, based on the effects that may occur as a result of a functional failure. A description of severity categories is shown in Table 2. A failure mode may be assigned to more than one category depending on the consequences that need to be considered. For this reason, the types of hazards within each category are divided into Safety (S); Environmental (E); Operational (O) and Cost (C).

35 The alpha character that represents each group is used to specify the type of hazard within each category. For example; a failure mode that prevents an aircraft from taking off, which induces a recovery cost of £15k, but does not affect safety or the environment, might attract hazard severity code of IIO.

36 The worst-case consequences of each category of hazard in Table 2 are provided as examples and may be tailored to suit any RCM programme. However, Analysis Managers must be mindful of the severity categories defined in safety management plans and of those prescribed in Def Stan 00-600. The categories adopted by the RCM programme shall be recorded in the RCMPP in accordance with Part 2 of Def Stan 00-45.

CRITICALITY ANALYSIS

37 The purpose of a criticality analysis is to assess the risk associated with a failure mode occurrence. The degree of risk, or criticality, is a function of the probability of occurrence and the hazard severity of the ensuing functional failure. The risk is quantified by using the criticality matrix shown in Table 3. The probability of occurrence levels and the hazard severity categories are assigned ratings of R_{POC} and R_{HS} respectively. These ratings are factored to produce FR_{POC} and FR_{HS}, where:

$$FR_{POC} = (R_{POC} + 1)$$

and

$$FR_{HS} = (2)^{R_{HS}}$$

38 The degree of risk, or criticality, is derived as the product of FR_{POC} and FR_{HS}, ie:

$$Risk = FR_{POC} \times FR_{HS}$$

39 The risk values are ranked in ascending numerical order and used to determine the criticality indices, as shown within the matrix of Table 3. The use of factored ratings creates a distribution that is biased towards the more critical hazards and failure probabilities. The ranking process also avoids any arbitrary allocation of progressive risk levels.

TABLE 2 EXAMPLE OF HAZARD SEVERITY CLASSIFICATION

CATEGORY	**Safety (S)**		**Environmental (E)**	**Operational (O)**	**Cost (C)**
	Third Parties (Note 1)	First and Second Parties (Note 2)	(Note 3)	Operational Capability	Repair or Recovery Costs
(I) CATASTROPHIC	Single death or multiple serious injuries or severe occupational illnesses	Multiple deaths	Major widespread damage or serious breach of legislation. Ineffective control measures	Loss of the platform or equipment	Greater than £500k
(II) CRITICAL	A single severe injury or occupational illness or multiple minor occupational illnesses	Death or multiple serious injuries or severe occupational illnesses	Noticeable widespread impact on the environment. Control measures minimally effective	Loss of mission capability	Between £200k and £500k
(III) MARGINAL	At most a single minor injury or a single minor occupational injury	A single severe injury or occupational illness or multiple minor injuries or multiple minor occupational illnesses	Minor impact on the environment. Control measures substantially effective	Limited mission capability	Between £10k and £200k
(IV) NEGLIGIBLE		At most a single minor injury or a single minor occupational illness	Little impact. Control measures comprehensive	Minimal disruption to mission capability	Less than £10k

Notes:

1. Third parties are members of the public, or any other persons not a first or second party, who are exposed to a hazard from an End Item or equipment, or their operations.

2. First parties are those persons directly concerned with the operation and immediate support of the End Item or equipment. Second parties are persons concerned with the indirect support of the End Item or equipment operation, or are passengers on board an End Item and who are not involved in its operation or support.

3. The environmental risks are based on definitions within Joint Service Publication 418.

TABLE 3 CRITICALITY MATRIX

		PROBABILITY OF OCCURRENCE				
		(A) **FREQUENT** $R_{POC} = 1$ $FR_{POC} = 2$	**(B)** **PROBABLE** $R_{POC} = 2$ $FR_{POC} = 3$	**(C)** **OCCASIONAL** $R_{POC} = 3$ $FR_{POC} = 4$	**(D)** **REMOTE** $R_{POC} = 4$ $FR_{POC} = 5$	**(E)** **EXTREMELY UNLIKELY** $R_{POC} = 5$ $FR_{POC} = 6$
HAZARD SEVERITY CATEGORY	**(I)** **CATASTROPHIC** $R_{HS} = 1$ $FR_{HS} = 2$	**1** **(risk=4)**	**2** **(risk=6)**	**3** **(risk=8)**	**4** **(risk=10)**	**5** **(risk=12)**
	(II) **CRITICAL** $R_{HS} = 2$ $FR_{HS} = 4$	**3** **(risk=8)**	**5** **(risk=12)**	**6** **(risk=16)**	**7** **(risk=20)**	**8** **(risk=24)**
	(III) **MARGINAL** $R_{HS} = 3$ $FR_{HS} = 8$	**6** **(risk=16)**	**8** **(risk=24)**	**9** **(risk=32)**	**10** **(risk=40)**	**11** **(risk=48)**
	(IV) **NEGLIGIBLE** $R_{HS} = 4$ $FR_{HS} = 16$	**9** **(risk=32)**	**11** **(risk=48)**	**12** **(risk=64)**	**13** **(risk=80)**	**14** **(risk=96)**

40 The magnitude of a criticality index, determines the acceptability of the effects of a failure mode. The values are grouped into levels of acceptability expressed either numerically or alphabetically, as shown in Table 4. However, these may be tailored to suit specific platform requirements. The levels of acceptability and the associated criticality indices should be recorded in the RCMPP in accordance with Part 2 of Def Stan 00-45. As with hazard severity classification and failure probability levels, due regard must be given to the risk levels defined in safety management plans.

TABLE 4 RISK CLASSIFICATION

CRITICALITY INDEX	RISK CLASSIFICATION	INTERPRETATION
1 to 5	**A**	**UNACCEPTABLE** – Failure mode must be subjected to RCM decision logic to determine the action required either to eliminate the possibility of functional failure or to reduce the severity of the possible failure effects to an acceptable level.
6 to 8	**B**	**UNDESIRABLE -** Failure mode must be subjected to RCM decision logic to determine whether some form of preventive maintenance activity is necessary or would be of benefit.
9 and 10	**C**	**TOLERABLE –** Failure mode must be subjected to RCM decision logic to determine whether some form of preventive maintenance activity would be of benefit.
11 to 14	**D**	**ACCEPTABLE –** Failure mode may be subjected to RCM decision logic; however, only simple tasks that require negligible maintenance effort are to be considered, otherwise no maintenance is required.

41 If the hazard severity classification includes the hazard type code S, E, O or C, then these can be used to identify the type of failure consequences upon which the associated criticality index is based. Using the example of an aircraft that fails to take-off, if the failure probability is occasional, then the resulting criticality indices and hazard codes would be 6O, 9C, 12S and 12E.

THE FMEA OPTION

42 Although a hazard severity category might be readily identified with a particular loss of function, there may be insufficient data available to determine a reasonably accurate probability of failure occurrence. This will preclude the possibility of doing a full criticality analysis to derive a criticality index. In such cases the criticality analysis element of an FMECA may be disregarded and the process then becomes a FMEA. If an RCM study elects to omit a criticality analysis and adopts the FMEA approach, then the failure modes of all plausible functional failures must be subjected to RCM analysis.

OUTPUT

43 The output of the FMECA or FMEA is a series of reports that record the details of each stage in the process, i.e. functions, the possible functional failures, their causes and their outcome in terms of local effects, the effects at the next higher level of functionality and their effect on End Item capability. Included in the FMECA is a measure of how critical each failure mode is, based on the severity of the hazard they present and the probability of occurrence. Each of the failure modes identified is subjected to the RCM decision logic to determine the most appropriate and cost effective maintenance actions.

CHAPTER 7

THE METRICS AND CHARACTERISTICS OF FAILURE

CONTENTS

INTRODUCTION

1 The principles of RCM stem from a rigorous examination of the nature of failure. In some cases, the failure mechanism is not fully understood or may occur at random and so for many complex types of equipment preventive maintenance is not possible. Indeed, in many cases, preventive maintenance is not desirable. In order to ascertain which type of preventive maintenance task is relevant, it is necessary to determine:

1.1 How a failure occurs.

1.2 What are the consequences of the failure?

1.3 How effective is preventive maintenance?

However, the overriding element in all maintenance decisions is not the failure of a given item, but the consequences of its failure.

2 It was once assumed that every failure should be prevented; consequently, considerable resources were committed to preventing failures. In many cases, there was little or no benefit from the preventive maintenance and in some instances failures were induced as a result. Overall, resources were often wasted as a result of an ineffective preventive maintenance programme. RCM, however, requires an evaluation of the consequences of failures. Where the consequences are deemed to be significant, then further evaluation is to be done and a maintenance task may be allocated. Within this concept it is possible to develop an optimized scheduled maintenance programme.

3 Certain specific information is nearly always unavailable at the time when an initial maintenance programme is being developed. Consequently, initial decisions must be conservative, erring on the side of caution, and may even be based upon previous experience or similar usage on other equipment. The development of an optimum maintenance programme requires a basic strategy for decision-making and refinement of these decisions once information has been gathered and analysed. The RCM process consists, therefore, of the following steps:

3.1 Selecting significant items, based on their consequences of failure.

3.2 Identifying significant failure modes for each significant item.

3.3 Evaluating the maintenance requirements that will protect each significant item from the consequences of functional failures and selecting only those tasks that will satisfy these requirements.

3.4 Identifying those failure modes for which no applicable and effective task can be found. Modification or other change actions are then recommended as alternative solutions to managing failures.

3.5 Selecting intervals for each derived maintenance task.

3.6 If necessary, establishing an age exploration programme to provide the information necessary to revise initial decisions.

4 An effective PM programme will realize much of the reliability of which the item is capable. However, no form of PM can improve the characteristics that are inherent in the design: if the level of reliability is inadequate, the only recourse is engineering redesign.

QUANTITATIVE MEASURES OF FAILURE

5 There are several common quantitative measures of failure and reliability indices based on the failure history of an asset; however, when interpreting failure data it is necessary to understand clearly the methods for deriving these measures and what each actually represents. The following paragraphs are intended to provide a general guide on how failure characteristics can be expressed and more detailed explanations should be sought from the Def Stan 00-40 series, covering Reliability and Maintainability (R&M).

Failure rate

6 The failure rate is usually expressed as the total number of failures divided by some measure of use such as failures per 1000 operating hours. However, failure rates can also be expressed as a non-dimensional factor. For example, 6 failures in 9000 kilometres can be expressed as 0.667 (ie, 6/9 failures per 1000 km). In this case the dimension is implied rather than explicit. To avoid any ambiguity the dimensions should be stated. It is also important to know the units of measurement (i.e. hours, calendar time, distance or events etc) when comparing failure rates. Failure rate plays a relatively unimportant role in deriving maintenance. The frequency of failure is useful in making cost decisions and in establishing appropriate maintenance intervals where a ‘life’ has been established. However, it conveys no information about the consequences of failure or the tasks necessary to prevent failure.

Mean time between failures

7 The MTBF is another reliability index and is the reciprocal of failure rate; thus, for the example of 6 failures in 9000 km, the MTBF is 9000/6, or 1500 km. It is important to note, however, that the MTBF is not necessarily the same as the average age of failure. For example, consider 50 newly installed engines, 21 of which fail before the first 2000 hours of operation. If these 21 units accumulated 18076 hours, the MTBF of the failed engines is 861 hours; however, the MTBF of the whole sample of 50 units would be expressed as shown in the following formula:

$$\frac{\textit{Accumulated hours of all 50 engines}}{\textit{Total number of failures}}$$

$$= \frac{18076 + (29 \times 2000)}{21} = 3622 \textit{ hours}$$

Unfortunately the MTBF is of little use in determining when a particular engine is likely to fail.

Reliability function

8 With extended operating experience, it is possible to determine the age-reliability characteristics of an equipment type; that is, the relationship between their operating age and their probability of failure. This leads to the establishment of a survival curve, which relates to the following definition of reliability as stated in Def Stan 00-40 Part 7:

‘Reliability is the ability of an asset to do a required function under stated conditions for a stated period of time’.

9 Therefore, the survival curve is commonly referred to as the Reliability Function. A survival curve is more useful than a simple statement of the failure rate, since it can be used to predict the percentage of units that will survive to some given age. Figure 1 represents an example of a survival curve.

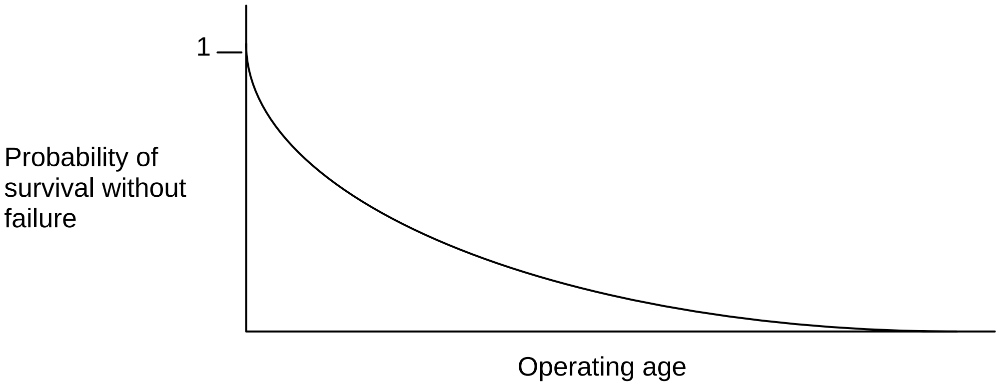


Figure 1 Example of a survival curve

Conditional probability of failure

10 The probability that an asset entering a given age interval will fail during that interval is called the conditional probability of failure. If the conditional probability of failure increases with age, we say that the asset shows 'wear-out' characteristics. Wear-out in this context describes the adverse effect of usage on reliability. Wear-out is often associated with an age limit; however, the effectiveness of these limits in controlling failure rates depends on an increase in conditional probability at higher ages and the probability of survival to those ages. Therefore, the desirability of an age limit on any asset cannot be investigated until there is sufficient operating data to construct survival and conditional probability curves.

AGE RELIABILITY CHARACTERISTICS

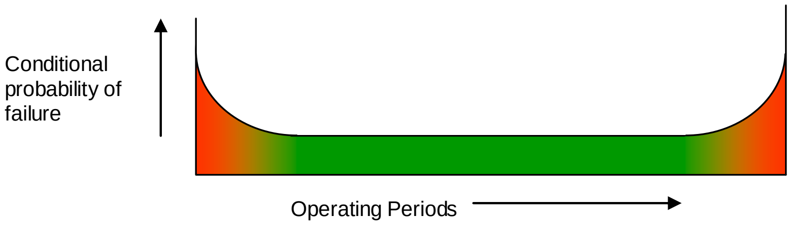
11 Research into failure patterns within the airline industry during the 1970s revealed that the majority of failures in modern complex equipment/systems did not follow the traditional bathtub curve. Figure 2 shows the 6 dominant failure patterns that were found.

12 Further research has shown that these failure patterns also occur within industrial plant, modern merchant ships and warships with advanced technologies.

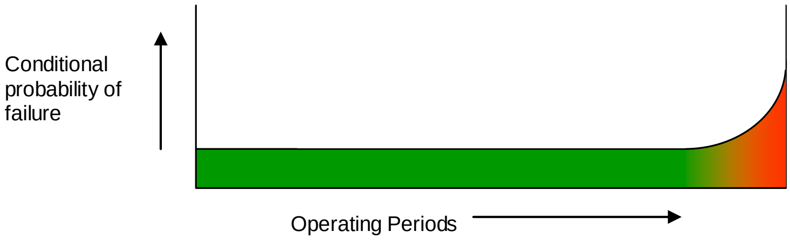
13 It will be seen that the majority of failures are random in nature and would not, therefore, benefit from a preventive maintenance regime based on equipment life or operating age.

14 Only failure patterns A and B exhibit a distinct wear out zone, indicating that failure modes that conform to these patterns would benefit from an age related maintenance strategy. The term “age related” is used to denote a period of exposure to stress, and might be measured in time, distance, events or cycles etc.

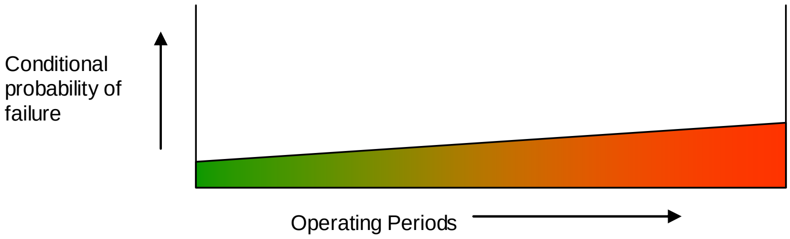
15 The observation that the vast majority of complex assets exhibit no perceivable wear out zone has important implications for maintenance. It follows that, unless the asset has a dominant failure mode that is age related, maintenance around an assumed age limit does little or nothing to improve overall reliability. In the case of pattern F, preventive maintenance would have an adverse effect.



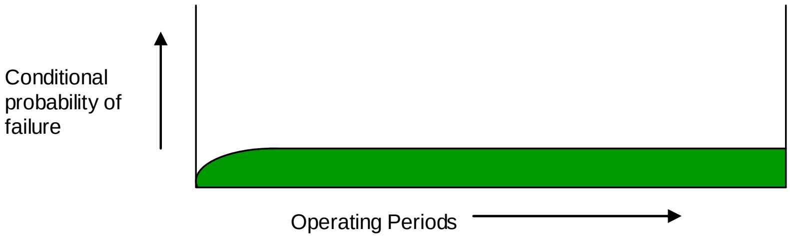
Pattern A – BATHTUB (<5%)
Infant mortality, then a constant or slowly increasing failure rate followed by a distinct wear out zone



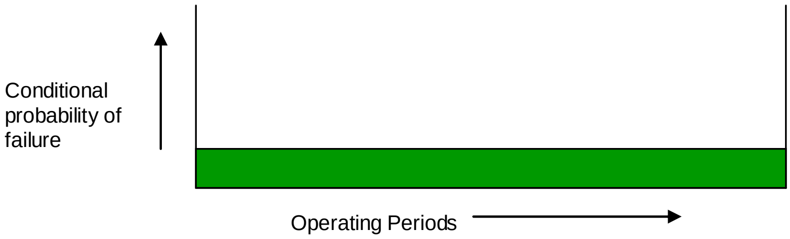
Pattern B – TRADITIONAL (<3%)
Constant or slowly increasing failure rate followed by a distinct wear out zone



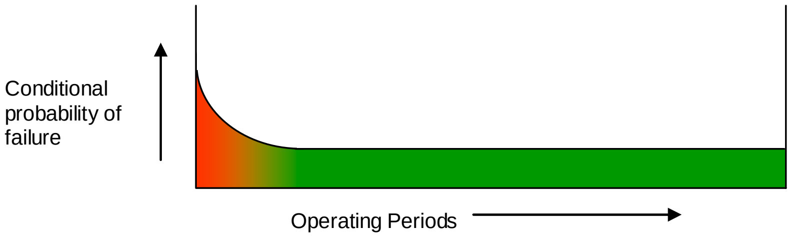
Pattern C (<6%)
Gradually increasing failure rate, but no distinct wear out zone



Pattern D (<8%)
Low failure rate initially, then a rapid increase to a constant failure rate



Pattern E – RANDOM FAILURE (<15%)
Constant failure rate in all operating periods



Pattern F (<65%)
High infant mortality followed by a constant or slowly increasing failure rate

Figure 2 Patterns of failure

CHAPTER 8

RCM DECISION LOGIC

CONTENTS

INTRODUCTION

1 The RCM decision logic process identifies the required actions necessary to avoid or alleviate the consequences of a failure that has a significant effect on safety, operational capability or cost. On completion of the FMEA or FMECA, each of the identified failure modes is subjected to the RCM Decision Logic Algorithm, which is shown in Figure 1.

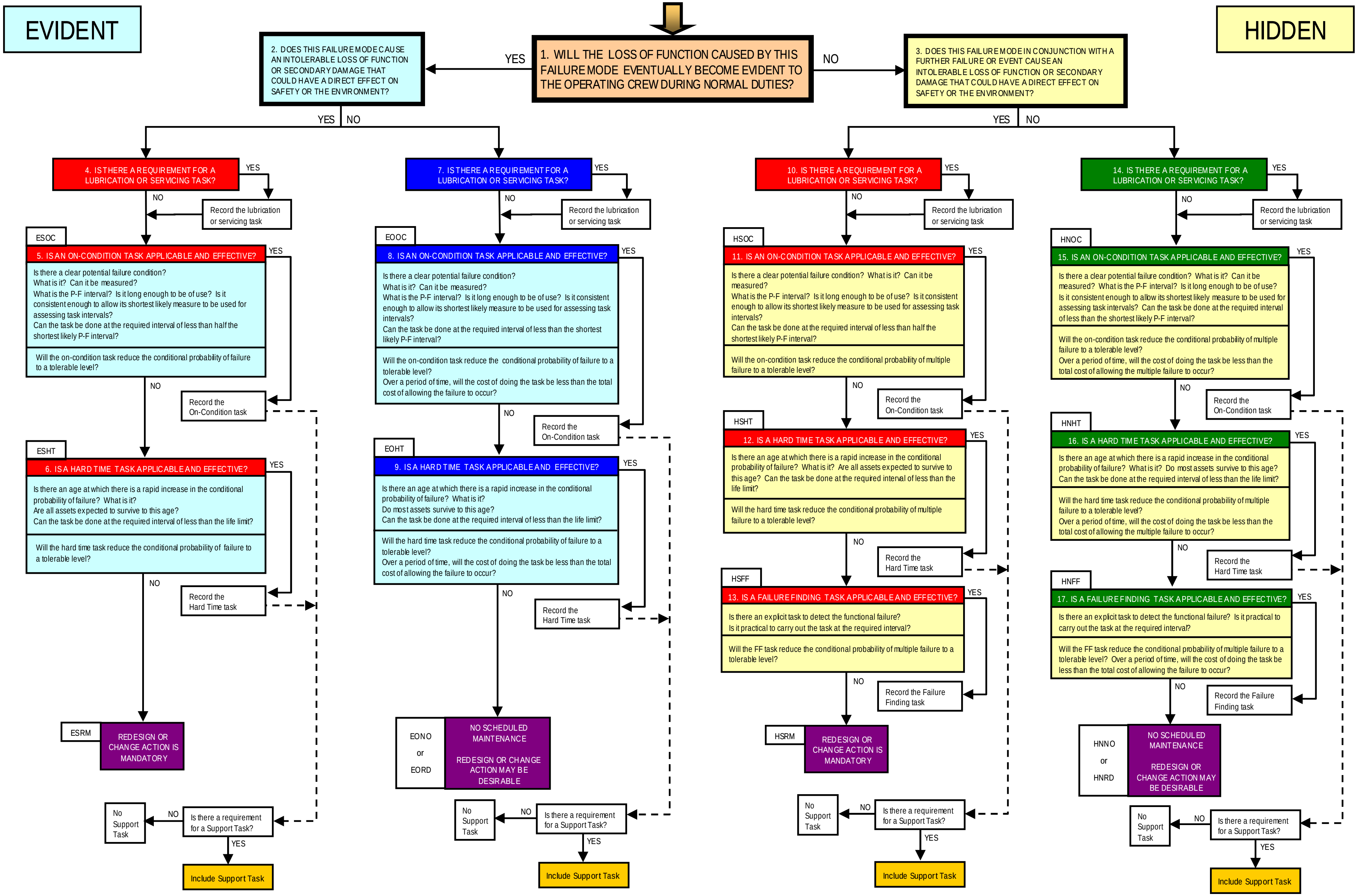


Figure 1 RCM decision logic algorithm

FUNCTIONAL FAILURE CONSEQUENCE ANALYSIS

2 The first three RCM decision logic questions in Figure 1 determine the consequences of each functional failure. A failure consequence is categorized under one of the following headings:

2.1 Evident Safety (ES).

2.2 Hidden Safety (HS).

2.3 Evident Operational/ Economic (EO).

2.4 Hidden Non-safety (HN).

3 The consequences of each failure identify which branch of the decision diagram to follow during task evaluation. Furthermore, the failure consequences also determine the criteria during task selection for task applicability and effectiveness, which is dealt with more fully later in this chapter:

Question 1

4 Will the loss of function caused by this failure mode eventually become evident to the operating crew during normal duties? For functions that are activated during flight, the flight crew or pilot would be the operator. For functions that aid ground support activities, such as those related to loading/unloading equipment, then the personnel responsible for operating the equipment would be the operator. For a functional failure to be evident, failure indications must be obvious to the operator during normal duties, without special monitoring. Normal duties for the flight crew are those procedures typically done during flight to complete a mission. Operational checks of systems during flight are considered valid methods of detecting failures if the checks are part of normal procedures. Flight crews operate some systems full time, others once or twice per flight 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 and therefore cannot be classified as 'normal' duties. The functional failure of an item is considered hidden from the operator if any of the following situations exist:

4.1 The item has a function that is normally active whenever the system is used, but there is no indication to the operator when that function ceases to be available.

4.2 The item has a function that is normally inactive and there is no prior indication to the operator that the function will not be available when called upon. The demand for active performance will usually follow another failure and the demand may be activated automatically or manually.

4.3 Infrequently used items may have evident functions but because the level of utilization is low, functional failures may go undetected until they are required; e.g., the missile system of an aircraft may have suffered an evident functional failure which will remain undetected until the system is required to do its intended function: therefore, if an item is infrequently used its function can be considered to be hidden.

Question 2

5 Does this failure mode cause an intolerable loss of function or secondary damage that could have a direct effect on safety or the environment? Consider this question for those functional failures that resulted in a 'Yes' answer to Question 1. Refer to the failure effects and compensating provisions provided by the FMEA or FMECA to assist in answering this question. Further guidance in answering this question is provided as follows:

5.1 To determine the effect on operating safety, consider not only the loss of the function, but also the effects of any possible secondary damage.

5.2 Each functional failure must be assessed to determine if there is a 'direct adverse effect on operating safety'. This means that the functional failure must have an impact on safety by itself, and not in combination with other functional failures.

5.3 The phrase 'adverse effect' means that the direct consequences of the loss of function are extremely serious or possibly catastrophic. During design, failures that cause the immediate loss of a vital function must be carefully identified. Most of these failures will be anticipated prior to service and there should be few failures that can have a 'direct adverse effect on operating safety'.

5.4 The functional failure must affect a function that is not protected by a redundant capability or protective device. That is, if the function is protected by a redundant capability or by a protective device, then its failure is considered not to have a direct adverse effect on operating safety.

Question 3

6 Does this failure mode in conjunction with a further failure or event cause an intolerable loss of function or secondary damage that could have a direct effect on safety or the environment? This question is asked for each functional failure which has a 'No' answer to Question 1. Consider this question in the same manner as Question 2, except that the effect of the single failure does not become apparent until a further failure or event occurs. Secondly, if the hidden failure by itself does not have an adverse effect on safety, consider the effects of the failure in combination with another failure; this additional failure must be in a related system to the system in which the hidden failure occurs. If another (Combined) failure is identified, record this failure in the record of analysis. A 'No' answer indicates the failure has hidden non-safety failure consequences involving economic or operational effects.

Analysis of redundant, emergency or standby systems

7 Redundant, emergency or back-up systems should be analysed independently, because single failures within these systems are not necessarily hidden and may have a direct effect on safety or operational capability. For example, consider the effects of the inadvertent operation of an ejection seat or the secondary damage that might ensue following the fatigue failure of a pressurised gas bottle or accumulator.

TASK AND DEFAULT ACTION EVALUATION

8 After the consequences of each functional failure have been determined, each failure mode is evaluated to determine if there is a requirement for a lubrication or servicing task. The evaluation then continues to determine whether a further RCM task is applicable and effective. This is accomplished by answering the remaining relevant questions of the RCM decision diagram shown in Figure 1. For each consequence of failure, consider potential PM tasks in the order presented in the algorithm.

APPLICABILITY AND EFFECTIVENESS CRITERIA

9 Wherever justified by the physics of failure, a PM task that can eliminate the probability of a functional failure or reduce it to a tolerable level should be selected, provided it meets the following criteria:

9.1 It is relevant and applicable to the characteristics of the failure mode.

9.2 It reduces the probability of failure to a tolerable level.

9.3 It is cost effective.

9.4 It addresses the root cause of the associated functional failure.

10 The applicability and effectiveness of each PM task must match the criteria set for the possible failure consequences as detailed in the RCM algorithm. Specific tolerable failure rates and probabilities of a multiple failure (for hidden failures) must be established prior to analysis. If the consequences of failure are safety or environmental related, then the tolerable probability of failure may be stipulated within a regulation such as airworthiness requirements or the criteria set in a Safety Management System (SMS). The tolerable probability of failure rate might be reduced further than required, by adopting the principle of As Low as Reasonably Practicable (ALARP). If the failure consequences impact on operational or mission capability, the PM task must reduce the rate of evident failure or the probability of multiple failures, to a level that is acceptable to the operating authority. In addition, this must be achieved at a cost that is less than that incurred by allowing failure to occur. If the failure consequences do not affect operational or mission capability, the PM task must be cost effective.

LUBRICATION AND SERVICING TASKS

11 Lubrication and servicing tasks are determined by design and not failure. Lubrication tasks are determined by the Original Equipment Manufacturer (OEM) or Designer to meet functional requirements and should not be changed without their approval. Servicing tasks include the expected replenishment of

consumables and simple preparation and recovery tasks. There are no applicability and effectiveness criteria for lubrication or servicing tasks.

ON-CONDITION TASKS

12 On-condition (OC) tasks are those that enable the detection of a condition which indicates the imminent occurrence of a functional failure. The operating age when this identifiable condition occurs is shown as point P in Figure 2 and is known as the point of potential failure. The major benefit of an OC task is that it allows an item to realize most of its useful life.

On-condition task applicability

13 For an OC task to be applicable, the following criteria must be met for each failure mode considered:

13.1 There should be a clearly defined and identifiable phenomenon which indicates a potential failure.

13.2 The time interval between such phenomena becoming detectable and the functional failure occurring (the P-F interval) must be measurable.

13.3 The P-F interval, minus the OC task interval, must be long enough for action to be taken to avoid or reduce the consequences of the failure.

13.4 If there is variation between the P-F intervals, the shortest likely interval is to be used to determine OC task intervals.

13.5 It must be feasible to do an OC task at the required interval.

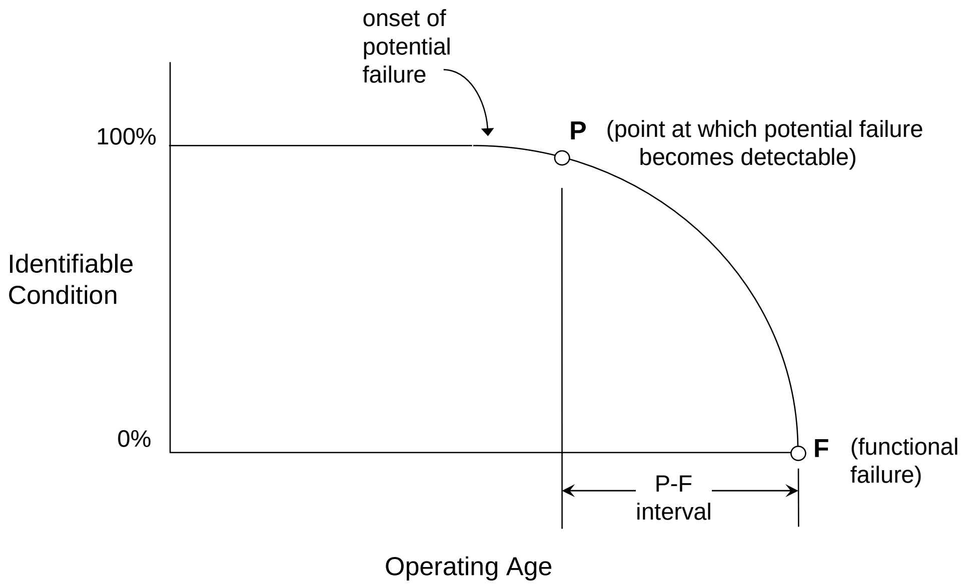


Figure 2 On-condition task considerations

Types of on-condition task

Crew or operator monitoring

14 Routine tasks to monitor system performance may be included in operating crew duties. Examples of such tasks are the routine checks of gauges and meters, whereby a potential failure condition will become evident before a functional failure occurs. These tasks will be done in accordance with aircrew operating manuals and should not be generated as a result of using RCM to develop a maintenance programme. The initiation of warnings or alarms should not be considered as on-condition crew monitoring, since these devices are intended to indicate that a functional failure has actually occurred (point F in Figure 2). Crew monitoring activities are not to be included in aircraft preventive maintenance schedules.

General visual examinations

15 General visual examinations are used to detect relatively obvious signs of accidental or environmental damage and they do not require the use of Remote Visual Aids (RVAs) (magnifiers, boroscopes, intrascopes etc).

Detailed examinations

16 Detailed examinations are directed to specific items to detect discrete failure modes such as structural cracking or chafed electrical cables etc. The use of enhanced lighting or an RVA may be required.

Special detailed examinations

17 Special detailed examinations are done by suitably qualified technicians and involve the application of specialist techniques such as Non-destructive Testing (NDT).

Functional tests and checks

18 Functional tests and checks are done to assess an item’s functional performance level or physical condition against a specified value to determine whether it can continue in service.

Condition monitoring

19 The types of scheduled maintenance OC tasks described thus far usually result in a single outcome - pass or fail. The exact condition of the item during examination or test is not normally recorded and therefore previous test results are not available to permit any form of failure prediction further than when the next maintenance is due. Condition monitoring is used to either periodically or continuously measure an item’s condition or performance level. The condition or performance data may be recorded and then analysed to provide a prognosis on the future condition of the item, thus allowing the expected continued use of the item to be assessed. The results of condition monitoring can also used to determine specified life limits, when items are removed from service for bay maintenance or overhaul. In cases where a reduction in performance or resistance to failure is detected, it may be possible to allow continued use of the item; however, this will normally require an increase in the frequency of condition monitoring and/or a de-rating of the item’s functional capability. Examples of periodic condition monitoring are wear debris monitoring and spectrometric oil analysis. Condition monitoring may be done on a sampling basis to establish the maintenance policy for an item.

20 The condition of an item may be continuously monitored while the associated system is in use. This type of condition monitoring employs the use of sensors and measuring devices to obtain data on an item’s condition or performance. The data may relate to physical phenomena or electrical values. Evaluation of the data may be instantaneous to indicate the functional status of the item to the operating crew; for example, systems that employ continuous or interruptive Built in Test Equipment (BITE). Alternatively the data may be stored and downloaded via an interface so that it can be evaluated remotely at a ground station; for example, the down loading of data from a Health and Usage Monitoring System (HUMS).

On-condition task intervals

21 In all cases, the interval between OC tasks must be less than the shortest likely P-F interval, in accordance with the applicability criteria detailed in the RCM Decision Logic Algorithm. If the consequences of failure are safety or environmental related, the task interval must be less than half the shortest likely P-F interval and assure the detection of potential failure.

22 The frequency at which an OC task is done will be influenced by the method used to detect item degradation. Specialist techniques such as NDT or thermography can be used to detect potential failure at an early stage, thus extending P-F intervals. The use of health monitoring systems or BITE can provide an

automated and continuous method of monitoring an item's condition while it is in use, although it may be necessary to schedule a maintenance activity to retrieve performance data for analysis. In all cases, the techniques used should be cost-effective. Trend analysis can be used to interpret this data and help predict when an item is likely to fail.

HARD TIME TASKS

23 Hard Time (HT) tasks are those that restore a condition or replace a component at a specified life to prevent or reduce the probability of a functional failure. If an HT task involves the replacement of a component that can be reconditioned so that its resistance to failure can be restored to an acceptable level, then the task is categorised as an HT restoration task. If an HT task involves the replacement of an item that cannot be physically or economically restored forward, then it is categorised as an HT discard task. In this case the removed item is scrapped disposed of in an appropriate manner.

HT task applicability

24 For an HT task to be applicable, the following criteria must be met for each failure mode considered:

24.1 There must be a clearly defined life at which there is a rapid increase in the probability of failure; eg, those derived from reliability statistical analysis or testing.

24.2 If a failure is evident, the defined life must make sure that the probability of failure is tolerable. However, if the consequences of failure affect safety or the environment, then the defined life must be one below which no failures are expected to occur.

24.3 If a failure is hidden, the defined life must make sure that the probability of the associated multiple failure is tolerable. However, if the consequences of multiple failure affect safety or the environment, then the defined life must be one below which no failures are expected to occur.

HT task intervals

25 In all cases, the interval between HT tasks must be less than the defined life of the item concerned in accordance with the applicability criteria detailed in the RCM Algorithm. For failure modes with safety or environmental consequences, the HT task interval must be short enough to expect all items to survive during that interval. For all other failure modes, the HT task interval must be short enough to reduce the probability of failure to a level that is acceptable to the operating authority.

FAILURE FINDING TASKS

26 The failure of a normally dormant protective device or standby system is classed as a hidden functional failure. However, if such failures remain undetected then the functions they provide will not be available should the need arise. In other words, a hidden functional failure increases the exposure to a potential multiple failure. A Failure Finding (FF) task is used to detect a hidden functional failure that has already occurred, but which is not evident to the operating crew. Thus, FF tasks are used to reduce the probability of a multiple failure to an acceptable level. An unexpected event or infrequent condition that invokes the need for a specific function can be treated as one of the elements of a multiple failure.

FF task applicability and effectiveness

27 For an FF task to be applicable, it should be capable of detecting whether the loss of function under consideration has occurred, without risking the consequences of a multiple failure. The effectiveness of an FF task will depend on the consequences of a multiple failure. If the consequences have an impact on safety or the environment, then the FF task must reduce the probability of a multiple failure to a tolerable level. If the consequences have an impact on operational capability or incur high repair costs, then the FF task must be cost effective and reduce the probability of a multiple failure to an acceptable level.

28 Invariably, an FF task is a check to verify that a hidden function is available, usually by operating the associated system or sub-system itself (eg, emergency undercarriage, secondary power supplies, ram air turbine etc). However, the operation of a system that employs one-shot devices, such as explosive initiators is clearly not practicable. In such cases, the serviceability of each element of the system must be verified during an analysis, thus verifying the availability of the system as a whole. In practice this involves doing electrical

resistance and continuity tests of the system with the initiators disconnected. This will verify that an adequate electrical power supply is available to the initiators when the system is operated. In addition, the initiators themselves will be allocated a safe-life during which no failures are expected to occur. Consideration should also be given to the possible failure modes of the remaining system elements (these may include the failure modes of items such as fire extinguishers, pipelines, spray nozzles, indicators, gas bottles, mechanical operating devices, flotation bags, cable cutters etc).

FF task intervals and hidden function availability

29 The frequency at which an FF task is done will influence the level of availability that is provided by a hidden function. Consider Figure 3, in which a hidden function fails (for whatever reason) once in a 500 flying hour cycle. The example is based on the assumption that the failure occurs after 100 hours, but it could have occurred at any point in the 500 hour cycle. This suggests that the more often a hidden function is checked, the higher its overall availability will be; however, it is usual to decide a tolerable level of unavailability for the item and then determine the frequency of the FF task (% unavailability = 100 - % availability).

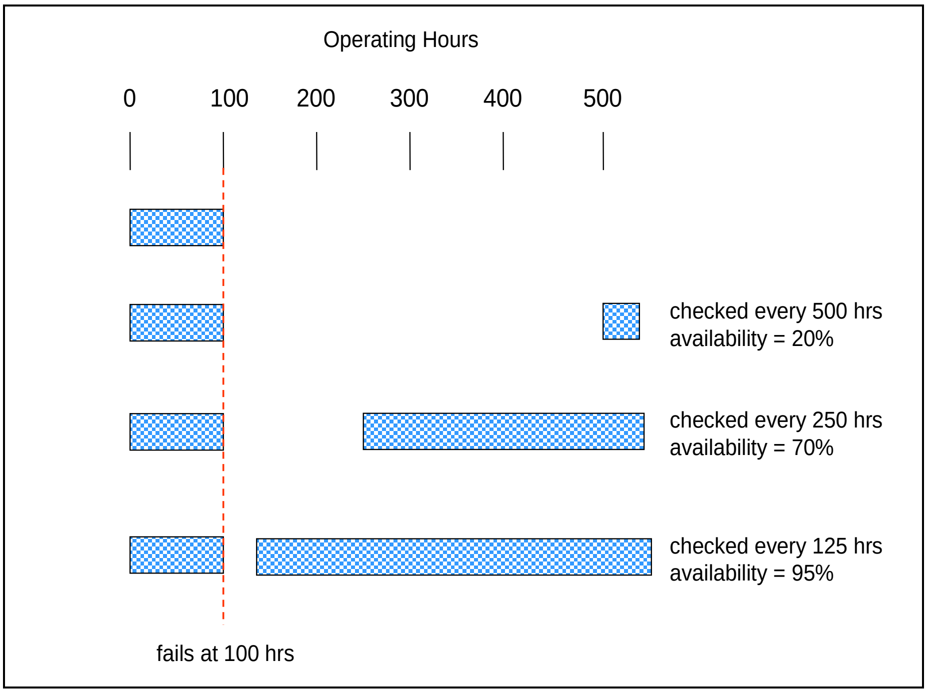


Figure 3 Example of hidden function availability

30 The expected availability can sometimes be approximated by assuming the age-reliability relationship to be exponential with respect to operating age. Note that this is a conservative assumption. Thus, the survival probability curve is as shown in Figure 4.

31 An end item component can have numerous failure modes and each failure mode could follow a different failure distribution. However, when looking at combined end item components, i.e. a system, the distribution tends to follow a pseudo-exponential distribution (Drenick's theorem). This phenomenon allows the derivation of an average availability without making reference to components reliability. It should be noted that the exponential distribution has no memory, and the probability of completing a frequency of say 500 hours is the same as completing a further 500 hours. But, completing 1000 hours would be different.

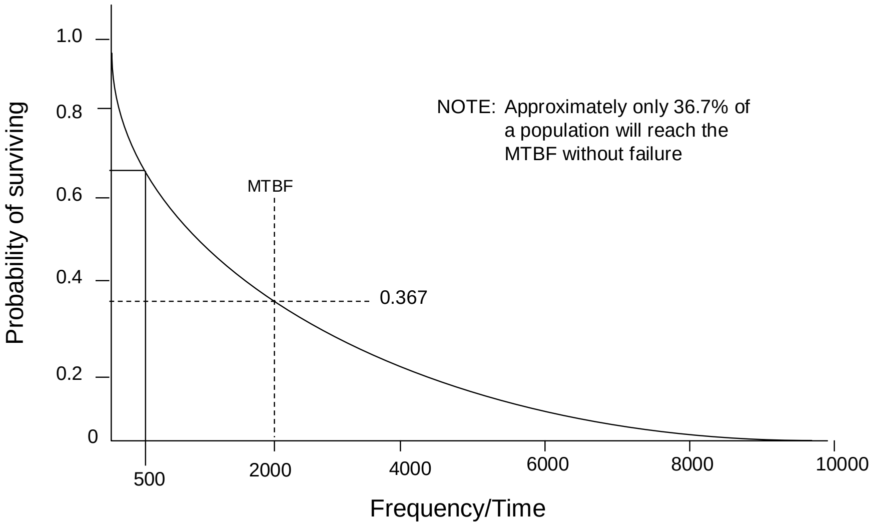


Figure 4 Exponential age-reliability relationship

The probability of survival is calculated using:

$$P(Survival) = \exp\left(\frac{-t}{MTBF}\right)$$

Using the above formula with an MTBF of 2000 hours and a frequency of 500 hours, would give a 78% probability (See Figure 4):

$$P(Survival) = \exp\left(\frac{-500}{2000}\right) = 0.78$$

The relationship between the frequency and the MBTF can be used to calculate an average availability: Using the following formula the above values would give an average availability of:

$$AverageAvailability = \frac{1+\exp^{-r}}{2}$$

$$= \frac{1+\exp^{-0.25}}{2} = \frac{1+0.78}{2} = 0.89$$

32 It can be seen that r = 0.25 and relates to 25% of the MTBF. This is simply the time or frequency divided by the MTBF. Thus a percentage of the MTBF can be used to calculate a required availability of the hidden function. The following table presents the results of this calculation using a few values of 'r':

TABLE 1 FAILURE FINDING INTERVAL (FFI) AS A FUNCTION OF AVAILABILITY

Required availability of the hidden function	99.5%	97.5%	95%	93%	91%	89%
FF frequency (as % of MTBF)	1%	5%	10%	15%	20%	25%

33 When using the above table, it is first necessary to establish the required availability. When safety is not affected, an availability of 95% is often used; however, this might not be cost effective and it may be necessary to consider a lower availability. It can be seen from Table 1 that for required availabilities of 95% or more, the failure finding intervals for the hidden function (As a percentage of MTBF) are twice the equivalent unavailability percentages. For example, the unavailability percentage for a 97.5% required availability is 2.5%. The failure finding interval as a percentage of MTBF is twice that, i.e., 5%. This linear relationship is known as the linear approximation to the exponential survival distribution and is valid for any level of availability between 95% and 100%.

Determination of FF task intervals for safety hidden functions

Observed MTBF

34 A system MTBF can be found in numerous ways, the easiest is to be told what it is by the Designer, others involve data sentencing and demonstrations, whilst another is to look at what is happening in real life. Data sentencing and demonstrations take time and expertise not readily available and to be told the MTBF is an obvious choice. Lessons have shown that predicted MTBFs are rarely demonstrated and should only be used in deriving a Failure Finding Interval (FFI) when an observed MTBF is not available. The measure of an observed MTBF is simply the total usage time divided by the number of failures.

Deriving the FFI

35 Detail on how to derive an FFI using system MTBFs is best done by walking through an example, as follows:

> During the maintenance schedule revision of a combat aircraft, it was discovered that over a sample period of 4 years there had been two reported incidents when the normal undercarriage lowering system had failed to operate. The emergency lowering system had been successfully activated and throughout the fleet there had been no failures discovered during routine testing of the emergency system. The fleet consisted of 50 aircraft and the average annual flying rate was 300 hours per aircraft. Expected availability of the systems is not to be less than 98%.
>
> One of two formulae can be used; the first is known as a Risk-biased formula:
>
> $$FFI(Risk) = \frac{2 \times M_{TIVE} \times M_{TED}}{M_{MF}}$$
>
> Where:
>
> M_{TED} =Protected System MTBF
>
> M_{TIVE} =Protective System MTBF
>
> M_{MF} =Acceptable Risk of Multiple Failure
>
> From the above example, the total usage divided by failures for Protected System is:
>
> $$M_{TED} = \frac{4 \times 50 \times 300}{2} \text{ =30000 hours}$$
>
> For the Protective system, as there have been no failures and to allow for division, a default of 1 failure is used. This means that the system has an MTBF of at least:
>
> $$M_{TIVE} = \frac{4 \times 50 \times 300}{1} \text{ = 60000 hours}$$
>
> For combat aircraft the accepted cumulative probability of a safety related failure is normally 1 in a million = 10^{-6}, so:
>
> $$FFI(Risk) = \frac{2 \times 60000 \times 30000}{1000000} \text{ = 3600 hours}$$

This may seem extreme, but equipment usage does vary and if the frequency exceeds the Major servicing then the task should be done during the Major servicing. Of course by definition the formula uses a level of risk and this level can be adjusted to suit the users acceptable level. Normally for combat aircraft this is 1 in a million (10^{-6}) and for transport aircraft it is 1 in 10 million (10^{-7}).

The second formula is known as the Availability formula:

$$FFI(Availability) = 2 \times M_{TIVE} \times U_{TIVE}$$

Where:

M_{TIVE} =Protective System MTBF

U_{TIVE} =Unavailability of Protective Device

Given that the user wants the system as a whole to be available 98% of the time; then using the above figures:

$$FFI(Availability) = 2 \times 60000 \times (1 - 0.98) \text{ = 2400 hours}$$

There are now 2 solutions to the problem where the higher frequency must always be the choice. Nevertheless, when only an Availability FFI is required, the risk-based calculation must also be done using the appropriate 10^{-6} level of risk. Then if the Risk-based FFI is less than the Availability FFI the risk is to be adjusted until the answers match; this then will reflect the level of risk that the availability formula is taking and informs the user. The Risk-based FFI can be used on its own.

Influence of total test time on FF task interval

36 Because of the high reliability levels built into the safety related systems of modern aircraft, the number of associated failures likely to occur is extremely low. Calculation of the failure finding task interval is therefore largely dependent on the total test time, since this in turn will influence to a high degree the values of the MTBFs as well as the acceptable degree of unavailability for the back-up system or protective device. Total test times that are relatively short due to small fleet sizes or inadequate sample periods are likely to produce failure finding task intervals that are unacceptably short. Since fleet sizes are usually fixed it is recommended that the sample periods used be as long as the availability of failure data allows. At least one routine check of the back-up system or protective device should also have been done on each aircraft in the fleet during the sample period. Furthermore, the calculation of failure finding task intervals should be regularly updated because of the continuously increasing accrual of equipment usage.

Formula validity

37 FFI formulae are only valid for required unavailability values of 5% or less. A check to establish whether the level of unavailability is within this range can be done using the following formula:

$$U_{TIVE} = \frac{FFI}{2M_{TIVE}}$$

Where M_{TIVE} is the MTBF of the protective device.

SUPPORT TASKS

38 A maintenance programme may include support tasks that supplement existing maintenance activities. A Support Task (ST) is a maintenance action that is necessary to enable other predefined tasks to be fulfilled. Support tasks are restricted to the following activities:

38.1 The capture of usage data.

38.2 The capture of performance data.

38.3 The retrieval of samples for condition monitoring.

Recording item usage

39 The scheduling and re-forecasting of PM tasks requires some method of monitoring the associated item usage. When PM tasks are grouped into maintenance packages, it will be necessary to track the intervals between those packages. The monitoring of item usage is a maintenance support activity that can be done in one of the following ways:

39.1 Manually recorded as a log entry by the operator/maintainer.

39.2 Automatically captured from counting devices such as Elapsed Time Indicators (ETI), start counters or fatigue meters.

40 The recorded usage data enables the identification and forecasting of maintenance activities. Generally, item usage recording should be included in after use procedures; however, certain recording tasks may be incorporated in maintenance schedules.

Collection of performance data

41 The downloading or transfer of performance data from a health monitoring system may also be incorporated into a maintenance schedule.

Retrieval of samples

42 The condition monitoring of certain systems may require samples to be retrieved from an item and dispatched to a specialist centre for analysis. Common samples include fuel, oil and ferrous deposits.

DEFAULT ACTIONS

43 When no PM task can be found to meet the criteria of applicability and effectiveness, one of three possible default actions commensurate with the failure consequences, will be identified. Default to redesign involves a modification or alteration to the features or characteristics of the item, while default to change action will include one of the following:

43.1 The physical relocation or re-configuration of an item.

43.2 Changes to operating procedures.

43.3 Imposing limitations on item performance levels or operating contexts.

43.4 Improving the capability of operators or maintainers through education and training.

44 If redesign or change action is not mandatory and is unlikely to prove beneficial, then the default action will be to repair the item when it fails (ie no scheduled maintenance).

Objectives of redesign or change action

45 The objectives of redesign or change action will be to do one of the following:

45.1 Reduce the likelihood of failure to a tolerable level.

45.2 Mitigate the consequences of failure to an acceptable level.

Default actions for failure modes with evident failure consequences

46 If the consequences of an evident failure have been evaluated as being safety or environmentally related, the criticality assessment should be reviewed and if necessary a formal risk assessment done in accordance with Def Stan 00-56. If the results of the analysis show an intolerable risk by allowing the failure to occur, a mandatory redesign or change action should be proposed to either eliminate the failure mode or render the consequences tolerable.

47 If the consequences of an evident failure are not safety or environmentally related, redesign or change action may be considered if this is cost effective.

Default actions for failure modes with hidden failure consequences

48 If the consequences of a hidden failure in conjunction with a second failure have been evaluated as being safety or environmentally related, the criticality assessment should be reviewed and if necessary a formal risk assessment done in accordance with Def Stan 00-56. If the results of the analysis show an intolerable risk is presented by allowing a multiple failure to occur, a mandatory redesign or change action should be proposed to either eliminate the failure mode or render the consequences tolerable.

49 If the consequences of the multiple failure are not safety or environmentally related, then redesign or change action may be considered if it is cost effective.

AGE EXPLORATION CANDIDATES

50 There will be occasions when there is insufficient data available to determine the necessity for a particular task or task interval. Other tasks may be derived using data based on calculated predictions from similar equipments. In these instances, the RCM solutions will tend to be conservative and the optimum maintenance requirements will not be realised until real usage data becomes available. This is only accomplished by monitoring targeted candidate items once the maintenance programme has been implemented. This is known as Age Exploration (AE) and is explained more fully in Chapter 10.

CONSOLIDATION OF TASKS

51 It is possible for several different failure modes to generate similar or even identical maintenance tasks on a single item. Consolidation of these tasks is needed to avoid unnecessary repetition in any ensuing maintenance schedule. However, their details must remain as part of the records of analysis.

TASK DESCRIPTIONS

52 Each PM task shall be described in sufficient detail to enable a definitive procedure for undertaking the task to be developed. This should include the correct asset nomenclature on which the task is to be done and any access or conditional requirements that may be necessary. A task description may include references to existing instructions and procedures, such as those contained in handbooks or maintenance manuals.

53 An OC or FF task, or a default to no scheduled maintenance, will necessitate corrective action in the event of an actual failure. If an RCM programme requires the recording of such remedial tasks, then they should be described in sufficient detail to enable a definitive maintenance procedure to be developed. Such a task description may include references to existing instructions and procedures, such as those contained in handbooks or maintenance manuals.

54 Supplementary information regarding each PM or remedial task, such as duration, location, skill level and labour costs, will be needed to assess their cost effectiveness.

55 The glossary of terms to be used in task descriptions and the requirement for additional supporting information are to be established and recorded as part of the RCMPP.

OUTPUT

56 The output from the RCM decision logic is the allocation and description of those PM activities necessary for the management of plausible failure modes identified by the FMEA or FMECA process. The output is supplemented by the following:

56.1 Mandatory redesign or change action recommendations for failure modes with safety or environmental consequences for which no PM task has been identified.

56.2 Desirable redesign or change action recommendations for failure modes which do not have safety or environmental consequences.

56.3 If required, corrective maintenance activities necessary for all plausible failure modes identified by the FMEA or FMECA process.

CHAPTER 9

AIRCRAFT STRUCTURES ANALYSIS

CONTENTS

INTRODUCTION

1 This chapter provides guidance for developing PM tasks for aircraft structure. Any aircraft can be divided into a number of structural elements that provide its load bearing or supporting framework. Each structural element is assessed in terms of the consequences of its failure and the ensuing threat to continuing airworthiness, which will thus determine the classification of each structural element. Maintenance activities are derived for each structural element based on its classification, design philosophy and its susceptibility to those failure modes that pose a threat to Structural Integrity (SI).

CLASSIFICATION OF STRUCTURE

2 Aircraft structural elements are classified as either ‘significant’ or ‘other’. Significant structural elements are those elements whose failure would have an unacceptable impact on the SI of the aircraft as a whole. These elements are identified as Structurally Significant Items (SSIs) as defined in ►MRP RA5720◄, which states:

> ‘A Structurally Significant Item (SSI) is any detail, element or assembly, which contributes significantly to carrying flight, ground, pressure or control loads and whose failure could affect the structural integrity necessary for the safety of the aircraft.’

In the context of the SSI definition, the terms 'detail', 'element' and 'assembly' are deemed to mean the following:

2.1 Structural detail. The lowest functional level in an aircraft structure. A discrete region or area of a structural element, or a boundary intersection of two or more structural elements.

2.2 Structural element. Two or more structural details, which together form an identified manufacturer's assembly part.

2.3 Structural assembly. One or more structural elements, which together provide a basic structural function.

It is the consequences of failure and not the vulnerability of an element that will determine whether it is structurally significant. Other structure consists of those elements whose failure would have little effect on the SI of an aircraft.

THREATS TO SI

Types of threat

3 The SI of an aircraft may be threatened from any combination of the following:

3.1 Overload.

3.2 Fatigue damage, fretting and wear.

3.3 Accidental Damage (AD).

3.4 Environmental Damage (ED).

3.5 Procedural (Design, Manufacturing, Maintenance or Supply) error.

Two or more of these threats may occasionally work in conjunction, further increasing risks to SI. Accordingly, measures must be taken to counter these threats and reduce risks to 'As Low as Reasonably Practicable' (ALARP) levels. The threats to SI are fully described in ►MRP RA5720◄ and a summary of them is presented in this chapter to aid in the guidance of developing preventive maintenance programmes for aircraft structure.

Overload

4 An aircraft encounters overload when subjected to forces that are above the design limits for the structure, so that permanent deformation or structural failure results. This may occur in extreme environmental, atmospheric or operational conditions. Specific examination and checks will be required following instances of overload to make sure that SI has not been compromised; however these will be event driven and are not included in a scheduled PM programme.

Fatigue damage, fretting and wear

Fatigue Damage (FD)

5 Fatigue is a process of progressive, permanent structural change occurring in a material that is subjected to fluctuating strains at nominal stresses below its static yield strength. FD begins and grows on a microscopic scale until it manifests itself as cracking. The propagation depends on material properties and geometry, the level, amplitude and frequency of fluctuating stresses and the number of cycles applied. Fatigue damage culminates in cracks that reduce the residual strength of the structure and cause fractures if the residual strength falls below the applied load. FD can develop into Widespread Fatigue Damage (WFD), which is defined as the simultaneous presence of cracks at multiple structural details that are of sufficient size and density whereby the structure will no longer meet its residual strength requirements.

6 The fatigue process can be portrayed in a similar manner to the P-F curve explained in Chapter 8, albeit with changed nomenclature as illustrated in Figure 1. Potential FD failure modes represent that point on the P-F curve when a crack can be detected. It follows that this point is a variable dependent upon the method used for crack detection. For example, it is possible to detect cracks whilst still at the sub-surface stage in thicker metallic sections if radiographic techniques are used. For most examination techniques, however, reliance is placed on the ability to detect cracks visually. It should be noted that, for some structural applications, failure may be occasioned by brittle fracture, when the points at which crack detection, critical

crack length and functional failure are virtually coincident. The time between crack detection and functional failure may, therefore, be insufficient for any examination task to be effective.

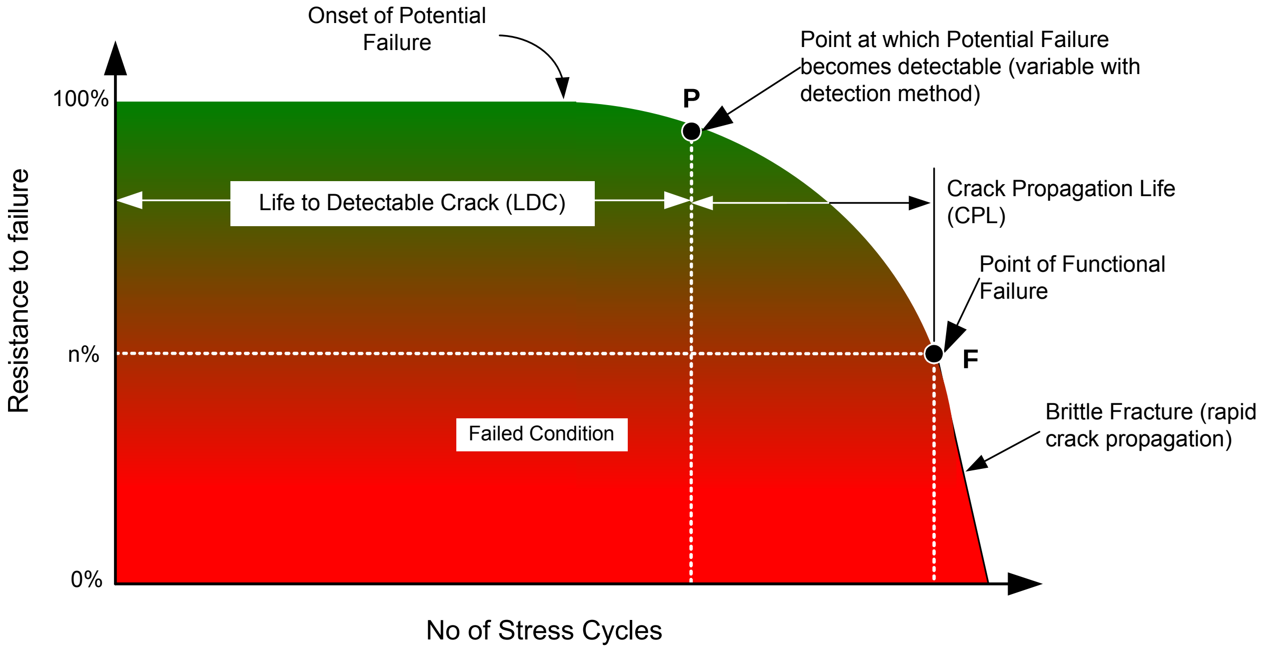


Figure 1 FD failure sequence

7 FD is most commonly associated with metal structures subject to alternating tensile stresses and is the predominant cause of catastrophic structural failure. Although composite materials also fatigue, they do so to a lesser degree in current designs.

Fretting

8 Fretting is a special wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force.

9 In the presence of an aggressive environment, the contact movement causes wear and material transfer at the surface, often followed by oxidation of the debris and the freshly exposed surface. The oxidized debris can further act as an abrasive and such degradation is termed fretting corrosion.

10 Fretting decreases the strength of materials operating under cycling stress. This can result in so-called fretting fatigue, whereby fatigue cracks can initiate in the fretting zone followed by propagation in the material.

Wear

11 Wear is the undesired cumulative change in dimensions brought about by the gradual removal of discrete particles from contacting surfaces in relative motion, predominantly as a result of mechanical action. The outcome of wear may result in the cumulative loss of material, and ultimately structural failure, when the residual strength of the structure falls below the applied load.

Accidental Damage (AD)

12 AD is the physical alteration of an item, normally caused by impact that occurs as random events, such as collision, lightning strike, severe hail, weapons release, ricochet, debris, spillage, or by the result of human error during manufacture, operation or maintenance of the aircraft. In addition, battle damage or sabotage, although not strictly accidental, may also be considered within this category, as the effects are comparable. Moreover, less obvious internal AD may arise from operator, passenger or maintainer activities, or from overheating. AD may manifest itself as distorted, torn, punctured or otherwise distressed structure, delamination or disbonding, or in less visible forms such as a change in tempering of metals or ‘barely visible impact damage’ to composite materials.

Environmental Damage (ED)

13 ED is the gradual physical degradation of structural material properties as a result of their interaction with the climate or localised environment. ED is normally caused by chemical interaction, erosion, fluid/gas absorption, thermal cycling or electro magnetic radiation. ED may manifest itself as corrosion, stress corrosion cracking, loss of surface finish, softening of composite material matrices (including adhesives used in laminated wood), delamination, disbonding or degradation of static, fatigue and/or impact strength properties.

Procedural error

14 Procedural errors can be the result of design, manufacturing, maintenance or supply errors. The various types of procedural errors are described in ►MRP RA5720◄. The prevention of failures resulting from procedural errors are training and quality matters, which cannot be resolved through PM activities, although they may be identified as a result of RCM analysis.

STRUCTURES DESIGN PHILOSOPHY

15 There are two separate design philosophies for aircraft structures, which are classified as ‘damage tolerant’ and ‘safe-life’.

Damage tolerant structure

16 The design of damage tolerant structure requires that adequate static strength and stiffness is retained, despite the occurrence of fatigue cracking, until any damage which does occur is found and repaired. Damage tolerant structures are designed so that any cracks occurring will grow slowly and must reach a considerable size before reaching critical length; such measures as crack-arrest features and redundant load paths are often employed. The threat posed to SI by fatigue is addressed by an examination which commences at the examination threshold (the life below which no cracks are expected to occur) and then repeated at specified intervals. Examination techniques and intervals will depend on the design and structural usage of the aircraft. A typical failure sequence of a single element of damage tolerant structure is shown in Figure 1. However, structural redundancy, termed Residual Strength (RS), may be provided by alternative load paths that redirect loads to adjacent structural members in the event of the failure of a single member (the fatigue life of the adjacent structure will be reduced as a result). The failure sequence for this multiple element type of damage tolerant structure is shown in Figure 2.

17 If, during RCM analysis, a perceived item of damage tolerant structure does not exhibit the fatigue failure characteristics described above, then the structure must be re-classified as ‘safe-life’ and analysed accordingly.

Safe-life structure

18 Safe-life structures have a finite service life within which the probability of fatigue cracks developing and compromising residual strength is acceptably low. Safe-life SSIs are those items of structure designed to have a fatigue life at least as long as the in-service life of the aircraft, or, those where application of a damage tolerant approach is not possible. The safe-life is qualified by a fatigue test and calculation. Safe-life SSIs are subject to an analysis of their vulnerability to AD and ED during the development of a maintenance programme. This analysis is essential because the life of an SSI can be adversely affected by both AD and ED and thus the occurrence of these threats must be detected by an appropriate examination regime.

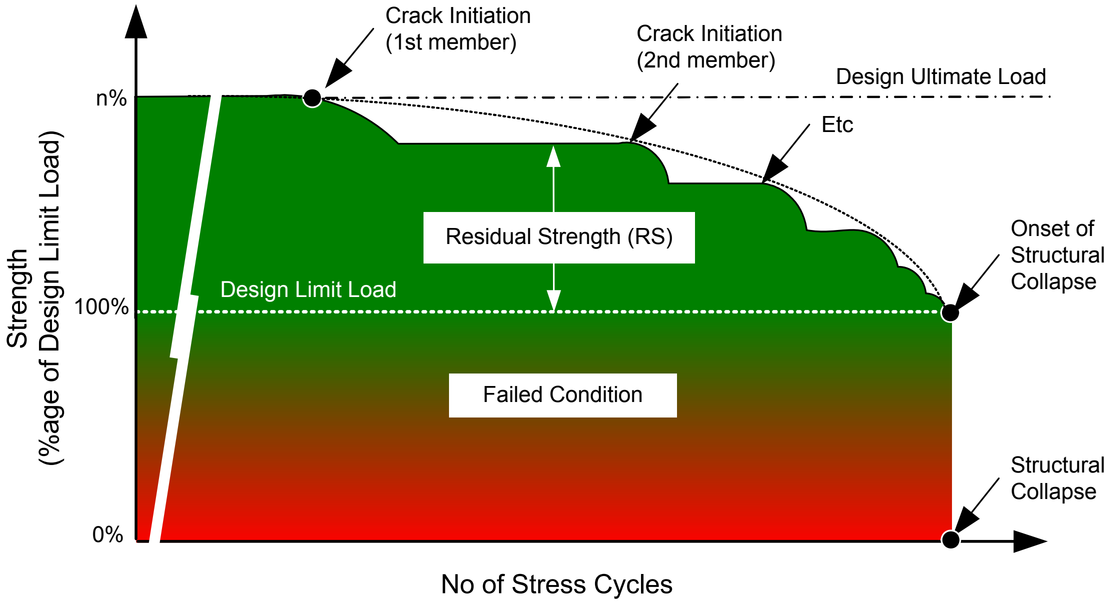


Figure 2 Typical failure sequence of multiple element DT structure

STRUCTURAL RATING FACTORS

19 Structural Rating Factors (SRFs) are numerical values or levels of sensitivity assigned to SSIs to gauge their susceptibility to AD and ED. The characteristics of composite structures differ greatly from the properties of metallic structures and a different set of rating factors is therefore used for each class of material. SRFs are used in the derivation of examination intervals for SSIs, based on their design characteristics and operating environment. For damage tolerant structure, SRFs are used to adjust the SSI examination intervals that were initially developed to detect FD. For safe-life structure, SRFs are used to derive examination intervals, usually as a proportion of the qualified safe-life of the SSI concerned. It is not the purpose of this publication to define a specific method to determine SRFs, since there are several rating systems in use by different manufacturers and each of these systems tend to be tailored to be aircraft type specific. However, an explanation of the design and operating characteristics that should be considered for rating is provided in the following paragraphs.

ED rating for metallic structures

20 All parts of metallic structure are susceptible to ED, particularly when they are exposed to abrasive or corrosive agents that generate a localized loss of material. Unless it is discovered in its earliest stages, this localized loss of material reduces the load carrying capability of the affected structure, accelerating the fatigue process. Its occurrence is usually proportional to calendar time, increasing with the age of the structure. Each metallic SSI should be rated for ED in three areas: material type, surface protection and exposure to corrosion. The ratings for ED are based on an item’s susceptibility to damage induced by the environment. When evaluating this SRF, the potential effectiveness and durability of surface protection systems should be considered. Attention should be given to the item’s anticipated operating environment and the likelihood of damage from contact between dissimilar metals and exposure to an adverse environment. Generally, areas exposed to moisture, dirt and heat are the most susceptible to corrosion and should be properly maintained with protective coatings (anti-corrosion treatment). The surface protection afforded to internal areas where free air circulation is not possible should also be considered (eg, the insides of box sections or tubes).

AD rating for metallic structures

21 AD is caused by the occurrence of some discrete event which reduces the inherent residual strength of the item. Such events are random in nature and have equal probability of occurrence throughout the life of the item. Each metallic SSI is rated for accidental damage in the following three areas: damage caused by operating conditions (ground and flight operations); damage caused by poor quality control during manufacture; and damage caused by the location of the SSI. Ground activities to be considered are freight and stores

handling, flight preparation/servicing and scheduled/corrective maintenance traffic. Flight activities may be done under harsh operating conditions (field or sea-borne); or involve a high sortie rate, thus increasing exposure to ground activities. Design and manufacturing deficiencies tend to increase with the items complexity and difficulty of manufacture: one such manufacturing problem is termed ‘pre-load’ - a condition caused by design, fabrication or assembly errors. The location of an item also has an influence on the accidental damage rating. Consider those external items that are exposed to foreign objects on runways or encountered during field operations. Thus, while the ratings for susceptibility to AD cannot be expressed in terms of a reference age, they are based on the item’s resistance to damage as well as the type and frequency of damage to which the item is exposed.

ED rating for composite structures

22 The ED associated with composites includes delamination/disbonding, blistering and the production of internal voids. Unless environmental damage is detected and rectified early, the load carrying capability will be adversely affected and the fatigue cycle will accelerate. Four rating factors are evaluated for each composite SSI, as follows:

22.1 Moisture. Honeycomb constructed composites suffer moisture intrusion much more so than those of non-honeycomb construction. However, all cored composites, honeycombed or not, are subject to internal damage if compromised by moisture. Also, various adhesives used in composite materials react to moisture, particularly those with high porosity characteristics. Even slight increases in humidity may result in a decrease in the stress durability properties of the adhesive.

22.2 Heat. Many composite items may be damaged if located near temperatures that could affect their resin matrix. Sources of heat include engines, APU, or drive system components, as well as exposure to intense sunlight.

22.3 Erosion/Abrasion. Many locations on an aircraft are susceptible to erosion/abrasion. Consider leading edges of wings, rotor blades, air intakes or any surface with a high angle of incidence to the airstream. Walkways and certain cabin areas may be exposed to repeated crew, troop or cargo movements.

22.4 Corrosion. Many composite items may suffer galvanic corrosion between the materials used in the fabrication and assembly process, especially when dissimilar materials with wide differences in electromotive potentials are sandwiched together. This rating factor assumes no isolating material has been placed between the dissimilar materials. However, a silicone rubber or polysulfide barrier between metallic and carbon layers can greatly reduce the risk of corrosion.

AD rating for composite structures

23 The three primary categories to be considered when rating the likelihood of AD for composite structures relate to design and manufacturing errors, the operating environment and the physical location on the aircraft.

RCM ANALYSIS OF AIRCRAFT STRUCTURE

24 To develop PM tasks for structures, it is first necessary to identify all SSIs. This is done by dividing the aircraft into a series of identifiable areas or zones. The items of structure in each zone are then categorized as structurally significant (SSIs) or as Other Structure. The design philosophy for each SSI must also be recorded, either as damage tolerant or safe-life.

25 Each SSI is then subjected to the FMEA and RCM decision logic processes described in Chapter 6 and Chapter 8 respectively to determine the preventive maintenance tasks or other actions necessary to sustain SI. The maintenance of Other Structure is derived as part of the Zonal Analysis process described in Chapter 10.

26 The scheduled structural PM tasks and intervals for each SSI are based on an assessment of the following factors:

26.1 Structural design philosophy.

26.2 Fatigue and damage tolerance evaluation.

26.3 Susceptibility to ED and AD.

27 For the purposes of RCM analysis, the possible functional failures and effects for each SSI are identical insofar as the functional failures can be expressed as a reduction in structural load bearing capability and the effect is the resulting threat imposed upon airworthiness integrity. The consequences of functional failure for each SSI will also be the same in that they will eventually become evident and be safety related.

28 Fatigue, ED and AD are each evaluated as separate failure modes during the RCM analysis process.

Fatigue failure mode - task analysis

Damage tolerant structure

29 The resistance of a damage tolerant SSI to fatigue damage is assessed against the time taken for a crack to develop, from the point when it can be detected, to the point when it reaches a critical length, whereby the residual strength of the SSI is no longer sufficient to withstand 80% of the Design Ultimate Load (DUL). The time taken for such a crack to develop is known as the Crack Propagation Life (CPL). On-condition tasks directly related to fatigue damage detection are based on an evaluation of crack development and the CPL. Such examinations are established by the manufacturer who is to demonstrate that applicable and effective examinations provide sufficient probability of detecting fatigue damage for each SSI.

Safe-life structure

30 Because examinations of safe-life structures cannot be relied upon to provide timely intervention between potential and functional failure, the SSIs should be designed to remain crack free during their service lives. Hard time tasks are selected to retire them from service before their probability of failure reaches an unacceptable level. The safe-life is identified as the qualified life derived from tests and evaluation done by the manufacturer. The qualified life is generally a proportion of the proven fatigue life demonstrated by the use of fatigue rig tests or evaluation modelling.

ED failure mode - task analysis

Damage tolerant structure

31 On-condition examination tasks for the detection of ED to damage tolerant SSIs are done at intervals that are derived from the ED SRFs. The presence of ED will have a direct impact on an SSI's resistance to FD and therefore needs to be detected early enough to avoid compromising the effectiveness of the examinations for FD. The examination interval is therefore determined by dividing the interval for FD by a number based on the ED SRFs.

Safe-life structure

32 On-condition examination tasks for the detection of ED to safe-life SSIs are done at intervals that are derived in a similar manner to that used for damage tolerant structure. However, in this case, the examination intervals are determined by dividing the qualified safe-life by a number based on the ED SRFs.

AD failure mode - task analysis

33 Although the effects of AD are primarily random, certain relationships do, in fact, exist. For example, an aircraft which is frequently exposed to sea-borne or field operations is certainly subject to a greater amount of risk than an aircraft operating from the more stable environment of an air base. Additionally, trends may indicate that design/manufacture error occurs mainly on certain types of SSI.

34 The presence of AD will also have a direct impact on an SSI's resistance to FD and therefore the tasks to detect AD are set frequently enough to avoid compromising the effectiveness of the examinations for FD. Examination tasks for damage tolerant and safe life items to detect AD are done at intervals based on the AD SRFs.

35 The examination of an SSI to detect AD can usually be achieved as a general visual examination, because the evidence of AD is generally obvious. When such a task is detailed as part of a Flight Servicing activity, it is promulgated as a 'Look for damage' task. When detailed as part of a scheduled maintenance package, the task can be incorporated into a 'Zonal Survey' task. Personnel required to do these tasks should be suitably trained, but they do not necessarily need to be qualified to do detailed examinations of SSIs.

36 There are exceptions when the use of a general visual examination is insufficient to detect AD and therefore a detailed On-condition task is required, as described in the following paragraphs:

36.1 When there is need to employ a form of acoustic or tap testing to detect hidden impact damage to carbon fibre composites.

36.2 When the construction of an SSI is complex and its fabrication is difficult. In this case, a directed examination is necessary to detect possible flaws resulting from its manufacture.

CONSOLIDATION OF MAINTENANCE TASKS

37 When the RCM analysis of each SSI is completed, the maintenance tasks derived from the FD, ED and AD evaluations are consolidated for inclusion into the aircraft maintenance schedules.

CHAPTER 10

ZONAL AND EXTERNAL SURFACE AREA ANALYSES

CONTENTS

Para

Table Page

Figure Page

INTRODUCTION

1 RCM decision logic is required to determine those actions necessary to prevent or minimise the consequences of functional failures that are considered significant because of their impact on safety, mission capability or cost of ownership. The logic is usually directed at system or sub-system level, or to SSIs. However, it is also necessary to monitor the condition of other structure and system components at the lower indenture levels to assure the continuous, safe and cost-effective use of the aircraft. For example, the failure of one clip that supports a cable loom may be of no consequence; but if several clips fail over a period of time and the loom becomes detached and obstructs a control mechanism, then the consequences may become considerably more significant. Similarly, the constant seepage from a small fluid leak may go unnoticed between replenishments, although the cumulative contamination damage induced in adjacent equipment, wiring or structure may be substantial. Furthermore, certain failures can be attributed to the combination and interaction of separate system failure modes: for example, the chafing of cable looms combined with the presence of a combustible material due to leaking pipe work (eg, fuel, oil mist, oxygen, etc); or the presence of lint and dust, or fuel vapour resulting from a leak or spillage, combined with the presence of a heat source (eg, a hot gas leak or the failure of heat insulation exposing a hot surface). The requirement to monitor non-significant structure and system components for Environmental Deterioration (ED) or Accidental Damage (AD)

can be met by the use of zonal surveys, which are general visual examinations based on three-dimensional compartments or zones, usually bounded by physical features such as bulkheads, flooring and outer skin. However, if a zonal analysis identifies the possible combination and interaction of separate system failure modes, then there may be a requirement for additional directed maintenance tasks. Zones can be defined for any aircraft, irrespective of size, complexity or design concept.

2 The general visual examination requirements of the External Surface Area (ESA) of an aircraft can be met in a similar manner to zonal surveys. The ESA is divided into specific areas and examined at intervals commensurate with their susceptibility to ED and AD.

3 The susceptibility to ED and AD will obviously depend on the locality of a particular area. For instance, aircraft leading edge profiles are the most prone to erosion, whereas under-wing and keel areas are more susceptible to damage caused by runway spray or debris.

4 Severe random accidental damage will obviously affect airworthiness and for this reason a general external surface area check is done as a flight servicing activity. However, this flight-servicing task is unlikely to detect the less obvious failures such as erosion, loose rivets, cracking and corrosion etc. A more detailed examination of external surface areas is achieved by dividing the entire surface area into smaller, manageable and identifiable areas, to which each is allocated a specific examination task. The frequencies of these tasks will depend on the area's degree of susceptibility to AD and on the anticipated rate of degradation caused by ED. Areas such as the upper surfaces of large aircraft are remote from most sources of AD and the examination frequency would perhaps coincide with a depth level maintenance package. In contrast, under-slung engine pods or cargo door surrounds are considerably more at risk from AD and their examination would be done more frequently, perhaps as part of a forward maintenance package.

5 Items of equipment that are attached to the outer surfaces of an aircraft should not be included in an ESA analysis. Such items (eg, aerials, equipment pods, pitot probes, avionic turrets, etc) should be analysed as part of their associated system analyses whereby their susceptibility to ED and AD can be addressed as discrete failure modes. For certain externally fitted items, it is common practice to subsume the examinations to detect ED and AD into the external areas ‘Look for damage and signs of leaks’ task that is detailed in every Flight Servicing Schedule (where it should be stated that ‘External areas include aerials, pylons, transparencies, etc). However, externally fitted items that are related to safety of flight systems (eg, pitot probes, ice detectors, etc) should be afforded dedicated directed ‘Look for damage’ tasks to detect ED and AD, as derived from the associated system analysis.

GUIDANCE

6 The content of this chapter provides a comprehensive explanation of the processes associated with Zonal and ESA analyses.

OBJECTIVES OF ZONAL AND EXTERNAL SURFACE AREA ANALYSES

7 Zonal and ESA analyses are done to develop a general visual surveillance programme for an entire aircraft to achieve the following objectives:

7.1 To monitor the condition of support items (non-significant components and structure) and external areas not selected for RCM analysis.

7.2 To provide protection against multiple failure modes contributing to a significant failure (usually a hidden or dormant condition).

7.3 To recognize unforeseen significant failure modes not identified during the initial RCM analysis (usually a hidden or dormant condition that can also arise when equipment is operated outside of specified design parameters).

7.4 To consolidate the general visual examinations within zones and on external areas derived as a result of RCM analysis.

7.5 To give appropriate attention to electrical wire installations and particularly where there is the potential presence of combustible materials.

7.6 To give appropriate attention to any zone where there is the potential for a combination of a combustible material and a heat source to be present.

8 In cases where a general visual examination has been derived as a result of RCM analysis, zonal surveys or ESA examinations may be the most appropriate method of examination.

ZONAL AND ESA ANALYSES

9 An overall view of the processes associated with Zonal and ESA analyses is shown in Figure 1 and Figure 2 respectively.

The zonal and ESA plans

10 Zonal and ESA analyses start with the production of a zonal plan and an ESA plan. The zonal plan defines the various zones contained in the entire aircraft and allocates an appropriate identification number and description to each zone. Guidance on the derivation of zones and their associated numbering systems is provided in ASD Specification S1000D. The ESA plan identifies all external areas that have a common susceptibility to ED and AD, the condition of which can be monitored effectively as part of a maintenance programme. Examples of external area descriptions might include terms such as ‘Nose cone’, ‘External surface area of centre fuselage between frames X and Y’, ‘Upper main plane’ and ‘Undercarriage doors’. The prime objective of the ESA plan is to make sure that all of the aircraft’s external areas are identified and that each of those areas is rated for its susceptibility to ED and AD.

The zonal analysis worksheet

11 A zonal survey should be derived using the following information, which is recorded on the zonal analysis worksheet:

11.1 Zone identification.

11.2 Details of all components contained within each zone.

11.3 Details of scheduled equipment removals.

11.4 Access requirements.

11.5 ED and AD assessments.

11.6 The zonal rating factor.

12 An example of a zonal analysis worksheet is shown in Figure 3.

The ESA analysis worksheet

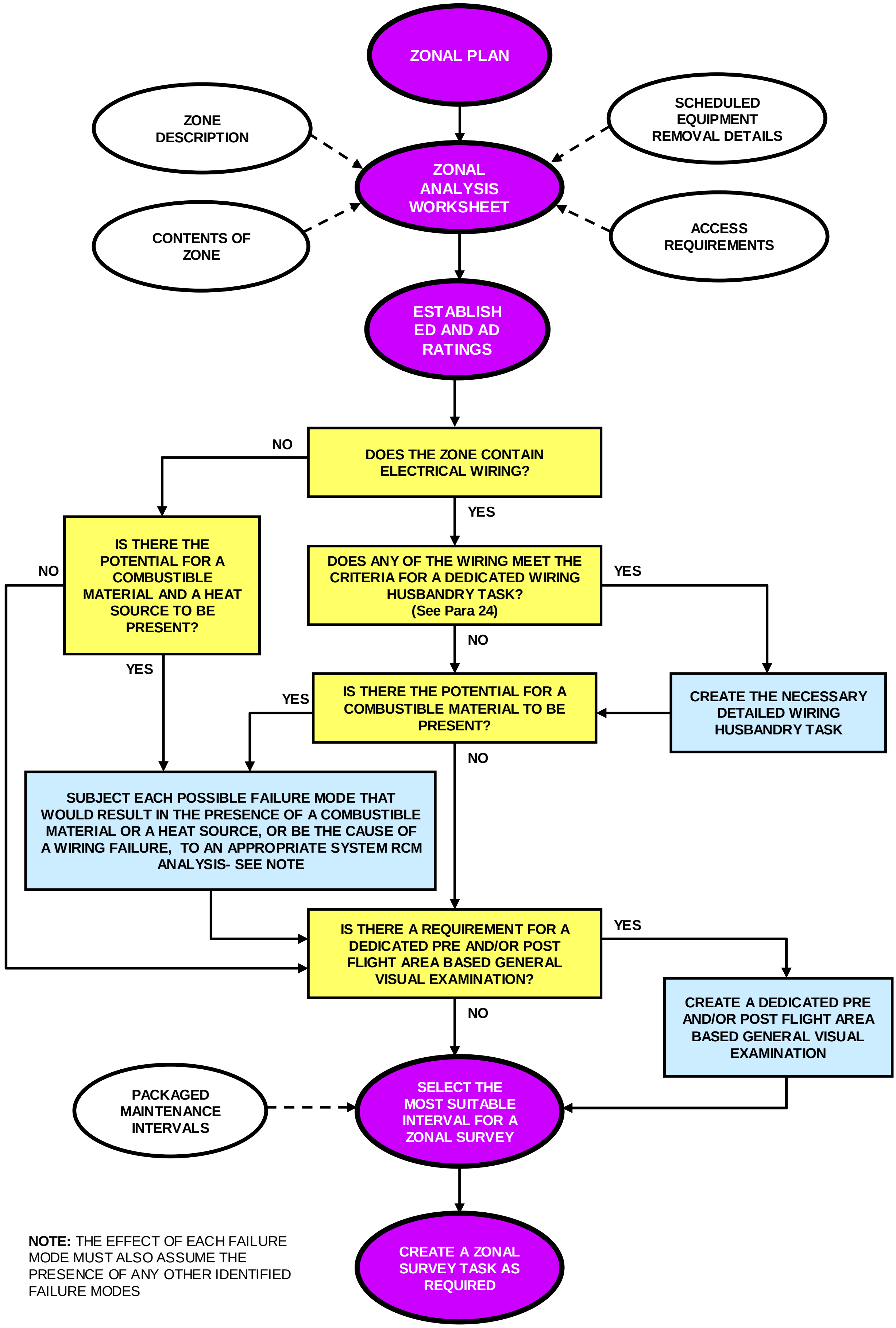
13 An ESA examination should be derived using the following information, which is recorded on the ESA analysis worksheet:

13.1 ESA identification.

13.2 ED and AD assessments.

13.3 The ESA rating factor.

14 An example of an ESA analysis worksheet is shown in Figure 4.



NOTE: THE EFFECT OF EACH FAILURE MODE MUST ALSO ASSUME THE PRESENCE OF ANY OTHER IDENTIFIED FAILURE MODES

Figure 1 The zonal analysis process

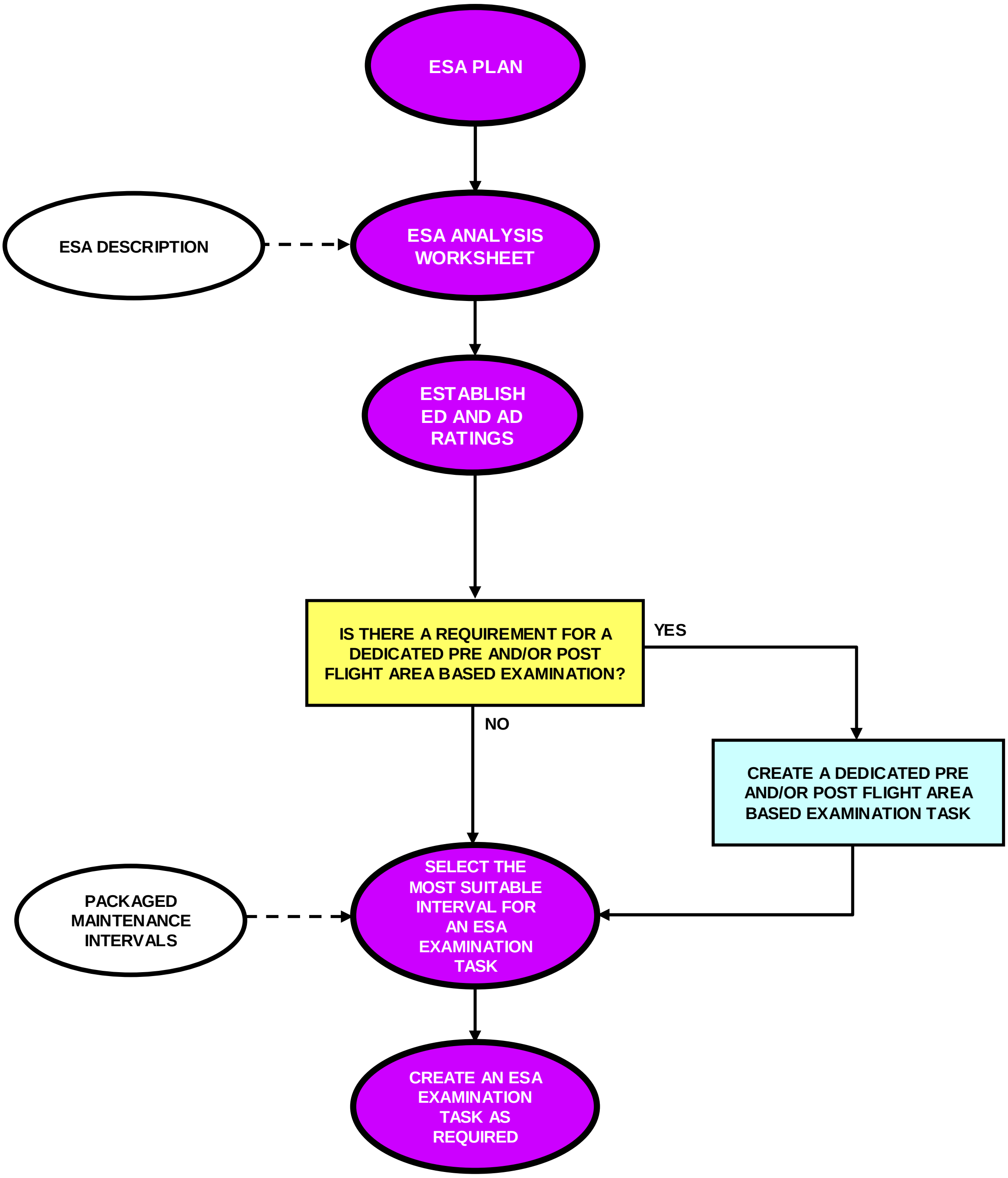


Figure 2 The ESA analysis process

ZONAL ANALYSIS WORKSHEET	Sheet No:

END ITEM NOMENCLATURE:

ZONE:	ZONE DESCRIPTION:

CONTENTS:

ACCESS REQUIREMENTS:	LEVEL OF ACCESSIBILITY	
	NORMAL	
	DIFFICULT	
	VERY DIFFICULT	

SOURCE	**ED RATING**				
	Negligible	Low	Medium	High	Very High
VIBRATION					
FLUID LEAKAGE					
EXPOSURE TO EXTREME TEMPERATURES					
PRESENCE OF ABRASIVE AND/OR CORROSIVE AGENTS					
STRESSES IMPOSED ON PIPEWORK OR CABLE WIRING					
COMPLEXITY AND DENSITY OF EQUIPMENT					

SOURCE	**AD RATING**				
	Negligible	Low	Medium	High	Very High
GROUND SUPPORT EQUIPMENT					
BIRD STRIKE/HAIL/LIGHTNING					
RUNWAY/OPERATING AREA DEBRIS/FOD					
FLUID SPILLAGE DURING REPLENISHMENTS					
MAINTENANCE/PASSENGER/OPERATOR TRAFFIC					

ZONAL RATING	Negligible	Low	Medium	High	Very High

ZONAL SURVEY TASK PM WORKSHEET ITEM IDENT CODE:

DOES THE ZONE CONTAIN ELECTRICAL WIRING THAT REQUIRES A DETAILED EXAMINATION TASK? **YES/NO**

IF YES, PM WORKSHEET ITEM IDENT CODE:

DOES THE ZONE CONTAIN ELECTRICAL WIRING AND IS THERE THE POTENTIAL FOR A COMBUSTIBLE MATERIAL TO BE PRESENT? **YES/NO**

IF YES, WHAT ARE THE FAILURE MODES THAT WOULD RESULT IN THE PRESENCE OF A COMBUSTIBLE MATERIAL?

IF YES, WHAT ARE THE SYSTEM ANALYSIS PM WORKSHEET ITEM IDENT CODES?

IS THERE THE POTENTIAL FOR A COMBUSTIBLE MATERIAL AND A HEAT SOURCE TO BE PRESENT? **YES/NO**

IF YES, WHAT ARE THE ASSOCIATED FAILURE MODES?

IF YES, WHAT ARE THE SYSTEM ANALYSIS PM WORKSHEET ITEM IDENT CODES?

IS THERE A REQUIREMENT FOR A DEDICATED PRE OR POST FLIGHT EXAMINATION? **YES/NO**

IF YES, WHAT IS THE PM WORKSHEET ITEM IDENT CODE?

DETAILS OF ANY SCHEDULED EQUIPMENT REMOVALS:

Figure 3 Example of a zonal analysis worksheet

EXTERNAL SURFACE AREA ANALYSIS WORKSHEET	Sheet No:				
END ITEM NOMENCLATURE:					
ESA DESCRIPTION:					
SOURCE	**ED RATING**				
	Negligible	Low	Medium	High	Very High
VIBRATION					
FLUID LEAKAGE					
EXPOSURE TO EXTREME TEMPERATURES					
PRESENCE OF ABRASIVE AND/OR CORROSIVE AGENTS					
SOURCE	**AD RATING**				
	Negligible	Low	Medium	High	Very High
GROUND SUPPORT EQUIPMENT					
BIRD STRIKE/HAIL/LIGHTNING					
RUNWAY/OPERATING AREA DEBRIS/FOD					
FLUID SPILLAGE DURING REPLENISHMENTS					
MAINTENANCE/PASSENGER/OPERATOR TRAFFIC					
	ESA RATING:				
	Negligible	Low	Medium	High	Very High
EXTERNAL SURFACE AREA TASK PM WORKSHEET ITEM IDENT CODE:					
IS THERE A REQUIREMENT FOR A DEDICATED PRE OR POST FLIGHT EXAMINATION? IF YES, WHAT IS THE PM WORKSHEET ITEM IDENT CODE?	**YES/NO**				

Figure 4 Example of an ESA analysis worksheet

ED assessment

15 Components or structure can be adversely affected by environmental conditions and the resulting deterioration may be time or usage dependent. Deterioration caused by the breakdown of surface finishes increases with calendar age, whereas deterioration resulting from hot gases, vibration and leakages, increases with equipment usage. High structural stress levels will increase the susceptibility to corrosion and high levels of vibration will reduce the resistance of structure and components to cracking. A rating is allocated to each of the factors related to ED as shown in Table 1. The description of each criterion is self-explanatory; however, when assessing the complexity and density of equipment within a zone, consider the potential for interaction. For example, is there the likelihood of cable looms or pipe work becoming chafed, or of a component developing a leak that might contaminate adjacent equipment? When determining the corrosion ratings, consider the effects of chemicals, fluids, fumes and grit; consider also the type of protection afforded within each zone: points to note are surface finish and the presence of sealant.

TABLE 1 SOURCES OF ED AND ASSOCIATED RATING FACTORS

SOURCE	ED RATING				
	Negligible	Low	Medium	High	Very High
Vibration					
Fluid leakage					
Exposure to extreme temperatures					
Presence of abrasive and/or corrosive agents					
Stresses imposed on pipe work and cable wiring (Not ESA)					
Complexity and density of equipment (Not ESA)					

AD assessment

16 Accidental damage is characterized by the occurrence of a random event, or events, which have an adverse effect on structural or system integrity. Because accidental damage occurs randomly, there is no calculable examination interval at which failures can be prevented; however, examinations for accidental damage increase the probability of discovering potential failures before functional failures occur. A rating is allocated to each of the factors related to AD as shown in Table 2. Each factor is directly related to the probability of AD occurrence.

TABLE 2 SOURCES OF AD AND ASSOCIATED RATING FACTORS

SOURCE	AD RATING				
	Negligible	Low	Medium	High	Very High
Ground support equipment					
Bird strike/Hail/Lightning					
Runway/Operating area debris/FOD					
Fluid spillage during replenishments					
Maintenance/Passenger/Operator traffic					

Zonal and ESA rating

17 The rating factor allocated to each zone or ESA will be the highest category identified during the ED and AD assessment.

Zonal survey and ESA examination intervals

18 The intervals at which zonal surveys and ESA examinations are done depend on the rating factor. These frequencies should be aligned with the packaged maintenance intervals of the aircraft to minimize the impact on availability. The ratings act as a guide to determine which maintenance package is the most appropriate to do each survey. A zone or ESA with a rating factor of ‘very high’ might require a general visual examination to be done daily or before and after use, whereas a rating factor of ‘negligible’ might only require a survey or examination to be done once during a maintenance cycle or maybe even not at all. The frequencies of zonal surveys and ESA examinations should be reviewed when sufficient In-service experience is gained.

19 Zonal surveys should also be done during major component/assembly removals and refits, since these are occasions when accidental damage is most likely to occur and when greater access to a zone is afforded. In some maintenance management systems, such as LITS or WRAM, difficulty may be experienced in generating survey tasks resulting from unscheduled equipment removals. It is therefore desirable that opportunity based surveys are included in the associated equipment removal/fit procedures and reference to the procedure should be recorded in the zonal analysis.

20 An example of how rating factors might be aligned to packaged maintenance intervals is shown in Table 3. The intervals shown are not definitive and may be reasonably adjusted to suit a particular aircraft's maintenance regime and operating conditions.

TABLE 3 EXAMPLE OF TYPICAL ZONAL SURVEY AND ESA EXAMINATION SURVEY INTERVALS

ZONAL OR ESA RATING	PACKAGED MAINTENANCE INTERVAL	
	USAGE BASED	CALENDAR BASED
Very High	Flight servicing and 125 Hours	Daily and Monthly
High	250 Hours	6 Months
Medium	500 Hours	1 Year
Low	1000 Hours	5 Years
Negligible	2000 Hours	10 Years

Equipment removals

21 To improve the survey of a zone, it may be necessary to remove flooring, lagging, soundproofing or items of trim. The removal of any other equipment should not normally be considered, since the maintenance effort involved is usually greater in terms of cost than the benefits to be gained from improved access. Furthermore, the removal and refit of equipment is more likely to induce failures and accidental damage. Zonal surveys can, however, be done on an opportunity basis when equipment is removed for a specifically directed examination, scheduled replacement or corrective maintenance. Such surveys should be included in the associated equipment removal or installation procedures as it is difficult to include them in a maintenance management system such as LITS or WRAM.

Access requirements

22 The description of a zonal survey task must contain details of any necessary access requirements, such as the removal of panels, flooring, soundproofing, insulation and lagging. Aircraft configuration or condition may also need to be stipulated (eg, doors open, tanks empty, airbrake out etc).

23 The susceptibility of a zone to ED and AD does, to some extent, take into account the accessibility, since the more accessible a zone is, the more prone it will be to AD and exposure to the surrounding environment. However, access to some zones may require a high degree of maintenance effort, particularly if the removal of access panels involves the de-stressing of structure or the breaking of hermetic seals. In such instances, selection of a greater survey interval may be necessary to reduce long-term maintenance costs; however, discretion must be used when deciding the optimal balance between maintenance costs and the potential consequences of less frequent survey intervals.

Electrical wiring installations

24 In most cases, the use of zonal surveys provides an adequate means of monitoring the condition of electrical wiring installations. However, there may be circumstances when detailed examinations of electrical wiring are required, as indicated by the following:

24.1 When specific instructions for the husbandry of electrical wiring are contained in policy statements, because there is concern about the type or age of the wiring in use, or how and where it is installed.

24.2 When the routing of wiring installations expose cables and connectors to potentially high levels of ED and AD, such as those routed externally or in areas of high maintenance or operator traffic.

24.3 When wiring installations are routed in compartments where there is the potential for combustible materials to be present (lint, fuel vapours, hydraulic oil mist etc).

24.4 When wiring installations are prone to chafing or fatigue induced fracture as a result of exposure to vibration.

24.5 When wiring installations contain ageing cables with questionable insulation properties.

24.6 When wiring installations are routed in close proximity (i.e., within 2 inches/50 mm) to both primary and back-up flight controls.

25 Detailed examinations of electrical wiring installations should be promulgated in an appropriate system chapter of the aircraft Topic 5A1 Master Maintenance Schedule. This will usually be as a sub-system chapter associated with the aircraft electrical power supplies or distribution.

26 It is arguable that wiring installations should be treated as a discrete sub-system of an aircraft electrical power supplies system and analysed accordingly using the RCM decision logic procedure detailed in Chapter 8. There are several reasons for not adopting this approach, which are as follows:

26.1 Wiring installations do not readily lend themselves to the functional breakdown required of a top-level system analysis and therefore a physical break down is needed to identify specific wiring installations. This is achieved by identifying wiring installations by their zone location.

26.2 Any one wiring installation within a zone may serve several aircraft systems. The RCM analysis of wiring installations would therefore be extensive and would need to include the functional failures, failure effects and failure consequences of all the systems associated with each wiring installation.

26.3 An RCM analysis of wiring installations would not consider the potential failures of other unrelated systems; ie, failures that might cause the presence of combustible materials.

27 The requirement and criteria for detailed electrical wiring examinations must be justifiable and recorded as part of the RCM analysis. Wherever possible, detailed examinations of cable installations should be done concurrently with the relevant zonal surveys to minimise the amount of intrusion.

Potential presence of a combustible material in zones that contain electrical wiring

28 Special consideration must be given to zones that contain electrical wiring and where there is also the potential for a combustible material to be present. Possible combustible materials that might be identified are oxygen leaks or fluids resulting from leaking ducts or pipework, fuel vapour, accumulated debris and hydraulic oil mist caused by a pressurised leak.

29 A dedicated wiring husbandry task will be required if there is the potential for a combustible material to be present. Additionally, the possible failure modes that could cause a combustible material to be present must be identified. Each failure mode should then be included in the RCM analysis of the appropriate system or sub-system. The analyses of these failure modes are to assume the presence of all other possible failure modes, including that of frayed or unprotected electrical wiring, and declared in the end effects of the associated FMEA or FMECA.

Potential presence of a combustible material combined with the presence of a heat source

30 Special consideration must be given to zones where there is the potential for a combustible material and a heat source to be present. Possible heat sources are hot gases or fluids resulting from leaking ducts or pipework and the heat that is emitted as the result of insulation failure.

Directed tasks resulting from zonal analyses

31 Each possible failure mode that could cause a combustible material or unintended heat source to be present must be identified. These failure modes should then be included in the RCM analysis of the appropriate system or sub-system so that suitable directed examination tasks can be generated as required. The analyses of these failure modes are to assume the presence of all other possible failure modes and declared in the end effects of the associated FMEA or FMECA.

Before and after use examinations

32 An aircraft may possess zones or external areas that are extremely vulnerable to AD, which is usually caused by the operating environment. Examples of these are the undercarriage bays, the leading profiles of the aircraft and the areas that may be in close proximity to ground support equipment. It may be prudent, therefore, to do some form of dedicated examination to detect obvious damage before, and/or after, an aircraft is flown. Under severe operational conditions, such flight servicing examinations are likely to be cursory in nature and should therefore be supplemented by less frequent surveys that can be done during more suitable circumstances.

Promulgating zonal survey and ESA examination tasks

33 The maintenance tasks derived from a zonal and ESA analysis are promulgated in an appropriate section of the aircraft’s Master Maintenance Schedule Topic 5A1, which is usually the section allocated to System 06, Dimensions and Areas. The one exception to this precept is the aircraft external area examination done at flight servicings, which is usually allocated to System 00-00, Aircraft – General.

AIRCRAFT EQUIPMENT UPGRADES AND MODIFICATIONS

34 An RCM analysis should be conducted whenever an aircraft is subject to an equipment upgrade or modification programme, so that any additional maintenance requirements can be identified and included in the aircraft’s maintenance schedules. The zonal analysis of the zones affected by such upgrades or modifications should be reviewed also, to make sure that all potential failures are considered.

IMPLEMENTATION OF ZONAL SURVEYS AND ESA EXAMINATIONS

35 Zonal surveys and ESA examinations contribute a great deal towards the integrity of a scheduled maintenance programme and should be done without the influence of operational pressures. Essentially, a zonal survey or ESA examination is a look for signs of failure or dormant failure. Evidence of some types of failure, such as structural cracks, may only be visible after a zone or ESA has been cleaned, whilst evidence of failures such as hot gas leaks may be lost as a result of any cleaning process. Consequently, the survey of zones and the examination of external areas must be done prior to, and after, any cleaning necessary to remove dirt, oils and other foreign material. Zonal surveys and ESA examinations should also be done in good lighting conditions by experienced and qualified personnel.

CHAPTER 11

LIGHTNING/HIGH INTENSITY RADIATED FIELD (L/HIRF) ANALYSIS

CONTENTS

BACKGROUND

1 Recent advances in technology have allowed for greater miniaturisation and complexity in integrated and discrete electronic circuit design. OEMs have taken advantage of the high reliability and low production costs offered by these circuits resulting in their use in a range of End Item systems. High-density electronic circuits tend to be populated with low voltage devices reliant on analogue and digital signal processing techniques to function. The disadvantage of this technology is that the probability of, and susceptibility to, Electro-Magnetic Interference (EMI) is greatly increased. The following forms of EMI can be generated in an L/HIRF environment:

1.1 Radio Frequency Interference (RFI).

1.2 Lightning events.

2 RFI occurs in specific frequency ranges and the energy received depends on the power of the source and the proximity of the End Item, Line Replaceable Item (LRI) and associated cabling to it. RFI may be generated on or off the End Item. Lightning occurs as a short duration high energy electro-magnetic pulse having a wide frequency spectrum. Both lightning and RFI can interfere with the operation of electrical and electronic systems by inducing energy in the form of sporadic voltages and currents into system wiring and components. Induced energy can have a potentially adverse effect on system functions and can cause physical damage. Furthermore, the vulnerability of safety and mission critical systems to EMI has been increased by the use of non-metallic composite materials with reduced shielding capabilities, as well as higher radio frequency energy levels from radar, radio, microwave and television transmitters.

3 To safeguard safety and mission critical systems from the effects of EMI, End Items operating in L/HIRF environments have their electrical and electronic systems protected. PTs should therefore implement a maintenance strategy to assure the continuance of this protection.

4 The guidance provided in this section relates to L/HIRF protection only and does not include personnel protection earthing requirements. Earthing features installed in systems and equipment to make sure that their operation is safe should be addressed as a separate function.

L/HIRF PROTECTION DEVICES

5 L/HIRF protection is achieved by the combination of complementary features as follows:

5.1 End Item structure conductivity and screening.

5.2 Electrical wiring installation protection.

5.3 Equipment protection.

6 Protection features afforded by End Item structure include the inherent conductivity and shielding of the structure itself, earthing and bonding straps, static dischargers, conductive mesh within composite materials and lightning conductors. Electrical wiring installations may incorporate shielded or braided cables, metallic

conduits and connectors with RF gaskets. Individual LRIs may be protected by electronic filter protection devices, which are passive networks usually connected on the input/output of a system LRI. The protection device acts as an electronic low pass filter with a predetermined insertion loss and response frequency (typically -50dB at 50MHz). Types of electronic protection devices include transient voltage suppressors (transorbs), filter pin connectors, filter adapters and filter seals.

MAINTENANCE OF L/HIRF PROTECTION DEVICES

7 The inherent conductivity of an End Item or equipment can be adversely affected by corrosion or accidental damage to bonding devices. Differences in electrical potential across an End Item or equipment may cause arcing to occur. Visual examinations and the continuity tests of bonding devices are therefore necessary to assess the integrity of their condition and functionality. The examination of visible bonding devices may be subsumed into zonal surveys; however, directed examinations will be required if the bonding device is specifically used for the management of static electricity or where bonding is a requirement of equipment performance. The frequency of a directed examination is based on a device’s susceptibility to ED and AD. The need and frequency of continuity tests should be based on the effectiveness of visual examinations and the expected deterioration rate of End Item conductivity.

8 The screening properties of braided cables and metallic conduit will be reflected by their physical condition and can therefore be adequately monitored by zonal surveys or general visual examinations at intervals based on the susceptibility of the installation to ED and AD.

9 End Item electrical installations may be fitted with filter pin connectors/adapters to limit the effects of L/HIRF. These filtering elements were initially considered to be ‘fit and forget’ items that would not require any form of maintenance. However, it is now accepted that environmental factors such as vibration, thermal cycling, electrical loading and corrosion degrade and eventually negate the effectiveness of filtering elements. PTs must therefore consult with OEMs/Design Authorities to identify the following:

9.1 The location of filter pins within safety and mission critical systems.

9.2 The types of filter pins used (tubular, planar).

9.3 The configuration of filter pin connectors/adapters (Pi, C, L or T filters).

9.4 The insertion loss/frequency response of filter pin connectors/adapters (usually presented graphically).

10 Although test equipment to measure filter degradation exists, it is difficult to determine a test interval because of the complex configuration, disposition and loading of filters that may be encountered throughout End Item electrical installations. Test intervals should therefore be based initially on OEM/DO advice and modified to reflect accrued test results and evaluations.

LRI PROTECTION

11 L/HIRF protection features may be incorporated inside an LRI. PTs should liaise with the suppliers of LRIs to make sure that the suppliers’ maintenance philosophy with regard to L/HIRF protection is reflected in the End Item and equipment maintenance schedules.

L/HIRF PROTECTION ANALYSIS PROCESS

12 The maintenance of L/HIRF protection devices is derived using the process illustrated in Figure 1 with the following additional guidance:

12.1 Block 1. Select those safety and mission critical systems that are L/HIRF protected. Include the aircraft in general as this will pertain to protection features such as inherent conductivity and static electricity dischargers.

12.2 Block 2. For each system, identify all the L/HIRF protection features and their location. For internal protection features within an LRI, it is only necessary to identify the LRI. Locations should be described in terms of zone identifiers.

12.3 Block 3. Identify the failure modes of each L/HIRF feature. Describe the physical condition that could be the root cause of any possible degradation to L/HIRF protection.

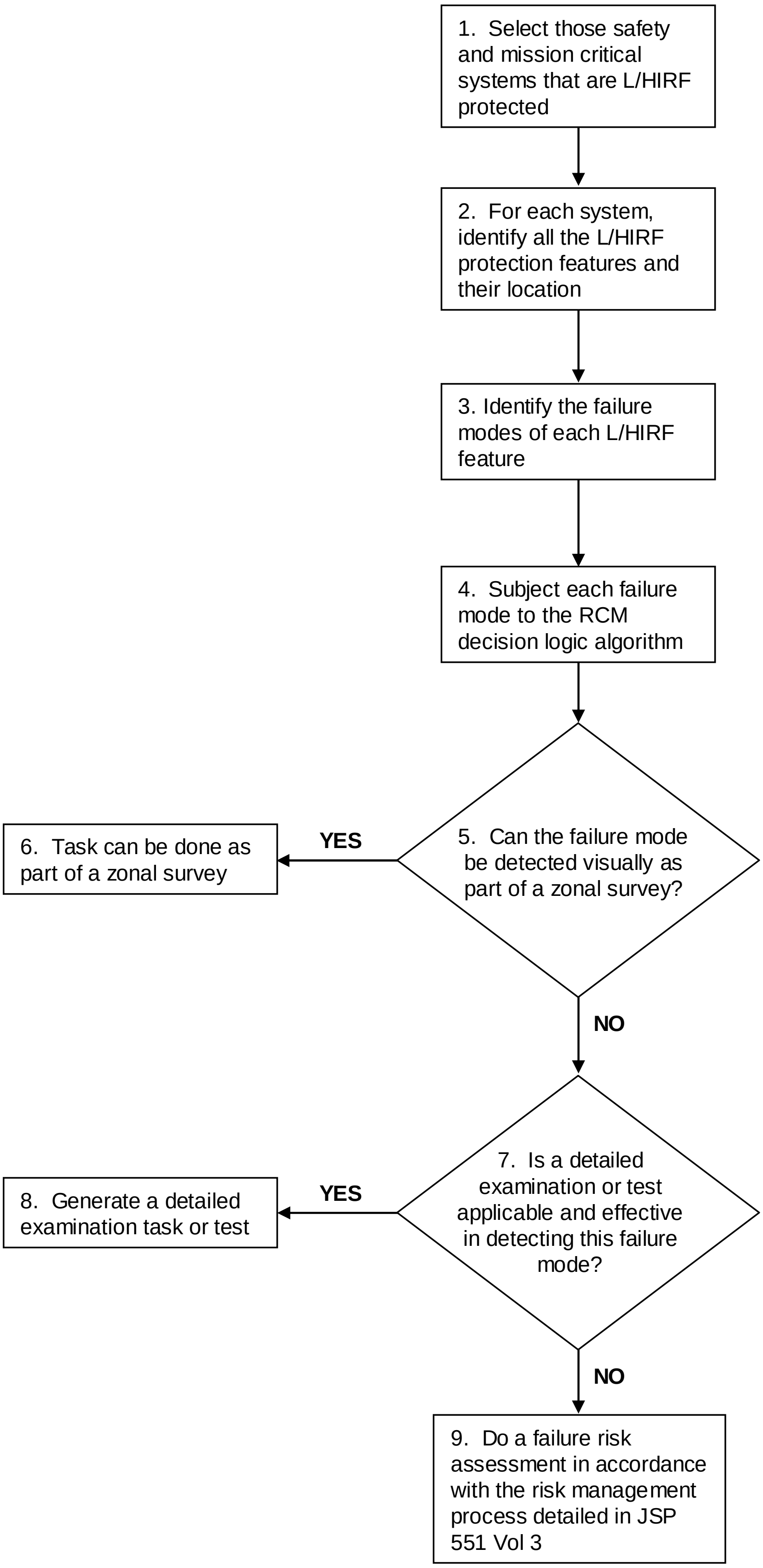


Figure 1 L/HIRF protection analysis process

12.4 Block 4. Subject each failure mode to the RCM decision logic algorithm to determine if a maintenance task is applicable and effective in detecting degraded L/HIRF protection.

12.5 Block 5. Can the failure mode be detected visually as part of a zonal survey? Consider the accessibility of the item and whether a visual examination can detect the root cause of any possible degradation to L/HIRF protection. The frequency of a zonal survey is determined by a rating value that is based on its susceptibility to ED and AD. The susceptibility of L/HIRF devices to ED and AD will usually equate to that of the zone in which they are located and therefore the frequency of zonal surveys should be adequate. However, if it is considered that a general visual examination of an L/HIRF device should be more often than the zonal survey, then a dedicated examination will be required.

12.6 Block 6. Task can be done as part of a zonal survey. Refer the task to the appropriate zonal analysis worksheet.

12.7 Block 7. Is a detailed examination or test applicable and effective in detecting this failure mode? Consider whether the level of L/HIRF protection can be determined by a dedicated visual examination, or by some form of test to measure its effectiveness. Where there is insufficient data to identify a suitable task or task interval, then advice should be sought from the OEM or DO. The maintenance of similar L/HIRF protection devices fitted to other aircraft may also be considered.

12.8 Block 8. Generate a detailed examination task or test. Also identify any specialist test equipment that may be required to do the task. A L/HIRF protection device may serve more than one system. For example, several safety or mission critical electronic LRIs may be located in a completely shielded compartment or zone. If a detailed examination of the shielding is required, it should be directed to the item of structure that forms the protective shielding. Similarly, if a L/HIRF protected cable loom serves more than one system and a detailed examination or test of the wiring and connectors is required, then it should be directed to the loom as a whole.

12.9 Block 9. Do a failure risk assessment in accordance with the risk management process detailed in JSP 551 Vol 3. If the condition of a L/HIRF protection device cannot be established by means of an examination or test, then the consequences of its failure should be considered as a risk hazard, which may prove tolerable, or otherwise be overcome by some redesign or modification action.

CHAPTER 12

CONDITION MONITORING AND CONDITION BASED MAINTENANCE

CONTENTS

Para

INTRODUCTION

1 Condition Monitoring (CM) is the collection and analysis of data from equipment to make sure that it retains the integrity of design and can continue to be operated safely. CM techniques can also be used to track equipment usage and to predict the condition of equipment at a defined point in its future operation. These usage tracking and diagnostics capabilities are prime features of a Health and Usage Monitoring System (HUMS). Condition Based Maintenance (CBM) is the maintenance that is initiated as a result of the knowledge of the condition of an equipment gained from routine or continuous CM.

2 CM is acknowledged within the philosophy of RCM in the following manner:

2.1 As a form of On-condition task insofar as the degradation of a function is monitored to the point when the level of degradation is unacceptable and corrective action has to be taken.

2.2 As an alternative to a Hard Time component replacement task, whereby a component can continue in service until the results of CM identify the need for replacement.

HEALTH AND USAGE MONITORING SYSTEMS

3 The condition, usage and performance capability of certain items of equipment may be monitored automatically by HUMS. Traditionally many of these tasks might have been done manually by a maintainer. An understanding of the functions and capabilities of HUMS is necessary to make sure that tasks are not replicated. HUMS functions themselves, must be analyzed to reveal failure modes requiring PM tasks.

4 A state of the art HUMS is capable of detecting potential failure conditions down to component level by monitoring the progression of failure modes. Through automated monitoring, a ‘prognosis’ of the ‘health’ of an item can be made. Degradation is monitored automatically as it progresses to a defined potential failure condition, at which point maintenance action will be required. Health monitoring systems do ‘automatic’ on-condition tasks at intervals, which often are extremely short or continuous. They use on-board sensors, algorithms, and diagnostics indicators (or indices) sensitive and accurate enough to detect or predict a potential failure condition.

5 When developing a FMECA, any existing HUMS used to monitor the item undergoing analysis, must be considered. This will help to make sure that failure detection methods and failure effects are properly stated. HUMS may have different failure detection methods for potential failures or functional failures; therefore, care must be taken to identify the level of failure being monitored.

6 HUMS may be used to automatically record the age or usage of components to promote cost-effective management of HT tasks. In this context, however, it is not sensing degradation, but merely usage. HUMS technology can reduce costs by automatically tracking age and triggering replacement or other maintenance action. It can also be used to reduce or eliminate dependence on manual recording systems.

7 In evaluating failure finding tasks during an RCM analysis, HUMS technology may be considered as an alternative to physical maintenance tasks where it can be shown to be cost effective or beneficial to safety or operations.

SPECIAL CONSIDERATIONS FOR HUMS DRIVEN TASKS

8 While HUMS introduce opportunities for detecting failure modes, tracking usage, or finding failures, they also introduce potential complications for maintenance scheduling. Since the maintenance will be ‘driven’ by an indication from monitoring or sensing devices, it must be well understood what is being monitored or sensed to properly plan maintenance. Although not exhaustive, the following examples will help to illustrate the special considerations necessary when maintenance is driven by HUMS.

9 HUMS may be doing an on-condition examination where it is detecting a potential failure condition prior to functional failure. To avoid disruption to operations, it may be possible to establish a ‘time to correction’ once the indication occurs, thus allowing corrective action to be planned at the most convenient time.

10 HUMS may be tracking usage for a hard time task. The indication of a need for the task should be set to allow time to plan the task for a convenient maintenance opportunity.

11 HUMS may be doing a failure finding task. In this case it may not be possible to delay maintenance once the failure is indicated.

12 Some HUMS installations require maintainers to record information periodically or do output checks. While often done as a flight servicing activity, some may require longer intervals that must be scheduled at appropriate opportunities. Again, the particular application and parameters must be well understood before deciding on the frequency of these actions.

13 In all the above examples, once the time for necessary action is identified, it must be detailed in the appropriate maintenance management procedures as required. If possible, the actions should be aligned with other scheduled maintenance activities to avoid unnecessary disruption to operations.

POLICY

14 The MOD policy for CM and CBM is contained in JSP 817.

CHAPTER 13

RATIONALIZATION OF PM TASKS AND THE DEVELOPMENT OF THE MAINTENANCE PROGRAMME

CONTENTS

INTRODUCTION

1 The intervals at which RCM derived PM tasks are done will vary according to the results of the analysis applied to each failure mode. These intervals are expressed in terms of operating cycles, such as calendar time, hours run, flying hours, numbers of landings, rounds fired etc. It may be possible to schedule PM tasks at their derived intervals if control of the maintenance programme is manageable and the opportunities for scheduled maintenance are frequent. In most cases, however, the PM tasks are consolidated and grouped into discrete work packages to minimise the number of required maintenance visits. This results in shorter intervals than is necessary for some PM tasks, but achieves optimization of aircraft availability. There is no single best way of packaging PM tasks, as this depends on factors such as the organisation and location of the necessary maintenance resources and the availability required of the aircraft.

2 Grouping PM tasks gives several benefits: it simplifies control, aids the selection of work locations and makes the best use of maintenance resources.

USE OF CONVERSION FACTORS

3 Each RCM task will have a frequency defined in units that reflect the usage of the associated asset. These units may be actual operating hours, calendar time, shots fired or any other appropriate measurement base. Aircraft maintenance programmes are generally packaged at intervals measured in terms of flying hours. Task intervals measured in different units will need to be converted, wherever possible, to those of the aircraft.

It is emphasised, however, that associated item usage must be relatively consistent in comparison with aircraft usage; if not, the task will need to be scheduled independently. The conversion factor is obtained by dividing the annual flying hour rate of usage of the aircraft by the annual rate of usage of the subject item. It is then used to convert the derived task interval of each PM task to a flying hour unit of measure, by multiplying the task's natural interval by the conversion factor.

LEVELS OF MAINTENANCE

4 Before any task packaging is attempted, it will be necessary to determine the level of maintenance required for each task. Initially, this will help to visualize and most effectively package those tasks that require remote or extensive logistics support, such as that provided at depot or ‘Depth’ levels of maintenance. Thereafter, it will be necessary to identify those tasks that require an intermediate level of support and those that can be done at a Forward (Fwd) operating base. A maintenance programme that best suits the operational requirements of the aircraft can then be defined.

TASK ELAPSED TIME

5 Packaged intervals are based on the times when the distributed workloads within a maintenance programme are most concentrated. To measure the work effort, an estimate is needed of the elapsed time for each task, including the time for supervision; the work hours to do the tasks are not important at this stage. The information is best obtained from those personnel who have experience of the task itself or of a similar task. The estimates should be made using the following assumptions:

5.1 The aircraft is located at the facility where the work is to be done.

5.2 All necessary staging, support equipment and tools are in place.

5.3 Any necessary spare or consumable is available.

5.4 There is no interference from other tasks.

6 When estimating the task elapsed time, the time taken by the following ancillary activities should be included:

6.1 Preparation and access, such as the removal of panels and doors, moving items for access, connecting ground or test equipment, jacking and supporting.

6.2 Supervision and quality assurance.

6.3 Reassembly and recovery, including refitting equipment doors and panels, which were removed to do the task, cleaning, filling etc.

6.4 Doing tests, including functional checks required as a result the task, provided the test is done at the work area and other work may be done simultaneously.

INITIAL PACKAGING ASSESSMENT

7 When the levels of maintenance and elapsed times associated with each of the preventive maintenance tasks are established, they are placed on a timeline using an appropriate measurement base to identify whether there are any naturally occurring peaks of maintenance effort. Separate timelines should be used for measurement bases that are not suitable for conversion into platform operating cycles (rounds fired, number of landings etc). This assessment of the spread of the preventive maintenance effort is illustrated in Figure 1.

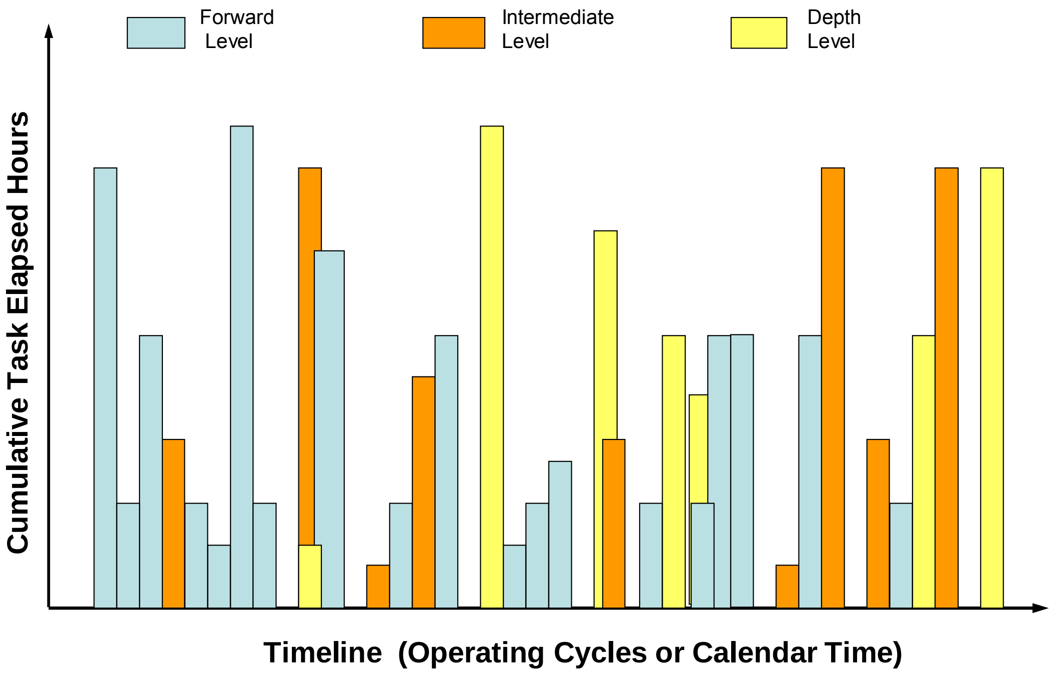


Figure 1 Task timeline

8 The framework of a maintenance programme is primarily determined by the intervals associated with depth levels of maintenance. Overlaid onto this framework are those preventive maintenance tasks that are capable of being done by the maintainer, or by maintenance organizations sited at aircraft operating locations. The specific levels of maintenance that are available, and their descriptions, will depend on the aircraft concerned and its user organization. Appropriate and available levels of maintenance for each RCM study should be established and recorded as part of the associated RCMPP.

PACKAGING THE DEPTH MAINTENANCE LEVEL TASKS

9 The depth maintenance level tasks are grouped together so that the associated grouped intervals are as large as possible without compromising the cost effectiveness of the schedule or its integrity with regard to safety issues. To do this will mean that some task intervals may need to be extended, and some shortened if they are to be included in the grouped package as illustrated in Figure 2. However, any increase in a derived task interval will increase the risk of failure occurrence and it must be understood that under no circumstances should a task interval be extended if the associated consequences of failure are safety or environmental related. Conversely, the reduction of a derived task interval will increase the maintenance cost. Packaged depth maintenance level tasks form the initial content of a Major Maintenance Schedule.

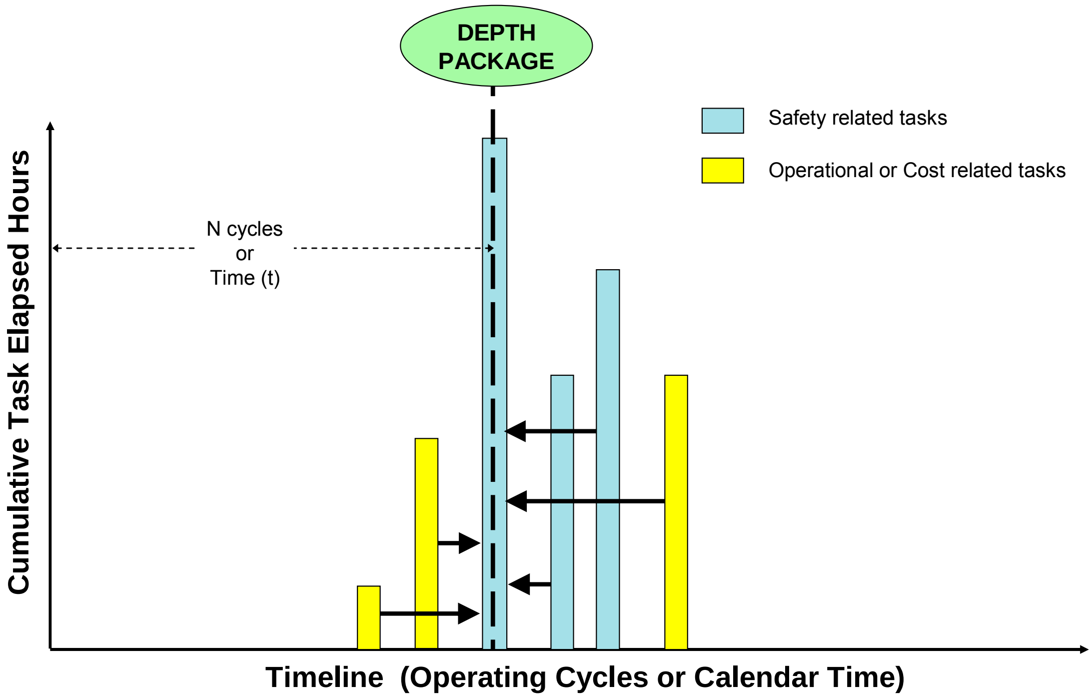


Figure 2 Grouping of depth maintenance level tasks – initial framework

10 The frequency of maintenance tasks that relate to failure modes with operational or economic failure consequences may be extended or reduced as required for the purposes of task packaging, but only with the consent of the Project Sponsor.

PACKAGING THE INTERMEDIATE MAINTENANCE LEVEL TASKS

11 Once the intervals between ‘Depth’ levels of maintenance are established, it will be necessary to package those PM tasks that require Intermediate (INT) levels of maintenance. These tasks will normally be done by maintenance support organizations that are located at aircraft operating units or areas. ‘Intermediate’ levels of maintenance are grouped in the same way as the ‘Depth’ levels, although it is usual for the group intervals to be synchronised with the ‘Depth’ levels of maintenance and also with each other. An example of this is shown in Figure 3. It can be seen that the there are three separately packaged groups of intermediate level tasks and that the elapsed time for each group is approximately the same. In the example shown, the maintenance tasks contained in the ‘INT 3’ package would be subsumed into the ‘DEPTH’ maintenance package.

12 An alternative approach to packaging the intermediate maintenance level tasks is to group them by task interval such that the interval of the highest frequency group is a proportion of the next higher frequency group and so on until the packages build up to the last group that is done at the lowest frequency as shown in Figure 3.

13 The main difference in this type of packaging is that the elapsed time to do maintenance increases with the number of groups that need to be done. This method of packaging creates a build-up type of maintenance programme since the maintenance done at each interval includes any higher frequency maintenance packages. The protracted down-time required at the larger maintenance groupings can provide the opportunity to incorporate aircraft modification or update programmes.

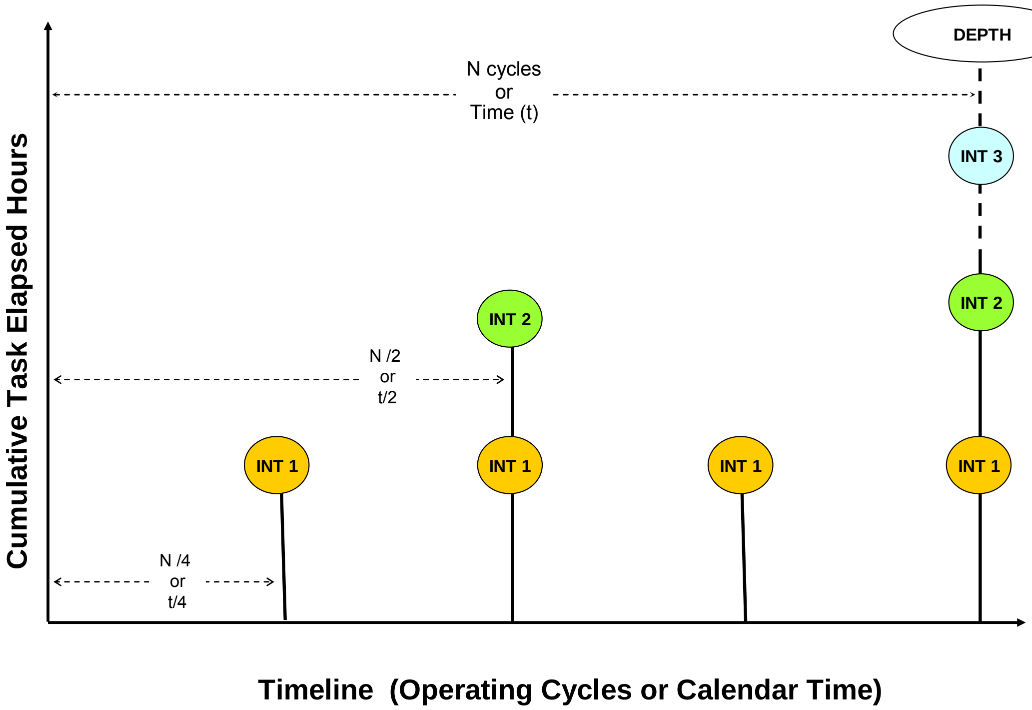


Figure 3 Grouping of intermediate maintenance level tasks

14 If the intermediate and depth maintenance level tasks are to be done at similar maintenance facilities, the INT 2, INT 3 and DEPTH tasks can be evenly distributed across the four INT 1 packages, whilst retaining their required task intervals. Each INT 1 package then becomes a discrete or 'Equalized' package as shown in Figure 4.

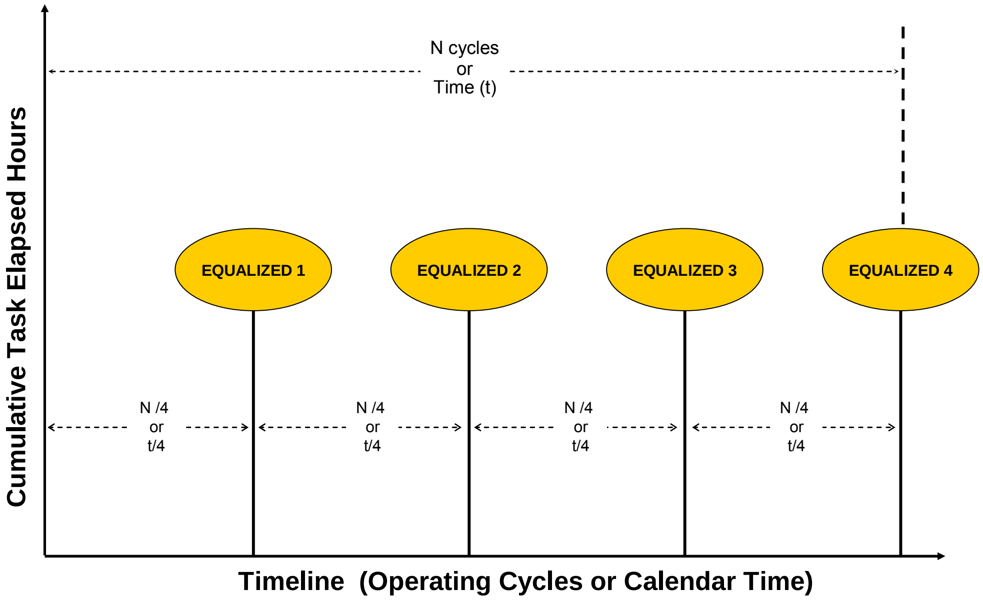


Figure 4 Equalized task packaging

PACKAGING THE FORWARD MAINTENANCE LEVEL TASKS

15 Fwd scheduled maintenance tasks are those that are done by the organization directly responsible for the routine preparation and usage of an aircraft and the packaging of these tasks will be determined by operational requirements. If a high degree of availability is required then maintenance activities should be as non-disruptive to operational capability as possible. This is particularly important if the numbers of aircraft are limited, as in the case of a single helicopter operating from the stern of a ship or when relatively small numbers of aircraft are detached from a main operating base during long term deployed operations. There may be a requirement for frequently prolonged operating periods that preclude the opportunity to do anything other than essential maintenance. This too will be a factor that will influence how first line maintenance tasks are packaged. There are currently three methods of packaging scheduled Fwd maintenance tasks, as follows:

15.1 Build-up packaging that forms the contents of discrete maintenance schedules such as a Primary and Primary Star or a Basic 1 and Basic 2.

15.2 Flexible packaging.

15.3 Flexible operations packaging, which is commonly known as ‘Flex-ops’ packaging.

Each of the methods described is supplemented with a Flight Servicing Schedule, which prescribes those routine maintenance activities that are necessary to prepare an aircraft for flight and to recover an aircraft to a useable state after it has flown.

Build-up packaging

16 Fwd maintenance tasks can be grouped by intervals in a manner similar to that described for the build-up type of packaging of the intermediate maintenance level tasks. The intervals between each package are proportional to the shortest intermediate maintenance level interval as shown in Figure 5.

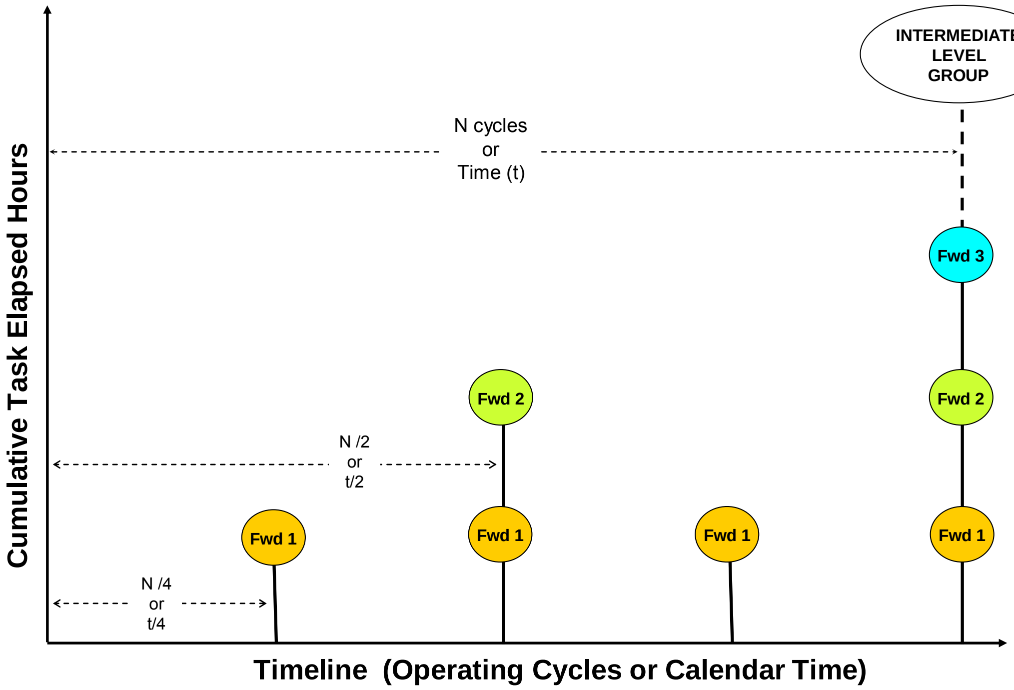


Figure 5 Build-up packaging of forward level scheduled PM tasks

17 It can be seen that the Fwd 3 package in Figure 5 coincides with the intermediate level group. The content of this package will therefore be subsumed into the intermediate level package. The maintenance tasks grouped in the Fwd 1 and Fwd 2 packages will form the content of discrete maintenance schedules such as a Primary and Primary Star or Basic 1 and Basic 2.

18 This method of packaging is ideally suited to large fleets of aircraft where the downtimes for scheduled forward maintenance have a negligible impact on operational capability.

Flexible packaging

19 An increase in aircraft availability can be achieved if the dedicated downtimes required for the build-up type of scheduled forward maintenance can be reduced. Adopting the flexible packaging method can do this. This involves spreading the content of the forward package with the shortest scheduled interval over a series of smaller groups that can be completed between aircraft operations. Each of the smaller groups is designed to be done at any time during the period to which it is assigned. This method is illustrated in Figure 6. In this example the content of Fwd 1 is spread over groups A to D and repeated again over groups E to H. The contents of Fwd 2 are then spread over all of the eight groups. The maintenance allocated to each group can then be completed at any time during the period to which it is assigned. When using this system it is important to note that each task should have sufficient latitude in its application requirements to permit an acceptable limit of flexibility. In the example shown the anticipation or extension of the Fwd 1 task intervals by up to 25% and the Fwd 2 tasks by 12.5% is already built in.

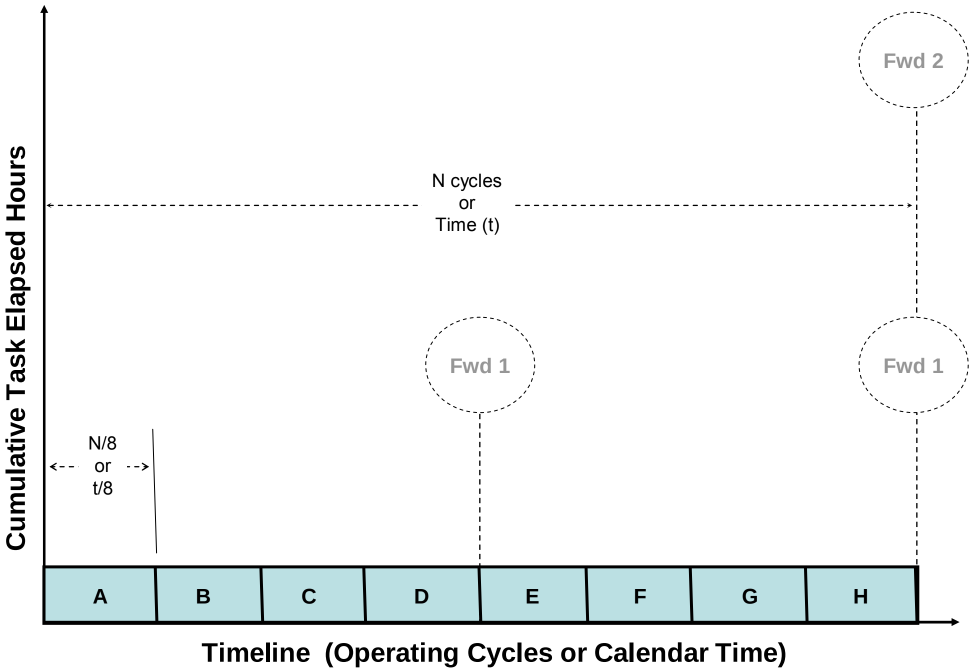


Figure 6 Flexible packaging of forward level scheduled PM tasks

Flex-op packaging

20 The need for extended periods of deployed operations using a limited number of aircraft has resulted in the adoption of 'Flex-ops'. This method involves the packaging of Fwd scheduled maintenance activities into a series of flex-ops, each of which must be capable of being done during short down-time periods (usually 3 to 4 hours) and completed between periods of operations. It is usual for the flex-ops to be area based as this minimizes the need to remove panels or equipment for access purposes. Flex-ops are managed and reforecast independently of each other at intervals that are based on both calendar time and operating cycles. The work cards for each flex-op also identify those flex-ops that are allied to the same work area, so that, time permitting, they too can be completed at the same opportunity, even though they are not actually due to be done. This flexibility of task completion can also be enhanced by the deferment of task completion that is allowed for each flex-op as defined in ►MAP-01 Chapter 5.3◄. Furthermore, there is no need to link task intervals to those of the intermediate or depth maintenance packages, although those with an equivalent interval can be subsumed into the respective higher-level package.

21 This method of maintenance may provide the flexibility required of operational needs, however, it does involve a high number of maintenance visits which can prove management intensive for relatively large fleet numbers that are centrally administered. Furthermore, a degree of over-maintaining will occur during extended

operating periods, because the maintenance due during these periods will have to be anticipated and done sooner than actually required, unless they can be postponed within the permissible limits of task deferment.

Flight servicing

22 As already stated, a flight servicing schedule prescribes those routine maintenance activities that are necessary to prepare an aircraft for flight and to recover an aircraft to a useable state after it has flown. However, simple Fwd scheduled maintenance tasks that need to be done at very short intervals can be included. Although these tasks will be done more often than required, the additional maintenance effort is negligible and the need to manage their implementation separately is eliminated.

OUT OF PHASE MAINTENANCE

23 Not all maintenance task intervals readily align themselves to a chosen method of task packaging and the associated tasks are therefore detailed separately as independent activities. These tasks are referred to as ‘Out of Phase’ maintenance and may be placed in this category for any one of the following reasons:

23.1 The task is to replace an interchangeable unit or assembly, which itself has a defined useable life.

23.2 The task interval is measured in operating units other than that used for the aircraft and is unsuitable for conversion.

23.3 The task is done on an opportunity basis as a result of major equipment removals.

23.4 The task interval is shorter than that of the highest frequency scheduled maintenance package.

RATIONALIZATION AS A RESULT OF EQUIPMENT REMOVAL

24 There are some maintenance tasks that will have access requirements involving the removal of major items of equipment. If, for other reasons, these items are routinely removed at frequencies greater than the PM task interval, then the task should be scheduled on an opportunity basis whenever these equipments are removed. Wherever possible these tasks should be incorporated in the relevant equipment removal or refit procedures.

USE OF MAINTENANCE BACKSTOPS

25 The periodicities of grouped maintenance tasks are normally expressed in terms of aircraft operating cycles such as flying hours, equipment running hours etc. However, during periods of low utilization there may be PM tasks within a particular maintenance schedule that need to be done within a specified calendar time limit. For example, an examination or series of examinations for corrosion that are embedded in a maintenance schedule defined in operating cycles. In such cases, calendar limits may be imposed to assure required reliability levels. Conversely, calendar based maintenance schedules may require operating cycle upper limits to compensate for unexpectedly high utilization rates.

RECORDING RATIONALIZED TASK INTERVALS

26 Following completion of the rationalization process, each rationalized task interval should be identified by the maintenance package to which it has been assigned and recorded alongside the RCM originally derived interval to provide audit traceability. The output from this activity is the formulation of the most effectively packaged maintenance programme for the aircraft concerned, which best meets operational needs.

MAINTENANCE TASK CODING

27 Certain tasks within the Master Maintenance List (MML) may be annotated with one or more codes that relate to the types of task packaging used to identify the maintenance requirements during specific operational circumstances. The codes, and the type of maintenance schedule in which the associated tasks are detailed, are as follows:

27.1 Cty/CTM - Contingency Maintenance.

27.2 ORS - Operational Readiness Servicing.

27.3 WFSMM - Waived Flight Servicing Mandatory Maintenance.

27.4 CCMM - Continuous Charge Mandatory Maintenance.

28 Complete descriptions of these coded maintenance packages are contained in ►MAP-01 Chapters 2.8◄ and 5.3 and each maintenance task that is derived from an RCM analysis should also be considered for inclusion into these schedules as required. The following paragraphs contain brief descriptions of each coded maintenance type and also provide guidance on the selection of appropriate maintenance tasks.

Contingency maintenance

29 'Cty/CTM' coded preventive maintenance tasks are those considered essential in operational circumstances when other forms of scheduled maintenance cannot be done. The following logic is to be used when determining the content of a contingency maintenance schedule:

29.1 Select high frequency packaged tasks for items whose failure would have safety and/or sortie abort consequences and are contained in systems with no redundancy and have a relatively high probability of failure. (The operating environment must be considered when assessing the probabilities of failure).

29.2 Select lubrication, replenishment and servicing tasks for items whose failure would have safety and/or sortie abort consequences. (These tasks usually form the bulk of a contingency maintenance schedule).

Implementation of contingency maintenance should be done in accordance with ►MAP-01, Chapter 5.3◄.

Operational readiness servicing

30 The ORS schedule contains the preventive maintenance activities necessary to maintain an aircraft in a state of continuous operational readiness for up to 30 days. An ORS is a substitute for the aircraft's basic flight servicing schedule, the requirements of which are suspended throughout the period of operational standby. Tasks annotated ORS are those contained in the B/F servicing schedule that are considered essential to maintain an aircraft in a serviceable condition during the standby-servicing phase of the ORS.

Waived flight servicing mandatory maintenance

31 Waived Flight Servicing Mandatory Maintenance (WFSMM) comprises the mandatory flight servicing maintenance tasks to be done when flight servicing between successive flights are waived during peacetime. WFSMM is only done in exceptional operational circumstances and the aircraft EA is to specify its limitation in terms of flying hours, elapsed time, number of landings and/or number of system operations, as appropriate. Tasks selected for WFSMM must have a flight servicing frequency and be considered essential in ensuring the aircraft is fit to fly during the specified period of WFSMM implementation.

Continuous charge mandatory maintenance

32 Certain aircraft are operated in such a way that demands that they land and stop their engine(s), then possibly refuel, restart engine(s) and take-off again in order to complete a particular mission. During such a mission the aircraft is not subject to normal flight servicing, but considered to be on 'continuous charge' and is the total responsibility of the aircraft captain. CCMM tasks are those considered necessary between successive flights and are selected on the basis that they must have a flight servicing frequency and be essential in ensuring the aircraft is fit to fly during the specified period of continuous operation.

CHAPTER 14

AUDITING

CONTENTS

Para

PURPOSE

1 The purpose of an RCM audit is to make sure that:

1.1 An analysis is compliant in all respects with Def Stan 00-45.

1.2 The decisions made by the study team are appropriate.

1.3 The technical details contained in the study report are accurate.

1.4 The maintenance recommendations are practical and viable.

1.5 The format and terminology used in RCM documentation conforms to recognized standards.

1.6 Records of an RCM analysis provide an audit trail for future users, including the logic, assumptions, study boundaries and recommendations.

TYPES OF AUDIT

2 There are three types of audit applicable to an RCM analysis; the process audit, the technical audit and the authorship audit.

Process audit

3 A Process Audit provides documented evidence that each stage of the RCM process has been fulfilled satisfactorily in compliance with the requirements stipulated in Def Stan 00-45.

Technical audit

4 A Technical Audit provides documented evidence that the technical detail contained in a recorded RCM analysis is reasonable and accurate. The audit also verifies whether the recommended maintenance actions are viable; ie, the necessary resources are available and the tasks are technically practicable.

Authorship audit

5 An Authorship Audit provides documented evidence that the maintenance tasks derived from an RCM analysis are accurately described and presented in a format that conforms to specified standards such as ASD Specification S1000D, Aviation Publication DAvP 70, Joint Air Publication JAP(D) 100C-20 or the JSP 180 series of Joint Service Publications.

AUDITORS

6 Process Audits are to be conducted by competent personnel who have received an advanced level of training and are experienced in RCM. They should have had no direct involvement in the study presented for audit.

7 Technical audits are to be conducted by authorised personnel who are familiar with the equipment concerned and who have responsibility for the associated maintenance schedules. These will usually be approved or authorised members of stakeholder PTs.

8 Authorship audits are to be conducted by personnel experienced and trained in technical authorship and who are familiar with the publications standards associated with the aircraft or equipment under consideration.

PROCEDURES AND DOCUMENTATION

9 The audit procedures and responsibilities applicable to a particular RCM Study should be specified in the RCMPP.

EXAMPLE CHECKLISTS FOR RCM AUDITS

10 Examples of checklists that can be used as guides to each type of audit are provided in Tables 1, 2 and 3, although their content is not exhaustive.

TABLE 1 RCM PROCESS AUDIT

RCM Phase	Checks Required
Aircraft or equipment operating context	Is there an operating context statement for the aircraft or equipment concerned? Does the operating context statement describe what the aircraft or equipment is required to do and the conditions under which it is required to operate? Is there a brief physical description of the aircraft or equipment? Where applicable, are there any variations in aircraft or equipment capability due to type variants or modification state? Where applicable, are the limitations of engineering resources and capability at each operational/maintenance level defined.
Aircraft or equipment functional modelling	Has the aircraft or equipment been functionally modelled to a level of resolution suitable for RCM analysis? Is each discrete system or sub-system identified by a unique identification number or code?
Analysis level operating context	Is there an operating context statement for the system or sub-system concerned, which adequately defines the modes of operation and performance requirements? Are all operating modes identified? Is there a brief physical description of the associated system or sub-system? Is there an illustration, schematic or block diagram attached? Where applicable, does the operating context contain details of redundancy features or compensating provisions? Are the functional boundaries of the analysis defined? Where applicable, are there any variations in functionality due to type variants or modification state?
Functions	Is the list of primary functions for each system or sub-system commensurate with the requirements detailed in the analysis level operating context? Have the secondary functions of each system or sub-system that is analysed been considered? Are the functions described using the correct performance and usage metrics?
Functional failures	Are the functional failure statements the antithesis of the function statements? Have partial and absolute failures been considered?

RCM Phase	Checks Required
Failure modes	Is each failure mode correctly constructed (ie, not expressed as an effect)? Is each failure mode a single entity?
Local failure effects	Does the local effect describe the immediately localised effects of the failure mode?
Next higher effects	Does the next higher effect adequately describe what happens at system level? Does the next higher effect adequately describe the possibility of physical damage to the system or other unrelated systems? Have actions to be taken by the operator to isolate or mitigate the failure been identified, including the time required to complete such actions? Is there any evidence that a failure has occurred or is occurring (eg; reduced or abnormal performance; alarms; visual, audible and physical indicators such as discolouration, noise or vibration)?
End effects	Does the end effect fully describe the effects to the End Item/personnel safety, environmental threats and operational capability? Has the MART for the primary and secondary damage caused by the failure been identified?
RCM decision logic	Are the consequences of failure correctly recorded and consistent with the failure effects declared in the FMEA or FMECA? Are the selected tasks or actions justifiable?
Task description	Has each task been described in sufficient detail to enable a technical author to compile the definitive procedure for undertaking the task? Where applicable, have access or task condition requirements been identified? Has the correct skill level and depth of maintenance been identified? Are tasks duration times included? Where applicable, are task locations or zone numbers correct?

TABLE 2 RCM TECHNICAL AUDIT

RCM Phase	Checks Required
Aircraft or equipment operating context	Is the operating context statement technically correct? Where applicable, are the declared limitations of engineering resources and capability at each operational/maintenance level accurate?
Aircraft or equipment functional modelling	Is the platform or equipment functional model technically correct?
Analysis level operating context	Is the operating context statement for the system or sub-system concerned technically accurate? Are all operating modes identified and technically correct?
FMEA or FMECA	Are all functions correctly identified? Are the details of the FMEA or FMECA technically accurate?
RCM decision logic	Are the recommended tasks or actions technically acceptable and executable?
Task description	Are the task descriptions technically correct? Are the maintenance and skill levels for each task correct?

TABLE 3 RCM AUTHORING AUDIT

Authoring Element	Checks Required
System or sub-system identifier	Is the system or sub-system correctly identified to an appropriate standard (description, SIN, LCN etc)?
Item quantity and location	Where applicable, does the description of the item quantity and location conform to the appropriate authoring standard?
Item description	Does the description of the item conform to the nomenclature used in prime publications? Are quantities described in the correct format?
Task descriptions	Do task descriptions conform to the required standards of terminology or glossary of terms? Are task intervals expressed in the correct terms? Are maintenance and skill levels expressed in the required standards of terminology or glossary of terms?

CHAPTER 15

CONDUCTING AN RCM STUDY

CONTENTS

Para

Annex

INTRODUCTION

1 This chapter describes how to conduct an RCM study in a way that has evolved through past experience and has proved successful in terms of RCM study management, execution and documentation. The study procedure is described with the assumption that the RCM analysis utilizes Engica Q^4W RCM application software and the associated Engica Schedules Production Database (SPD), and that the RCM study stakeholders are sufficiently familiar with this software tool, or the printed reports it generates, to enable them to satisfactorily contribute to the study.

SCOPING STUDY

2 An RCM study begins with a scoping study to establish the requirements and objectives of the main RCM task. The scoping study should consist of the following activities:

2.1 Production of the RCM project plan. The RCM Project Plan (RCMPP) is produced in accordance with Def Stan 00-45 Part 2. The plan is designed to act as an agenda for RCM planning meetings and to stipulate the requirements, assumptions, responsibilities, time-scales and data sources that are specific to an RCM study programme. It also identifies the major stakeholders involved in the project and the roles assigned to them. The RCMPP subsequently provides the basis of a binding agreement between the RCM study stakeholders.

2.2 Opening brief. The Study Team Leader should give an opening brief to all stakeholders involved in the study to explain the review process. Guidance should also be provided to the sponsoring PT to assist them in identifying their specific requirements, which are to be recorded in the RCMPP.

2.3 Development of the work breakdown structure. Topics 5 series maintenance schedules are currently produced in accordance with the standard formats defined in JAP(D) 100C-20, Preparation and Amendment of Maintenance Schedules. These standard formats require all maintenance tasks to be assigned to a Schedules Identification Number (SIN), which links the tasks to their associated systems and sub-systems as defined in the Standard Numbering Systems detailed in known standards, such as ASD Specification S1000D, International Specification for Technical Publications. If one does not exist, it will be necessary to create a system and sub-system numbering structure that conforms to ASD Specification S1000D, so that each task derived from the RCM analysis can be assigned to an appropriate SIN. The system and sub-system numbering system will form the Work Breakdown Structure (WBS) and is detailed in the RCM Study Workbook.

2.4 Creation of an RCM study workbook. An RCM Study Workbook is created as a spreadsheet that forms a living document to record all the elements of the RCM analysis process and, where applicable, their current status as the study progresses.

2.5 Preparation of an Engica Q^4W RCM database. An Engica Q^4W RCM Database is created to record the RCM analysis and the derived maintenance tasks that are ultimately detailed in the aircraft Topics 5 maintenance schedules.

2.6 Structurally Significant Items (SSIs) list. The Study Team Leader should request the PT to provide details of the SSIs associated with the aircraft. This information is usually provided by the aircraft Design Organization (DO) and should include recommendations for structural examinations.

2.7 Preparation of a list of Technical Instructions (TIs) to be reviewed. An RCM study should include a review of extant TIs that are repeated at periodic intervals, whereby the effectiveness of each TI is verified using the RCM analysis methodology. If the TIs prove justifiable they should be incorporated into the aircraft maintenance schedules, although this may first require the inclusion of associated procedures into the Topic 1 Aircraft Maintenance Manuals (AMMs).

2.8 Modifications list. The Study Team Leader should request the PT to provide details of all modifications embodied in the aircraft fleet.

SUPPORTING DOCUMENTATION AND DATA

3 The study team should obtain, or have access to, sufficient documentation and data to satisfy the needs of the RCM study. Useful sources of information are provided in the following list:

3.1 Topic 1 Aircraft Maintenance Manuals.

3.2 Topic 1 Equipment Maintenance Manuals.

3.3 Topic 3 Aircraft Illustrated Parts Catalogues.

3.4 Aircraft Statement of Operating Intent and Usage (SOIU).

3.5 Topic 14 Flight Reference Cards.

3.6 Topic 15 Aircrew Manuals.

3.7 Manufacturers' bulletins and drawings.

3.8 Failure data records (these may be available on LITS or WRAM).

3.9 Aircraft Support Policy Statement (Topic 2(N/A/R)1).

3.10 ►MAP-01 (Manual of Maintenance and Airworthiness Processes)◄.

PRODUCTION OF A ZONAL AND ESA PLAN

4 A Zonal and ESA plan is produced to define the various zones and external areas of the aircraft as explained in Chapter 10.

RCM STUDY WORKBOOK

5 The RCM Study Workbook spreadsheet consists of a series of worksheets that are used to record all the elements of the RCM analysis process and to display the outcomes of the study as it progresses to completion. A worksheet dedicated to each of the study elements is contained within the workbook and these are briefly described as follows:

5.1 RCM study task list. The RCM study task list details the various actions required in chronological order that are necessary to complete the RCM study. The list also indicates the ownership, target date, location and status associated with each action.

5.2 Points of contact details. The Points of Contact (PoC) worksheet lists the names, locations, roles and contact details of all stakeholders involved in the RCM study.

5.3 Active assumptions list. The RCM study team may need to make a number of assumptions regarding the conduct and requirements criteria of the study. These are recorded on the Active

Assumptions List worksheet. The list should be presented to the sponsoring PT and their responses, including any actions to be taken, are also recorded on this worksheet.

5.4 Questions list. Various queries will arise during the conduct of the study and these are recorded in the Questions List worksheet. The answers to these queries and the details of any required follow up actions are also recorded on this worksheet.

5.5 Active risks list. All the probable risks that could be encountered during the course of the study are registered on the Active Risk List worksheet. Included in this worksheet are the mitigating actions required to avoid each risk and the consequences that would ensue if the risks are not mitigated.

5.6 Zonal and ESA information. The Zonal and ESA information worksheet lists the various zones and areas contained in the Zonal Plan along with the respective ratings and survey intervals that are derived from the Zonal and ESA analysis.

5.7 Work breakdown structure. The Work Breakdown Structure (WBS) worksheet lists the systems and sub-systems employed on the aircraft. The systems and sub-systems are identified in accordance with an appropriate Standard Numbering System (SNS).

5.8 Task progression chart. The task progression chart is used to track the progress of individual systems analyses and maintenance schedules production on a calendar basis through to study completion.

5.9 Maintenance comparator. The purpose of the Maintenance Comparator (MC) worksheet is to indicate that all the maintenance tasks contained in the pre-study maintenance schedules are considered during the RCM analysis, either by referring them to the associated SINs of the revised schedules or by providing the justification of their omission from them. Any new tasks created as a result of the study are also listed in the MC worksheet.

5.10 Structurally Significant Items (SSIs). The SSI worksheet contains a list of all Structurally Significant Items.

5.11 Unsatisfactory Feature Reports (UFRs). The UFR worksheet is a register of all Forms F765 that are to be addressed during the course of the RCM study. The register is updated as each F765 is finalised.

5.12 List of Modifications. The Mods worksheet lists all the modifications embodied on the aircraft.

5.13 Technical instructions. The TI worksheet lists all the TIs that are to be considered in the RCM study.

5.14 PT/DO Specified Tasks. The PT is responsible for validating the current lubrication and NDT tasks.

6 The Study Team Leader is responsible for the control and management of the RCM Study Workbook.

UNSATIFACTORY FEATURE REPORTS

7 An RCM study should include the investigation of all outstanding MoD Forms F765, Unsatisfactory Feature Reports. However, the progression of any additional MoD Forms F765 should be suspended during the course of an RCM study. The one exception to this precept is if the MoD Forms F765 subject is of an urgent nature that could have an impact on airworthiness integrity.

RCM ANALYSIS

8 The technique used to do the RCM analyses should be based on a functional top-level system approach. This is the preferred method of addressing all possible functional failures associated with each system, as opposed to the physical breakdown approach that was previously accepted. Instructions for conducting a top-level RCM analysis are detailed in Annex A.

9 The RCM analyses are recorded on an Engica Q^4W database and the results can be reproduced in report format as RCM PM Worksheets 2. Instructions for recording an RCM analysis using Engica Q^4W are detailed in Annex B.

10 When an RCM analysis identifies the need for a hard time task, whereby a component is to be replaced at a specified age or ‘life’, then the task recorded on the Engica Q^4W database will refer to the Component

Replacement List (CRL); ie, ‘See CRL’. The component in question is then analysed separately and the associated maintenance recommendations are recorded on an RCM PM Worksheet 2A. This worksheet is not generated using the Engica Q^4W software, but created separately as a text document. Further guidance on the analysis of lifed components and the completion of RCM PM Worksheets 2A is detailed in Annex C.

ZONAL AND ESA ANALYSIS

11 A zonal and ESA analysis should be conducted in accordance with Chapter 10.

STUDY TEAM FIELD VISITS

12 Members of the RCM study team should regularly visit nominated user units so that individual analysts can gain physical access to the aircraft and engage unit personnel to answer technical queries.

TASK PROGRESS MEETINGS

13 A series of task progress meetings should be included in the RCM study plan for the following purposes:

13.1 To review the progress of the study against the estimated timescales promulgated in the Task Progression Chart worksheet of the RCM Study Workbook.

13.2 To discuss emergent issues encountered during the study and to determine what actions, if any, are required to resolve them.

13.3 To review the actions taken to address previous emergent issues.

13.4 To deliver PM2 Worksheets to the PT for audit and receive completed worksheets that had been approved by the PT.

13.5 To review the comments made by the PT following an PT audit of PM2 worksheets.

SCHEDULES PRODUCTION

14 When the RCM study is completed, the details of the derived maintenance tasks are transferred electronically from the Engica Q^4W RCM database to the SPD in preparation for the schedules production phase of the maintenance schedules review. The resulting maintenance schedules are then produced to the requirements stipulated in the RCMPP.

UPDATING THE ENGICA Q^4W DATABASE

15 When the details of the RCM derived maintenance tasks are transferred to the SPD, the items associated with each task are numbered by system in sequence automatically, in the order of the zone numbers in which they are located. This process determines the final digits of each item’s Schedules Identification Number (SIN). When the Master Maintenance List (MML) has been produced on the SPD, it will be necessary to update the SINs recorded on the Engica Q^4W RCM database to reflect those of the MML. This will establish a correlation between the tasks detailed in the aircraft maintenance schedules and those recorded in the Engica Q^4W RCM database.

CHAPTER 15 ANNEX A

TOP-LEVEL SYSTEM OR SUB-SYSTEM RCM ANALYSIS USING ENGICA Q^{4}W APPLICATION SOFTWARE

CONTENTS

Para

PREPARATION

1 Before attempting a top-level system or sub-system RCM analysis using the Engica Q^{4}W application software, an RCM analysis should be done using draft (quick and dirty) PM worksheets (either hard copy or electronically using a spreadsheet or text document table). This will break down the analysis into identifiable blocks of work that can be readily adjusted and reorganized, if required, with the minimum of effort. It is also advisable at this stage to acquire or produce a hard copy schematic diagram or system map that adequately illustrates the functionality of the system or sub-system.

CREATING A TOP-LEVEL ANALYSIS PM WORKSHEET 2

2 The recording of a top-level system or sub-system analysis begins with the creation of an Engica Q^{4}W PM Worksheet 2 as follows:

2.1 From the main menu of Engica Q^{4}W select RCM Data Summary.

2.2 Select Equipment/Add to open a new Item Form.

2.3 In the LCN and Item Ident Code boxes enter a SIN that consists of the System number to start with, followed by the Sub-system number if a sub-system analysis is to be done. The remainder of the SIN is then made up of zeroes (e.g. 2100000 and 5490000).

2.4 Enter the System name and where applicable the Sub-system name in the Item box and add the phrase '– Top-level RCM analysis'.

2.5 Use the drop-down menu to enter the System number and where applicable the Sub-system in the System LCN and Sub-system LCN boxes respectively.

2.6 Select the '?' button next to the category box and answer questions to return an FSI selection.

2.7 Select 'Proposal' and provide a *brief* description of why the analysis is being done, i.e., MoD Form F765 action (quote Serial No.) or RCM Task (quote Task No.). Follow this with a description of the System or Sub-system 'Operating Context'. Whenever possible, an operating context should be supplemented with hard copy illustrative and schematic diagrams; these will aid the reader's understanding of the system or sub-system functionality. All supporting diagrams should be produced in hard copy and attached to the associated printed PM worksheets. An analysis level operating context statement should describe the following features and attributes, where applicable, of the system or sub-system to be analysed:

2.7.1 A brief physical description that includes details of any indication, protection or control mechanisms and the expected localized operating conditions of the system or sub-system. Details of item location should also be included.

2.7.2 Define system boundaries.

2.7.3 A system or sub-system operating description that includes all the functional requirements and operating modes.

2.7.4 The availability of any design or operator compensating provisions that will mitigate the consequences of a functional failure; e.g. the existence of any standby systems, built-in redundancy or emergency operating procedures.

2.7.5 All modes of operation.

2.7.6 Any variations in system capability due to type variants or modification states.

2.7.7 The requirement for support activities such as the recording of asset usage or performance data.

2.7.8 The existence of any before or after use checks.

2.8 Close the Equipment Summary list and return to the Main Menu.

COMPLETING A TOP-LEVEL SYSTEM OR SUB-SYSTEM RCM ANALYSIS

3 When a top-level analysis PM Worksheet 2 has been created, the associated RCM analysis is recorded as follows:

3.1 Select RCM analysis from the Main Menu and enter the top-level analysis worksheet number in the LCN box, then press return and select.

3.2 Add new study and complete study details.

3.3 Using the information contained in the quick and dirty worksheets, complete the RCM analysis on Engica Q^4W and record task recommendations as described in the following text.

RECORDING MAINTENANCE TASKS

4 When an RCM top-level analysis identifies the need for a maintenance task, a new PM worksheet 2 must be raised against the *item* associated with the task. The item may be the system or sub-system itself as is the case when a system test is required. If a PM worksheet for a particular item already exists from a previous study, then a new study is raised on that worksheet. New worksheets are to be created in accordance with the following guidelines:

4.1 Number new worksheets sequentially as the analysis progresses and repeat these numbers in the respective worksheet Item Ident Code fields.

4.2 PM worksheets for recording tasks are created as blank studies that contain no analysis details.

4.3 Insert task details as normal and in the task remarks field provide references to the originating top-level analysis worksheets as per the following example:

‘The analysis related to this task is detailed at PM Worksheet 5490000, FFMC ***.’

4.4 Additional tasks may be entered in an item’s PM worksheet as the top-level analysis progresses.

5 The details of each task are also recorded on the top-level analysis PM Worksheet, including the nomenclature of the item described in the associated blank study worksheet, the task itself along with its frequency and a statement that the task has been transferred to a new PM Worksheet; for example:

Task Description	**Freq (Prelim)**	**Freq (Pack)**
Reservoir. Check contents. (Task transferred to Worksheet Item Ident Code ********	Before and after each flight	B/F T/R A/F

6 With the exception of CRL tasks, the preliminary and packaged frequencies of each task are included in the top-level analysis PM Worksheet; however, *trade descriptions are not to be entered* as this will cause details of the top-level analysis PM Worksheet to be read across to the SPD if an Engica Q^4W database is transferred to it.

7 If the logic of a top-level RCM analysis defaults to ‘No Scheduled Maintenance’, then enter “No scheduled maintenance required” (or words to that effect) in the Analysis Remarks and Task Details.

8 If the logic of a top-level RCM analysis defaults to ‘On-condition’, but the failure mode is ‘user monitored’, then enter a statement to say so in the Task Details and Task Remarks – *a blank study worksheet is not required*.

9 If the logic of a top-level RCM analysis defaults to ‘Redesign’, then enter a statement to say so in the Task Details and explain the justification in the Analysis Remarks. Any proposals for interim measure tasks should be included and then entered onto an appropriate blank study worksheet.

10 The task details contained in a blank study worksheet must be complete and conform to the authoring standards detailed in JAP(D) 100C-20. Particular attention must be given to the following:

10.1 Correct System and Sub-system identification, including the SIN numbering.

10.2 Zone numbering is to be at a consistent level, i.e. do not mix sub-sub zones with sub-zones.

10.3 Item descriptions are to be presented in sentence case as single articles with quantities in parenthesis, ending with a full stop. Conditions, including access requirements, may also be added in parenthesis, if required, as shown in the following example:

‘EAPS module (1 each zone) (If fitted).’

10.4 Complete the ‘Mk’ field as applicable (leave blank for ‘All Mks’).

10.5 Complete ‘Code’ field as required (Tech, Y, Cty etc).

10.6 With the exception of Flight Servicing, only one packaged frequency is to be assigned to a task entry. If more than one task frequency is required, such as an alternative backstop measure or an opportunity based interval, then the task is repeated for each additional frequency.

11 When a Top-level RCM analysis is completed, print all worksheets and double check that any cross-references between the top-level analysis and the blank study worksheets are correct.

CLOSURE

12 The maintenance tasks identified in the blank study worksheets of a Top-level RCM Analysis will ultimately be incorporated into the appropriate Topic 5 maintenance schedules. During this process it is likely that the SIN identifications contained in the PM worksheets will be adjusted to conform to the correct sequence of numbering as dictated by schedules authoring standards. When the schedules authoring phase of the RCM study is concluded, it will be necessary to make sure that SIN identifications contained in the maintenance schedules are reflected in the associated RCM PM Worksheets and it may therefore be necessary to renumber the SIN references of the PM worksheets accordingly. For traceability purposes, the Item Ident Codes of the PM worksheets will remain unchanged.

ANALYSIS OF LEGACY RCM STUDIES

13 The practice of conducting top-level RCM analyses was introduced as the preferred method of RCM analysis when reviewing aircraft maintenance schedules within the Military Air Environment (MAE). Prior to this, maintenance schedules reviews were conducted by applying the RCM analysis methodology to each of the existing entries contained in a maintenance schedule. Essentially, this was a physically based process that was directed only to those items that were subject to some form of maintenance activity as stipulated in the maintenance schedule under review. This approach did not address those system items that did not feature in a maintenance schedule and consequently there was the possibility that certain functions of a system could be overlooked. Nevertheless, it is possible to conduct a top-level system analysis using an Engica Q^4W RCM database that was created during a previous RCM study that was item based. The use of an existing database is convenient for a partial review when an RCM analysis might be confined to a single system. However, should a full schedules review be required, it is preferable to create an entirely new database; otherwise the subsequent analysis will become overcomplicated.

14 When a top-level RCM analysis is conducted using an existing Engica Q^4W RCM database, it is likely that the PM worksheets will already exist for those items to which the RCM derived maintenance tasks are to be

assigned. When this occurs, a new study should be created on the existing worksheets and the tasks recorded as previously explained. When the analysis is completed, the database should be checked to make sure that all the tasks contained in the previous study are accounted for. Tasks from the previous study that cannot be justified by the later analysis should be deleted, but not before checking that these tasks might address failure modes that were not identified during the top-level analysis.

CHAPTER 15 ANNEX B

RECORDING AN RCM ANALYSIS USING ENGICA Q^4W APPLICATION SOFTWARE

CONTENTS

INTRODUCTION

1 Engica Q^4W is a software package that can be used to record an RCM analysis. It can also generate PM Worksheets 2, which are printed reports that document the details of an RCM analysis and the associated derived maintenance recommendations. When completed, the worksheets should present the analyses as briefly, but as concisely as possible. The logic and reasoning used in the analyses should be clearly presented and written using the rules of normal Service Writing. The number of worksheets produced during the course of a schedules review is vast and these worksheets have to be read and approved by the appropriate PT. The efforts of the RCM team will certainly not be appreciated if the worksheets are poorly written, overcomplicated, repetitive, or littered with unnecessary statements. The maintenance tasks recommended on the worksheets should also conform to the authoring standards detailed in JAP(D) 100C-20, so that corrections do not have to be made during schedules production. The purpose of this Annex is to provide some instruction to RCM analysts on how to effectively complete Engica PM Worksheets 2. An example of a top-level system analysis PM Worksheet 2 front page is shown in Figure 1 and an example of a scheduled maintenance task PM Worksheet 2 front page is shown in Figure 2.

SYSTEM AND SUB SYSTEM

Part A: Recommended Maintenance		
System:	**40 POWER PLANT**	
Sub System:	**80 ENGINE CONTROLS**	
SIN	**Zone**	**Item**

2 The aircraft systems and sub systems descriptions are those given in the Topic 1, Aircraft Maintenance Manual (AMM).

SCHEDULES IDENTIFICATION NUMBER (SIN)

Part A: Recommended Maintenance		
System:	**40 POWER PLANT**	
Sub System:	**80 ENGINE CONTROLS**	
SIN	**Zone**	**Item**

3 Enter the SIN provided in the existing Topic 5A1 Master Maintenance List (MML). If analysis requires a new SIN to be generated, enter the next number in sequence for the associated system and sub system. For example, if the last SIN for system 40-80 was 4080009, then a new SIN would be recorded as 4080010. Avoid the use of special characters for new SINs; ie, do not create a new SIN as '4080***A'. This will only complicate any audit trail and will make future cross-referencing difficult. If an RCM review involves the amalgamation of the schedules for different Mks of aircraft, then the SINs for one of the Mks of aircraft are used to populate the Engica database. The SINs of the extra items contained in the Topics 5A1 for the remaining Mks of aircraft are then added to the database. However, an alphabetic character is added to the end of these SINs to distinguish the different Mk of aircraft (this also prevents the duplication of SINs on the database).

ZONE AND ITEM

Part A: Recommended Maintenance		
System:	**40 POWER PLANT**	
Sub System:	**80 ENGINE CONTROLS**	
SIN	**Zone**	**Item**

4 Make sure that the item is actually contained in the zone or zones listed. If the item is a complete system or involves the entire aircraft, then the term '**GEN**' or '**000**' is to be entered into the zone field. If an item is contained in more than 6 zones, wherever possible, identify the zones at the next highest level; for example, zones 111 to 117 would be identified as zone 110 and zones 510 to 570 would be identified as zone 500.

ITEM DESCRIPTION

5 Item descriptions should reflect those given in the AMM and written in sentence case. Only one full stop is to be used and placed at the end of the item description. Statements in brackets such as '(If fitted)' are to begin with an initial capital. This convention is also applicable to the 'Task Description'. Care must be taken when entering item quantities. If there are two items and both are located in one or more zones, then the quantity is entered as '(2 off)'. However, if the two items are located in separate zones, then the quantity is entered as '(1 each zone)'. If the quantity of an item differs between Mks of aircraft, then each quantity is to be shown separately, for example (1 off (K3)) (2 off (K4)). Similar items that share a common operating context, such as main undercarriage legs, wing pylons, elevators etc, are to be combined and detailed as a single SIN.

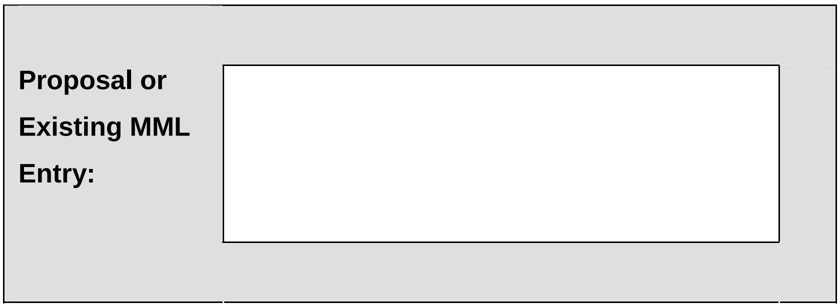
ITEM IDENT CODE

Item Ident Code:	Page: 1
Version: 1.9/RAF/11	Date: 11/10/2001
RCM Study Reference: Task 1234/00	

6 The Item Ident Code field is used to provide a unique identifier for the worksheet. The SPD automatically renumbers the SINs of a Draft Master Maintenance List (DMML) during schedules production and consequently any references to the original SINs may be lost. To enable audit traceability, the original SINs are also

recorded in the Item Ident Code field and will remain unchanged. If a new SIN is generated during RCM analysis, then the number is to be followed by the suffix ‘**-NEW’**. This allows all new SINs that are generated during the course of a revision to be listed separately, if needed, by interrogating the Engica database using the search criteria ‘*N*’.

PROPOSAL



Proposal or Existing MML Entry:

7 The proposal box is accessed through the ‘Item Details’ button of the ‘Item Study’ screen. Enter the details of the existing MML entry. When generating a new SIN insert ‘**NEW ITEM**’.

8 RCM analysis depends upon a thorough understanding of the functions of the item concerned. The documented analysis therefore begins with an analysis level operating context statement as described in Chapter 5 of this publication. A photocopied diagram or CDROM print from the aircraft Topic 1 will add clarity to an operating context statement and can save a lot of typing. An analyst may find it helpful to make a list of all the functions before attempting any FMEA or FMECA.

ANALYSIS AND TASK REMARKS

9 The analysis and task remarks fields are used to record information that supports the results of an RCM analysis.

Analysis observations

10 Use the analysis observations field to record details of failure data, investigations and other background information such as related incident signals, reports, policy statements, MoD Forms F765, TIs, comments from Unit personnel, etc. Whenever possible, display failure data separately on a spreadsheet – this avoids cluttering the analysis details.

Analysis remarks

11 Confine analysis remarks to the justification of tasks and frequencies (or their deletion). Do not repeat the functions or failure effects, as these should have already been explained in the analysis operating context statement and the FMEA or FMECA.

Task remarks

12 Use the task remarks field to record details of the recommended tasks and any additional information that is relevant to a task.

TASK DESCRIPTIONS

13 Task descriptions are to comply with the glossary of terms detailed in JAP(D) 100C-20. If a task is to be done in accordance with a specific maintenance procedure, then enter the MP reference in parenthesis after the task, as follows:

Do the *(specify)* test (MP 40-80/1).

14 When an MP does not exist and the task details are embedded in the text of the AMM, then enter (**AMM**). In cases where tasks are detailed in different sub-systems, then specific reference should be made to the AMM system and sub-system, as follows:

Do the *(specify)* test (AMM Chap 40-80).

PRELIMINARY AND PACKAGED FREQUENCIES

15 Preliminary frequencies are to be expressed in terms of usage or condition; eg, flying hours, number of landings, after each flight, Elapsed Time Indicator (ETI) count etc. Use the correct authoring terms for the packaged frequencies and place flight servicings in the correct order. Do not use full stops or extra blank spaces.

WRITING STYLE

16 Each person has their own style and level of ability when they express thoughts and ideas in writing. There is no specific standard for RCM analysis recording; however, the following simple rules can vastly improve the presentation of an analysis worksheet:

16.1 Focus on the point you wish to put across – don't repeat yourself or drift into other subjects.

16.2 Avoid colloquialisms, slang and jargon.

16.3 After writing something, consider whether it could be made shorter without losing essential information.

16.4 Use references correctly. References provide additional information to a document and should be listed in the order they appear in the text.

16.5 Be factual rather than imaginative, decisive rather than leisurely and at all times make sure that what you are writing is relevant.

16.6 Type your analysis as a text document and use the grammar and spell checker. The text can then be copied and pasted onto the PM worksheet. Save the text if it likely to be used on other worksheets.

RECORDING HIDDEN MAINTENANCE

17 There may be instances when an identified task is embedded in a maintenance procedure that relates to a separate task, which is detailed at higher system indenture level, or to a maintenance procedure that permits additional tasks to be done on an opportunity basis. For example, RCM may identify the need to examine a magnetic chip detector every time an oil system is drained and filled again. However, this is included in the drain and replenishment procedure, which is to be done in accordance with MP40-70/3. If there were also a requirement to do the drain and replenishment procedure every Minor, then both tasks would be presented on the PM worksheet 2 in the following manner:

SIN	**Oil system.**	**Drain and fill again (MP40-70/3).**	**Prop**	**M**
SIN	**Magnetic chip detector.**	**Examine.**	**Prop**	**Every oil system drain and fill again (MP40-70/3)**

Similarly, the examination of the engine mountings may be included in the engine removal procedure, which for arguments sake let us call MP40-10/1. If the examination of the mountings is to be on an opportunity basis at every removal, then the examination is to be detailed on the PM worksheet 2 as follows:

SIN	**Engine mounting (2 off).**	**Examine.**	**Prop**	**Tech**	**Every ECU removal (MP40-10/1)**

These examples indicate to the schedules author that although RCM has identified maintenance tasks to examine the magnetic chip indicator and the engine mountings, these tasks are included in the drain and replenishment and engine removal procedures respectively and are classified as 'hidden maintenance'. There is no requirement to raise any 'Out of Phase' codes in the Topic 5A1 for the chip detector or engine mountings. The purpose of the Topic 5A1 Section 1 entries is solely to indicate to any interested party that specific tasks do exist, but that they are actually done as part of separate activities.

PM Worksheet 2 RCM Analysis Record	**ANY AIRCRAFT – ALL MKS**	**Item Ident Code: 3600000**	**Page: 1**
		Version: 1.9/AIR/2.7	**Date: 19/01/09**
		RCM Study Reference: Task 1234/1	

Analyst	**Name:**	**Signature:**	**Post:**	**Date:**
Checker	**Name:**	**Signature:**	**Post:**	**Date:**
Equipment Authority	**Name:**	**Signature:**	**Post:**	**Date:**
Aircraft Authority	**Name:**	**Signature:**	**Post:**	**Date:**

Part A: Recommended Maintenance			**Checked Status: Passed**							
System:		**36 PNEUMATIC SYSTEM**	**Location:**							
Sub System										
SIN	**Zone**	**Item**	**FFMC**	**DM**	**Task Description**	**MK**	**Code**	**Trade**	**Freq (Prelim)**	**Freq (Pack)**
3600000		**Top level system analysis – Pneumatic system.**	**1A1**	**F**	**Engine driven compressor. Fill (Caster oil BSS L/N 3976) (Panel 5 removed). X-refer to worksheet Item Ident Code 3600001 – NEW for task.**				**After each flight**	**T/R A/F**
			1A2	**F**	**Air filter. Make sure that it is clean (removed). X-refer to worksheet Item Ident Code 3610001 – NEW for task.**				**60 Hours**	**P**
			1A3	**F**	**System. Do a pressure check (200 +/- 20 psi). X-refer to worksheet Item Ident Code 3600002 – NEW for task.**				**Before each flight**	**B/F T/R**
			1B1		**No scheduled maintenance required.**					

Make sure that the system description is correct

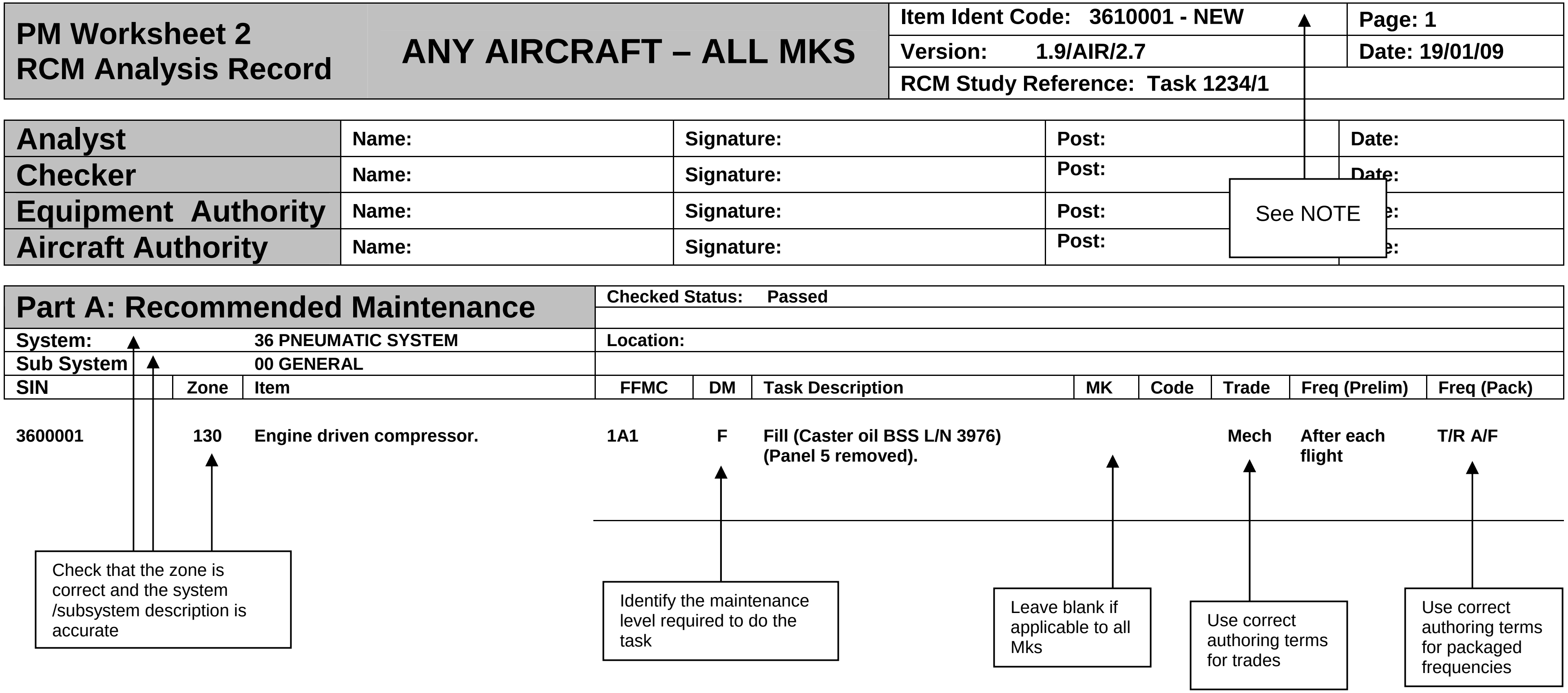
Identify the maintenance level required to do the task

Leave blank if applicable to all Mks

Leave blank in system level analysis worksheets

Use correct authoring terms for packaged frequencies

Figure 1 Example of a top-level system analysis PM worksheet 2



PM Worksheet 2 RCM Analysis Record	**ANY AIRCRAFT – ALL MKS**	**Item Ident Code: 3610001 - NEW**	**Page: 1**
		Version: 1.9/AIR/2.7	**Date: 19/01/09**
		RCM Study Reference: Task 1234/1	

Analyst	**Name:**	**Signature:**	**Post:**	**Date:**
Checker	**Name:**	**Signature:**	**Post:**	**Date:**
Equipment Authority	**Name:**	**Signature:**	**Post:**	
Aircraft Authority	**Name:**	**Signature:**	**Post:**	

See NOTE

Part A: Recommended Maintenance		**Checked Status: Passed**
System:	**36 PNEUMATIC SYSTEM**	**Location:**
Sub System	**00 GENERAL**	

SIN	Zone	Item	FFMC	DM	Task Description	MK	Code	Trade	Freq (Prelim)	Freq (Pack)
3600001	130	Engine driven compressor.	1A1	F	Fill (Caster oil BSS L/N 3976) (Panel 5 removed).			Mech	After each flight	T/R A/F

Check that the zone is correct and the system /subsystem description is accurate

Identify the maintenance level required to do the task

Leave blank if applicable to all Mks

Use correct authoring terms for trades

Use correct authoring terms for packaged frequencies

NOTE: If a new SIN is created, allocate the next number in sequence for the relevant system/sub system. Also record the new SIN with the suffix – NEW.

Figure 2 Example of scheduled maintenance task PM worksheet 2

CHAPTER 15 ANNEX C

RCM ANALYSIS OF LIFED COMPONENTS AND THE COMPLETION OF RCM PM WORKSHEETS 2A

CONTENTS

Para

INTRODUCTION

1 The RCM process determines what PM, if any, should be applied to sustain the required functionality of an aircraft system or sub-system, based on the consequences and characteristics of failure. The recommendations for PM may include the requirement for a hard time task to replace a component at a specified age or ‘life’. The removed component may then be subjected to some form of maintenance or overhaul to restore its condition, or it may be discarded if repair is impractical or uneconomical. RCM analysis can be applied to any lifed component to determine the age when the component might be replaced and if there is any applicable and effective maintenance that could be adopted to restore a component’s functionality.

2 Ideally, major aircraft components or assemblies, such as engines, ejection seats and complex electro-hydraulic units should be subjected to independent RCM studies to determine their PM requirements, both on and off aircraft. However, the manufacturers of lifed components usually do some form of reliability testing and analysis to enable them to establish appropriate component maintenance programmes. It is reasonable, therefore, for RCM analysts to accept the maintenance recommended by a component manufacturer, since an analyst is unlikely to have a sufficient depth of knowledge of the component or have access to adequate failure or test data. However, this does not prevent an analyst from questioning the fallibility of the recommended maintenance, particularly if the component is operated under conditions that the manufacturer may not realise or expect. There are various sources of data available to establish the effectiveness of component PM and these should be investigated to make sure that any maintenance requirements are properly fulfilled.

DATA SOURCES

3 Data on components and their associated failures may be available from many sources. The quantity and quality of data may vary considerably and it is important, therefore, that any PM recommendations are based on as much useful information as is available. Analysts should consider each of the following data sources:

3.1 Declaration of Design and Performance (DDP). The DDP is a Design Organisation document detailing the original design limits/performance and expected maintenance for a specific component. These may be available from the PT or from the manufacturers themselves. Manufacturers may also have additional data that may be of interest.

3.2 Logistic Information System (LIS) databases. Faults data for aircraft systems and components are reported on the Maintenance Data System (MDS) and recorded on either LITS or WRAM logistic information databases. Requests for fault data can be made through either the Rotary Wing (RW) or Fixed Wing (FW) teams within Engineering and Asset Management (Air).

3.3 Component Engineering Record Cards (ERCs). ERCs are used for the recording of maintenance, elapsed life and fitment details mainly of critical components for aircraft. A list of components requiring ERCs is contained in the relevant Topic 5A1. A Unit Engineering Records Section generally controls the ERCs of fitted components, although it is now common practice for aircraft operators to be in possession of their ERCs. Components not fitted to aircraft, either in-storage, at repair/overhaul or in-transit will be accompanied by their ERC.

3.4 Narrative fault reports MoD Forms 760/760A/761. These reports detail specific serious faults/defects found with components, which were reported to the manufacturer and contain the manufacturer's response. Reports are archived and available from DES SCS-Progs MI, Fault Reports (FR). PTs may have copies of more recent or ongoing narrative reports.

3.5 Component Maintenance Manuals (CMMs). CMMs should be used to establish how a component operates coupled with its current maintenance requirements.

3.6 Maintenance personnel. Maintenance personnel are an invaluable source of data. While all maintenance should be done following proper procedures and documented, human nature and abbreviated computer input tend to distort fault information. Maintenance personnel can provide an insight to actual in-use behaviour or observed weaknesses in the design or maintenance of a particular component.

3.7 Policy documents. Within the RAF there are various policy statements regarding the maintenance of particular equipment; eg, compressed gas cylinders, safety equipment and explosives. The particular policy may dictate maintenance requirements or maximum usage intervals for repair or finite life. However, as technology changes current policy may be inappropriate and require amendment.

3.8 Similar equipment. If only limited information is available on a component, an analyst may wish to consider examining details of other similar in-use components. This approach may be particularly helpful if the same component, albeit slightly modified to fit another aircraft, has identical functional and performance characteristics. However, extreme care must be taken when using this type of data, particularly when considering the usage and operating environment of the 'similar' component.

DOCUMENTATION

4 The RCM PM Worksheet 2A is used to present the recommendations resulting from the analysis of a lifed component. It is also used to record data sources, and the justification for any recommendations that are made, based on the data available at that time. PM Worksheet 2A is divided into two discrete parts as follows:

4.1 Part A. The Part A is used to present any existing off aircraft component maintenance and any recommendations for future hard time maintenance activities. Component lives are promulgated in the relevant aircraft Topic 5A1, Sect 2 CRL. Part A reflects the layout of a CRL entry in accordance with JAP(D) 100C-20 and should be completed accordingly. Part A is also used to record the analyst's details and the authorization of the recommendation from the specific equipment and the aircraft PTs responsible for the platform in which the equipment is installed.

4.2 Part B. Identifies all data used during the analysis, specifying its source, document dates / amendment states, data time periods, manufacturer / maintenance unit contacts and any relevant observations or remarks. Justification for any recommendation is to be given, citing usage data for major failure modes (If available), results of mathematical analysis (If applicable) or other factors that had a direct influence in determining any recommendation made including the identification of any Support Authority imposed PM requirements for lifing.

An example of Part A and Part B of an RCM PM Worksheet 2A is shown in Figure 1 and Figure 2 respectively. The details of Part B may be included as part of the analysis documented on PM Worksheet 2.

RCM PM WORKSHEET 2A – CRL REVISION (PART A)	DATE: 12/3/09

TASK No: 165860-092-1-2	AIRCRAFT: Puma	ANALYST: Mr A Mann	POST: RCM 1Con2	Ext: 4553 MW

EXISTING COMPONENT REPLACEMENT LIST ENTRY	AP 101C-0801-5A1 5th Edition	AL STATE: 8

SIN	ITEM	CRITICAL	QTY	FREQUENCY	REASON	MK	LOCATION	IN PHASE
3095009	Bullet electro-valve 3089-100		2	500 Hours	BM		1 each zone 423 and 424	**YES**

RECOMMENDED COMPONENT REPLACEMENT LIST ENTRY

SIN	ITEM	CRITICAL	QTY	FREQUENCY	REASON	MK	LOCATION	IN PHASE
3095009	Bullet electro-valve 3089-100		2	640 Hours	BM		1 each zone 423 and 424	**YES**

AIRCRAFT SA TO NOTE: The relevant Supply Chain authority is to be informed if the recommendation has an impact on the scaling of spares

EQUIPMENT SA AUTHORIZATION	NAME:	SIGNATURE:	POST:	DATE:
AIRCRAFT SA AUTHORIZATION	NAME:	SIGNATURE:	POST:	DATE:

Figure 1 Example of RCM PM worksheet 2A (Part A)

RCM PM WORKSHEET 2A – CRL REVISION (PART B)	**SIN 3095009**

ITEM DESCRIPTION: Bullet electro-valve	**Part No: 3089-100**	**NSN/Sect Ref:**

DATA SOURCES:

See References

References:

A. AP101C-0801-5A1 Sect 1.
B. Programme Recommande D'Entretien (PRE).

REMARKS AND OBSERVATIONS (*Include details and effects of Modifications, Technical Instructions etc if applicable)*

1. The failure mode identified during the previous aircraft revision, Task 2144, was internal failure, which unless there is an internal dominant failure mode tends to be neither usage nor calendar related. The identified failure mode and analysis remains extant although random failure means that it is not possible to accurately determine the most appropriate task interval.

2. The current Reference A recommended task to bay maintain the valve is still considered effective although it does not address a number of potential failure modes. Reference B does not detail this task to be done.

3. User unit personnel state there are no significant issues associated with the valve.

JUSTIFICATION OF RECOMMENDED CRL ENTRY *(Include details of component failure/usage data and results of component lifing analysis):*

1. It is recommended that an entry be made in the CLR as per Part A of this PM Worksheet 2A.

Figure 2 Example of RCM PM worksheet 2A (Part B)

CHAPTER 16

MAINTENANCE PROGRAMME SUSTAINMENT

CONTENTS

INTRODUCTION

1 When an aircraft or equipment is first introduced into service, the amount of available operating experience and usage data will be limited. As a result, an RCM derived maintenance programme may, in some instances, have to be based on various techniques or measures, such as the following:

1.1 Assumed methods of operation.

1.2 Calculated predictions.

1.3 System modelling.

1.4 Manufacturers’ recommendations.

1.5 Experience of similar assets that are used in the same operating context.

1.6 Controlled test results.

2 When sufficient in-service knowledge and usage data is accrued, it will be necessary to review the maintenance programme to ascertain its effectiveness and to assess the accuracy of the rationale that was used during the initial RCM analysis. The accomplishment of a maintenance programme review will require maintenance organizations to collect, analyze and respond to in-service data. The interrogation and interpretation of the information gathered may indicate the need to revise the original RCM analyses, which subsequently may initiate changes to the maintenance programme.

3 As an aircraft or equipment matures, adjustments to the maintenance programme may be needed as a result of changes in operation, modifications, updates and unpredicted events or issues. The review and refinement of a maintenance programme must therefore be continuous and responsive, if its effectiveness is to be sustained throughout the life of the End Item. Coherent with the DLO Strategic Plan, RCM is identified as a Key Support Area (KSA) within the Support Solutions Envelope (SSE) and its use during acquisition and through life is mandated within the KSA Guiding Principles.

COLLECTING PERFORMANCE AND USAGE DATA

4 The first stage of monitoring an aircraft or equipment under actual operating conditions is to gather relevant information regarding the failures experienced during known periods of usage. The facility to capture failure and usage data may be embedded in the associated maintenance management system, as it is in LITS

and WRAM; if it is not, a dedicated data repository will be needed, such as that found in a Data Reporting, Analysis and Corrective Action System (DRACAS). An RCM analysis will benefit only if the failure data collected is accurate and useable. Ideally, such information would include the following:

4.1 Platform and system identification.

4.2 Symptoms experienced during failure occurrence.

4.3 The circumstances under which a failure is discovered; eg, during a specific mission phase or maintenance activity.

4.4 The root cause of the failure.

4.5 The consumed life of the equipment at the time of failure.

4.6 The recovery actions taken to restore equipment capability.

4.7 The platform and/or equipment life at the time of recovery.

4.8 Associated work reference, if the failure is found during a maintenance activity.

4.9 The identification of any spares used during the recovery action.

4.10 The consumed life of spares fitted, where applicable.

5 General data related to maintenance and operations, such as that gathered for statistical returns, are also useful during the continuous monitoring and review of maintenance programmes.

INTERPRETATION OF PERFORMANCE AND USAGE DATA

6 The objectives of the sustainment process are to monitor and optimize the current PM programme, delete unnecessary requirements, identify adverse failure trends, address unforeseen failure modes and improve the overall efficiency and effectiveness of maintenance effort. Sustainment activities should be structured such that the results can be effectively used to support RCM analysis updates. The process of monitoring existing PM tasks entails reviewing the many sources of task effectiveness information and maintaining accurate and efficient analysis data. The types of efforts used in the RCM sustainment process include Top Degrader Analyses, Trend Analyses, Task Packaging Reviews, Fleet Leader programmes, Age Exploration (AE) tasks, responding to emergent issues and PM Programme Continuous Reviews.

Top degrader ranking

7 Top degrader ranking indicates which systems and components are having the greatest impact on operational effectiveness or support costs. This impact can be expressed in a variety of metrics, such as the following:

7.1 Corrective and preventive maintenance man-hour expenditures.

7.2 Maintenance man-hours per unit operating cycle.

7.3 Operational availability.

7.4 Mission abort or failure rates.

7.5 Deep level maintenance repair costs.

8 The identification of top degraders usually entails detailed data analyses, and interface with operators and maintainers. This type of analysis identifies only the worst performing items, not those that are in the process of degradation. The RCM analyses for items that are deemed problematic should be reviewed and updated as necessary.

Trend analysis

9 A trend analysis provides an indication as to whether a system or component is more or less likely to be problematic with continued use. The analysis is based on the rate of change of reliability that is currently being experienced and the measurement factors used for trending may be the same as those used for top degraders, although the most usual method is to measure the rates of system or component failure. When doing trend analyses, it is the rate of change in value, rather than the values themselves, which is important. Various

software tools are available to assist with the interpretation of failure data and can provide graphical representations of system and component behaviour.

Task packaging reviews

10 Task packaging is the process of grouping PM tasks into optimum intervals that are repeated throughout the life of an End Item. Groups of PM tasks with similar intervals may be formed into blocks and done concurrently to maximize maintenance free periods; however, this causes periods of down time during which the platform or equipment is out of use. Alternatively, the maintenance groups may be done as smaller discrete packages that can be done flexibly between periods of normal operation, although this approach does force a need to over-maintain during periods of extended operations. The type of packaging that is adopted is entirely dependent on operational requirements and if these requirements change, there will be a need to review the grouping of PM task intervals. Due to changes over time, the original packaged interval may no longer be optimal. Task packaging reviews should be conducted periodically to evaluate the packaged maintenance intervals, thus ensuring that as maintenance tasks are added, deleted, or modified, optimum packaged intervals are maintained. The cumulative effect that a change of packaging might pose to the PM programme should be evaluated prior to implementation.

Fleet leader programmes

11 A fleet leader programme is used to detect the onset of system or component failures that were not expected to occur when the original reliability predictions were established. Fleet leader requirements may be established when the consequences of failure are severe, and experiential data is limited. A more recent example of fleet leader examinations is the physical verification of equipment condition protected by HUMS to make sure that a system is properly predicting true equipment condition. The objective of fleet leader Programmes is to identify specific problem areas and to periodically examine these areas on one or more of the most used End Items or assets. A programme may also include specific AE tasks. Appropriate sample sizes should be established to support conclusions desired, based on valid statistical techniques.

12 Specific requirements for a fleet leader programme should be developed as RCM analyses are completed. Fleet leader examinations may then be documented as AE tasks within the RCM analysis.

Age exploration tasks

13 An AE task may be designed and implemented when insufficient real time data necessitated the use of assumed data during an initial RCM analysis. AE task data are fed back to the analyst for use in updating the RCM analysis. The requirements for AE tasks become evident during the RCM analysis. AE is covered in detail in Chapter 17. The RCMPP should provide guidance for implementing AE tasks.

Emergent issues

14 An RCM sustainment programme must establish a process to deal with emergent technical issues and unpredicted events that need to be analyzed via the RCM process, and determine the appropriate response or corrective action. Sources of emergent issues include defect reports, engineering/operational incident reports, change request proposals, quality deficiency reports, locally generated maintenance activities, depot level summary reports and OEM feedback reports. The cause of any emergent issue will need to be identified and engineering investigations instigated to gather pertinent information, which can then be analyzed and the results used to determine the requirement for any maintenance action. These investigations may take the form of defect investigation reports, technical instructions or fleet-wide condition monitoring instructions.

15 The preliminary analysis may sometimes reveal problems that need immediate attention due to safety, operational or cost concerns. Examples of interim actions include issuing maintenance bulletins, applying temporary operational restrictions and implementing operating safety measures.

16 Certain emergent issues such as procedural and technical publication discrepancies may be addressed by corrective actions for which an RCM analysis is not required. However, change requests or amendment proposals that impact on the technical application of a maintenance schedule should be addressed by applying the RCM methodology.

ENGINEERING AND OPERATIONAL INFLUENCES

17 Changes in engineering and operational requirements will invariably have an impact on maintenance requirements. In circumstances when these changes occur it becomes necessary to re-evaluate the maintenance programme via the RCM process to make sure that it continues to be effective.

18 Changes to the way an aircraft or equipment is operated, or the environment in which it is operated, will impact on its capability requirements. If demands on performance or operating conditions change, then so will the terms of functional failure, which in turn may be reflected by a change in failure consequences or the introduction of previously unexpected failure modes. The embodiment of modifications and updates may also alter capability requirements and any associated maintenance will similarly need to be addressed within the RCM process.

19 Proposed changes to engineering support policy statements may invoke the need to reconsider existing maintenance regimes. For instance, proposals to increase the latitudes of maintenance constraints or the intent to extend the periods between maintenance packages must be subjected to the rigours of RCM analysis; otherwise, the effectiveness of existing maintenance programmes might be adversely affected.

FEEDBACK FROM IN-SERVICE ENGINEERING LOGISTICS

20 Other aspects of in-service engineering logistics can act as indicators to prompt the re evaluation of an RCM analysis, which include the following:

20.1 Abnormal spares consumption rates.

20.2 The results of condition monitoring and HUMS activities.

20.3 Fatigue test reports.

PT INPUTS

21 PTs may wish to initiate an RCM analysis to resolve issues that arise as a result of their routine activities, such as actions generated by safety management or structural working group meetings.

PM PROGRAMME CONTINUOUS REVIEWS

22 It is not sufficient to simply target the PM programme sustainment effort at emergent issues, modifications, efficacy measures and changes in operating context or support policy. The sustainment effort must also make sure that over a period of time the entire maintenance programme is reviewed. This will help to reveal outdated maintenance processes, techniques or technologies, or bring attention to obsolete tools and outdated supplies. The continuous review will provide opportunities to update PM requirements that will improve effectiveness or lower life cycle costs. Examples of opportunities afforded by this type of review include incorporating new non-destructive examination techniques or applying advanced HUMS sensor technology that detects smaller flaws or monitors growth rates allowing longer (or possibly eliminating) periodic manual examination intervals.

23 During the process of continuous review it will be necessary to prioritize the elements of a maintenance programme to which the sustainment effort will be directed in order to optimize the potential benefits. To this end, a review strategy that is sufficiently flexible in its responsiveness must be agreed by the PM programme sponsor and declared in the RCMPP.

24 The generation of a maintenance programme that is to be derived and sustained using the RCM methodology, either as an integral element of an ILS programme or as a stand alone legacy study, must be considered as a continuous and dynamic process of improvement. These improvements are based on an ever increasing knowledge base of equipment usage, the accrual of performance and management data and the ability to respond to emergent issues and changing requirements. This process and the various elements involved are depicted in Figure 1.

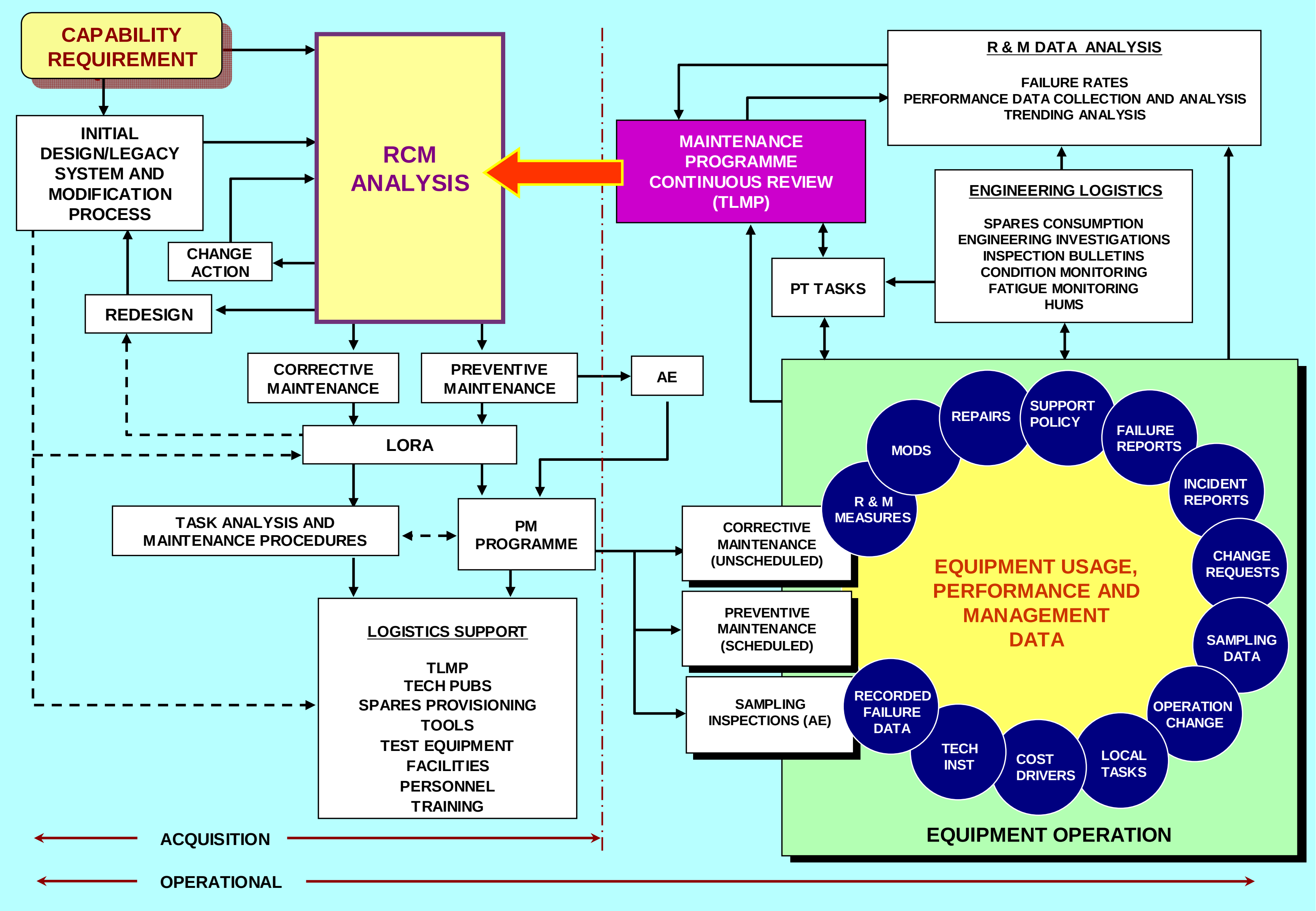


Figure 1 RCM as a dynamic process of continuous improvement

CHAPTER 17

AGE EXPLORATION

CONTENTS

INTRODUCTION

1 Age Exploration (AE) is used to collect specific data from actual use or controlled tests on items for which there is insufficient information to substantiate an RCM analysis decision or on legacy items with existing maintenance tasks that are inadequate. This may include maintenance actions developed on assumptions or conservative estimates. Lack of data is particularly prevalent to items in the process of procurement, where any Availability, Reliability and Maintainability (ARM) data is likely to have been derived over a relatively short time-scale, from a small population of pre-production equipment.

2 The manner in which AE is done depends on the consequences of the failure mode being considered. If the failure consequences affect safety or the environment, AE must be strictly controlled. If the failure consequences do not affect safety or the environment, AE may include the interrogation of historic failure data to determine the most suitable maintenance actions.

OBJECTIVES, PRINCIPLES AND GUIDELINES

3 AE is an essential part of PM; it is the process used to sustain and improve the PM programme. As equipment matures, its use may change or it may be modified and new PM requirements may need to be developed. In certain instances, the RCM analysis takes a conservative approach in allocating types of tasks and frequencies because of the lack of information. AE provides a systematic procedure for collecting the information necessary to reduce or eliminate this knowledge gap. AE encompasses structural and equipment age-reliability information that is derived from usage data.

4 The requirement for AE is not a substitute for PM. Some sort of interim task must be done to protect an item from failures during the AE programme. The function of AE is the accumulation and analysis of data, the results of which are used in the RCM process to confirm the need or frequency of a PM task. The goal of an AE programme is, therefore, to provide information to support decisions that affect PM.

5 AE is fundamental to an RCM derived maintenance programme. By collecting relevant maintenance and reliability data, RCM analysis decisions can be updated to improve scheduled maintenance. The updated RCM is fed back into the overall LSA process to assess the impact on existing ILS requirements and may result in a change to resources. Generally, the maintenance burden is reduced, resources are used more efficiently and the user benefits from increased availability.

6 It is important to minimise the impact of AE on equipment downtime. This can be achieved by structuring AE tasks to be done in-situ, if possible, and concurrently with PM tasks. AE should be conducted at the most appropriate level of maintenance.

7 The AE programme should make use of existing support resources. In addition, existing data collection systems can be used to process information. The need to provide project-specific support equipment and training for AE must be minimized and any such requirements approved by the Analysis Sponsor.

8 AE data should be collected from a sample of adequate size to produce the required levels of statistical confidence in the results. Analysis of a full set of data from a fleet of aircraft or items would only be done if the population was small.

9 Except for a few AE structural examination tasks, all AE tasks are finite. They are used only for as long as necessary to gather sufficient data to make a reasoned decision. Limits are set by either choosing a specific calendar time interval or a defined amount of data.

10 A plan, which outlines the scope, intent and implementation of AE tasks to specific items, must be developed before the programme is implemented. It should be periodically updated to help determine accurate through life costs.

11 AE candidate items are identified directly from the RCM analysis. An AE programme requires the following steps:

11.1 Selection of candidate items for the programme.

11.2 Design of the tasks.

11.3 Collection of the data.

11.4 Data analysis.

11.5 Re-application of RCM analysis using AE results.

12 Many modern systems make use of state-of-the-art technologies for which little or no data exists to determine appropriate PM tasks. This could produce a large and potentially unmanageable list of AE candidate items. In these cases, the cost of implementing all the AE requirements may not be justified and priorities must be set.

13 AE tasks should be done as an integral part of scheduled maintenance, but may require additional data recording and reporting. When existing PM tasks do not provide adequate or timely information, additional AE tasks may required. All AE tasks should be cost effective.

ANALYSIS TECHNIQUES

14 Numerous techniques can be applied to AE analysis ranging from standard statistics to specialised methods such as Weibull Analysis. It is an advantage, when developing AE tasks, to understand the various techniques and to understand when each is appropriate. The most commonly used techniques are Degradation Analysis and Actuarial Analysis.

Standard Errors

15 For an effective task determined by RCM, the analyst must consider two kinds of standard errors: errors of omission (Replacing too late, called Type I in this document) and errors of commission (Replacing too early, called Type II). The correct standard lies between these two errors. Type II errors are often ignored, even though they are often inefficient and very costly. For example, a premature discard task can result in loss of a great deal of the useful life of the item. AE can effectively minimize such errors by optimizing the task interval. If the affected failure mode threatens safety, the task interval must reduce the risk of failure to zero or near zero (i.e. a Type II error). If the affected failure mode has economic consequences, but no safety consequences, the most effective task interval will usually permit some failures (Type I).

Degradation Analysis

16 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 failure mode that drove a PM requirement, not upon the general equipment deterioration. Degradation can be monitored to establish P-F intervals and prevent undesirable fault conditions. There are many kinds of degradation which can be monitored, including:

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

16.2 Corrosion (material loss due to chemical reactions).

16.3 Hardening or softening (a particular characteristic of non-metals).

16.4 Cracking (often associated with fatigue).

17 Degradation analysis uses measurements to determine the onset and rate of progression of a specific failure mode. The most appropriate way to do this is in association with OC tasks. Its primary purpose is to verify the effectiveness of an existing OC task interval or to optimize its frequency.

On-condition (OC) Tasks

18 The analysis of OC tasks uses measurements to determine the onset and rate of progression of a P-F curve for a specific engineering failure mode. The most appropriate way to do Degradation Analysis is to do it in association with OC tasks. Its primary purpose is to either verify the effectiveness of an existing OC task interval, or adjust the interval to the best frequency. The item may be an inexpensive filter whose function is to clean the hydraulic oil, or it may be an expensive gas turbine combustor manufactured from an exotic alloy that contains the flame inside a gas turbine engine.

19 In the case of the filter, the required AE task may involve examining a small sample of filters periodically at increasing ages to determine the rate at which they clog, and from this, determine an effective and efficient discard standard, i.e. a quantitative amount of degradation which must not be exceeded, and a scheduled maintenance interval. For such items, Type II errors are relatively inexpensive because of the low cost of the filters; so choosing a conservative standard to minimize Type I errors is a good idea.

20 In the case of the gas turbine combustor, the characteristics of the combustor are established by testing until failure. Such testing is required during the initial design process. In-service AE may be done at any level of maintenance. For critical items, the impact of a functional failure requires a high level of assurance that such a failure will not occur. The resulting standard may, therefore, have a relatively high Type II error. In cases where physical failure does not result in functional failure, but reliability of the equipment is low, some failures may be acceptable. In these cases the condition standard, or task interval, may permit some failures, i.e. Type I errors. Figure 1 illustrates a typical application of degradation analysis for tyre tread wear.

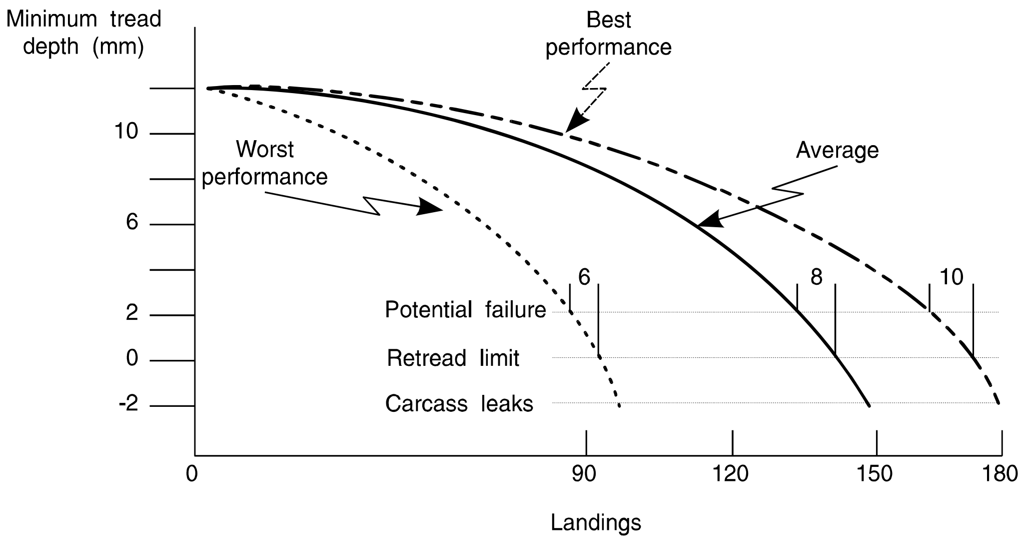


Figure 1 Determining the on-condition task interval for aircraft tyres

21 AE tasks may be initiated when the equipment is new or immediately following overhaul, at which time the conditions to be measured meet some common standard; alternatively, they may be initiated at any time in service prior to failure, provided the time in service at the start of the AE task can be accurately determined. The second alternative will often reduce the time necessary to complete the task. For example, consider an analysis to measure the relationship between the extension length of the brake wear indicator pin and the number of aircraft landings. The AE task can be:

21.1 Data collection from newly installed brakes, or data collection using a random sample of brakes already installed, provided the 'age' of each brake assembly can be determined.

21.2 Data collection from a broad range of brake wear pins. As a result, the time to acquire the needed data would be much shorter than if data were taken only from newly installed brakes.

22 The following information may be required for a degradation analysis:

22.1 The specific objective of an AE task.

22.2 The identity of the affected item(s).

22.3 The identity of the items selected for sampling.

22.4 Description of appropriate data collection procedures.

22.5 The identity and description of each data element and its source.

22.6 The necessary measurement techniques, tools and equipment.

22.7 The duration of the sampling period.

22.8 The definitions of potential and functional failure limits.

22.9 The description of the method of analysis.

22.10 Any other special conditions.

22.11 The expected costs and potential benefits.

Actuarial analysis

23 Actuarial analysis is applicable to HT tasks and is the processing of failure data to determine the effect of age on the probability of failure. Its original commercial use was by actuaries employed by life insurance companies whose principal interest was to understand the effect of ageing on the conditional probability (or likelihood) of people dying. Note that actuarial analysis requires life data, meaning the point at which all failures occur, not simply a count of failures during some particular period.

24 Actuarial analysis can be used to study equipment failures and produce graphs that predict behaviour in two particular areas of interest. These are shown by the conditional probability of failure curve and the survival curve.

25 The conditional probability curve (Figure 2), 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 PM task (specifically a HT task) is applicable. Many people believe *incorrectly* that the periodicity of such a preventive task is determined by the items' Mean Time Between Failures (MTBF). The MTBF is an absolute value of reliability, which identifies the average age of failures, not when one half of the population are expected to have failed. For example the mean of an exponential distribution occurs at about the 63rd percentile. Thus, if an item with a 1000 hour MTBF had to operate continuously for 1000 hours, there would only be a 37% probability of success. The location of the MTBF is dependant on the distribution of failures that the failure pattern exhibits. As all failures are random about a distribution, there is no guarantee that failed items actually failed near the MTBF. In fact, some of the failures may have occurred very early in the equipments' life as shown in Figure 3. A scheduled restoration task applies 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.

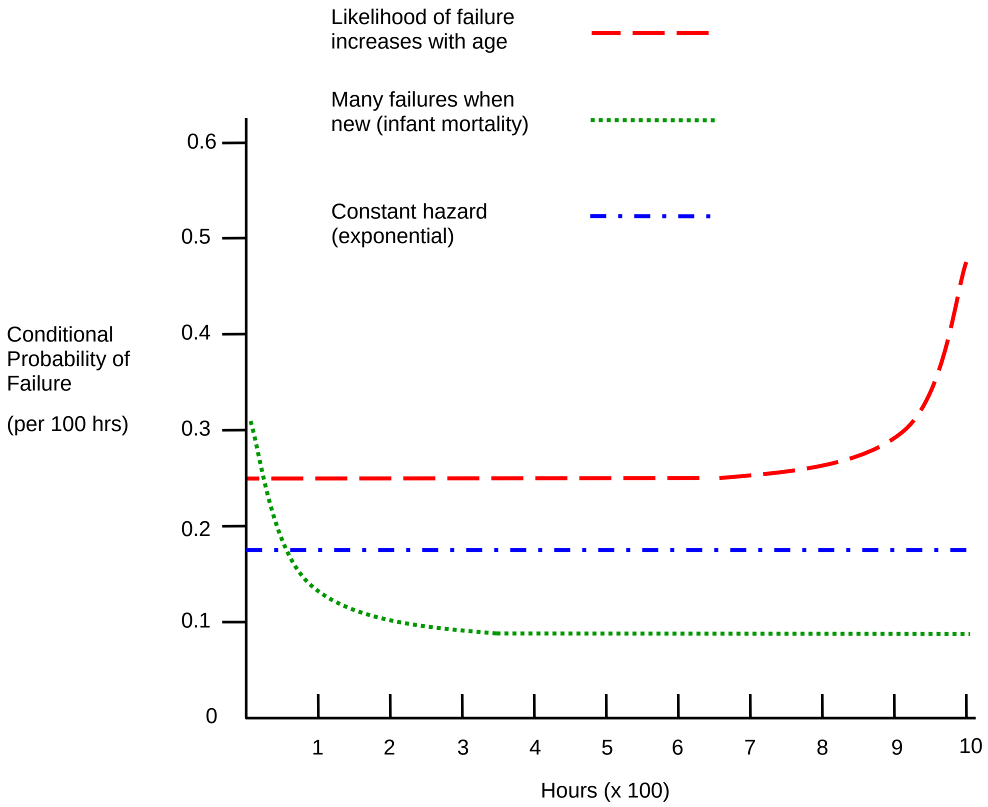


Figure 2 Conditional probability of failure curves

26 The survival curve, sometimes called the reliability function, shows the probability of an item surviving to a particular age as illustrated in Figure 4. The survival curve is used to establish the percentage of items, which will live to the wear out age. The percentage of items that survive can be used to determine the effectiveness of the HT task.

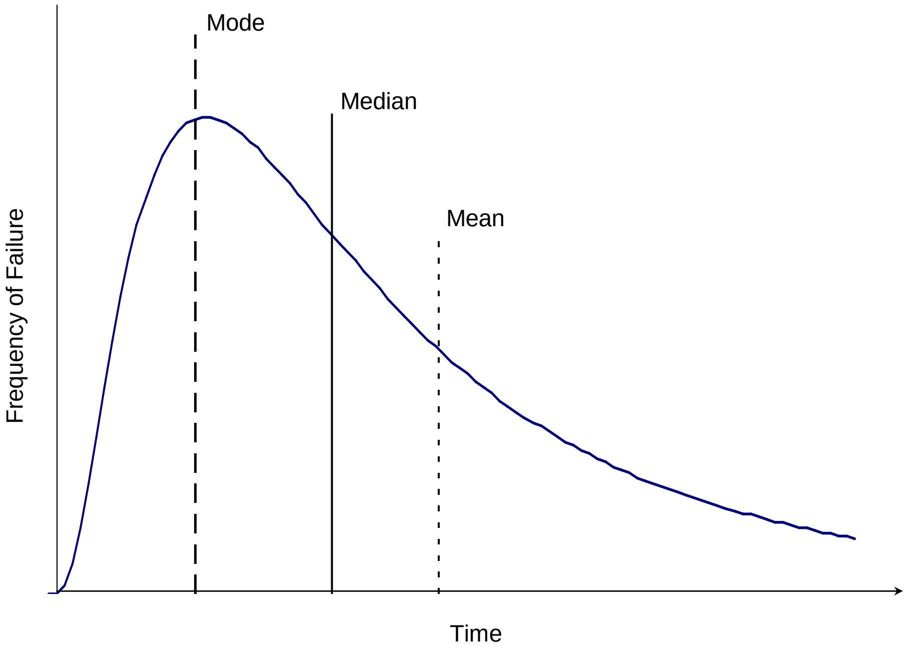


Figure 3   Mean time between failures

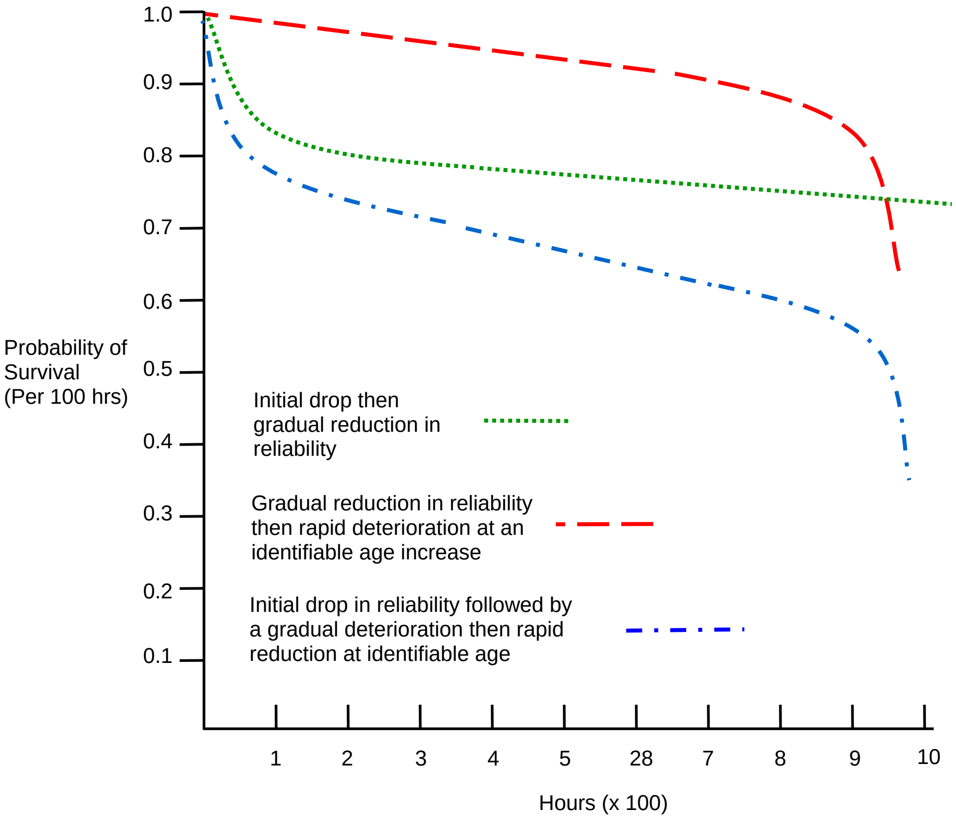


Figure 4   Survival curves

27 Data can be collected for Actuarial Analysis in two different ways; either as life test data, in which a selected group of items start at zero age and are operated until all have failed, or In-service data bounded by two calendar dates. In either case, it is important to remember that actuarial analysis is done to study the age-reliability characteristics that are associated with a single failure mode. Actuarial analysis is often used in design and development. At any particular point in calendar time, In-service items usually have a wide range of ages, which is why it is convenient to observe their activity during some calendar period. This requires the ages of the items at the beginning of the study period to be recorded, along with the ages at which failures and other important events occurred. If items are very reliable, it can require several years to collect sufficient life data.

28 Actuarial analysis can be used to determine the applicability, effectiveness and intervals of HT tasks. Inputs are generally derived from observing failures over a specified period of use. Each item is permitted to operate until it has either failed or has reached the end of the specified test period. The following information may be required:

28.1 The specific objective of an AE task.

28.2 The identity of the affected item(s).

28.3 The identity of the items selected for sampling.

28.4 Description of appropriate data collection procedures.

28.5 The identity and description of each data element and its source.

28.6 The necessary measurement techniques, tools and equipment.

28.7 The duration of the sampling period.

28.8 The definitions of potential and functional failure limits.

28.9 The description of the method of analysis.

APPLYING SAMPLING TECHNIQUES

29 AE programmes can be costly and should be restricted to sample sizes and periods just sufficient to achieve the AE objectives. Care must also be taken when selecting analysis techniques because sophisticated methods are often misapplied or their results misinterpreted. The objective of AE is to get useful, unbiased results with the least amount of effort and investment.

30 Sometimes AE analysis must be done with a small sample when the cost of testing is very high. A life limit based on such a sample is set at a fraction of the demonstrated life to make sure of a low risk of failure. The AE analyst must be aware of the limitations of sample sizes. Commercial airline experience indicates that actuarial analysis requires at least 20 failures from a sample of 30 aircraft and when measuring degradation, a minimum of 30 independent sets of data are required.

31 It is desirable to select samples that are uniform in nature. If, for example, all serial numbers of an item below 100 are known to be different in characteristics from serial numbers 100 and above, care must be taken to avoid mixing the data from the two populations. Likewise, it is desirable to have data sets from several sources and not rely on single user.

32 There are various sampling methods that can be used in AE programmes and the analyst must carefully consider which is the most beneficial for the task. In some cases, combining two or more sampling methods may achieve the optimum sample.

RANDOM SAMPLING

33 Random sampling is the most likely to achieve unbiased results, however, it can be inconvenient to implement. It is often difficult to gain access to randomly selected items and circumstances may force the samples to be taken from items that are readily available. Random sampling should therefore only be applied when practicable.

OPPORTUNITY SAMPLING

34 Opportunity sampling is the process for acquiring information as the result of a random event. For example, AE programmes may arrange to examine the splined drives of 20 alternators, when they are removed for repair or other reasons. Opportunity sampling can minimize the maintenance activity necessary to meet the AE requirements.

THRESHOLD SAMPLING

35 Threshold sampling is often used when new equipment is introduced into service and little useful information is available on which to base its PM programme. Threshold sampling requires control of the fleet leaders and rapid acquisition of relevant data. There are three methods of threshold sampling: single; opportunity and dual.

Single threshold

36 There are two approaches to single threshold sampling: one is to remove and examine a fixed number of items at a specific age, ie the threshold. The threshold is then adjusted by an increment based on the conditions found. Examined items are not repaired unless they are unfit for further service (unnecessary repair of AE sampled items interrupts the chain of data). Thresholds should be continuously increased until the conditions found allow PM task intervals to be firmly established; the second approach is to establish an initial threshold at which a small number of items are removed for test and examination. The condition is noted, and the item restored to a zero age standard. The threshold is increased incrementally until conditions indicate a need for an HT limit.

Opportunity threshold

37 A threshold is established after which the first item is examined at a suitable opportunity afforded by another maintenance operation. If the findings are satisfactory, the actual age of the examined item becomes the new threshold. Thereafter, the next item that exceeds the new threshold becomes the new sample. This process builds a record of the condition of parts in which the sample closely follows the oldest item in service. Parts are not be repaired or discarded unless they are unfit for further service.

Dual threshold

38 Upper and lower thresholds are established and the AE tasks are done on the candidate items, as opportunities arise between these limits. If there are insufficient opportunities to examine a sample, the remaining AE candidates must be replaced and assessed before they age beyond the upper threshold. Both thresholds are reset using information gained from the AE analysis. This process is continued until the age-reliability relationship has been established.

FLEET LEADER SAMPLING

39 Fleet leader sampling is the concentration of sampling tasks on items which are either the oldest or which have the highest use. The fleet leader sample identifies the first items to reach the age or interval at which sampling begins (initial interval or threshold). These items are normally expected to lead the fleet in revealing failure trends.

CONSTANT DENSITY SAMPLING

40 Constant density sampling examines a fixed percentage of items, at specific intervals. Samples are rotated so that all items are examined before reaching the fatigue design life. This process provides a constant flow of knowledge about the condition of an item with increasing age, while permitting a significant reduction in required examinations.

STRUCTURES SAMPLING

41 The technical characteristics and the environment of a structural element determine the sampling process. Two types of sampling techniques are used for structures during AE: fleet leader sampling and constant density sampling. Fleet leader sampling is best used on equipment operated in a consistent

environment, where age and usage will affect the fleet in a similar manner; constant density sampling is particularly useful when a fleet is operated in a variable environment.

42 Structures sampling is relevant to safe life and damage tolerant structure. Experience shows that safe life structures can fail from fatigue before they achieve their design life. Although such failures should be detected by controlled fatigue testing, it is also prudent to monitor the condition of the fleet in an operational environment. With regard to damage tolerant structure AE can be used to validate or confirm crack detection thresholds and crack propagation rates.

43 The sample sizes and task intervals chosen for structural AE tasks are influenced by a variety of factors. For instance, if an SSI retains a high proportion of its residual strength following the failure of some elements, it is not necessary to explore a large portion of the fleet. If AE is done to verify crack detection thresholds, the initial and repeat task intervals depend on the level of confidence in the design of the structure. If a sampling programme is established to detect fatigue damage, it must be scheduled against the most relevant measure of fatigue consumption; for instance: flying hours, wave encounters, fatigue index, landings, pressurisation cycles, etc.

AE PRIORITIES

44 Since many of the RCM logic decisions and task intervals are selected without sufficient data, default decision logic is applied to obtain a conservative task interval. An RCM analysis may produce a large number of AE candidates, which must be prioritized before developing the AE programme. Figure 5 is used to determine the priority to be applied to the collection of AE data. The AE investigation priorities are:

44.1 Priority 1. Safety related failure modes where subjective judgement has been used to determine PM task intervals.

44.2 Priority 2. Non-safety related failure modes for which data collection is not resource intensive and where significant savings might be realised.

44.3 Priority 3. Non-safety related failure modes for which data collection might be resource intensive, but where there is the potential to realise savings.

AE TASKS FOR SAFETY RELATED FAILURE CONSEQUENCES

45 The two recommended ways of developing AE tasks for items with safety related consequences of failure are controlled AE tasks and operational AE tasks.

Controlled AE tasks

46 A laboratory controlled task (or a task where the item concerned is removed from the aircraft is used when failure information is required and safety considerations prohibit collecting information from operational activities. This task is an engineering devised test to failure process to determine safe life limits where an HT task is being considered. Safe life limits are determined by statistical analysis. This involves doing tests to failure on a sample of items and basing the safe life limit on the failure distribution.

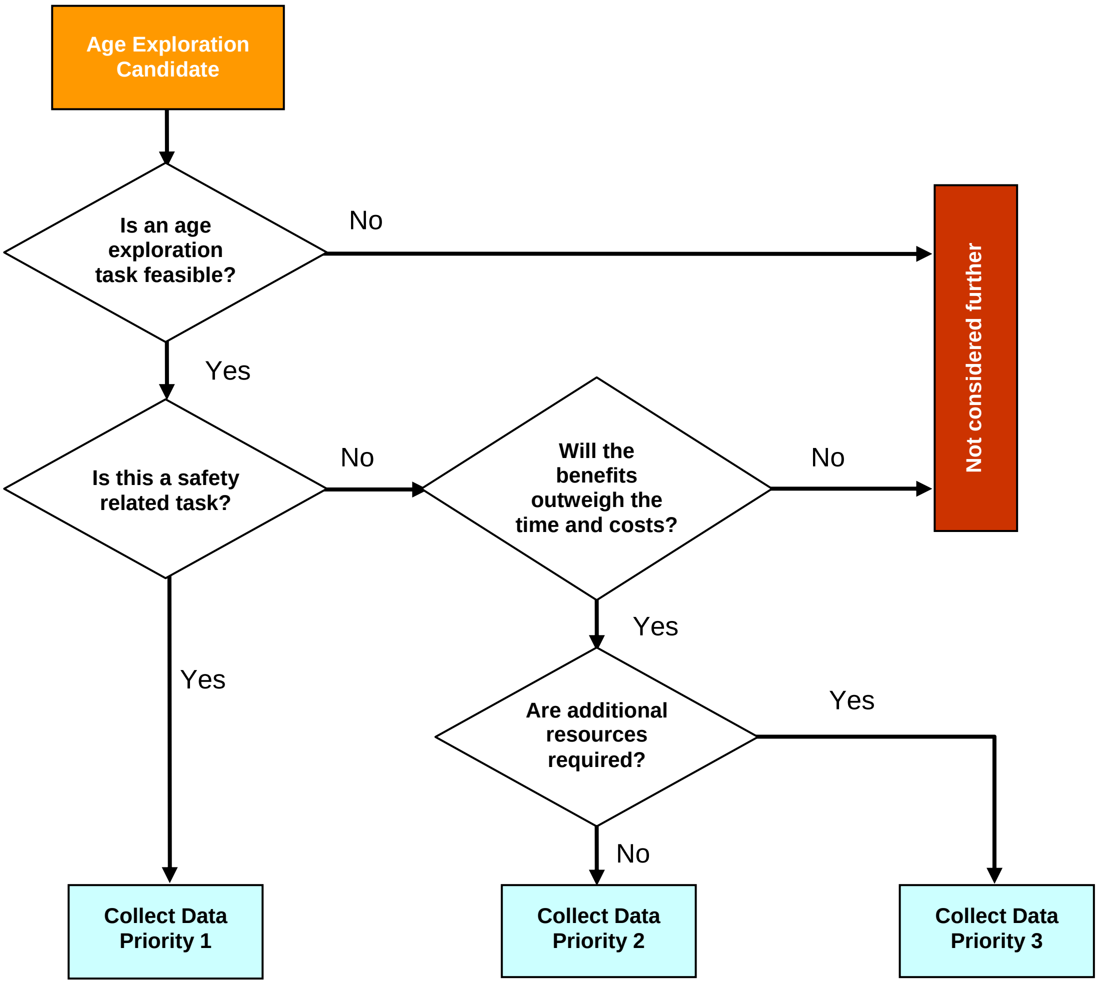


Figure 5 Age exploration decision logic

Operational AE tasks

47 While an item is in normal operational use, a task can be used to collect data on the rates of degradation, even though an item may have safety related failure consequences, providing potential and functional failure limits have been set. Data should be collected up to the point at which a failure symptom is identified or an item removed. For example, an operational environment AE task may be used to verify or determine the crack propagation rate for a damage tolerant structure, taking care that the item being studied never reaches the functional failure condition. However, an operational environment task of this nature must never be used to establish or validate a HT task. If there is doubt about the adequacy of the age for HT removal, it must be resolved by a controlled task where the item is removed from the aircraft. Evidence of no failures up to the time for removal is not justification for increasing the interval for HT removal. An AE task done in an operational environment must be implemented at conservative intervals to minimize disruption.

AE TASKS FOR NON-SAFETY RELATED FAILURE CONSEQUENCES

48 This type of task is designed to collect AE data on items whose loss may have a significant impact on the intended mission or cost, but does not affect safety. AE for such items may be done in an operational environment or by routine monitoring of existing maintenance information systems. Laboratory or other equipment-controlled tasks are not usually required. For example, this type of task may be conducted over a finite time period to determine the effectiveness of an HT task through an actuarial analysis, allowing the sample to fail while in operational service.

AE DATA COLLECTION

49 An AE programme provides a systematic approach for collecting and analysing operational data to establish the best maintenance parameters. Whatever system is used to manage AE data it must be flexible. The AE information reporting requirements must be carefully structured to avoid accumulation of unnecessary data.

APPLYING THE RESULTS OF AN AE ANALYSIS

50 The last requirement of the AE process is applying the results of the analyses to the PM programme. It is important to remember that the AE programme is firmly tied to RCM. AE cannot change the PM requirement without revising the RCM analysis. AE results may be applied to any level of maintenance.

Adjusting maintenance intervals

51 As a result of an AE task, it may be found that the existing maintenance interval is not the most effective. The results of an AE task allow the P-F interval or HT interval to be determined for an item.

Adjusting maintenance tasks

52 At the completion of an AE analysis, one of the results may be the refinement of an existing PM task. This may change the task method, add tasks, delete tasks, or change the task altogether (e.g. going from an OC task to an HT removal).

Modifying AE sampling programmes

53 Another output of an AE task may be to recommend a modification to an AE task. This may occur when the results are not conclusive. The task modification may be as simple as changing the number of samples undergoing analysis or as complex as rewriting the task and data recording process. An effective AE programme should undergo constant refinement, such as adding new candidates, deleting completed or unsuccessful tasks, changing sample sizes, or adjusting task intervals.

RECOMMENDATIONS FOR AE

54 It is emphasised that any RCM study recommendation for an AE investigation is just that. Unless an AE task is safety related, in which case it becomes mandatory, the RCM Analysis Sponsor should decide whether to conduct AE investigations.

OUTPUT

55 The output from the AE analysis process is sufficient information to enable an RCM logic decision to be made with a high degree of confidence, based on the collation of accurate data.