Preparedness and the Maintenance Function

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About the Author

Squadron Leader Peter McLennan joined the RAAF in 1980 to undertake an Engineering cadetship at Engineer Cadet Squadron, Melbourne. He graduated as an Engineer Officer in 1983. Through postings to Nos 2 and 3 Aircraft Depots (now Nos 503 and 501 Wings) he gained experience in maintenance management. Squadron Leader McLennan has also been involved with the development of a number of maintenance management computer systems. His preparedness goals was kindled through postings to the F-111 Systems Engineering and Maintenance Engineering Analysis cells in Logistics Command.

Acknowledgments

I am most grateful to CAS and the staff at the Air Power Studies Centre for permitting me the opportunity to study this topic, and for the guidance the latter provided in the production of work such as this.

Many people throughout the ADF were consulted during the writing of this volume; despite universally high workloads, everyone I visited willingly and cheerfully gave of their time. To all concerned, thank you. I am particularly grateful to those who proofread my drafts, despite being under no obligation to do so.

Thanks also to my father, for divining and rectifying numerous grammatical infelicities. And lastly, thanks to my wife Diane, for her unswerving support and encouragement.

Abstract

This book was prepared at the Air Power Studies Centre as a Chief of the Air Staff's Air Power Fellowship in 1994. The fellowship scheme commenced in 1990, and aims to develop awareness and foster understanding of air power in the Australian context. The aim of this fellowship was to explore the relationship between preparedness and aircraft maintenance.

The first part of the study reviews relevant aspects of strategic guidance and preparedness concepts, and outlines the nature of preparedness goals. Part 2 provides a broad overview of many facets of the maintenance function, including maintenance requirements determination, unscheduled maintenance, modification, and maintenance management.

Part 3 aims to assess the implications of preparedness for the maintenance function. Firstly, the priorities for contingency maintenance goals are determined. The maintenance requirements determination process is then revisited, to assess the nature of changes required to scheduled maintenance programs. A theoretical approach to the determination of contingency maintenance requirements is described, and the issues involved underpin much of the remaining discussion.

Implications for the maintenance requirements determination process itself are also discussed, as well as contingency maintenance performance measurement and trials, and battle damage repair.

Examples of aircraft modifications that may be associated with the transition to a contingency are listed, and implications for the management of such modification programs (and configuration in general) are derived.

The appropriate location and organisation for performing contingency maintenance is examined in some detail. Issues include the extent to which maintenance should be performed on deployment, the appropriate allocation of maintenance workload between the ADF and industry, and the need to ensure that some maintenance capabilities are developed or retained in Australia. The relationship between operational and maintenance elements within the RAAF is also discussed.

Miscellaneous topics also addressed include the implications of the use of advanced technology equipment, the importance of personnel in achieving maintenance effectiveness, and maintenance management in a contingency.

Contents

Abbreviations

A_O	Operational Availability
AAP	Australian Air Publication
ACOPD	Air Command Operational Preparedness Directive
ACPP	Air Command Preparedness Project
ADF	Australian Defence Force
ADFP	Australian Defence Force Publication
ADT	Administrative Delay Time
AFMC	Air Force Materiel Command (USAF)
AFTA	Hornet Avionics Fault Tree Analyzer
AHQ	Air Headquarters
AIRSIM	Hornet Aircraft [Systems] Simulator
AO	Area of Operations
ARDU	Aircraft Research and Development Unit
ASI	Aircraft Structural Integrity
ATA	Air Transport Association
ATE	Automatic/Automated Test Equipment
BITE	Built-In Test Equipment
BDR	Battle Damage Repair
BPR	Biannual Preparedness Report
CAA	Civil Aviation Authority
CAMM	Computer-Aided Maintenance Management
CAS	Chief of the Air Staff
CDF	Chief of the Defence Force
CDFS	Chief of the Defence Force Staff
CFU	Carried-Forward Unserviceability
CLSS	Combat Logistics Support Squadron
CPD	CDF Directive on ADF Preparedness
CPLT	Cold Proof-Load Test
CSP	Commercial Support Program
BDR	Battle Damage Repair
DADTA	Durability and Damage Tolerance Analysis
DDI	Hornet Digital Display Indicator
DI(AF)	Defence Instruction (Air Force)
DID	Defence Industry Development
DI(G)	Defence Instruction (General)
DLM	Depot Level Maintenance
DM	Deeper Maintenance
DSTO	Defence Science and Technology Organisation
ECM	Electronic CounterMeasures

EFD	Early Failure Detection
FAK	Fly-Away Kit
FEG	Force Element Group
FFBNW	Fitted For But Not With
FMECA	Failure Modes, Effects and Criticality Analysis
FMS	Foreign Military Sales
FOD	Foreign Object Damage
FPR	Failure Progression Rate
GSE	Ground Support Equipment
HQADF	Headquarters Australian Defence Force
HQLC	Headquarters Logistics Command
HQTC	Headquarters Training Command
ILS	Integrated Logistics Support
ISO	International Standards Organisation
JIT	Just-In-Time
LDT	Logistics Delay Time
LMSQN	Logistics Management Squadron
LOC	Lines of Communication
LOGCAS	Logistic Capability Assessment
LRU	Line Replaceable Unit
LSA	Logistic Support Analysis
LSAR	Logistic Support Analysis Record
MAARS	Maintenance Analysis and Reporting System
MDT	Mean DownTime
MEA	Maintenance Engineering Analysis
MIEC	Mission Item Essentiality Code
MIL-STD	US Military Standard
MLOC	Minimum Level of Capability
MRD	Maintenance Requirements Determination
MRP	Manufacturing Resource Planning
MRU	Manpower (or Members or Personnel) Required in Uniform
MSA	Main Support Area
MSG	Maintenance Steering Group
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
MTTR	Mean Time To Repair
NATO	North Atlantic Treaty Organisation
NBC	Nuclear, Biological and Chemical
NDI	Non-Destructive Inspection
NFMC	Not Fully Mission Capable
NSN	NATO Stock Number
OC	On Condition

OEM	Original Equipment Manufacturer
OLOC	Operational Level of Capability
OM	Operational Maintenance
OPD	Operational Preparedness Directive
OVP	Operational Viability Period
OVR	Operational Viability Resources
PDF	Probability Density Function
PERT	Program Evaluation and Review Technique
PLOC	Present Level of Capability
POC	Period of Contingency
R&M	Reliability and Maintainability
RAAF	Royal Australian Air Force
RAF	Royal Air Force
RAM	RADAR Absorbent Material
RCM	Reliability Centered Maintenance
RDMI	Region of Direct Military Interest
RFD/RFW	Request for Deviation/Request for Waiver
RI	Repairable Item
ROE	Rate Of Effort
ROLT	Reduction Of Lead Time
RPSI	Region of Primary Strategic Interest
SR	Sustainability Resources
SRM	Structural Repair Manual
STI	Special Technical Instruction
SWAM	Surface Wave Absorbent Material
TAT	Turn Around Time
TMS	Time to Make Serviceable
TOC	Theory Of Constraints
TQM	Total Quality Management
TTR	Technical Trades Restructure
UMO	Unit Maintenance Order
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
VIP	Very Important Person
WSSF	Weapon System Support Facility

Chapter 1
Introduction

AIM

The aim of this study is to assess the implications of preparedness requirements for the maintenance function.

Hopefully, this volume can provide some assistance to those responsible for the RAAF's maintenance function, to assist in ensuring that it can best meet contingency demands by methodical process improvement. Other readers may be influenced to at least *think* about and be more aware of contingency-related issues. Non-technical readers should gain an understanding of the opportunities, problems and needs of the maintenance function.

RELEVANCE

What is the relationship between preparedness and maintenance? Simplistically, preparedness requires (*inter alia*) that a specified number of aircraft be available for operations *within* a specified period of time, and *for* a specified duration. There is therefore a direct relationship between preparedness and aircraft *availability*. Contingency operations (and preparedness goals) also require that aircraft have adequate levels of airworthiness and missionworthiness, but the major emphasis is on availability—this is certainly the greatest difference between peacetime and contingency maintenance requirements.

Does maintenance have a direct bearing on aircraft availability? There is significant evidence that maintenance requirements adversely affect aircraft availability more than any other factor—more than all other factors combined, in fact.[1] Spare parts shortages are often thought to be the main cause of aircraft unavailability, but in fact 'hands-on' maintenance work consumes much more time. The Pareto principle suggests that the largest source of lost availability should be considered first when attempting to improve availability.[2]

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1 DLDP AF91/7557 Pt 1 (13), *A Study of RAAF Aircraft Availability and Cost Factors*, DLDP, 17 September 1991, showed that 88.25 per cent of unavailability was attributable to the performance of maintenance tasks during peacetime (although there are some caveats on the accuracy of the data). The proportion of downtime attributable to maintenance during wartime is expected to be similar, even though overall availability should increase. In at least one case during the Gulf War, availability actually *decreased* as a result of maintenance requirements, Murray Hammick, 'Report from the Front: AMUs Underrated in USAF's Success', *International Defense Review*, 5/1991, pp. 451–452.

2 The Pareto principle originally espoused that 80 per cent of a country's wealth is owned by 20 per cent of the population. A broad analogy is that a large proportion of any problem can be traced to a relatively small number of most significant causes. It therefore makes sense to address these causes as a priority, since their effect on the outcome is greatest.

It is also commonly felt that spares shortages should be largely avoidable, by allocating adequate funds to the procurement of spares, and by judicious choice of the particular parts procured; conversely, the maintenance burden is often thought of as basically immutable, and therefore not worthy of further examination. However, strategies *do* exist to minimise the impact of maintenance on availability (and hence preparedness). Unfortunately, some of these strategies tend to be highly complex, and are not practised (or even known) widely throughout the RAAF. Regardless, working smarter with regard to maintenance in a contingency can provide a direct and significant improvement to availability, and hence preparedness.

SCOPE

Coverage

There is nothing in the definition of preparedness that limits its application to short-warning conflict and peacetime operational tasks. However, current practice is to limit consideration of preparedness to these roles, presumably since strategic guidance accords lower priority to the other roles (expansion for major conflict, and contributions to multinational security forces, eg. peacekeeping). This emphasis is generally adhered to in this volume, but the implications of preparedness for the other roles are also discussed when significant.

This study concentrates largely on aircraft, as most of the RAAF's preparedness goals concern aircraft. However, most of the discussion applies equally well to other items of technical equipment (some of which are also subject to preparedness requirements). To a large extent, the use of aircraft-specific terminology is adopted merely to simplify the grammar.

Most aspects of maintenance are addressed in this study, including such issues as commercial and overseas support, technology, and organisational aspects. However, the main emphasis is on the determination of contingency maintenance requirements, and this theme recurs throughout. The approach taken basically aims to relate maintenance requirements to performance against maintenance goals (such as availability). Thus, the consequences for maintenance programmes of changes to maintenance goals (eg. an increased emphasis on availability) can be established.[3]

The maintenance function is highly dependent upon the supply and repairable item pipeline management functions. The relationship between these latter functions and preparedness

3 An attempt was made to distil a rigorous procedure for relating maintenance policies to maintenance goals (in particular, Chapters 11 and 13). Such a procedure is outlined in qualitative terms; the mathematical basis required to implement the approach is beyond the scope of this study.

4 Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994.

has been previously studied;[4] therefore, this volume does not address these functions in detail.

The current rate of organisational and procedural change in the ADF means that this document will be somewhat out of date even before it can be published. There is a preponderance of references to draft documents, and newly released information is becoming available with great regularity. Some documents referred to in draft form (eg. DI(AF) LOG 13-7) have recently been issued in definitive form. Time did not permit the review of these recent releases and updates.

Depth

Rather than simply document current projects and practices, this study aims to cover the theory and principles underpinning the relationship between preparedness and maintenance. Hopefully, this concentration on higher-level issues results in a volume of more enduring usefulness.

Classified information is not quoted in this study. This limits the description of preparedness goals, which in turn precludes deriving many conclusions that may be drawn from applying preparedness goals to maintenance principles. ADF readers (who need to know) are encouraged to access the classified documents referred to in the text, and draw their own conclusions based on the principles described herein.

Readership

This study is intended to be comprehensible to a wide audience, including senior management, aircrew, engineers, tradesmen, and supply personnel; and even non-ADF readers. Important technical and RAAF-specific terms are generally described in the early chapters, or in footnotes.

The maintenance function does not exist in a vacuum, and readers from non-technical backgrounds should hopefully gain useful insights into the possibilities, limitations and needs of the maintenance function. This cross-specialisation understanding greatly assists the integration of the maintenance function with other closely related functions (such as operations, engineering, and other aspects of logistics). It is only through such integration that maximum contingency performance overall can be achieved, and suboptimisation avoided.

That said, the application of many of the concepts in this book falls to RAAF engineers, and some chapters indulge in a greater amount of theory and detail to provide additional guidance to these members. Topics which are particularly technical or peripheral are relegated to Annexes.

Organisation

This study is divided into three parts. Part 1 describes strategic guidance and preparedness concepts and goals. Various aspects of the maintenance function are discussed in Part 2, although without specific reference to preparedness or contingency issues. Part 3 covers the implications of preparedness for the maintenance function. Parts 1 and 2 are intended to provide background material to assist the comprehension of Part 3, and may be skimmed by readers already familiar with the subject matter.

Part 1

Preparedness

Chapter 2
Strategic Guidance and Defence Policy

INTRODUCTION

Preparedness denotes the ability of force elements to undertake operations in a timely manner, and to sustain those operations.[1] A thorough appreciation of specific preparedness levels requires some understanding of the underlying strategic guidance on which they are based.

In addition, there are some facets of preparedness that are not expanded upon in generic preparedness definitions and goals, such as the geographical locations in which operations may be conducted. This information must therefore be obtained from higher level strategic guidance.

This chapter outlines aspects of strategic guidance that are relevant to an understanding of preparedness, provide supplementary information, or have other implications for the performance of maintenance to meet specific preparedness goals.

WHAT IS STRATEGIC GUIDANCE?

Formally, strategic guidance comprises 'the general concepts of how strategic aims of war are to be achieved. Guidance may include: appreciations; concepts for operations; translations of political objectives and constraints into unambiguous directions for military operations; intelligence interpretations; and definitions of areas of operations and resources available.'[2] It may be thought of as covering relevant political aspects of national will and military capability, and therefore provides the broadest statements of requirements for the capabilities of the ADF.

WHY DOES AUSTRALIA HAVE A DEFENCE FORCE?

The Australian Defence Force exists for the defence of Australia. However, its existence also provides the Government with a resource capable of fulfilling other roles when it is not

1 ADFP4, Operations Series, *Mobilisation Planning*, First Edition, draft, 1994, Glossary.

2 ibid.

required to actively pursue the duties for which it is primarily established.[3] A series of roles therefore emerges for the ADF, with differing levels of priority.

The document that currently states Government defence policy is *Defending Australia 1994* (DA 94).[4] The contents of this document were endorsed by parliament in 1994. DA 94 indicates four fundamental objectives of Australia's defence policy:

a. independent defence of Australia and its interests,

b. promotion of strategic stability and security in our region,

c. meeting mutual obligations with our allies, and

d. contribution to strategic security at the global level.[5]

These considerations lead to three major functions for the ADF:

a. undertake current and foreseeable peacetime operational tasks,

b. deal effectively with the levels of credible contingencies that could arise over shorter timescales,[6] and

c. provide a suitable basis for timely expansion to meet higher levels of threat if Australia's strategic circumstances deteriorated over the longer term.[7]

A fourth function is activity in multinational security operations, eg. contributions to United Nations peacekeeping forces.[8] This function has been increasingly emphasised in recent years, and this trend seems likely to continue.[9]

Before the requirements for the four ADF functions may be discussed in more detail, it is first necessary to define the fundamental concepts of *self-reliance* and *depth in defence*, as well as some geographical terms.

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3 *Defending Australia*, AGPS, Canberra, 1994, pp. 5, 14, 15; 'Peacekeeping: Our Future Involvement', *Defence Update*, December 1993, pp. 44–45; B. Fetherston, 'Australian Defence Policy: Peacekeeping', *Pacific Research*, August 1993, pp. 35–38; *Peacekeeping Policy – The Future Australian Defence Force Role*, Department of Defence, Canberra, 1993, p. 5; and *Strategic Review 1993*, Departmental Publications, Canberra, 1993, p. 16.

4 *Defending Australia*, pp. 5, 14, 15.

5 ibid., pp. 3, 16, 85, 103.

6 ibid., p. 24, refers to *short-warning conflict*.

7 ibid., p. 23; ADFP4, p. 1-2; and *Strategic Review 1993*, p. 16.

8 *Defending Australia* does not explicitly enumerate ADF functions. However, it does cover the defence of Australia including short-warning and major conflict, 'peacetime operational activities' (p. 42), and peacekeeping (p. 104).

9 *Strategic Review 1993*, p. 16.

DEFINITIONS

Self-Reliance

At face value, 'self-reliance' appears to be synonymous with 'self-sufficiency'. However, this is not the meaning of the term when used with regard to Australia's defence policy.[10] The term's subtle connotations are best comprehended by contrasting it with alternative defence policies.

Historically, Australia's defence policy has involved heavy reliance on larger, more powerful allies (Britain, and more recently, USA). Australia's military forces would be used as a contribution to the forces of our ally in support of shared political aims, and the security of Australia was considered to be dependent on that of our allies.[11] A basic assumption was that if Australia's sovereignty was threatened, our ally would come to our aid, and Australian military forces would again be merely a contribution to this larger effort. This kind of policy may be thought of as 'ally-reliance'.[12]

More recent international developments have lead Australia to reassess the validity of such a policy. Involvement by powerful allies in regional disputes is not assured; therefore, smaller nations must provide more for their own defence.[13] This is the essence of self-reliance: Australia having the ability to defend itself without depending on help from other countries' combat forces.[14]

However, just as 'ally-reliance' involved some contribution from indigenous military forces, self-reliance may include external assistance through alliances and agreements.[15] Where 'ally-reliance' involved Australia helping an ally to defend Australia, self-reliance means allies helping Australia to defend Australia. The concepts are not opposites, but involve a change of emphasis.

Self-reliance may now be contrasted with self-sufficiency. Whereas self-sufficiency would not require any dependence on support from external powers through alliances or agreements, self-reliance allows this.

It is possible to consider self-sufficiency as a part of a larger continuum, ranging from total reliance on an ally, to total self-sufficiency (see Figure 2-1).

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10 *Defending Australia*, p. 15; and *Strategic Review 1993*, p. 53.

11 DI(AF) AAP 1000, *The Air Power Manual*, Air Power Studies Centre, Canberra, 1990, p. 57.

12 Author's term.

13 DI(AF) AAP 1000, p. 57.

14 *Defending Australia*, p. 13.

15 op cit., p. 15.

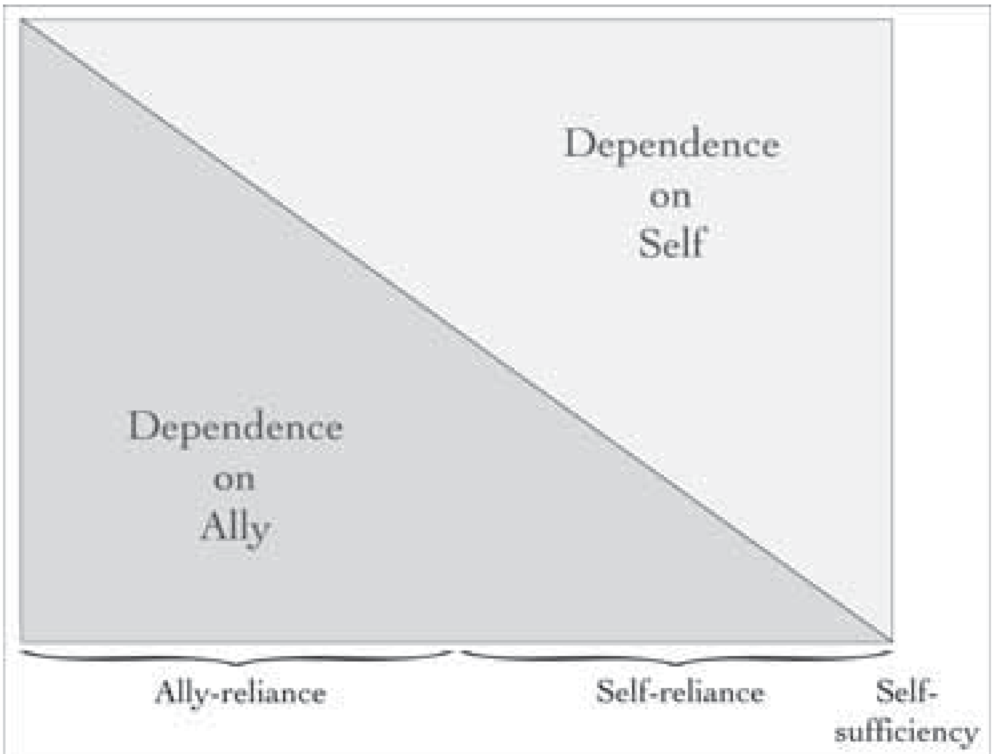

Figure 2-1: Self-reliance

Figure 2-1 shows that self-reliance is itself a continuum. A balance must be struck between the extent of our dependence on alliances and agreements with external powers, and the extent to which we strive for self-sufficiency. Considerations influencing such decisions include:

a. commercial competitiveness of Australian suppliers,

b. ability of overseas suppliers to meet the unique needs of Australian defence,

c. strategic importance of the capability,

d. reliability of suppliers,

e. political or national disclosure constraints of overseas suppliers, and

f. desirability of establishing a local capacity for a new capability.[16]

Australia's overseas alliance agreements provide significant assistance to Australia. Logistics benefits include preferred status in military equipment purchasing, access to training courses, supply of munitions and equipment in an emergency, and access to technology.[17] Of Australia's allies, the United States provides Australia with the greatest logistics assistance.

16 *Strategic Review 1993*, p. 55.

17 *Defending Australia*, p. 97.

Depth in Defence

The concept of 'depth in defence' emphasises that Australia should have a *comprehensive array* of military capabilities. Capabilities should allow defensive and offensive operations. Forces should be highly mobile. To achieve such depth in defence capabilities, considerable reliance on the commercial sector is necessary.[18]

Australia's intention is to terminate any conflict promptly to reduce the risk of escalation.[19] This policy aligns with current US force employment doctrine, which advocates a commitment to overwhelming technological capability and level of forces (as was evidenced in the Gulf War).[20] This approach may be contrasted with earlier US doctrine, in which force levels were limited in an attempt to achieve the same outcome (avoidance of escalation). This approach risks significantly extending the conflict (eg. the Vietnam War).

An additional facet of depth in defence is the desire to keep the adversary 'at an arm's length'. This involves exploiting the isolation of the Australian continent and the harsh environment of its northern area. Operations may therefore need to be mounted over long distances.[21]

Geographical Regions

In general, the extent of military interest and probability of executing military operations diminishes with increasing distance from Australia. It is convenient to define some geographical regions which may be subsequently used to indicate the extents of Australia's military interests and capabilities.

Australia's region is considered to be the Asia-Pacific region, including the Indian subcontinent, South-East Asia, North-East Asia and the South-West Pacific.[22] This area covers some 25 per cent of the earth's surface.

Australia's nearer region is defined to be South-East Asia, the South-West Pacific and the nearer reaches of the Indian Ocean.[23] This area stretches some 7000 kilometres east to west, and covers about ten per cent of the earth's surface.

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18 ibid., p. 28.

19 *Strategic Review 1993*, pp. 44, 45; and *Defending Australia*, p. 15.

20 Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, p. 8.

21 *Strategic Review 1993*, loc cit.

22 ibid., p. 1.

23 loc cit.

FUNCTIONS OF THE ADF

Peacetime Operational Tasks

Peacetime operational tasks include natural disaster relief or security assistance to countries in Australia's nearer region, assistance to the civil community, aid to the civil power, counter-terrorism capabilities, fisheries patrol, coastal surveillance, and certain other activities in support of regional security.[24]

A quick response is potentially required for many peacetime operational tasks.[25] Strategic guidance does not comment on the possible duration required for such tasks, nor the level of defence involvement required. However, many of the tasks are explicit in nature, and are subject to more detailed contingency plans.[26]

Peacetime operational tasks do not determine the ADF's force structure,[27] although they may influence preparedness planning.[28]

Short-Warning Conflict

Threat equals capability plus intent. Although no country currently shows any intention to threaten Australia, intentions can change relatively quickly. The scope of short-warning conflict is therefore defined by the current and prospective military capabilities that could be brought to bear against Australia in the near term.[29] Military activity against Australia in the shorter term would probably take the form of limited war, involving low-level or medium-level conflict.[30]

Because of the short timescales associated with the outbreak of such conflict against Australia, the ADF should be capable of countering it essentially from the force-in-being.[31]

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24 *CDF Directive on ADF Preparedness 1993*, Canberra, 1993, p. 2; *Strategic Review 1993*, p. 46; and *Defending Australia*, p. 32. 'Tasks in support of regional security' appears to overlap with 'tasks in support of regional friends and allies'. The emphasis in the latter category is in peacekeeping and related operations, generally under the auspices of the United Nations.

25 *CDF Directive on ADF Preparedness 1993*, p. 2.

26 See p. 16.

27 *Defending Australia*, p. 5.

28 ibid., p. 32.

29 ibid., p. 23.

30 Classes of war and levels of conflict are described in DI(AF) AAP 1000, pp. 9–10. Although *Defending Australia* does not explicitly indicate what class of war may be encountered in short-warning conflict, it *does* contrast short-warning conflict with 'major conflict'. The class of war and levels of conflict may be surmised by studying the scenarios involved.

31 *Defending Australia*, p. 24. 'Force-in-being' is the Australian Defence Force as it exists at any given time, including its state of preparedness (*CDF Directive on ADF Preparedness 1993*, Glossary).

Despite the possibility of short warning, ADF elements may be required to operate for lengthy periods to counter threats at this level.[32]

Forces may need to operate in dispersed and remote locations.[33] The ADF should be able to mount military operations anywhere within Australia's nearer region, and not merely provide 'continental' defence.[34] However, for defence against short-warning conflict, emphasis is placed on operations in the North and North-west of the continent, and Australia's offshore territories.[35]

Short-warning conflict considerations are the primary determinant of the ADF's force structure and preparedness.[36]

Major Conflict

Prospective aggressors would need to mount a significant military expansion[37] program to be able to involve Australia in major conflict. Long lead-times would be required for this, and such a build up would be clearly evident.[38] There is therefore a significant warning time for major conflict in this region.

Australia has considerable potential for military force expansion, and could expect to counter the threat of major conflict with reasonable confidence.[39] Moreover, the United States retains a significant interest in the stability of the Asia-Pacific region,[40] and the relationship between Australia and the United States gives even greater reason for confidence in the event of a major conflict.[41]

Because of the long warning time involved, major conflict considerations should not determine the ADF's force structure or preparedness.[42]

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32 *Strategic Review 1993*, p. 49; *Defending Australia*, p. 24.

33 loc cit.

34 *Defending Australia*, p. 15.

35 *Strategic Review 1993*, p. 43; *Defending Australia*, pp. 21, 30.

36 *Strategic Review 1993*, p. 49; *Defending Australia*, pp. 5, 23, 86, 154.

37 *Force expansion* is the process by which military forces are increased in size and/or capability by the acquisition of additional trained personnel, equipment, facilities or other resources. ADFP4, Glossary.

38 *Strategic Review 1993*, p. 43; *Defending Australia*, p. 23.

39 loc cit.

40 *Strategic Review 1993*, p. 8; *Defending Australia*, p. 8.

41 *Strategic Review 1993*, p. 35.

42 *Strategic Review 1993*, p. 43; *Defending Australia*, pp. 24, 154.

Multinational Security Operations

Multinational security operations include peacekeeping and peace enforcement, and are generally (although not invariably) conducted under the auspices of the United Nations.

Peacekeeping has been the ADF's growth area. Current ADF participation in peacekeeping and similar operations is at an all-time high,[43] and current policy is to maintain, if not further increase, these levels of involvement.[44]

Despite the increasing emphasis on peacekeeping, this function is not a determinant of force structure or preparedness.[45] ADF forces structured to perform other functions (particularly, to defend against short-warning conflict) provide the Government with many options for contributions to multinational security operations. The preparedness of units (based on requirements for the defence of Australia) is sufficient to permit deployment for multinational security purposes within acceptable timescales.[46]

Australian forces may be requested to contribute to such operations anywhere on the globe. However, more importance is attached to operations within Australia's region, as the stability of our own region more directly enhances the security of this country. Accordingly, requests for Australian participation in security operations in this region will be looked upon more favourably by Government, and may justify somewhat larger and longer contributions.[47]

The Government has indicated to the United Nations that it may be willing to make available the following aircraft forces:

a. one transport squadron,

b. one light and one medium helicopter squadron, or

c. one fixed wing short or medium range air transport flight.

These forces may not be offered concurrently. Australian involvement in peacekeeping operations may be protracted; provision is made for the rotation of personnel at six to nine month intervals.[48] The actual forces to be committed to an operation will be determined on a case-by-case basis.

43 *Peacekeeping Policy – The Future Australian Defence Force Role*, p. iii.

44 *Strategic Review 1993*, p. 75.

45 *Peacekeeping Policy – The Future Australian Defence Force Role*, p. 3.

46 *Strategic Review 1993*, p. 16; *Defending Australia*, p. 106.

47 *Strategic Review 1993*, p. 16; *Defending Australia*, p. 104.

48 *Peacekeeping Policy – The Future Australian Defence Force Role*, p. 11.

FROM STRATEGIC GUIDANCE TO PREPAREDNESS

Concepts

Strategic guidance leads directly to military capability, which is one means that a government may use to exercise (or continue to exercise) independent action, despite the intentions of another state. The military capability of a nation is its ability to apply, or threaten to apply, violence through the combat power of its armed forces,[49] and is the combination of force structure and preparedness.[50] Figure 2-2 shows these relationships.

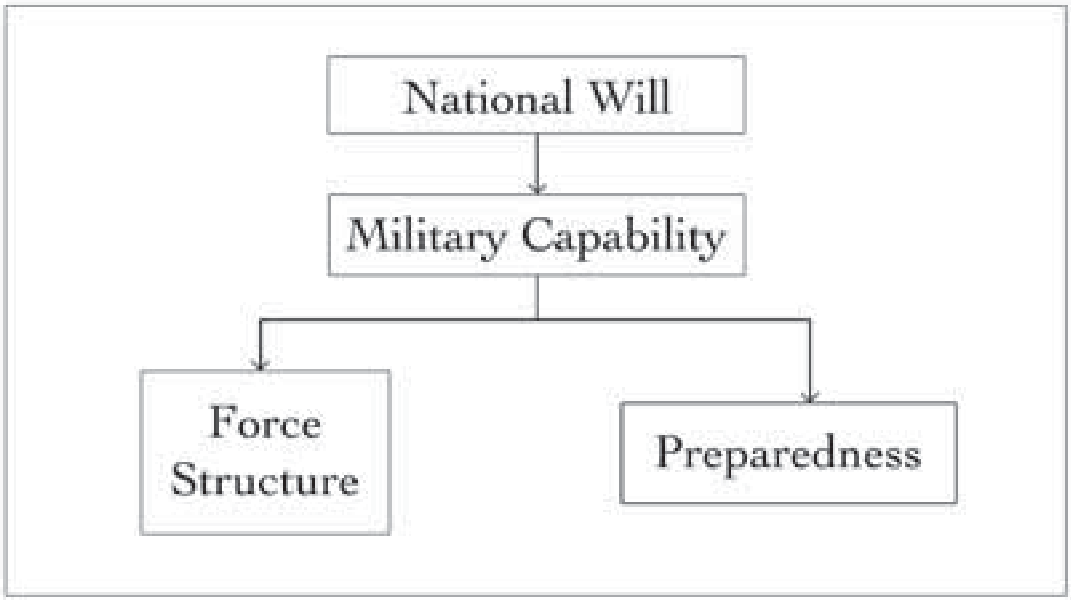

Figure 2-2: From National Will to Preparedness

Documents

Detailed preparedness objectives do not flow directly from the very broad requirements given in strategic guidance documentation. Intermediate planning documents are necessary to provide more detail on the tasks required of the ADF before explicit preparedness objectives can be derived.[51]

A Concept of Operations is the broadest statement of the approach that the ADF would use when performing a given function.[52]

49 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, p. 16.

50 ADFP4, Glossary. Force structure 'refers to the size, organisation, and technical and operational characteristics of the force-in-being'.

51 The contents, and even the names, of some of the documents described in this section are highly classified. Therefore, the description of these documents must be necessarily broad and general.

Contingency Plans are then developed for various scenarios, based on the Concept of Operations. They are relevant to peacetime operational tasks and to short-warning conflict scenarios. However, Contingency Plans do not need to be developed for major conflict, as the warning time for this is such that contingency plans could be developed, and their implications addressed, within the time available from when such a threat could be identified.

Some Contingency Plans exist for tasks in support of regional friends and allies. The need for contingency plans for ADF involvement in multinational operations is small, since ADF operations would be guided by the controlling body of the operation (usually, the United Nations).

From the individual contingency plans, it is finally possible to deduce some basic preparedness goals. These are published in the *CDF Directive on ADF Preparedness* (CPD).

The relationship between these documents is shown in Figure 2-3.

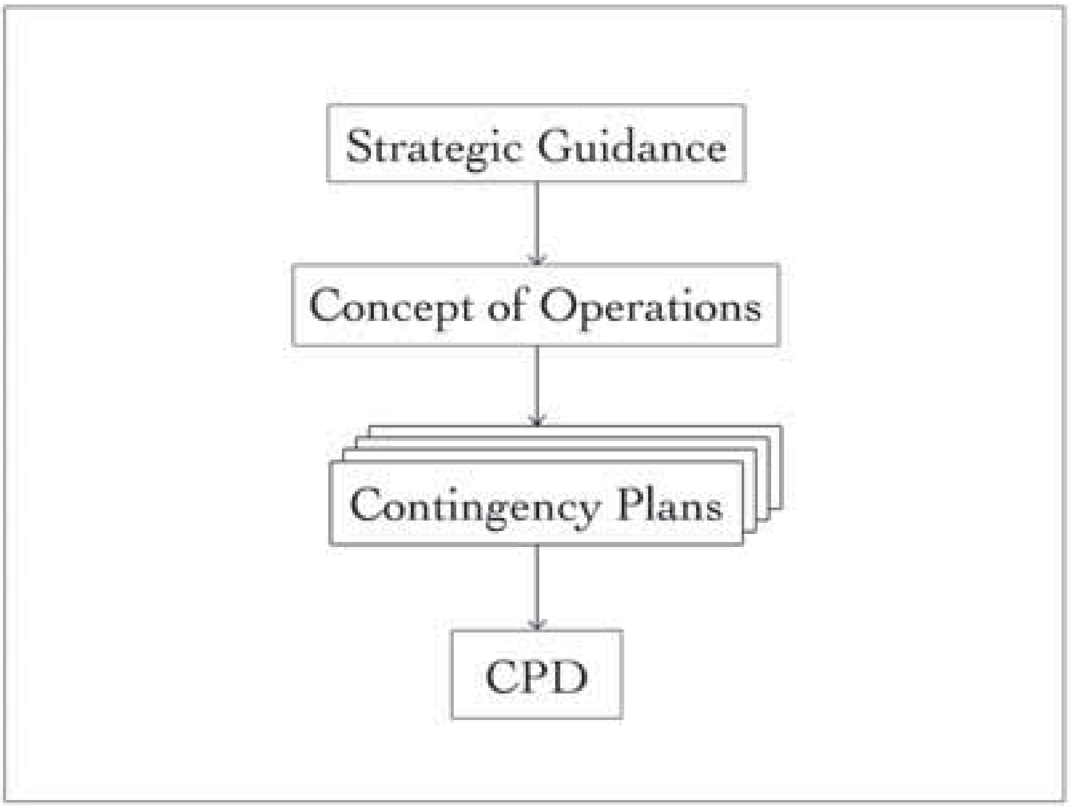

Figure 2-3: Hierarchy of Preparedness Documents

52 *A Concept of Operations* is not related to the *Operational Concept Papers* that are used in the Force Development process. To avoid the risk of confusion, the latter have been renamed *Strategic Concept Papers*.

In the near term, the CPD is also based on papers which discuss regional military capabilities, the nature of short-warning conflict, and the required concurrency of operations (ie. which operations may need to be performed by the ADF at the same time).

SUMMARY

Strategic guidance provides the broadest statements of requirements for ADF military capabilities, and hence preparedness. Current Australian strategic guidance requires that Australia be self-reliant in its ability to defend itself, and identifies four major roles for the ADF: peacetime operational tasks, defence of Australia against short-warning conflict, defence of Australia against major conflict, and contribution to multinational security operations. A hierarchy of subsidiary plans progressively refines strategic guidance requirements into specific preparedness goals.

Preparedness doctrine and concepts are explained in Chapter 3; Chapter 4 describes the nature of preparedness goals.

Chapter 3
Preparedness Concepts

INTRODUCTION

The ADF is not required to be able to carry out all of its roles instantaneously. This is because strategic guidance[1] states that there is no immediate threat to the security of Australia, and that there would be a warning time before ADF operations would be necessary. Therefore, ADF elements can be maintained at levels of capability below that required for active service; this realises significant cost savings. However, it is necessary to ensure that ADF elements can be brought to operational levels of capability within appropriate timescales. Preparedness denotes the ability of force elements to undertake operations in a timely manner, and to sustain that activity.[2]

Although focused on the conduct of operations, preparedness is a peacetime pursuit. The ADF must plan to be able to execute required operations within appropriate timescales. Preparedness is therefore a form of mobilisation planning.[3]

This chapter defines several key concepts relating to preparedness, including readiness, sustainability, levels of capability, timescales, and categories of resource.

PREPAREDNESS

Preparedness concepts and definitions cover the areas of capability, timescale, and resource requirements. To a large extent, the concepts are defined with reference to one another.

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1 Strategic guidance is described in the previous chapter.

2 ADFP4, Operations Series, *Mobilisation Planning*, First Edition, draft, 1994, Glossary; and DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, p. 67.

3 This is the title of the primary repository of ADF preparedness doctrine, the ADFP4. Mobilisation is defined to be 'the act of preparing for war or other emergencies through assembling and organising national resources (national mobilisation); and the process by which the armed forces or part of them are brought to a state of readiness for war or other national emergency including assembling and organising personnel, supplies and materiel for active military service (Defence mobilisation)' (ADFP4, Glossary and paragraph 401). Elements of mobilisation include force development, force structure, and preparedness (ADFP4, Foreword).

Preparedness

Preparedness denotes the ability of force elements to undertake operations in a timely manner, and to sustain those operations.[4] That is, preparedness combines *readiness* and *sustainability*. Preparedness requirements essentially stipulate relationships between capability and timescale.

Readiness

Readiness is the ability of designated forces to be committed to conduct specified operational roles and tasks within a nominated time at specific strengths and capabilities.[5,6]

Sustainability

Sustainability is the ability to support forces on operations.[7] Sustainability is therefore closely related to the duration that specified operations can be conducted.

LEVELS OF CAPABILITY

Readiness and sustainability objectives require that a specified *level of capability* be reached and maintained (respectively). In this context, capability comprises equipment levels, equipment condition, personnel and training.[8] Because a unit's level of capability will vary with time, preparedness doctrine defines three levels of capability:

a. Operational Level of Capability (OLOC): the level of capability at which units or force elements have the necessary training and resources to conduct specified operational roles and tasks.[9]

b. Minimum Level of Capability (MLOC): the lowest level of capability from which a unit or force element may achieve OLOC within the assigned readiness notice period.[10]

c. Present Level of Capability (PLOC): the level of capability of a unit or force element at any given time.[11] PLOC should not be lower than MLOC; if it is, the unit or force element concerned will probably not be able to achieve OLOC within the permitted readiness

4 ADFP4, Glossary.

5 loc cit.

6 DI(AF) AAP 1000, p. 68.

7 ADFP4, Glossary.

8 ibid., paragraph 115.

9 ibid., Glossary.

10 loc cit.

11 loc cit.

notice period. Conversely, it is unnecessary, and wasteful of peacetime resources, to maintain a unit at a PLOC significantly above MLOC. In practice, PLOC will vary over time.[12]

TIMESCALES

Warning (warning time) is an assessment of the time that would most likely be available before a potential enemy with hostile intent could practicably undertake specified military action.[13] Warning time varies for different levels and types of hostile action; accordingly, the time available for an Australian response also varies.

Readiness Notice is 'the specified time in which a unit or force element must be capable of being made ready to conduct specified operational roles and tasks'.[14] That is, readiness notice is the time available to bring a unit from its minimum (peacetime) status (usually MLOC) up to the required operational level of capability (OLOC).

Readiness Leadtime is the period of time actually required for a designated unit or force element to reach its operational level of capability.[15] Readiness leadtime should not be longer than the stipulated readiness notice period.

On initially deploying, units cannot expect immediate external logistics support. Accordingly, they must be largely self-sufficient for a period of time while an external logistics train is established to support the deployment. The period of time for which a unit must be capable of conducting operations without external support is the *Operational Viability Period (OVP)*. The OVP is the initial period of sustainability.[17]

The total period of time that a unit must be able to maintain its operational level of capability is the *Period of Contingency (POC)*.[18]

Figure 3-1 illustrates the relationships between the levels of capability and timescales defined above.

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12 *ADF Reserve Stockholding Policy Implementation Guidance*, HQADF Logistics Divison, December 1993, p. 8.

13 ADFP4, Glossary.

14 loc cit.

15 loc cit.

16 OVP is not explicitly defined in the ADFP4 (Glossary); however, its meaning may be deduced from paragraphs 204 and 208. The term is explicitly defined in *ADF Reserve Stockholding Policy Implementation Guidance*, p. 7.

17 ADFP4, paragraph 205.

18 ibid., paragraph 208.

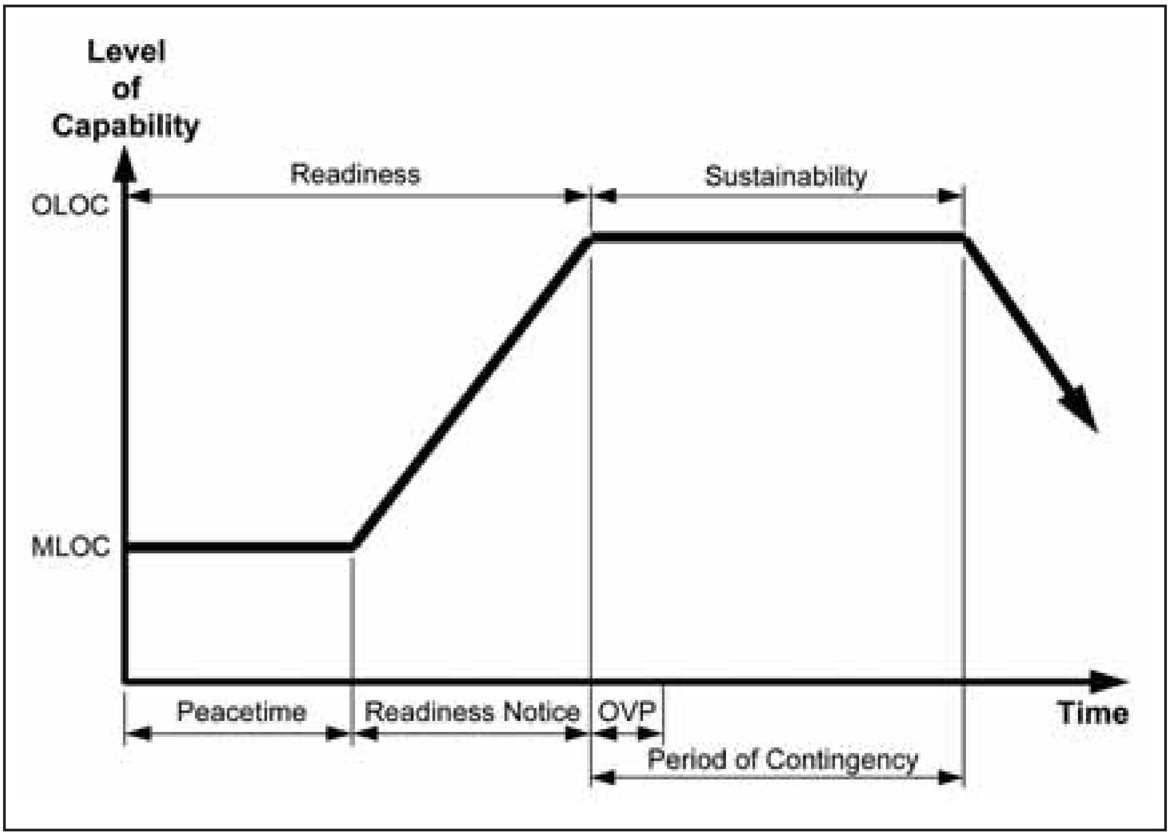

Figure 3-1: Preparedness Concepts

RESOURCES

Within the framework of the timescales described above, and their corresponding levels of capability, resource requirements may be defined. Preparedness resources consist of the equipment, personnel, stocks, facilities, finance, training and maintenance requirements necessary for readiness and sustainability.[20]

Categories of Resource

A unit's resource consumption will vary between the different levels of capability. In addition, transitions from one level of capability to another create different resource demands again. Preparedness doctrine defines four resource categories; the first three correspond to readiness requirements, the last corresponds to sustainability. The categories are:

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19 Based on ADFP4, Annex A to Chapter 1 and Annex A to Chapter 2; and *ADF Reserve Stockholding Policy Implementation Guidance*, Figure 1-1.

20 ADFP4, paragraph 201.

21 ibid., paragraph 204.

a. Minimum Resources: resources required to maintain units or force elements at their minimum level of capability (MLOC).[21]

b. Work-Up Resources: resources necessary for raising the level of capability to a level which would permit deployment on, or commitment to, operations; ie. from minimum level of capability (MLOC) to operational level of capability (OLOC), as would occur during the readiness notice period.[22]

c. Operational Viability Resources (OVR): resources required to enable forces to conduct operations for a specified period after deployment or commitment to operations without external logistic support.[23] OVR will potentially be *consumed during* the Operational Viability Period (OVP).[24] Although operational viability resources would be consumed during the sustainment of operations (ie. sustainability), they must be *available prior* to deployment (ie. as part of readiness).[25] Therefore, for a unit to be considered able to meet its readiness requirements, it must be able to reach the required operational level of capability within the required readiness notice period, and then be able to continue that level of capability for the duration of the OVP without relying upon external support. A typical example of OVR in the RAAF is the Fly-Away Kit (FAK).[26]

d. Sustainability Resources (SR): resources required to support forces after the consumption of OVR.[27]

Activity Levels and Usage Rates

Activity levels are the tempo and intensity at which operations will take place. From given activity levels, corresponding rates of consumption of resources—*usage rates*—may be inferred.[28] Each of the different categories of resource (defined above) will generally have different activity levels, and hence usage rates, associated with it. These may be deduced from the appropriate readiness and sustainability requirements (levels of capability and timescales). Figure 3-2 illustrates this relationship.

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22 loc cit.

23 ibid., Glossary.

24 *ADF Reserve Stockholding Policy Implementation Guidance* indicates that OVR will not necessarily be consumed during the initial period of the contingency. In fact, this document shows the consumption of OVR at the end of the contingency; in this situation, OVR acts as a buffer for the duration of the contingency.

25 This distinction between demand and usage is expanded in *ADF Reserve Stockholding Policy Implementation Guidance*, p. 25.

26 In practice, not all deployment sites can accommodate the full OVR requirement for all resources, so some resupply of certain commodities will be necessary during the OVP. However, the need for such resupply must be minimised.

27 ADFP4, Glossary.

28 ibid., paragraph 217.

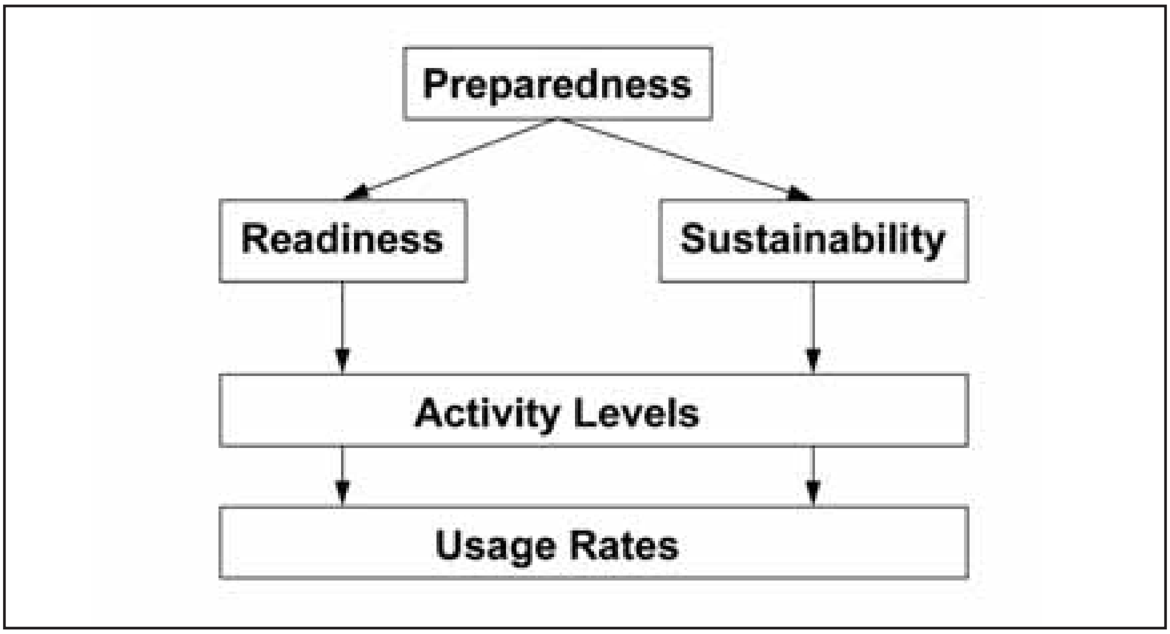

Figure 3-2: Resource Determination

In practice, the only level of capability for which activity levels are easy to predict is MLOC, ie. the normal peacetime operations. For the RAAF, peacetime activity levels are generally specified in terms of aircraft Rates of Effort (ROE): the number of flying hours to be flown in a certain period of time.[29] Due to the variability of contingency operations, and the infrequency of contingencies, activity levels for higher levels of capability are more difficult to estimate. Historical data, objective assessment and professional judgement are required to attempt to derive such data.[30]

Consequently, the determination of usage rates is similarly problematic. Usage rates for peacetime operations are easier to estimate due to the historical data available.

In a resource-constrained environment, it is necessary to set priorities for resource allocation. Strategic guidance places priority on the performance of peacetime tasks and preparation for contingencies credible in the shorter term. Accordingly, the determination of activity levels and usage rates for these activities, and the provision of the resources deemed necessary, have the highest priority.[31]

29 Peacetime ROE requirements are revised annually and promulgated in ACD 171.

30 ADFP4, loc cit.

31 ADFP4, paragraph 218.

SHORT-WARNING CONFLICT

Recent study on the nature of short-warning conflict allows further refinement to be made to the preparedness model. Of course, these refinements only apply to preparedness for short-warning conflict, and not to any other ADF functions for which preparedness goals may be set (eg. peacetime operational tasks).

Within the period of contingency, there is expected to be only a relatively short duration of actual combat. The remainder of the period of contingency is considered to be *sustainment*.

A modified version of Figure 3-1 that represents these short-warning conflict expectations is at Figure 3-3.

Work-Up Training

For the RAAF, activity levels during the period of work-up are based on aircrew training needs, which may be accurately forecast.

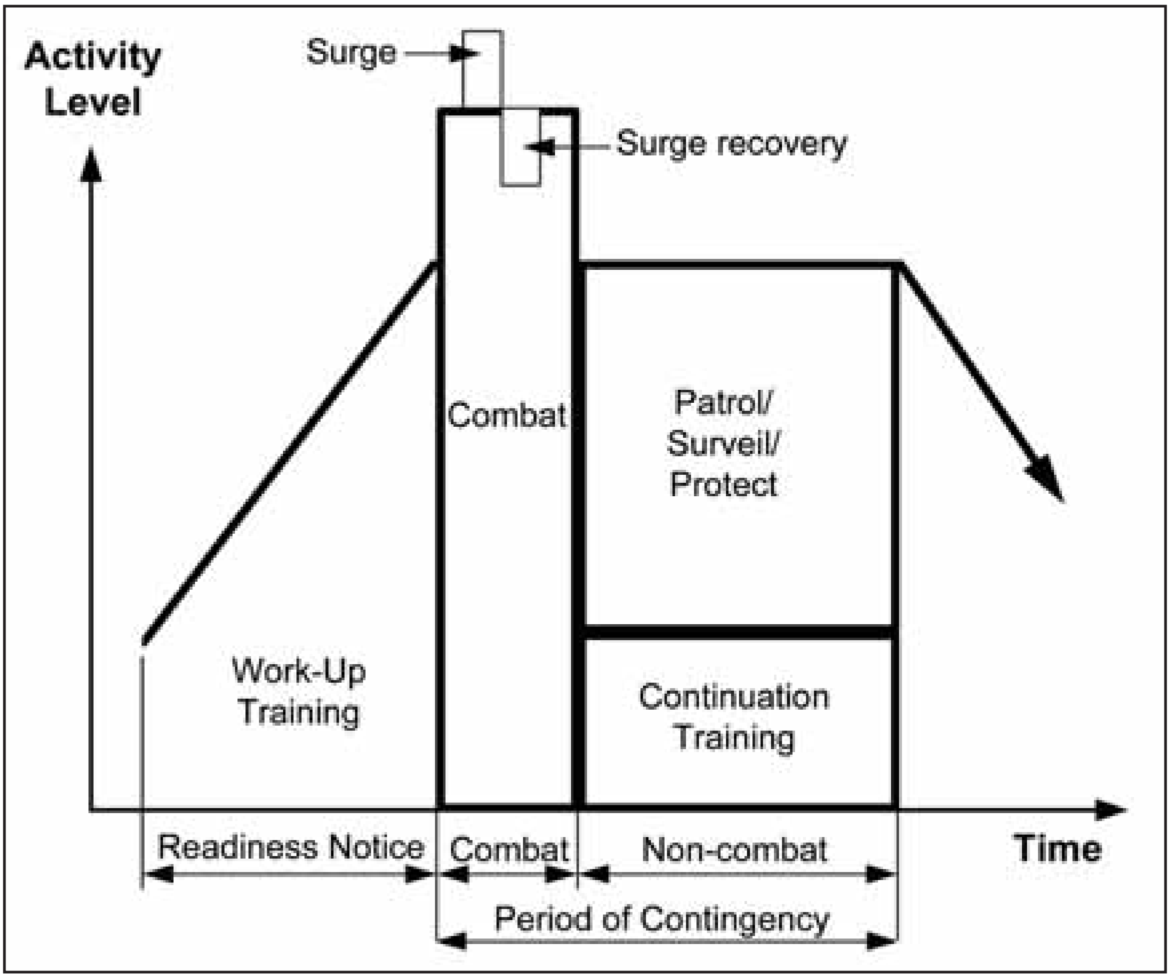

Figure 3-3: Short-Warning Conflict Preparedness Concepts

Combat

Short periods of combat may be required at any time during the contingency. For planning purposes, the most demanding assumption is made that there will be only one combat period, which will occur at the start of the period of contingency (as shown at Figure 3-3). The duration of this period is the sum of all the combat periods that may otherwise be distributed throughout the period of contingency.

During the combat period, aircraft will perform their assigned combat roles. The difficulty in forecasting the nature of combat makes it difficult to accurately estimate the required activity levels (aircraft rates of effort) required during combat; however, they are likely to be higher than non-combat levels.

Even within a combat period, there may be surges of even higher activity levels, sustained for a short period of time. After such surges, the achievable level of capability is expected to drop somewhat, to allow recovery of aircrew and aircraft.

Sustainment

During the sustainment period(s), some level of training will be necessary to maintain aircrew at the required operational level of capability. In addition, patrol, surveillance and protection missions will be flown. Activity levels required for training can be accurately estimated; levels for other sustainment tasks are more difficult to predict.

SUMMARY

Preparedness embraces readiness and sustainability; readiness is the ability to *achieve* a specified level of capability within a nominated period of time; sustainability is the ability to *continue* that level of capability for a nominated period of time.

Because preparedness specifies an interplay between levels of capability and timescale, there are formal definitions for various levels of capability and time periods. Resource requirements will also vary with time; therefore, categories of resource are also formally defined.

The basic preparedness model has been adapted to cover the expected nature of short-warning conflict. This involves dividing the period of contingency into combat and sustainment periods.

Chapter 4 describes the nature of the preparedness goals specified for RAAF force elements.

Chapter 4
Preparedness Objectives

INTRODUCTION

Chapter 2 described strategic guidance, which provides the highest level indications of preparedness requirements. Definitions and terminology associated with preparedness were covered in Chapter 3. This chapter describes documents and projects which mandate or provide clarification on detailed preparedness objectives.

CDF DIRECTIVE ON ADF PREPAREDNESS

The highest level document that specifies preparedness objectives in the ADF is the CDF Directive on ADF Preparedness (or 'CDF Preparedness Directive' – CPD).[1] This document is prepared by HQADF Operations Division, Joint Plans Staff, with input from the individual services. Air Force Office and Air Headquarters Australia (AHQ) are able to suggest changes or additions to the RAAF content of the CPD. Thus, the content of the CPD is refined iteratively; a revised edition is issued annually.[2]

Contents

The bulk of the CPD comprises a number of annexes; one for each Service, with some additional annexes for certain other organisations. Within each annex, the preparedness requirements for each of that Service's force elements are listed.[3] In the RAAF case, this covers most of the aircraft in the RAAF's order of battle, as well as a number of significant items of ground equipment, and certain command and control organisations.

Each individual preparedness objective is referred to as a 'serial'. Some force elements have multiple serials applicable to them, to cover different roles or levels of capability that may be required, or different readiness notice requirements, arising from the need to cover the various roles of the RAAF.

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1 *CDF Directive on ADF Preparedness 1993*, Canberra, 1993.

2 Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994, p. 6-7.

3 A force element is a unit or association of units having common prime objectives and activities—*CDF Directive on ADF Preparedness 1993*, Glossary. RAAF force elements within Air Command are organised into Force Element Groups, comprising Tactical Fighter, Strategic Reconnaissance, Maritime Patrol, Air Lift, and Operational Support.

The CPD has an overall security classification of secret. The security classification of each individual serial is indicated in the CPD annexes.

Each serial contains the following information:

a. The force element is identified, in terms of force element group, and the type and quantity of weapon system (or equivalent) that must be available for this serial. The number of platforms stipulated should be available and mission-capable at *any* time during the contingency—this will generally require the deployment or unit to have a greater number of aircraft at its disposal, to allow for downtime.[4] This requirement is one measure of the required Operational Level of Capability (OLOC).

b. Roles or tasks expected are listed using abbreviations for general roles, or by listing the name of the relevant contingency plan where one exists.[5] Many CPD serials have amplifying comments which clarify the nature of the intended capability. This is another facet of OLOC.

c. The readiness notice ('notice') requirement is stated as a specified number of days. Because warning times vary with different levels and types of hostility, and because force elements would be mobilised at different times in an Australian response to a particular contingency, readiness notice requirements vary between serials.

d. Other timescales are given under the heading of 'Resources'. The Operational Viability Period (OVP) is given, and the total duration for which the specified roles or tasks must be maintained is listed under 'sustainability'. This latter figure is effectively the Period of Contingency (POC).[6]

An example of a hypothetical RAAF CPD serial is at Figure 4-1.

4 Downtime is discussed in Chapter 11, p. 96.

5 Contingency plans are discussed in Chapter 2.

6 These terms are defined in Chapter 3.

SERIAL NO	SECURITY CLASS	FEG (1)	FE (2)	NOTICE	ROLES/ TASKS	PREPAREDNESS RESOURCES	FMC (3)	FMC MLOC (4)
C 38	UNCLAS	SRG (5)	3 RF111 (6)	17 Days	STRATINT	Operational Viability 30 Days Sustainability 180 Days	4	3

Notes

1 Force Element Group

2 Force Element

3 Number of Fully Mission Capable Crews needed

4 Minimum number of fully mission capable crews from which FMC can be obtained within notice

5 Strike Reconnaissance Group

6 Weapon system (General Dynamics F-111 modified for reconnaissance)

7 Strategic intelligence

Figure 4-1: Example of CPD Serial (RAAF)[7]

Scope and Omissions

Strategic guidance states that preparedness considerations should be primarily determined by requirements for short-warning conflict. Accordingly, the CPD includes serials for short-warning conflict scenarios. It also covers some requirements for peacetime operational tasks. However, no serials are dedicated to major conflict or to multinational security operations.

Given the significant warning time available before Australia could be involved in major conflict, the need for preparedness objectives for major conflict is not a high priority. The force development process is more concerned with the longer term considerations applicable to major conflict.[8,9]

Multinational security (eg. peacekeeping) tasks are not to be a determinant of ADF preparedness or force structure.[10] Such tasks can be met by units structured and prepared to meet short-warning conflict requirements. Preparedness 'requirements' for multinational security operations must therefore be no more demanding in capability or timescale than objectives for short-warning conflict; the inclusion of CPD serials to address multinational

7 This Figure is based on *ADF Reserve Stockholding Policy Implementation Guidance*, HQADF Logistics Division, December 1993, Figure 1-2.

8 DI(G) ADMIN 05-1, *The Force Development Process*, 23 December 1991.

9 ROR 71/1988, *Review of ADF Operational Readiness – Final Report Chapter on Terms and Concepts*, DGROR, 8 September 1988.

10 See Chapter 2.

security operations would therefore not alter the overall requirements currently laid down. However, planning for multinational operations could be assisted by such inclusion.

The 1994 issue of the CPD indicates concurrency requirements; ie. which CPD serials represent the most demanding requirements for each aircraft fleet. If the flagged serial can be met, other likely combinations of serials can also be met, as they will be less onerous (even in combination). Thus, more detailed planning should normally be based on the requirement to meet the flagged concurrency serial.

The minimum level of capability (MLOC) is not specified in the CPD.[11] MLOC should be derived by working backwards from OLOC by the duration of the readiness notice, taking into account the rate of work-up (ie. how quickly the unit could increase its level of capability). Shorter readiness notice periods will require MLOC to be near to OLOC, since there will be little time for work-up. Also, units which can rapidly increase their capability may have a lower MLOC than those which are slower to work up. Thus, the ADF's peacetime capabilities should be derived from contingency requirements.

The CPD does not stipulate the activity levels that must be sustained, although the OLOC criteria include descriptive information on the role required or the relevant contingency plan. It remains for the individual defence services to 'flesh out' the requirements of the CPD to determine activity levels, and hence usage rates. Where a contingency plan exists, it will provide a good indication of the activity levels that would be required; in other cases, requirements must be deduced from more general considerations (such as the ADF Concept of Operations).

Geographical information (eg. the expected area of operations) is not given in the CPD for individual serials. Similarly to activity level considerations, geographical requirements may be derived from contingency plans (when relevant), or more general documents in other cases. Often, strategic guidance provides the required information. Future editions of the CPD will include a section covering key judgements on the military capabilities which may be brought to bear against Australia, including some additional geographical information.

Preparedness Reports

Joint Commanders are required to submit Biannual Preparedness Reports (BPRs) to CDF, covering currently outstanding deficiencies and forecast deficiencies in meeting CPD requirements. The sustainability part of the BPR requires only subjective assessment at this stage, pending the development of further guidance in areas such as stockholding, sustainability and concurrency.

In addition to the regular reporting cycle, force elements with a readiness notice of 28 days or less are required to immediately report on any inability to meet preparedness objectives.[12]

11 An exception is the FMC MLOC figure, which is effectively the MLOC requirements for the number of trained aircrews.

12 *CDF Directive on ADF Preparedness 1993*, pp. 10–11, and Annex E.

AIR COMMAND PREPAREDNESS PROJECT (ACPP)

The preparedness objectives given in the CPD are not specific enough to allow resource requirements (or maintenance requirements) to be determined directly. Detailed activity level information is required to enable planning for the logistics aspects of preparedness, and it is the responsibility of the individual Service Offices and Joint Commanders to translate the CPD requirements into more detailed activity level guidance. Such guidance should contain:

a. more detailed descriptions of roles and tasks to be met;

b. the tempo, intensity and duration of each task;

c. the conditions under which operations will be conducted; and

d. the level of performance required.

Of most importance for logistics determinations are *quantitative* measures of activity levels, such as overall flying hours, numbers of sorties in particular roles, sortie duration, etc.[13]

The Air Command Preparedness Project (ACPP) fulfils this role for the RAAF.[14] The project is broken into two phases, which loosely align with readiness and sustainability.

ACPP Phase One

The objective of Phase One of the ACPP was to develop operational level objectives from the CPD serials. Each serial was analysed by the relevant FEG under the guidance of AHQ, and assumptions and data such as activity levels were agreed. The analysis concentrated mainly on readiness aspects (rather than sustainability), as that was the focus of the CPD at that time. Only parent equipment items (such as aircraft) and operational consumables (such as weapons) were considered.[15]

Air Command Operational Preparedness Directives

In June 1992, Air Command issued a series of Operational Preparedness Directives (OPDs) to FEG commanders. These are the culmination of Phase One of the ACPP. These directives provide detailed planning assumptions and readiness objectives for each CPD serial.

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13 *ADF Reserve Stockholding Policy Implementation Guidance*, p. 11.

14 The ACPP was initiated several years before the requirement for such additional information was promulgated by HQADF. Its creation was directed by the then Air Commander in 1990, to 'provide some operational level direction for force element group preparedness in the short term, and influence longer term ADF preparedness outcomes from an informed position'. (Maclean, *Preparedness and Repairable Item Management*, p. 7-2). At the time ACPP Phase One was commenced, the CPD was known as *CDF's Operational Readiness Directive*, or *CORD*.

15 Maclean, *Preparedness and Repairable Item Management*, loc cit.

FEG Commanders are required to monitor and advise on the validity of the directives, and to report on any inability to meet any of the objectives. In addition, FEGs are required to determine the amount of equipment necessary to allow them to meet operational viability requirements.[16]

For each CPD serial, OPDs specify the following additional requirements and guidelines:

a. number of aircraft to be deployed (as opposed to number of aircraft to be available, given in the CPD);

b sortie duration;

c. number of sorties to be flown per day (which may be variable or cyclic);

d. aircraft systems required to be serviceable; and

e. working hour shift arrangements applicable to contingency operations.

OPDs are currently being amended to include additional information relevant to short-warning conflict preparedness. Activity levels (aircraft rates of effort) corresponding to the combat and non-combat periods will be stated. However, no indication of possible surge levels will be given, and any drop in activity level necessitated by surge recovery will be considered to be a transient, and therefore may be neglected.

ACPP Phase Two

OPDs do not provide detailed resource requirements, but do give information from which such requirements may be derived. ACPP Phase Two was intended to provide the 'quantification of the non-manpower resource implications of preparedness and planning and provisioning of such resources'.[17] In June 1992, HQLC accepted responsibility for this task, although the scope of the task was rapidly narrowed to cover 'the reserve stock requirements for all operational consumables and for a selected range of repairable items (RIs) and Break Down Spares'.[18]

Work on this task is ongoing, however it is no longer clearly associated with the ACPP (although the OPDs still form an important source of data). The scope of the task has been further narrowed to consider the sustainability made possible by the ten most problematic RIs (during peacetime). This subtle change means that, instead of calculating spares requirements to *meet* sustainability targets, the sustainability *achievable* with given spares holding levels is assessed.[19] To fulfil the ultimate need to ensure that preparedness requirements can be met, the model would need to be run repeatedly, adjusting the input

16 Operational viability is discussed in Chapter 3.

17 Maclean, *Preparedness and Repairable Item Management*, p. 7-4.

18 loc cit.

19 Group Captain G. Chandler (Ret'd), *Sustainability Model for Repairables*, DLPM-LC, 19 October 1994.

stockholding levels as required until the sustainability estimate meets or exceeds the CPD requirement. This would need to be done for *all* components that may limit achievement of sustainability goals.

The assumption that those components which cause peacetime problems will be the critical components during a contingency is of some concern. There is much evidence (and policy) to suggest that components that do not cause problems during peacetime can become 'showstoppers' during a contingency as a result of environmental or usage-related variations.[20] The need for such a simplifying assumption arises from a lack of contingency-related data, and from isolating the spares determination process from the technical considerations of reliability and maintenance requirements determination.

Software (*SUSMOD*, a stand-alone spreadsheet model) has been distributed to all logistics management squadrons (LMSQNs) for their use. This approach should serve to validate the model and provide approximations to the current level of RAAF sustainability. However, to achieve the full scope required for this task, such software should ultimately be integrated with existing databases to facilitate more thorough and automatic determination of all component stockholding levels.

No work associated with the ACPP considers the requirements for contingency maintenance,[21] or the benefits and impact that maintenance may have on availability and sustainability.[22] A macro level maintenance goal may be obtained by comparing the CPD-specified number of *available* aircraft with the OPD-specified number of *deployed* aircraft. This yields an aircraft availability target, which may be expressed as a percentage of the deployed (or entire) fleet size.

SUMMARY

There are two main sources of preparedness objectives. The higher level document is the CPD, which stipulates multiple objectives (serials) for each operational weapon system. PD serials specify the number of aircraft required to be available at OLOC, the nature of the required task, readiness notice, operational viability requirement and period of contingency. CPD serials cover expected requirements for short-warning conflict and some peacetime operational tasks, but not major conflict or multinational security operations.

The Air Command Preparedness Project expands on the requirements of the CPD. Operational Preparedness Directives specify additional information for each CPD serial,

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20 *ADF Reserve Stockholding Policy Implementation Guidance*, p. 41; Marygail K. Brauner, Daniel A. Relles, and Lionel A. Galway, 'Improving Naval Aviation Depot Responsiveness', RAND, Santa Monica, 1992, p. v.

21 *Contingency Maintenance* comprises modified maintenance procedures and schedules adapted to suit contingency needs.

22 The only maintenance expedient modelled in the HQLC sustainability software is cannibalisation.

including expected sortie durations and rates, numbers of aircraft on deployment, critical aircraft systems, etc.

Subsequent work on the sustainability implications of the OPDs is continuing in HQLC. A basic software model has been developed to allow current levels of sustainability to be approximated.

Little of this work considers the need for, or implications of, contingency maintenance, although aircraft availability requirements can be derived from CPD and OPD data.

Part 2

Maintenance

Chapter 5
Maintenance in Context

INTRODUCTION

The maintenance function relates closely to several other functions. The nature of these other functions, and the nature of the interfaces between them, are important as they provide the context within which maintenance exists. Failure to recognise the interdependencies between the functions can lead to suboptimisation.[1]

This chapter defines maintenance and the functions of which it is part or to which it relates, and briefly describes the relationships between the functions.

MAINTENANCE AND RELATED FUNCTIONS

Maintenance

The maintenance of technical equipment embraces all action taken to retain equipment in a serviceable condition or to restore it to serviceability.[2] It includes inspection, testing, servicing, classification as to serviceability, repair, rebuilding, reclamation, and modification incorporation (or removal). In a wider sense, any such actions implementing configuration management or engineering standards requirements is also considered maintenance.[3]

Maintenance can be thought of as virtually anything done to an item to keep, or make, it serviceable; or to improve its usefulness. This includes software rectification and configuration changes. Replenishments, such as the provision of fuel, lubricants, coolants, ammunition and weapons, are not explicitly covered by the formal definition unless they are considered to be servicings (or parts thereof). This is often the case in practice, and since replenishments are

1 'Suboptimisation' is a TQM or RAAFQ term, which properly means that one part of a system is optimising its own performance to the detriment of some other part of the system, and to the detriment of the performance of the system as a whole. It does *not* merely mean 'less than optimum' (although this is the ultimate effect). The important distinction is that one part of a system can improve, even optimise, its internal performance while degrading the performance of the system of which it is a part.

2 Equipment is said to be serviceable if it is fit for its intended use. JSP(AS) 101, *Australian Joint Services Glossary Part 1*, Edition 3, 1984.

3 This extended definition is a combination of definitions given in JSP(AS) 101, and DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, p. 1. Another definition may be found in DI(AF) AAP 7001.042-1, *RAAF Maintenance System for Technical Equipment*, 1984, p. 2. This definition also includes the determination of resources (including spares) as a facet of maintenance. Other definitions, and that preferred here, exclude resource determination.

often either to retain serviceability (eg. lubricants) or change configuration (eg. armaments), it is generally prudent to consider replenishments to be within the scope of maintenance.[4] Maintenance will be broken into three main areas for consideration in later chapters:

a. scheduled maintenance (eg. servicings);

b. unscheduled maintenance (ie. repair); and

c. modification.

Engineering

A (military) definition of engineering is 'the practical application of science to create a weapon or role-functional system that satisfies an operational or other need, and the possible enhancement of that system throughout its service life. Further, engineering is an essential ingredient in the preservation of the asset.'[5]

'Preservation of the asset' will generally require the performance of servicings or repairs at some stage. These tasks are forms of maintenance, so the definition of engineering can be seen to encompass all aspects of maintenance. In addition, engineering covers the initial design and production of equipment; maintenance is generally concerned only with in-service equipment (although modification activity may occur during the design and production phases). Engineering is generally considered to be a more cognitive domain, whereas maintenance is more 'hands-on'. Maintenance can be considered to be the executive arm of in-service engineering.

Supply

Supply is the process of provisioning, storage, distribution and transportation of material.[6] Of particular relevance is the term *provisioning*: the determination and procurement of future requirements of stores and equipment, including assessment and requirement computation.[7]

Logistics

Historically, the RAAF has maintained clear distinctions between the technical (or engineering) function and the supply function. While there were documented interfaces between the two regimes, often there was no collocation and less than desirable communication. This lead to suboptimisation of the support system as a whole, as the subsystems within it operated more independently than was desirable. To move away from this situation, the RAAF has adopted a logistics-oriented approach. Logistics is defined as

4 The issue of replenishments is touched on in DI(AF) AAP 7038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, p. 2-3. The final outcome is inconclusive.

5 DI(AF) ENG 0-1, *Glossary of Engineering Instruction Terminology*, 20 December 1993.

6 JSP(AS) 101.

7 loc cit.

the science of planning and carrying out the movement and maintenance of forces. In its most comprehensive sense, it includes:

a. design, development and maintenance of materiel;

b. acquisition, storage, movement, distribution, evacuation and disposition of materiel;

c. movement, evacuation and hospitalisation of personnel; and

d. acquisition or furnishing of services.[8]

The RAAF usage of the term 'logistics' emphasises the first two components, which equate to the engineering and supply functions.

More colloquially, logistics has been said to be 'getting the right part in the right place at the right time'.[9] This definition may appear to emphasise supply distribution aspects, but it must be borne in mind that the 'right part' that must ultimately be delivered into the hands of the operators must be a serviceable, reliable and correctly configured part.

Integrated Logistics Support

Integrated Logistics Support (ILS) is the practice of considering all aspects of logistics support (as well as performance and cost criteria) in concert for a weapon system throughout its complete life cycle.[10] ILS thus emphasises the relationships between the various facets of logistics, and encourages an iterative approach to management with the aim of achieving weapon system preparedness requirements at minimum life cycle cost.[11]

ILS provides a detailed breakdown of the facets of logistics. The elements of ILS are:

a. management;

b. engineering support (the process of ensuring design integrity);

c. maintenance support (considerations necessary to ensure an optimally supportable weapon system with a defined maintenance support structure);

d. supply support;

e. technical data;

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8 loc cit.

9 Quotation from Air Commodore E. McL. Weller, Commander Logistics Support Agency, Logistics Command.

10 A weapon system's *life cycle* consists of four phases: concept, acquisition, inservice, and disposal. DI(AF) LOG 5-1, *Application of Integrated Logistics Support in the RAAF*, 1991, p. 1.

11 *Life Cycle Cost (LCC)* is the total cost (both direct and indirect) to the RAAF of a weapon system over its entire life cycle, ibid.

f. support equipment;

g. packaging, handling, storage and transportation;

h. manpower and personnel;

i. training and training support; and

j. facilities.[12]

INTERFACES

Figure 5-1 illustrates the relationship between the major domains defined above, plus operations.

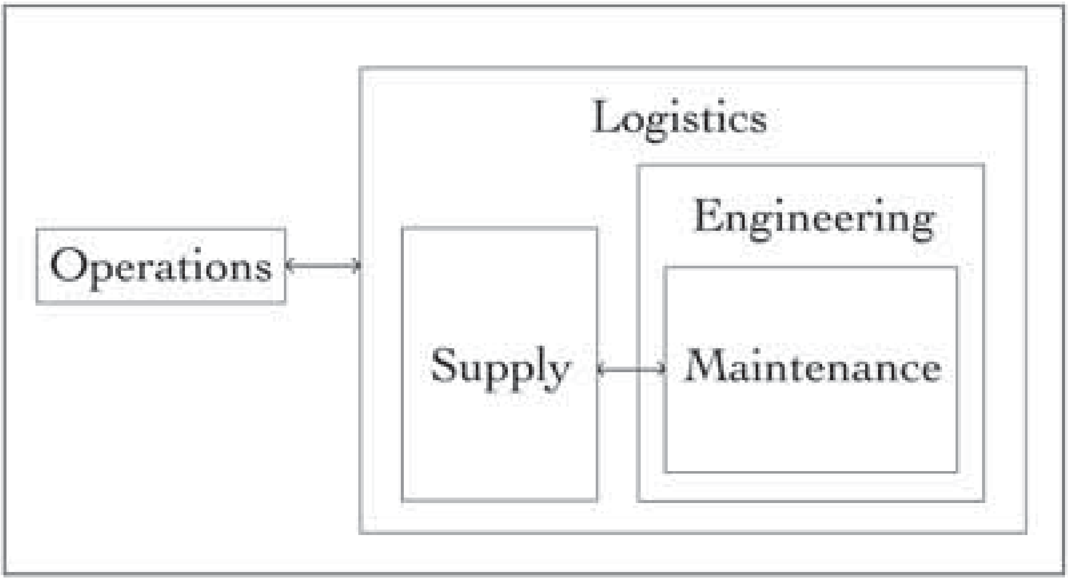

Figure 5-1: Maintenance in Context

Operations-Logistics

The operations-logistics interface provides many of the goals for the maintenance function. These include availability targets, and missionworthiness criteria.[13] Information about logistics capabilities and constraints, such as inabilities to meet operational goals (or the cost of doing so), flows from logistics to operations. This information may cause operational goals to be re-evaluated, forming a feedback loop.

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12 DI(AF) LOG 5-1, Annex A.

13 Operational staff are certainly concerned about airworthiness; however, detailed airworthiness standards (goals) are usually originated within the engineering function.

The importance of this link argues for a close organisational relationship between operations and logistics planning staff. This is discussed further in Chapter 21.

Maintenance-Supply

Maintenance and supply are very closely related (hence the benefits expected of a more integrated approach), so the maintenance-supply interface carries much information. Resupply (eg. procurement) costs influence whether a component should be maintained or discarded on failure. Maintenance policies determine the reliability that may be expected of maintained components, and hence the rate of demand for replacements. Maintenance activity also consumes spare parts, so the frequency of maintenance affects the demand for such spares. The performance of the supply system directly affects maintenance efficiency; eg. spares unavailability can result in servicings being extended, items being cannibalised,[14] etc.

Maintenance is often considered to be but one small part of a larger supply, or Repairable Item (RI), pipeline—and so it is, for equipment that is removed from the aircraft for maintenance. Then considering the turnaround times achievable from a pipeline, maintenance must indeed be considered in this context. However, the very *need* for such pipelines originates from the need to perform maintenance.[15] The extent of the maintenance requirement is a major determinant of the required *capacity* of repair pipelines (and of supply pipelines for items and products consumed in the maintenance process).[16] Many studies have been conducted on the RI pipeline system to improve its efficiency. These studies generally do not question the maintenance requirement, but attempt to optimise other variables. However, a very direct means of reducing the overhead associated with RI pipelines is to optimise the maintenance requirement.

SUMMARY

Maintenance encompasses virtually anything done to an item to keep (or make) it serviceable, or to improve its usefulness. It therefore includes servicing, repair and modification. The maintenance function is the executive arm of in-service engineering.

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14 In maintenance parlance, *cannibalisation* is the practice of removing a serviceable component from one aircraft to install it on another. This can allow at least one of the aircraft to be made serviceable. However, the practice results in additional maintenance effort required to remove and refit the component from the cannibalised aircraft. Thus, although cannibalisation can enhance availability in the short term, it is a source of inefficiency which could adversely affect availability in the longer term if not closely controlled. See also p. 87.

15 Maintenance may be preventive (to avoid a failure) or corrective (to repair after failure)—see next chapter.

16 There are many other influences here; eg. transportation times, the need for surplus stocks because of the spasmodic nature of arisings, the need for reserve stocks to cover contingency requirements, etc. See Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994.

Maintenance (and engineering) are facets of logistics, as is supply. Integrated Logistics Support (ILS) groups all of these functions (and more), and provides a link with operational (preparedness) requirements.

The next few chapters describe the main maintenance processes in more detail: Chapters 6 and 7 cover scheduled maintenance; Chapter 8 covers unscheduled maintenance; and Chapter 9 covers modification.

Chapter 6
Maintenance Concepts

INTRODUCTION

The determination of maintenance requirements requires the appraisal of many different considerations, which frequently conflict with each other. This chapter explains a number of general terms, concepts and considerations which will be used in subsequent chapters.

FAILURE AND RELIABILITY

Failure and Failure Modes

Equipment failure is a condition which results in a loss of specified performance.[1] By this definition, an item does not have to be totally inoperative to be considered to have failed. If the performance specification of an item requires it to operate with a certain accuracy, the item is considered to have failed if it does not operate within the set accuracy limits. An item may fail from a number of different causes. The most apparent case is where the item fails of its own accord, eg. it wears out or becomes damaged while being used in the normal way. However, failures can be induced by incorrect usage; eg. abnormal operation, foreign object damage, damage caused by maintenance error, secondary damage,[2] or damage arising from some other abnormal environmental cause.[3,4] It is not always appropriate to consider such failures when determining scheduled maintenance requirements, as maintenance processes cannot delay damage caused by incorrect usage. However, these failures can still generate demands for replacement components, and must therefore be taken into account when considering stockholding levels, etc.

Even disregarding failures caused by incorrect usage (etc), a single component can often fail in a number of different ways, or *modes*. For example, a structural component can be deemed unserviceable due to the presence of excessive corrosion or fatigue cracking. A complex assembly can have multiple failure modes corresponding to failures of its various subcomponents. Even though the symptoms of different failure modes may be identical, it is still often necessary to distinguish between failure modes as they will usually differ in

1 JSP(AS) 101, *Australian Joint Services Glossary Part 1*, Edition 3, 1984.

2 Secondary damage is damage to a component arising from the failure of a nearby or connected component.

3 HQLC LSAM 4200/8/1/1 (61), *Meantime [sic] Between Failures*, SOLSA-LC, 15 March 1993.

4 W. Carroll Widenhouse, '"MTBF" – What Does This Term Really Mean?', *Air Force Journal of Logistics*, Summer, 1991, pp. 4–10.

their rate of onset (ie. how quickly the failure mode progresses), relative frequency, means of detection or prevention, etc.

Reliability and MTBF

Reliability is the *probability* that an item will perform its *intended function* (ie. not fail) for a *specified period* used under *specified conditions*. For example, a car may have a 70 per cent chance of operating without failure for 10,000 km, when used for normal domestic driving. The same car may have only a 50 per cent chance of operating without failure for 20,000 km under the same conditions, and a 60 per cent chance of operating without failure for 10,000 km if used as a taxi. It is clearly important to specify the period and conditions to which a reliability figure applies; often this information is left implicit.

A simplistic measure of reliability is Mean Time Between Failure (MTBF). MTBF is a measure of the average interval of time that an item operates without failure. It may be calculated as:

$$MTBF = \frac{\text{time in service}}{\text{number of failures}}$$

The definition or interpretation of MTBF depends on the definitions used for failure, and even for time.[5] Moreover, MTBF measurements of a component's reliability will differ when the component is subject to maintenance, compared to the value that would be obtained if no maintenance (or different maintenance) were to be performed.[6] The reliability of multi-component systems can be found by combining the reliability figures of its components. There are two basic ways in which two components may be related: series and parallel (see Figure 6-1).

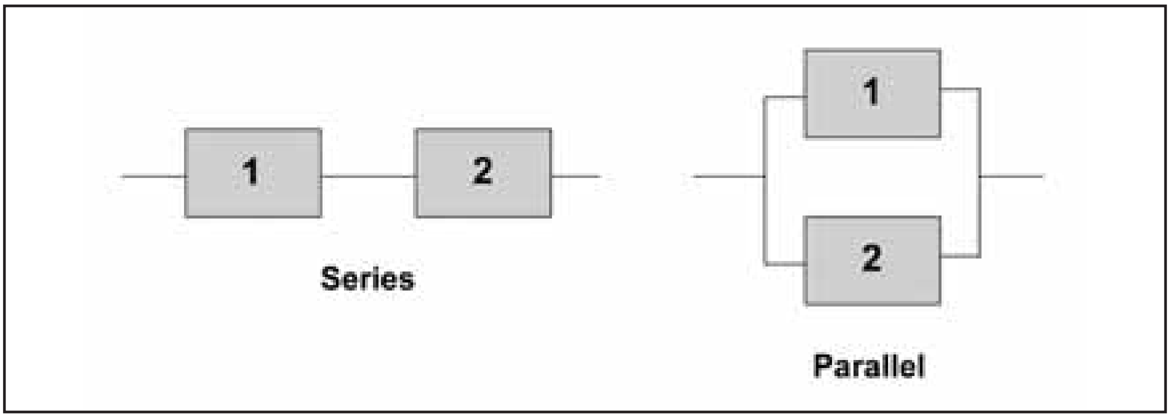

Figure 6-1: Components in Series and Parallel

5 Widenhouse, '"MTBF" – What Does This Term Really Mean?', recommends that MTBF not be used for serious reliability work due to its potential ambiguity. Certainly, the definitions and assumptions relating to any particular use of MTBF should be clearly specified.

6 I. Bazovsky, *Reliability Theory and Practice*, Prentice-Hall, New Jersey, 1961, p. 215. This is an important, but little realised point. It is further discussed (and demonstrated) on p. 301.

In a series arrangement, *both* components must be working for the system to work. In this case:[7]

$$1 - \frac{1}{MTBF_{SYSTEM}} = \left(1 - \frac{1}{MTBF_1}\right) \times \left(1 - \frac{1}{MTBF_2}\right)$$

For example, if one component has a MTBF of 200 hours, and the other has a MTBF of 500 hours, the MTBF of the two components in series will be 143 hours: somewhat less than either of the components individually.[8]

In a parallel arrangement, *either* of the components must be functioning for the system as a whole to work; ie. the system has *redundancy*. In this case:

$$MTBF_{SYSTEM} = MTBF_1 \times MTBF_2$$

If components having MTBFs of 200 and 500 hours (as above) were connected in parallel, the system reliability would be 100,000 hours—a very significant improvement in reliability over either component alone.

The basic equations given above can be easily extended to allow calculation of the reliability of a system containing arbitrarily many components in series or parallel, not just two. Furthermore, most systems contain both series and parallel arrangements of components within them. These can be analysed by first calculating the reliability of a group of components in series or parallel, and then treating that group as if it were a single component having the reliability calculated. This process is repeated until the reliability of the whole system is found.

Using these means, the reliability of complex systems can be calculated from the reliability of the individual components within them; these in turn can be combined to determine the reliability of the aircraft as a whole.

Failure Pattern

An item's *failure pattern* is a description of the distribution of its failures over time. Mechanical components, if unmaintained, generally become less reliable as time progresses, due to the onset of failure modes such as corrosion, cracking, wear, etc. These failure modes

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7 The equations given here only apply if the reliability of each of the components is independent of that of the other components. Typically, this means that the components should have no failure modes in common, such as both failing as a result of an overstress. In practice, this assumption often does not hold.

8 Increasing complexity of aircraft systems usually results in more components needing to be serviceable at the same time for the system as a whole to work; ie. a series arrangement. As this example shows, system reliability will diminish in this situation—unless other strategies are used to combat the tendancy, such as redundancy or the use of higher reliability components. Complexity is further discussed in Chapter 18.

take some time to develop into serious problems. Accordingly, components subject to *wear-out* failure modes will become less reliable as time progresses.

Often, wear-out failure modes will not result in failures at all for a certain period of time. For example, in a fairly stable environment, the corrosion process will proceed at a slow rate, and cannot reduce metal thicknesses to unacceptable levels within a certain period of time. During this initial period, no failures can occur. This is not to say that no damage is being done, or that no maintenance tasks could be effective in delaying the corrosion damage during this period.

Figure 6-2 graphs the probability of an item failing against time, assuming a wear-out failure pattern with an initial 'growth' period.[9]

Many components, however, are not subject to failure modes that exhibit wear-out. Components with no moving parts, such as electrical and electronic components, do not wear out *per se*; rather, the probability of an item failing remains constant over time. An example is a light bulb, which is as likely to fail one hour into its life as it is after 1000 hours (assuming that it didn't fail earlier). Figure 6-3 illustrates such a *random* failure pattern.

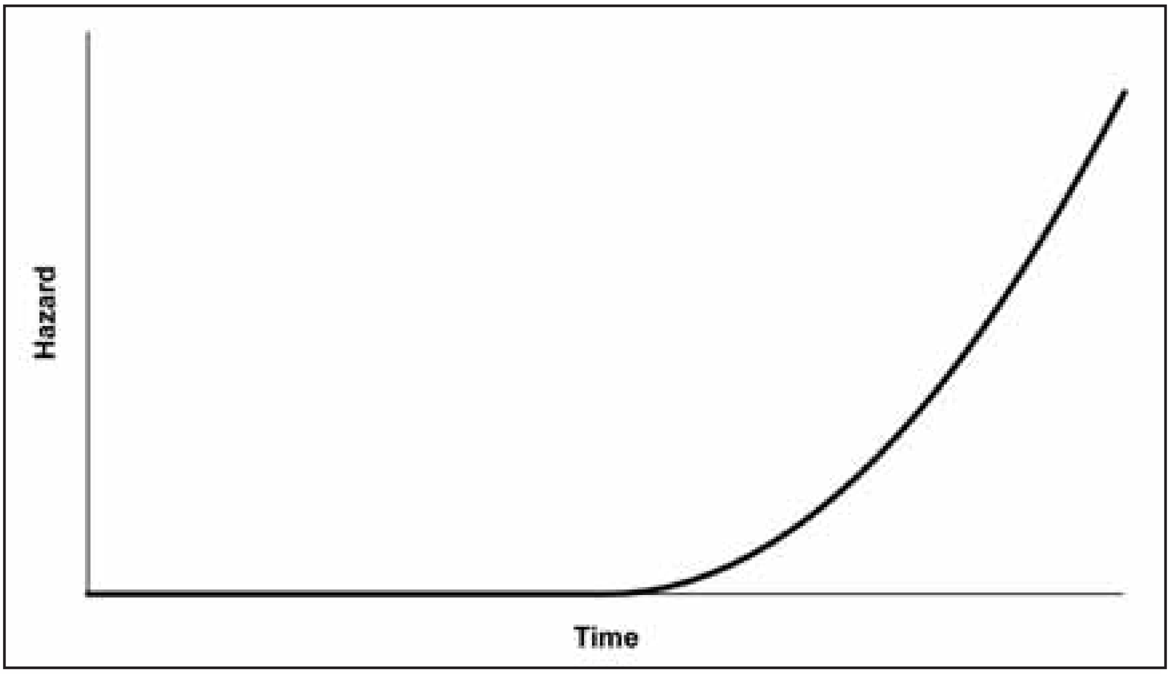

Figure 6-2: Wear-out Failure Pattern

9 Figure 6-2 actually graphs the *hazard function*. Annex A explains the proper meaning of hazard function. It is used here as it is the most intuitive representation of reliability trends.

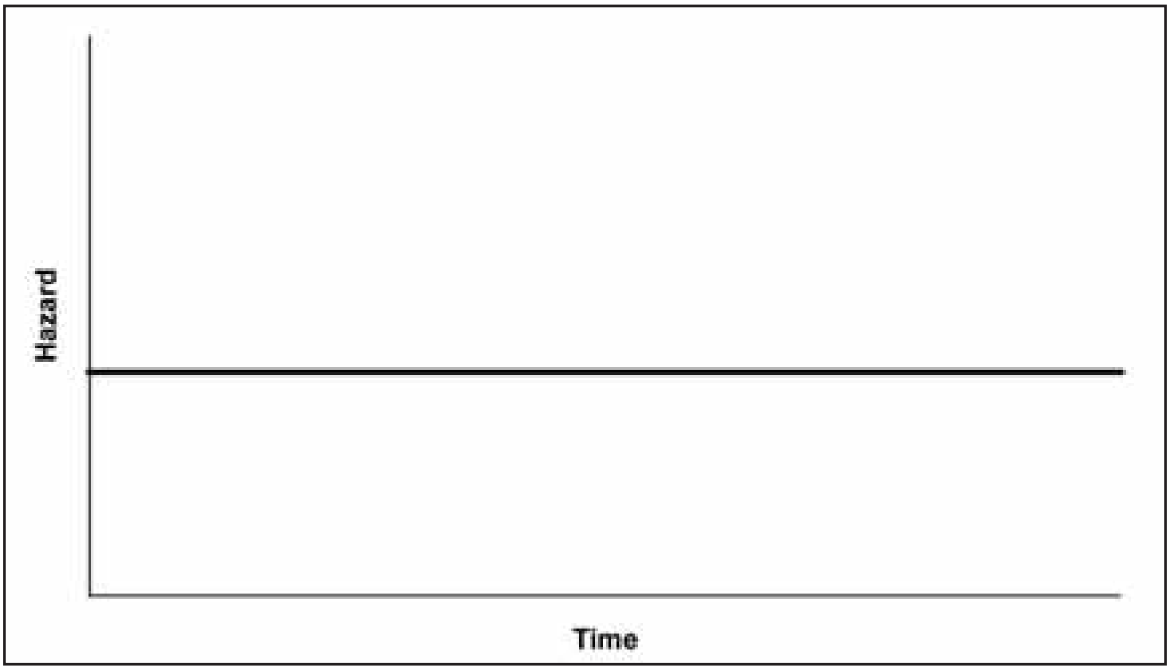

Figure 6-3: Random Failure Pattern

A third type of failure pattern is *wear-in*. Components subject to wear-in failure modes become *more* reliable as they age. Wear-in failure modes are often associated with production or maintenance problems, such that a poor quality item will not survive long in operation. This is called *infant mortality*. Thus, there is a spate of early failures as the lower quality items succumb; once these have all failed, the remainder of the items (those of quality) will survive. Figure 6-4 illustrates a wear-in failure pattern.

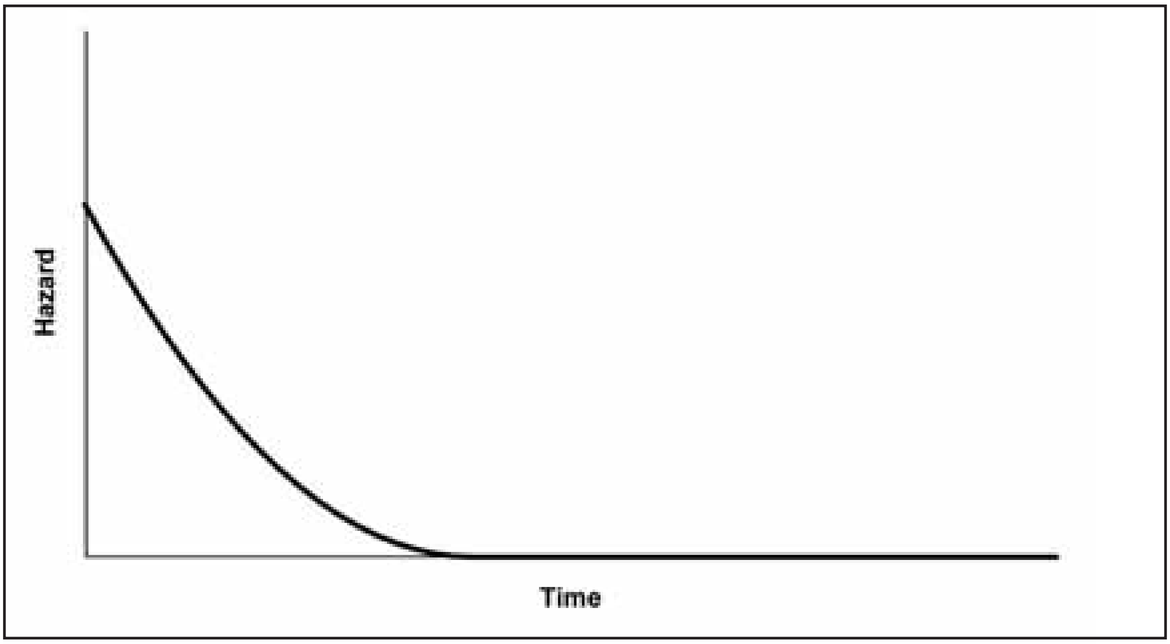

Figure 6-4: Wear-in Failure Pattern

Wear-in failures are, to a point, avoidable. The initial period of unreliability can sometimes be removed by test running components before they are released into service. This process is called *environmental test screening*; 'soak tests', 'burn-in' and 'running in' are examples of this practice. The nature of this testing need not be representative of in-service conditions, but may be whatever is necessary to 'shake out' the poorer items. Improvements in manufacturing and maintenance quality will also reduce the incidence of wear-in problems.

As stated previously, many items are subject to a number of different failure modes. Very rarely do these modes all exhibit the same failure pattern. An item may exhibit wear-in, a period of random failure, and finally wear-out over time. The combination of these failure patterns gives a so-called 'bathtub' curve; see Figure 6-5.

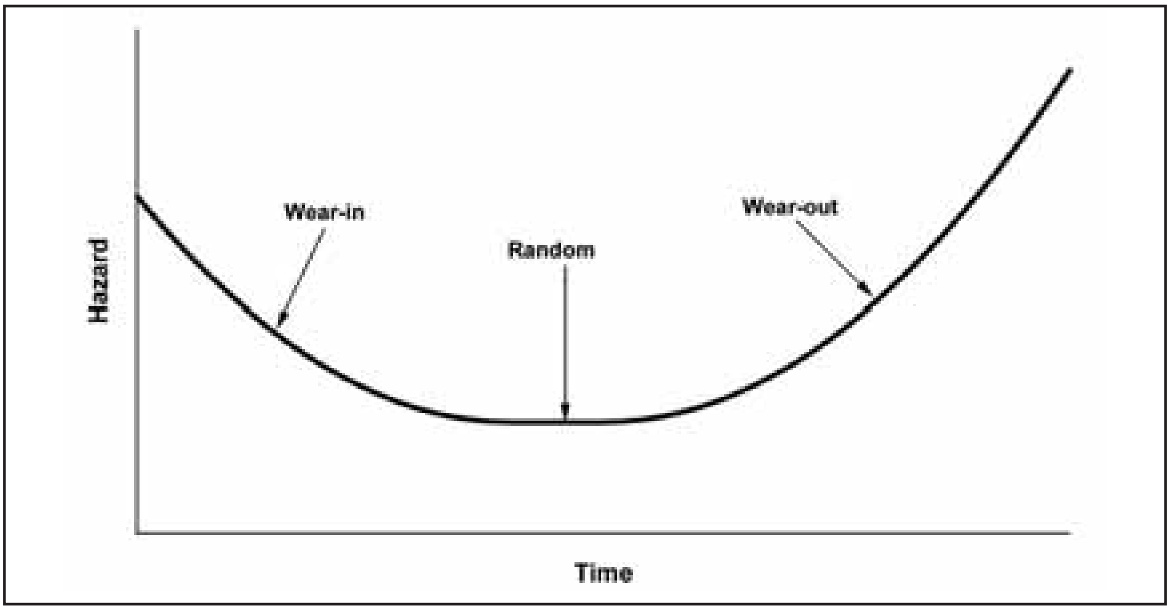

Figure 6-5: Composite Failure Pattern

There can also be variations within failure modes of the same kind; eg. wear-out can advance rapidly or more slowly. The combination of such modes creates additional kinks and bends on the overall hazard function graph.

Statistical methods can be used to determine a mathematical function that approximates a particular failure pattern. This function can then be used in calculations to determine such information as the risk of in-service failure under a given maintenance policy; the optimum interval for scheduled maintenance; etc. Two common mathematical failure distributions are introduced in Annex A.

Criticality

Criticality ratings are assigned to items (and systems) to indicate the significance of failure. The RAAF currently uses a three level criticality rating system:

a. Safety-critical items (or systems) are those that would have a direct and immediate adverse effect on safety if they failed.

b. Mission-critical items (or systems) would either cause a mission to be aborted, or would cause serious degradation in the performance of a primary role, if they failed.

c. Non-critical items are those items which are neither safety-critical nor mission-critical.

The potential for secondary damage must also be taken into account when assessing item criticality. For example, the failure of an item itself may not be very significant; however, if it may cause the failure of other more critical items when it fails, its own effective failure criticality should be upgraded.[10]

Likewise, any item *redundancy* should also affect the criticality rating.[11] The level of redundancy may vary from *full*, where the function can continue with the same capability, through to *survival*, where the function performs with very degraded capability. The *level* of redundancy should also be considered when assessing criticality.[12]

Rather than assigning criticalities to items and systems, there is benefit in assigning criticalities to *failure modes*. Different failure modes may result in different effects on the item or system; one failure mode may have a safety-critical effect, another may only be mission-critical. Maintenance tasks are (or should be) directed to address specific failure modes, rather than everything that can necessarily go wrong with an item. It is beneficial to be able to relate maintenance tasks to the failure modes, and hence the criticality of failure, that they are intended to prevent. In this way, it is possible to think of maintenance tasks having criticality ratings: tasks intended to prevent safety-critical failure modes are safety-critical tasks; tasks intended to prevent mission-critical failure modes are mission-critical tasks; other tasks may be deemed non-critical (or cost-effectiveness-critical).[13]

The criticality of an *item* should be the 'greatest' criticality[14] of the failure modes it exhibits. However, if criticality is considered and applied in terms of failure *mode* criticality, the

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10 The RAAF does not explicitly alter item criticalities based on the secondary damage that may result. However, the potential for secondary damage is considered when determining maintenance requirements.

11 *Redundancy* is the provision of 'parallel or standby items or systems ... to enable a function to continue to be performed after a failure has occurred'. DI(AF) AAP 7001.038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, p. 4-5.

12 The current RAAF system will 'downgrade' a tentatively safety critical item or system down to mission critical if sufficient redundancy is provided. This is a misleading practice, as the item may have nothing to do with mission performance *per se*. This point becomes particularly significant when attempting to relate preparedness objectives (especially those in the Air Command Preparedness Project—see Chapter 4) to RAAF maintenance records.

13 This effectively aligns maintenance *tasks* with maintenance *goals* (introduced on p. 54), and would facilitate the practical implementation of a shift in emphasis between the maintenance goals.

14 Safety-critical is considered greater than mission-critical; mission-critical is greater than non-critical.

need to assign criticality to an item for maintenance requirements determination purposes is much reduced.[15]

The RAAF's entry into Integrated Logistics Support (ILS)[16] will probably change the way in which criticalities are assessed and used. One of the ILS modules that the RAAF has adopted is *Failure Modes, Effects and Criticality Analysis (FMECA)*.[17] The FMECA approach requires that failure modes be methodically identified, their implications assessed (including the effects of possible secondary damage), their frequency of occurrence estimated, and a final criticality rating assigned. The FMECA criticality rating is based on the failure frequency and the seriousness of failure effects (and is often simply defined as the product of the two).

The FMECA criticality rating is not directly comparable with the existing RAAF criticality scheme, as the former takes failure frequency into account. The FMECA *failure effects rating* is more closely aligned to the RAAF concept of criticality; this rates the significance of failure in the range 0 to 5, with 5 representing catastrophic failure.[18]

Life Units

A human's age, or lifetime, is normally measured as the number of years that have elapsed since birth. However, other measures are possible. The 'age' of an individual could be measured in terms of the distance they have walked since birth, or it could be measured from some other starting point, eg. number of years since entering a particular job.

The most useful measure of age for technical equipment is that which gives the best indication of how reliable it will be, or how 'used up' it is. Whereas people generally age in relation to the elapsed time since birth, equipment generally ages in relation to the total time it has spent actually being used. When unused, equipment does not tend to deteriorate at the same rate.[19] This gives rise to measures of life such as 'airframe hours' (the number of hours the airframe has been used for flight), 'engine hours', etc. Guns may deteriorate in proportion

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15 Item criticality would still be of use to other elements of the logistics function. *ADF Reserve Stockholding Policy Implementation Guidance*, HQADF Logistics Division, December 1993, p. 49, identifies the requirement to consider item criticality when attempting to relate CPD requirements to item provisioning priorities. Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994, p. 7-6, arrives at the same conclusion when attempting to determine critical repairable items based on Air Command Preparedness Project guidance. A single database of failure mode criticalities would allow the relevant information to be extracted at failure mode, maintenance task, item, or system level, hence satisfying all requirements.

16 See Chapter 5.

17 FMECA is fully documented in US MIL-STD-1629 and MIL-STD-1629A, *Procedures for Performing a Failure Mode, Effects, and Criticality Analysis*, 24 November 1980.

18 H.M. Williamson, 'Reliability in Design', in RAAF Reliability Management Course Notes, Canberra, 1994, pp. 5–21.

19 Of course, there are exceptions. Corrosion damage tends to accrue at a constant rate, regardless of usage (unless usage occurs in a particularly corrosion-prone environment).

to the number of rounds they have fired, so 'number of rounds fired' should be the life unit in this case.[20]

When used in MTBF, it is most common to use the item's operating hours in the equation, so this becomes the units of MTBF; ie. operating hours per failure.

Some components have their age measured in two (or more) life units simultaneously. For example, an aircraft may be 1000 airframe-hours old, and four elapsed years old. It is desirable to use multiple life units when an item may deteriorate in different ways (eg. fatigue cracking and corrosion), and when the rates of the different forms of degradation are related to different life units. For example, the progress of fatigue cracking is approximately related to airframe usage, and hence airframe hours; the progress of corrosion is more related to elapsed time, whether the aircraft has been flown or not.

Some maintenance actions are considered to return the item to 'as new' condition. Therefore, when such maintenance is performed, the age of the item is set back to zero. In more complex cases, where an item (such as an aircraft) is subject to a number of different servicings, the age since the last servicing *of the same kind* needs to be monitored. So, an aircraft may have flown 100 hours since its last R3 servicing, and 600 hours since its last R4 servicing.[21]

MAINTENANCE

Forms of Maintenance

The RAAF employs three basic forms of maintenance, which are distinguished by the aim of the maintenance; ie. whether it is intended to repair, prevent, or detect failures.

Corrective Maintenance. When an item has failed, corrective maintenance is used to restore the serviceability of the item. Repair work is the most common example of corrective maintenance.

Preventive Maintenance. The aim of preventive maintenance is to do something to the item *before* it fails, with the intention of preventing or delaying it from failing. The application of lubrication is a preventive maintenance task, as it aims to stop the seizure of components such as bearings.[22]

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20 The most complete source of failure data available in the RAAF is the *Maintenance Activity Analysis and Reporting System* computer *(MAARS)*. Unfortunately, MAARS does not record the usage of individual components at all, but only records the usage of the parent equipment (eg. aircraft), in terms of flying hours. Therefore, MAARS MTBF figures are always quoted in terms of (fleet) flying hours. The reliability of many components will not relate to flying hours, so MAARS data must be used with great caution in this regard.

21 This picture can be complicated further when 'hierarchical' servicings are used, in which one servicing resets (sets to zero) the life of other servicings. See p. 69.

22 DI(AF) AAP 7001.038-1, p. 2-1.

Surveillance Maintenance. Surveillance maintenance involves determining the condition of an item, either by examination (passive) or testing (active). If the condition of the item is found to be satisfactory, nothing further is done; if the item's condition is unsatisfactory, other maintenance tasks are performed to restore the item.[23] Surveillance maintenance can be contrasted with the preceding two forms, in that surveillance maintenance on its own does not improve the condition of the item, but merely assesses it. Surveillance maintenance is only of benefit when used in conjunction with preventive or corrective tasks to rectify any unsatisfactory condition detected.

In this context, 'unsatisfactory' does not necessarily mean failed or unserviceable. Some types of failures are preceded by a relatively long period of degradation which may be monitored (ie. a slow *Failure Progression Rate* – FPR). When this degradation reaches an advanced stage, indicating that failure is near, the item should be withdrawn from use and undergo preventive maintenance. The primary example of this approach is *Early Failure Detection* (EFD). A common form of EFD used in the RAAF is the Spectroscopic Oil Analysis Program (SOAP), which attempts to ascertain the health of inservice engines and gearboxes by monitoring the build-up of metallic debris in oil samples regularly taken from the component.[24] When the level of debris gets too high, the engine is withdrawn from service and the reason for the high debris readings is investigated.

The concept of surveillance maintenance is closely related to the concept of *on-condition* (OC) maintenance. Maintenance tasks are referred to as on-condition when they are performed only when the item's condition warrants it. On-condition tasks can therefore be 'triggered' by an unsatisfactory finding during surveillance maintenance. However, if the condition of the item can be monitored by aircrew, aircrew reports can be used to trigger on-condition maintenance.[25]

Scheduled and Unscheduled Maintenance

Preventive and surveillance maintenance tasks are performed at regular intervals, and are thus referred to as *scheduled* maintenance tasks. Since corrective maintenance tasks are performed only when an item is discovered to have failed, the period between corrective maintenance tasks cannot be set; corrective maintenance is therefore *unscheduled*.

Scheduled maintenance tasks are often grouped together to form scheduled *servicings*. These servicings frequently contain extensive surveillance maintenance, which often reveals components to have failed (or to be in an unsatisfactory condition, eg. corroded). In addition, the rectification of such conditions detected in operation *before* the servicing may have

23 ibid., p. 2-2.

24 There are also other methods of EFD, including wear debris analysis (often using magnetic chip detectors), vibration analysis and performance monitoring. Non-Destructive Inspection (eg. radiographic, ultrasonic, fluorescent penetrant (etc) inspections) can also be considered to be surveillance Maintenance. Likewise, visual inspections (eg. zonal inspections) are surveillance maintenance.

25 Aircrew are effectively performing surveillance maintenance in their role of monitoring the serviceability of aircraft systems.

been deferred to be done *during* the servicing.[26] Thus, a significant amount of *unscheduled* maintenance may be performed during 'scheduled' servicings, to rectify the anomalies identified. In practice, 50 per cent (or more) of the duration of a scheduled servicing may be attributable to the need to perform unscheduled tasks. This does not change the fact that the servicing is scheduled, and the corrective maintenance tasks are unscheduled—the timing for the latter tasks could not have been predicted (although, on balance, it is reasonable to expect, and plan for, some unscheduled maintenance during scheduled servicings).

On-Equipment and Off-Equipment Maintenance

Maintenance tasks on an item may often be performed either with the item fitted to its parent equipment[27] (*on-equipment* or *on-aircraft*) or after the item has been removed (*off-equipment* or *off-aircraft*). Additional maintenance workload is generally required to perform off-equipment maintenance, as the item must be removed and refitted (which often entails additional testing). Additional spare items are also required in the maintenance pipeline so they can be fitted while other items are undergoing maintenance.[28] Additional transport and storage costs will be incurred due to the need to move components between operational units and maintenance venues.

However, many maintenance tasks cannot be performed when the item is fitted to an aircraft due to accessibility problems, or because the nature of the maintenance tasks requires that the component be isolated (eg. for lathe work or electroplating, or because necessary test equipment is not portable). A major benefit of performing off-aircraft maintenance is that the aircraft can be made serviceable faster, by the fitting of spare serviceable components in lieu of those removed for maintenance.

When on-aircraft maintenance work is required, the maintenance resources (manpower, equipment, facilities, etc) must be located where the aircraft is, or the aircraft must be brought to where the resources are. Off-aircraft maintenance reduces the need for this collocation.

Table 6-1 summarises the advantages and disadvantages of on-aircraft and off-aircraft maintenance.

Effectiveness of Maintenance Tasks

Some maintenance processes are assumed to return the item to 'as new' condition. In this case, the failures prevented or repaired by the maintenance process should be as unlikely to

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26 Cases where corrective maintenance is deferred to a later time are called *Carried-Forward Unservicabilities*, in RAAF parlance.

27 An item's *parent equipment* is the highest level assembly (or application, weapon system) to which it is fitted. For components fitted to aircraft, the aircraft is the item's parent equipment. (The term is somewhat misleading, as the aircraft may not be the item's *immediate* higher level assembly; the aircraft may actually be a grand-parent or even more distant ancestor, in the analogy.)

28 This is not necessary when the intention is to refit the originally removed item back to the aircraft from which it came, before flying the aircraft again. This can occur during major servicings, when the aircraft will be on the ground for long enough to perform the component maintenance.

occur as when the item was new, and should take as long to recur after maintenance as they took to develop initially. An example of such a process is component *overhaul*.

Other maintenance processes are not intended to be as thorough. Examples are minor aircraft servicings, component *bay services*, and repairs. These processes are only intended to allay certain failure modes, by maintaining only some of the subcomponents of the item that are subject to failure, and/or by applying more limited tasks. Such processes will inhibit the onset of certain failure modes, but not others.

Criterion	On-aircraft	Off-aircraft
Component access and isolation	Degraded	Enhanced
Aircraft availability	Degraded	Enhanced
Maintenance effort	Reduced	Increased
Need for spares	Reduced	Increased
Need for local maintenance capability	Increased	Reduced
Need for a maintenance pipeline to transport items to and from maintenance	No	Yes

Table 6-1: On-Aircraft vs Off-Aircraft Maintenance

Some potential (and actual!) scheduled maintenance tasks are not effective at all; that is, they do not serve to delay or prevent any failure modes. Needless to say, such maintenance tasks provide no benefit, and should not be performed.

MAINTENANCE GOALS

The maintenance function has several goals. These goals often represent conflicting requirements, and the priorities of the various goals vary with circumstances. Detailed maintenance goals may be determined from the mission and objectives of maintenance. The mission is to support operational preparedness.[29] The objective is 'to keep RAAF aircraft and other technical equipment in an approved design condition such that it is safely operable and properly configured to meet its intended purpose, in an efficient and effective manner'.[30] From these requirements, the following goals can be distilled:

a. high levels of airworthiness (or safety),

b. high levels of missionworthiness,

29 DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, p. 3. From a maintenance viewpoint, preparedness requires the availability of weapon systems properly configured and sufficiently reliable to undertake assigned missions.

30 loc cit.

c. high availability, and

d. low cost.

In addition, the criteria of *mission generation* and *asset preservation* introduce a time basis for these four goals. Furthermore, specific operational needs must also be taken into account.

Airworthiness

An aircraft is deemed *airworthy* if it complies 'with the regulations prescribed by the competent authority certifying fitness for flight'.[31] Other definitions refer to 'suitability for flight'.[32,33]

The Civil Aviation Authority (CAA) is the 'competent authority' controlling airworthiness of civilian aircraft in Australia. CAA executes its role, *inter alia*, by mandating minimum maintenance requirements for civilian aircraft.[34] The ADF is not bound to follow CAA maintenance regulations, but is answerable directly to Government for the safety record of its aircraft.[35] Thus, the ADF has a regulatory role in addition to an operational role, whereas civilian operators such as airlines do not have regulatory autonomy.[36]

The second part of the definition of airworthiness refers to 'fitness for flight'. To be fit for flight, an aircraft must have a sufficiently low probability of being involved in a major accident.[37]

Airworthiness is closely related to the concept of reliability. Airworthiness requires high reliability in those components or systems that are safety-critical.[38]

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31 JSP(AS) 101.

32 DI(AF) AAP 7001.042-1, *RAAF Maintenance System for Technical Equipment*, 1984, p. 1-1.

33 DI(AF) ENG 1-1, *The Discipline of Engineering and its Application to RAAF Aircraft and other Technical Equipment*, 1992, p. 1.

34 Often, this is done by reviewing and accepting aircraft manufacturers' recommendations.

35 An exception is RAAF aircraft which have civil registration.

36 However, employees within airlines (or other companies) may be licensed by CAA to be able to make certain regulatory decisions. When performing in this capacity, such people are considered to be acting as CAA representatives.

37 The acceptable probability of being involved in a major accident varies between airworthiness authorities. Figures quoted range between 10^{-6} and 10^{-9} per flying hour. (DI(AF) ENG 5-2, *Aircraft Structural Integrity Management*, 1993, p. 1.)

38 To be more precise, high reliability in safety-critical failure *modes* is required. A safety-critical item may have a failure mode that does not jeopardise airworthiness. For example, a blockage may result in inability to ignite an afterburner, which may not be considered to affect airworthiness (although it may affect missionworthiness). However, other failure modes of the afterburner assembly, such as excess fuel flow, could certainly jeopardise airworthiness.

Aircraft Structural Integrity (ASI) is a special case, and subset, of airworthiness management. ASI concentrates on safety-critical aircraft structure, but not other safety-critical components (such as engines). The types of damage considered by ASI are fatigue,[39] corrosion, and structural repairs.[40] The primary emphasis is on fatigue management. ASI is discussed in more detail in Annex B.

For non-flying weapon systems; the equivalent goal to airworthiness is safety. Safety is, in fact, the over-arching concept behind airworthiness; the term ‘airworthiness’ can be considered to be safety of aircraft operations.[41]

Missionworthiness

In many ways, missionworthiness is parallel to airworthiness (or safety). A missionworthy aircraft has a high probability of successfully executing assigned missions.

An aircraft that is not airworthy is also not missionworthy. Missionworthiness is therefore a broader concept than airworthiness: missionworthiness requires airworthiness in addition to high reliability in those components or systems that are mission-critical.[42] Therefore, missionworthiness requires high reliability in components or systems that are safety- and/or mission-critical.[43] The distinctive facet of missionworthiness is that it requires reliability in certain non-safety-critical systems, and it is in this sense that the term is usually used.

Availability

The RAAF definition of availability is ‘the proportion of time that an aircraft is available to carry out its designated function’.[44,45] This definition agrees with the definition of *operational availability* (A_O), which is ‘the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon’.[46] A_O can be expressed as follows:

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39 Fatigue is a phenomenon whereby the strength of some materials reduces over a period of time if the applied load varies with time. Aircraft components are generally subject to various forms of cyclical loading, including vibration from engines/gearboxes, wind gusts, takeoff/landing cycles, manoeuvre loads, etc.

40 Structural repairs may be considered a form of damage because, even though they endeavour to restore the structure to its original characteristics (eg. static strength, durability, corrosion resistance, etc), almost invariably some form of degradation remains.

41 ‘Airworthiness’ may also have additional legal implications, depending on the definition adopted.

42 To be more precise, high reliability in mission-critical failure *modes* is required.

43 To be more precise, high reliability in safety- and/or mission-critical failure *modes* is required.

44 DI(AF) AAP 7001.038-1, p. 1-2.

45 A discussion of the current RAAF method of measuring availability, and the meaning of ‘designated function’, is given in Maclean, *Preparedness and Repairable Item Management*, p. 3-6.

46 Benjamin S. Blanchard, *Logistics Engineering and Management*, Third Edition, Prentice-Hall, New Jersey, 1986, p. 65.

$$A_O = \frac{\textbf{Time available}}{\textbf{Total time}} = \frac{\textbf{Uptime}}{\textbf{Uptime + Downtime}} \quad \textbf{(over a given time period)}$$

The figure used for 'Uptime' can be the average time that elapses between maintenance arisings (whether scheduled or unscheduled). This is referred to as the *Mean Time Between Maintenance* (MTBM).

If MTBM is used for 'uptime', the average duration of each maintenance action, or *Mean DownTime (MDT)*, should be used for 'downtime'. The availability equation then becomes:

$$A_O = \frac{\textbf{MTBM}}{\textbf{MTBM + MDT}}$$

MDT does not consist entirely of 'hands-on' time; ie. time actually spent performing maintenance tasks. This component of MDT is the *Mean Time to Repair* (MTTR). Other components are the *Logistics Delay Time* (LDT) (time spent waiting for spares, test equipment, transportation or facilities), and *Administrative Delay Time* (ADT) (time delays associated with waiting for or processing paperwork, assignment of personnel, etc).[47]

The above equation indicates several strategies that can improve availability. Availability will improve if MTBM can be increased with little effect on MDT. MTBM can be increased by reducing the frequency of scheduled maintenance (by adopting greater intervals between servicings), or by reducing the frequency of unscheduled maintenance (eg. by improving component reliability so that less failures occur).

Alternatively, availability can be improved by reducing MDT so long as MTBM does not change significantly. MDT can be reduced by reducing MTTR (ie. by completing hands-on work in less time), LDT (eg. by minimising spares delays), and/or ADT (eg. by improving paperwork systems, avoiding maintenance backlogs, etc).

In practice, the maintenance parameters in these relationships cannot be adjusted without affecting other parameters. For example, reducing the frequency of scheduled maintenance generally causes an increase in the frequency of unscheduled arisings (ie. items fail more often). Reducing MTTR often results in lower quality work, hence increased frequency of corrective maintenance (or increased frequency of preventive maintenance to retain high reliability). Maintenance requirements determination involves a complex balancing of these, and other, parameters.

Some strategies that may be used to improve availability do not require tradeoffs between availability parameters. Improved reliability by acquiring better quality parts will always improve availability, especially if scheduled maintenance programs are adjusted to take

47 Williamson, 'Reliability in Design', pp. 5–11.

advantage of the situation. Improved spares support (by smarter or greater holdings, quicker delivery, etc) will reduce LDT. Although these factors will not have any detrimental side-effects in the availability equation, there is often a financial premium.

Cost

There are only two kinds of in-service logistics costs: those associated with the provision of replenishments, and those associated with maintenance.[48] The maintenance function incurs costs in many ways, including wages for tradesmen's time, procurement of spare parts, procurement and maintenance of facilities and equipment used in maintenance, transportation costs, contract costs, etc. Since these costs are incurred by maintenance, they may be adjusted by maintenance planning.

As with availability considerations, there are compromises possible within the cost criterion. A good example is the determination of whether an item should be maintained or not. Even though there may be effective preventive maintenance tasks for an item that could restore its serviceability, it may be cheaper to throw the item away and replace it with a new one whenever required. (This is usually the case with cheaper components, where the cost of labour usually exceeds the cost of procurement.) There is thus a balance required between manpower costs and procurement costs.

Operational Requirements

There are other operational needs that should be supported by the maintenance function, in addition to availability, airworthiness and missionworthiness. The maintenance program should be tailored to meet operational requirements such as aircraft usage rate (rate of effort),[49] mission mix, and mission profiles. The environment in which aircraft are operated and based also has implications for the maintenance program. Lastly, operational flexibility should be supported by the maintenance program, by avoiding the need to impose limitations on allowable manoeuvres.

Compromises

Just as there are compromises possible *within* many of the goals described above, there are also compromises required *between* the various goals. For example, high levels of airworthiness and missionworthiness usually require a large amount of maintenance, and hence (all else being equal) availability suffers. Conversely, seeking maximum availability

48 This assumes that the removal and replacement of non-repairable items (eg. those damaged beyond repair or subject to a 'throw-away' policy) is a maintenance function. This seems a reasonable assumption, since these requirements are determined by maintenance analysis staff and are promulgated in maintenance plans. A case could be made to include replenishment costs as part of maintenance costs, since the replenishment tasks are usually maintenance tasks. However, this would seem to be stretching the point. Moreover, during a contingency, tasks such as refuelling an rearming may not be done by technical personnel to the same extent as in peacetime.

49 An aircraft's *rate of effort* is typically measured by the number of flying hours expected to be flown each year.

will require maintenance to be cut back, which will reduce levels of airworthiness and/or missionworthiness.

Many actions that can be taken to reduce downtime, and hence increase availability, have significant cost. Alternatively, seeking cost savings can reduce airworthiness, missionworthiness and/or availability. Reducing operational flexibility can improve availability and other goals. These and other tradeoffs are further discussed in Chapters 7 and 11.

The determination of maintenance requirements must balance all of these conflicting goals. The relative priority of the various goals will often change during significant changes in circumstances: most notably, during transition to contingency operations. A set of maintenance plans that are optimal for peacetime will probably not be optimal during a contingency. Contingency maintenance goals are discussed in Chapter 12.

Mission Generation and Preservation of the Asset

At a more superficial level, maintenance tasks are often divided into the categories *mission generation* and *asset preservation*. Mission generation tasks are those tasks required to allow the next mission (or few missions) to fly. Such tasks are focused on short-term benefits, and are usually performed frequently. *Operational maintenance* (OM) comprises mostly mission generation tasks.[50]

Asset preservation tasks aim to ensure that the equipment will be able to remain in service for its allotted life of type. (In addition, the residual (resale) value of the equipment will be increased.) Often, these tasks do not need to be performed very frequently, and are usually the responsibility of *deeper maintenance* (DM) units or contractors.[51]

Much of the guidance on contingency maintenance goals is expressed in terms of mission generation and preservation of the asset, rather than the four goals described previously. It is therefore desirable to develop a relationship between these two categories and the four goals.

The criteria of mission generation and asset preservation introduce a *time* dimension to the four goals. More specifically, mission generation requires adequate levels of airworthiness, missionworthiness, and availability *in the shorter term*; asset preservation requires that adequate levels of airworthiness, missionworthiness, availability and cost-effectiveness be sustainable *over the longer term* (ie. for the desired life of type of the equipment).[52]

The reason for introducing this time dimension is that it permits yet another level of compromise or flexibility. Some maintenance tasks may be deferred with little detriment

50 DI(AF) LOG 2-1, p. 5.

51 loc cit.

52 Note that mission generation does *not* require cost-effectiveness as a priority (at least during a contingency).

in the short term; such deferral reduces the amount of downtime and hence increases availability in the short term. However, this practice may result in slow but unchecked degradation which would reduce airworthiness, missionworthiness and/or availability (and also increase maintenance costs) in the longer term.

The terms *mission generation* and *asset preservation* are also often used as indications of whether maintenance tasks are operational or deeper maintenance (OM or DM). This latter distinction is important when considering which maintenance tasks need to be performed within the ADF, and which may be contracted out. This issue is discussed in Chapter 19.

SUMMARY

An item may fail in a number of different ways, or *modes*. The item's failures will be distributed over time in a particular pattern, which may represent wear-in, wear-out, random failure, or any combination of these. An item (or its failure modes) may be assigned a *criticality* based on the consequences of failure (and possibly the frequency of failure).

Reliability is the probability that an item will not fail within a specified period when used under specified conditions. MTBF is an alternative, cruder, measure of reliability. The age (or life) of an item is measured in units that relate to how the item will wear out or fail; sometimes multiple lives and lifing units are needed for a single item.

Maintenance may be *corrective*, *preventive*, or *surveillance*. Preventive and surveillance maintenance tasks are *scheduled*; corrective tasks are *unscheduled*. In addition, tasks may be performed *on-equipment* (*on-aircraft*) or *off-equipment* (*off-aircraft*).

Maintenance has four main goals: *airworthiness*, *missionworthiness*, *availability*, and *cost-effectiveness*. *Mission generation* and *asset preservation* introduce a time dimension to these goals. Many compromises are possible between, and within, the goals; this gives rise to the possibility of adjusting the maintenance program should the relative emphasis on the various goals change.

The process of deciding how much scheduled maintenance should be performed is called *Maintenance Requirements Determination*; this is the subject of the next chapter.

Chapter 7
Maintenance Requirements Determination

INTRODUCTION

There are many different methods for determining the scheduled maintenance requirements necessary to support an item of equipment. This chapter does not attempt to cover any of these in great detail, but provides a broad overview of the generic considerations and methods that apply, and is biased towards those concepts that will prove to be of most utility when considering the development of contingency maintenance requirements. This chapter builds upon many of the concepts introduced in the previous chapter.

STANDARDS

Figure 7-1 shows a simplified genealogy of maintenance requirements determination standards. Most relevant modern guidelines for the determination of maintenance requirements stem from the documents produced by the Maintenance Steering Group of the American Air Transport Association, which comprises representatives from American airlines and airliner manufacturers. Their first document, MSG-1[1], was produced in 1968; MSG-2[2] followed in 1970.

Until recently, the RAAF's equivalent system was called Maintenance Engineering Analysis (MEA),[3] which was developed from MSG-2. The MEA logic followed MSG-2 closely, but provided much more specific guidance in the form of detailed flowcharts and forms (the MSG documents are largely conceptual; process requirements are very broad and must be tailored to permit implementation).

MSG-2 was significantly revised in 1979; as a result, MSG-3[4] was published in 1980. The RAAF did not formally update its MEA logic to reflect the changes in MSG-3, although many of the changes were covered either by the more specific nature of the MEA documentation, or by amendments incorporated since its introduction.

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1 Properly titled *Maintenance Evaluation and Program Management.*

2 Properly titled *Airline/Manufacturers Maintenance Program Planning Document.*

3 MEA is documented in DIs(AF) AAP 7001.038-1 and -2.

4 Properly titled *Maintenance Program Development.*

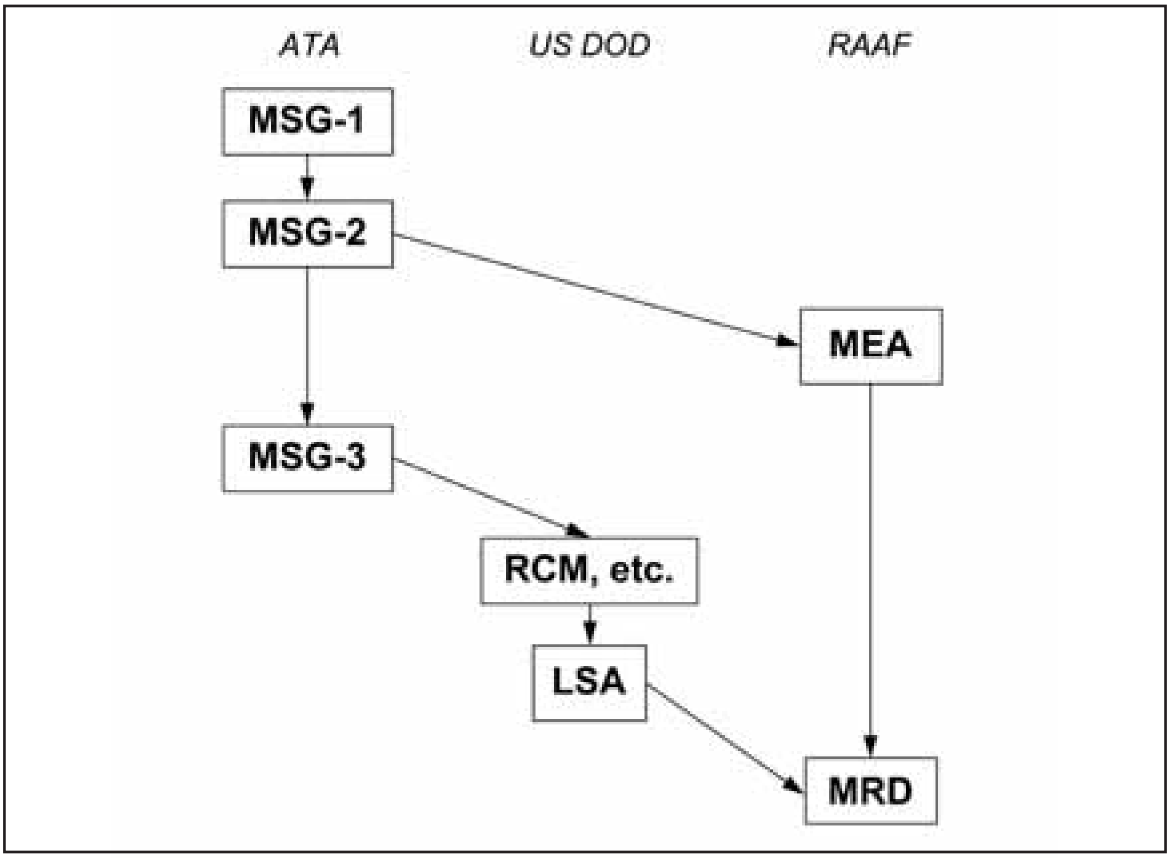

Figure 7-1: Maintenance Requirements Determination Standards

The US Military have developed a series of processes and Standards that are derived from, and expand on, MSG-3. The closest parallel is the Reliability-Centered Maintenance (RCM) system,[5] although other systems closely relate to this, and cover some aspects of MSG-3.[6]

Historically, the interfaces and relationships between the various aspects of logistics analyses have been only loosely defined. To improve the effectiveness of the logistics system as a whole, the US Department of Defense has adopted Integrated Logistics Support (ILS).[7] ILS includes the Logistic Support Analysis (LSA) process[8] which provides a framework within which all procurement project logistics assessments are conducted, including maintenance requirements determination. Significantly, the RCM (and related) processes and standards still exist in their own right; LSA stipulates the relationships between them, and documents a data structure (the Logistic Support Analysis Record – LSAR) to allow necessary information to flow from one type of analysis to the next.

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5 MIL-STD-2173(AS), *Reliability Centered Maintenance*, 21 January 1986.

6 In particular, a logical precursor to the RCM process is *Procedures for Performing a Failure Mode, Effects and Criticality Analysis*, MIL-STD-1629A, 24 November 1980.

7 See p. 39.

8 MIL-STD-1388-1A, *Logistic Support Analysis*, 21 January 1993; and MIL-STD1388-2B, *DOD Requirements for a Logistic Support Analysis Record*, 21 January 1993.

The RAAF is adopting ILS, and with it the LSA approach. The soon-to-be-implemented CAPLOG computer system will provide a LSAR database and software tools to manipulate the data, including tools to perform Reliability-Centered Maintenance and the other related functions.[9] These tools should be used for acquisition and for in-service reviews of logistics processes (including maintenance requirements determination). Therefore, from a maintenance requirements determination perspective, the RAAF is about to move from a local adaptation of MSG-2, past one or two generations of development (MSG-3 and the discrete US Military Standards), into the age of integration and Logistic Support Analysis.[10] The MEA process has been revised and updated to suit this new niche; the revised process is referred to as Maintenance Requirements Determination (MRD).

Significantly, the LSA process as originally defined, and subsequently implemented in software, is only intended to support the procurement phase;[11] the RAAF intends to use the same tools throughout the entire life cycle. While this will require some tailoring of the database and software, and will create some teething problems, the concept of re-using data collected during procurement to ensure that logistics support remains optimal throughout the life cycle is eminently sensible.

LSA has the ability to address multiple scenarios, eg. peacetime and contingency.[12] The RAAF is not initially intending to use this facility, but it should be used subsequently to guide reserve stockholding and contingency maintenance development.

TIMING

Acquisition (Project)

Before an item of equipment can be introduced into service, its maintenance requirements must be forecast, and maintenance venues must be established and prepared to perform the work when it arises.[13]

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9 Due to the specialised nature of the maintenance requirements determination processes (as exemplified by the separate MIL-STDs for them), the integration of the applicable software tools with the LSAR is problematic. Either simplified RCM (etc) tools that are limited to full compatibility with the LSAR can be used, or fully-fledged tools can be used that may require some separate data storage and may not be totally integrated with the system as a whole. The RAAF is currently pursuing the first of these options.

10 The changes required by this rapid progress can be expected to be many; it is a concern that the manpower available to manage this change has been significantly reduced at the same time.

11 MIL-STD-1388-1A, p. iii.

12 ibid., paragraph 205.2.1.

13 There are many other reasons for forecasting the maintenance requirements, eg. spares assessing, support equipment procurement, provision of technical data and training, costing, availability estimation, etc. These considerations should influence the choice of equipment to be procured, and the quantity procured.

While the acquisition is in project stage, there are three sources of data available on which to base maintenance requirements determinations:

a. Manufacturers will generally recommend a maintenance policy for their equipment, based on engineering assessments (forecasts) of the behaviour of the equipment.

b. Other operators of the equipment may have refined the maintenance program based on their experience of operating the equipment in their environment.

c. The RAAF may have experience in operating similar items of equipment in its own environment.

All of the information available from these sources should be adapted to meet expected local requirements. In practice, this is very hard to do, and frequently information obtained from foreign sources must be adopted virtually verbatim.[14]

In Service

Because of the uncertainties associated with the prediction of maintenance requirements during the project phase, it is most important to conduct a review of the performance of the maintenance program after the equipment has been in service long enough for sufficient data and experience in its operation to have been gathered. The potential reliability of new equipment can rarely be achieved without a period of maturing in service.[15] Service with other operators (eg. foreign air forces) will identify many problems with the initial maintenance program, but local conditions and usage[16] will invariably be different, and the maintenance program should be adapted accordingly. The RAAF aims to fully review the maintenance program after newly acquired equipment has been in representative service for three years.[17]

Beyond the initial in-service review, further reviews may be beneficial. Changing circumstances can invalidate assumptions that were true when the maintenance requirements were first determined (or previously reviewed). Changes in the equipment's role, conditions of use, environment, and age-related degradation can warrant the review of some or all of the maintenance program.[18]

14 DI(AF) AAP 7001.038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, p. 7-3. Changes to maintenance venues must be made, but the nature of the maintenance tasks and intervals often remains unchanged.

15 *Report of the MOD(AFD)/MOD(PE)/SBAC/EEA Working Group on Ways of Securing Improved Reliability in RAF Equipment*, July 1984.

16 The environment, roles, rates of effort, and flying habits all influence maintenance requirements. See Chapter 11.

17 DI(AF) AAP 7001.038-1, p. 7-5.

18 loc cit.

A fourth source of information is available for equipment that has been operating in the local environment for some time. RAAF experience in operating and maintaining the equipment obviously provides the most relevant source of data to indicate the performance and problems encountered in RAAF usage.

Unfortunately, there are difficulties in obtaining and using this data. Data collection systems often do not provide all of the information that is necessary; with the increase of contractor maintenance, this problem may worsen.[19] Another problem is that the RAAF usually buys items in smaller quantities than some other operators (most notably, the USAF). As a result, few failures may occur, and the small amount of data thus available may not support the analysis necessary to ascertain problems and solutions.[20] Because of these limitations, it is always wise to balance local experience with other sources of data.

Modification

A modification should be treated similarly to an acquisition project (for such they are, in many cases). Maintenance requirements for the modified equipment must be re-evaluated, as the modification may significantly change the characteristics of the modified (and interfacing) areas.

THE MAINTENANCE REQUIREMENTS DETERMINATION PROCESS

Fundamentally, for each item in the equipment, it is necessary to determine the following:

a. Should it be subject to scheduled maintenance?

b. If so, then:

    (1) How often, or under what circumstances?

    (2) What should be done to it, and how?

    (3) By whom, and where?[21]

This information (particularly the 'what' and 'how often' aspects) is frequently referred to as the item's *maintenance policy*.

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19 By analogy, access to maintenance personnel is a good source of information; obtaining such access to contractors is also problematic. It is plausible that RAAF sections that win Commercial Support Program (CSP) in-house options will be equally inaccessible, due to the absence of capacity to take on what may appear to be a secondary task.

20 That is, the results may not be statistically significant.

21 MRD considers other logistics requirements as well, but these are the main maintenance outcomes.

The major considerations necessary to determine answers to these questions involve:

a. the criticality of the item (ie. what could happen if it were to fail);

b. the characteristics of possible failure modes (eg. failure pattern); and

c. economic considerations.

Whether to Maintain

The decision about whether an item should be preventively maintained or not has a profound influence on the reliability (and hence airworthiness, missionworthiness, and cost-effectiveness) and availability that may be achieved. The main issues that guide this decision are:

a. Failure Pattern. If the item does not wear out,[22] but exhibits wear-in or random failures, no scheduled maintenance task can delay or prevent failures.

b. Failure Progression Rate. Regardless of the failure pattern, it is possible to prevent or delay failures if an *impending* failure can be detected sufficiently early. Some failure modes progress relatively slowly from first signs of degradation to final failure; in these cases, surveillance maintenance can detect initial symptoms that may lead to failure; preventive maintenance can be performed to remedy the situation when required.[23]

c. Hidden Function. Items with hidden function are those items for which a failure would not normally be noticed. This situation can arise in two ways:

(1) the item is seldom used (eg. defensive systems, ejection seats); or

(2) although used, failure of the item does not give any aircrew-detectable indication (eg. a system with a backup or redundancy, but no cockpit indication of failure). It may be desirable to perform regular checks on items with hidden function to give some assurance of the serviceability of the item, even though they may not possess a wear-out failure pattern or a slow failure progression rate.

d. Effectiveness of Maintenance. Even if the preceding considerations indicate that preventive maintenance should be considered, if there are no *effective* maintenance tasks that can inhibit the degradation, there is no point performing any scheduled maintenance (it would not be preventive, but would only consume time and resources). In general, omponents should not be overhauled, inspected, checked or tested unless these actions, or

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22 More precisely, if the item has no failure *modes* that exhibit wear-out...

23 A prime example of this is fatigue cracking, which may appear to initiate at any point in time. However, once initiated, many fatigue cracks propagate fairly slowly, and inspection techniques can be put in place to regularly check for their existence. Once a crack is detected, preventive maintenance may be triggered to circumvent failure.

some action that may arise from them, can inhibit degradation. Occasionally, such tasks actually *increase* the degradation of the component. (A policy of 'maintain by replacing' will always be effective, albeit often not *cost*-effective.)

e. Worthwhile. Whether a maintenance task is worthwhile depends on the whether the benefits that accrue from performing the maintenance task outweigh the costs of doing it. The item (or failure mode) criticality influences this issue; eg. any task that can prevent failures of safety-critical items will generally be considered worthwhile;[24] tasks that avoid mission-critical failures should generally be performed;[25] preventive maintenance on non-critical items should only be performed when it is cost-effective to do so.

When to Maintain

Having determined that an item should be subject to scheduled maintenance, the timing of that maintenance needs to be decided. Scheduled maintenance may be stipulated using either of two types of interval:

a. Fixed Intervals. The maintenance is to be performed at regular intervals. The duration of the intervals should be expressed in terms of the relevant lifing units for the item, eg. elapsed days, hours used, or a combination.[26]

b. On-Condition (OC). An 'interval' of on-condition can be used to trigger maintenance based on the condition of the item. This is most appropriate when the failure progression rate is sufficiently slow to enable detection and avoidance of the impending failure before it actually occurs.

Fixed maintenance intervals are appropriate for items that exhibit wear-out failure patterns. The level of reliability achieved in service (ie. the number of failures occurring, or measured MTBF[27]) can be 'controlled' by the frequency of preventive maintenance. Likewise, costs can be optimised by balancing the proportion of items that must be repaired or replaced due to failure against the proportion of items that are subject to preventive maintenance. A means of determining maintenance policies to achieve these balances is described at discussed at Annex C.

Items with hidden function may also be maintained on a fixed interval, despite not having a wear-out failure pattern, to control the level of reliability that will be achieved in service. A method for determining the appropriate interval to achieve a desired level of reliability is outlined at Annex D.

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24 There are some cases where this is not so. Some structural inspections in inaccessible areas would cause considerable downtime if regularly performed. When the risk of failure from such areas is very low, risk management principles apply, and a small airworthiness risk is accepted for a considerable increase in availability and cost savings.

25 A balance between desired levels of mission reliability and the cost of achieving it should be struck.

26 See p. 50. When multiple units are used, the maintenance task must be performed when any of the component's maintenance lives 'expires' (ie. whichever one becomes due first).

27 See Annex A.

On-condition maintenance may be used on items that demonstrate a slow failure progression rate (regardless of the basic failure pattern), and for which the degradation towards failure may be conveniently and reliably monitored. There are two means of meeting this latter criterion:

a. surveillance maintenance, which must be carried out at fixed intervals and at sufficient frequency to give an acceptably high probability of detecting an impending failure;[28] and/or

b. aircrew monitoring during operation, eg. by observing item performance, noise, vibration, etc.[29]

Without one of these forms of surveillance, on-condition maintenance will degenerate into 'on-failure' maintenance, since failure will be the first indication of unsatisfactory condition.[30] This then ceases to be preventive, but becomes solely corrective maintenance. The identification and implementation of adequate surveillance measures is critical to the success of on-condition maintenance intervals.[31]

Aircraft Structural Integrity (ASI) tasks are often managed as oncondition maintenance, by the use of scheduled inspections to monitor the condition of relevant structural components. Annex B discusses some of the issues and methods used to determine inspection intervals for ASI purposes.

Where suitable means of surveillance exist for items with hidden function (such as a check/test), such items may also be subject to on-condition maintenance intervals (see Annex D).

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28 This means that the interval must be somewhat less than the failure detection period. How much less depends on the probability of detecting the incipient failure at various stages of its progress, the criticality of the item, etc. This analysis is most clearly defined in the Durability and Damage Tolerance Analysis that often accompanies the safety by inspection philosophy of assuring aircraft structural integrity (see Annex B) and is also appropriate to Early Failure Detection.

29 Arguably, aircrew monitoring is just surveillance maintenance performed by aircrew (with a very short frequency of inspection) during flight. However, because the task does not fall to maintenance tradesmen and is not documented in maintenance publications, aircrew monitoring is not generally deemed to be surveillance maintenance. Conceptually, however, it is no different.

30 There is some evidence that the Orion MEA review conducted about 1990 did not rigorously follow this approach. Many maintenance tasks were moved from fixed intervals to on-condition, but the 'condition' was generally not specified, and surveillance tasks were not instituted. This approach minimises the amount of scheduled maintenance performed, but leads to higher levels of unscheduled maintenance (ie. suboptimisation). Monthly Maintenance Report (MMR) data shows significant increases in the frequencies of in-flight failures, maintenance arisings, Aircraft-On-Ground (AOG) spares delays, etc, from about 1990.

31 Arguably, the term 'on-condition' is not entirely an alternative to 'fixed interval'. The associated surveillance *must* be conducted at some fixed interval (which may be virtually continuous in the case of aircrew monitoring). The preventive or corrective tasks will be on-condition, and may therefore not be performed regularly, but all such tasks must be associated with a fixed interval (or ongoing) surveillance task.

Servicing Packaging

Having determined the optimum maintenance intervals for individual items, it is necessary to aggregate these into groups to form servicings (it is not efficient, or manageable, to maintain items all at different frequencies). This generally requires the intervals of the various tasks to be adjusted so that they fall into groups, which will become servicings. There are three main types of servicings:

a. flight servicings,

b. special servicings, and

c. routine servicings.

Maintenance tasks of particularly short interval will generally be packaged into flight servicings, such as Before Flight, After Flight, and Turnaround. The tasks in flight servicings are usually considered mission generation tasks; flight servicings are therefore usually an operational maintenance responsibility. These servicings also include most replenishment tasks. The optimum way to group appropriate tasks into flight servicings is usually apparent.

Some tasks do not need to be performed at regular intervals, but only when some unusual circumstance arises, such as a heavy landing, operation in adverse environmental conditions, etc. These requirements are grouped into special servicings, which are only performed when the appropriate condition occurs. The grouping of these tasks into servicing packages is straightforward.

Other tasks that need to be performed at regular intervals (whether the interval is based on elapsed calendar time or item usage) are grouped into routine servicings. Most scheduled maintenance comes into this category. Unlike flight and special servicings, the determination of the optimum way to group tasks into servicings is not obvious. There are three basic approaches:

a. Periodic Servicings. Periodic servicings group all tasks of similar intervals into single servicings. For example, a single servicing could be formed consisting of all tasks needing to be performed at about 100 hours of usage. Another servicing can be created for tasks needing to be performed at a 200 hour interval; this servicing may also incorporate the 100 hour servicing tasks.[32] Periodic servicings can result in a spasmodic maintenance workload (especially with small fleets), and large periodic servicings can keep the aircraft on the ground for extended periods.

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32 This combination of shorter interval tasks into longer interval servicings creates *hierarchical* servicings, whereby a larger servicing may fully incorporate one or more smaller, more frequent, servicings. A side-effect of this is that a so-called deeper maintenance servicing may in fact include many operational maintenance tasks. This has implications for deployability and commercialisation (see Chapters 16 and 19).

b. Phased Servicings. Tasks required to be performed at similar intervals are grouped into *multiple* servicings under the phased concept. This is equivalent to breaking a periodic servicing into parts, and performing the parts in a distributed manner over time. Tasks to be performed at longer intervals can be distributed amongst phased servicings. Phased servicings may not be as efficient as periodic servicings because of the possibility of duplicating work required to prepare the aircraft for maintenance, gain access, etc. However, the maintenance workload is smoother, and individual servicings are shorter.

c. Flexible Servicings. The flexible servicing concept is effectively an extreme form of phased servicings, where the maintenance tasks are managed individually for every item requiring maintenance, or very small task groups are formed. The main advantage of flexible servicings is that it may be possible to perform the maintenance entirely during nonflying periods, eg. overnight. This can result in virtually continuous apparent availability (unscheduled maintenance excepted). However, access requirements can hinder the practicality of flexible servicings, and intense management effort is required to control the system.[33]

How to Maintain

In many cases, components may not be economically (or even feasibly) maintainable or repairable. When it is impossible to restore an item to a satisfactory condition, or the cost of doing so exceeds the cost of replacing the item with a new one, the old item should be discarded and simply replaced.[34] When deciding whether an item should be maintained or discarded, the full costs of maintenance should be considered, including the costs of supporting a more complex maintenance pipeline, contract management costs, etc. However, a replacement policy may preclude the RAAF, or Australian industry, from gaining any expertise in the maintenance of such items; this may limit flexibility in times of contingency, should a ready supply of replacement items not be forthcoming.

If maintenance (as opposed to replacement) is deemed appropriate, the tasks to be performed should be those which have been assessed as being effective and worthwhile, as a first approximation. However, given that some maintenance tasks must be performed on an item at a particular time, it is often worthwhile to also perform other tasks at the same time that may not have been justified on their own. The incremental cost and time required to perform additional tasks is often small, and such tasks may become justifiable on this basis. Thus, an item overhaul generally attempts to fully recondition the item, even though the basic requirement for a servicing is usually only justified on the basis of one or two critical failure modes of a small number of critical subcomponents.

33 For this latter reason, flexible servicings are not currently approved for use in the RAAF (DI(AF) AAP 7001.038-1, p. 3-6).

34 The RAAF has recently introduced a policy of 'Throw Away to Store', whereby items considered unrepairable, or not economically repairable, are withdrawn from service but retained in case subsequent repair becomes feasible, cost-effective, or essential.

Generally, the need for access, test equipment or rework will determine whether an item needs to be removed from its parent equipment for maintenance or not. In some cases, either option is feasible, and the decision should be based on the criteria in Table 6-1.

Manufacturers generally specify recommended servicings for their equipment, which detail the tasks to be performed, and the frequency with which they should be performed. Historically, the RAAF has methodically and periodically adjusted the intervals of on- and off-equipment maintenance tasks, and has significantly modified the details of on-equipment servicings, but has not reviewed the content of off-equipment servicings (such as component overhauls), except when problems become obvious. Inefficiency in off-equipment servicings can be offset by the provision of additional spares maintenance capacity; availability need not be affected, but maintenance cost-effectiveness will suffer.

Where to Maintain

Decisions about where maintenance tasks should be performed are made after the individual maintenance tasks have been packaged into servicings. Issues that must then be decided are:

a. echelon (eg. operational or deeper maintenance); and

b. agency (RAAF unit or contractor).

Maintenance Echelon. An issue in determining whether a servicing should be deemed operational or deeper maintenance is whether it contributes to mission generation or asset preservation (respectively)[35]. More useful criteria are the resource levels necessary, and the possible need to perform the servicing on deployment. Any servicing that may need to be performed on deployment (eg. on-equipment tasks) will generally be considered operational; tasks that require more specialised equipment or skills will generally be considered deeper maintenance.[36]

Agency. The determination of the appropriate agency to perform a particular maintenance task is very complex. It requires balancing many issues, including:

a. the need for the task to be performed on deployment, possibly in an area of conflict;

b. the geographical location of the various agencies (there are some benefits to collocation with equipment operators or other related agencies);

c. the need to retain some level of specialist skills and capacity in uniformed personnel (see Chapter 19);

d. the need to be able to influence the performance of the agency;

35 DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, p. 5.

36 These issues are inter-related; see also Chapter 19.

e. turn-around times achievable (this can mitigate against overseas contractors);

f. the need to support Australian industry, or to establish a local capability for strategic reasons (see Chapter 20);

g. existing and proven capabilities of the competing agencies; and

h. economics.

SUMMARY

The RAAF is about to undergo significant change in the way in which it determines scheduled maintenance requirements, as a result of rapidly updating its processes.

Scheduled maintenance requirements need to be estimated during equipment acquisition, and maintenance programs should be thoroughly reviewed after the equipment has been in service for some time. Reviews thereafter many also be beneficial, especially when major modifications are made to the equipment.

An item's maintenance policy consists of when, how, where and by whom it should be maintained. There are many considerations and tradeoffs required in the determination of this information. When all component maintenance requirements have been determined, they are grouped into servicings. There are different ways of doing this; again, there are many considerations and tradeoffs required.

A consequence of determining a component's scheduled maintenance program is that the component's requirements for *unscheduled* maintenance are effectively determined as a result. Unscheduled maintenance is discussed in the next chapter. Chapter 11 examines the influence of various factors (such as maintenance goals) on the MRD process; Chapter 13 assesses the effect that contingency requirements should have on the MRD process.

Chapter 8
Unscheduled Maintenance

INTRODUCTION

The previous chapter outlined the means of determining scheduled maintenance requirements. This chapter explains the processes associated with unscheduled maintenance (ie. repair).

UNSCHEDULED MAINTENANCE REQUIREMENTS DETERMINATION

At first, it seems incorrect to consider the determination of requirements for unscheduled arisings; ie. planning for unplanned events. Although the most apparent product of the maintenance requirements determination process outlined in the previous chapter is a set of *scheduled* servicings, the process also determines the extent of *unscheduled* maintenance. To a very large extent, maintenance requirements determination involves a balancing of scheduled and unscheduled maintenance requirements. A hidden output of the maintenance requirements determination process is the amount of unscheduled maintenance that may be expected for every item considered, potentially including failure modes, frequencies of occurrence, extent of damage arising, costs and times to repair, etc.[1] In addition, unscheduled arisings will occur as a result of oversights in the maintenance requirements determination process.

The fact that components fail in service does not necessarily indicate that the maintenance requirements determination process has failed. It is not the aim of maintenance requirements determination to reduce the incidence of in-service failures to zero (this would be impossible). Rather, a certain number of in-service failures are to be expected.

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1 In practice, this information is seldom fully quantified, unless a detailed statistical analysis has been performed to fully optimise a particular item's maintenance policy. Weibull analysis can be useful for this purpose (see Annexes A and C).

REPAIR METHODS

Repair by Replacement

Often, the easiest means of repair is replacement. This approach can be hierarchical; eg. an aircraft may be repaired most expediently by replacing the failed 'black box', which may later be repaired by replacing the circuit card that was found to be faulty. The circuit card may be made serviceable by replacing the faulty component. The faulty component may be discarded, being uneconomical to repair.

Repair by replacement is often the quickest way to return the higher assembly (eg. the aircraft) to a serviceable state, which increases availability. The defective component that was removed can be repaired at a later date. The disadvantage of this approach is that additional spare components must be provided in the pipeline.

Repair by replacement is usually performed on aircraft system components (as opposed to structure), such as instruments, hydraulic components, etc. The replacement is usually carried out at operational squadrons (or a support wing where the squadron has no maintenance capability[2]). The removed component is generally repaired at a deeper echelon of maintenance, such as a depot or contractor.

Repair by Alteration[3]

Some components cannot be feasibly removed from the aircraft for repair. This is generally the case with structural components, which must be repaired in situ. This necessity directly impacts airworthiness, as the aircraft cannot be flown until the damage is repaired.[4]

Aircraft maintenance manuals (typically, Structural Repair Manuals) document processes that can be used to repair certain kinds of failures or damage. These repairs are provided for the problems that are most likely to arise, and can be applied to the aircraft with no additional design or analysis work necessary.[5]

Any damage beyond the documented repair limits, or damage in an area not covered by standard repairs, will require that a new repair be designed and authorised.[6] This can be a time-consuming process, and may need to be referred back to the aircraft's manufacturer.

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2 For example, Nos 36 and 37 Squadrons.

3 Such a repair can be considered to be a modification that is incorporated only when required by the presence of damage. Managing repairs in this manner would certainly improve the configuration management of repaired structures.

4 Often, minor damage is 'carried forward' to be repaired at the next convenient servicing. Doing so requires an assessment that the damage will not result in loss of the aircraft, and will not deteriorate significantly in the meantime.

5 However, it is always wise to consider the engineering implications of the repair. Repairs can interact with other repairs or non-standard configuration structure in ways that were not predicted, which may reduce static strength and/or durability. The incorporation of any repairs must always be documented in aircraft configuration records.

The process by which new repairs are authorised is a Request for Deviation/Request for Waiver (RFD/RFW).[7]

The approval of newly designed repairs is a significant issue. Some repairs may be directly related to airworthiness, in the same way that some scheduled maintenance requirements are safety critical. Accordingly, the level of engineering approval required for such repairs should be similar to that required for scheduled maintenance requirement determinations.[8] However, a critical difference between these two cases is that an aircraft is often grounded while a repair is being designed and approved, and so the pressure to achieve quick approval is frequently greater.[9]

Similar considerations are necessary to allow the (continued) use in service of components that do not meet specified functional performance levels, eg. a hydraulic actuator that marginally fails a test bench check.

Structural repairs can be incorporated by any unit with the required capability. More substantial repairs (typically those beyond repair manual limits) are beyond the scope of operational squadrons, and must be performed by deeper maintenance personnel, often using specialised equipment.

SUMMARY

The amount and nature of unscheduled maintenance required is a by-product of the scheduled maintenance requirements determination process. There are two main ways of effecting repairs: replacement or alteration. Repair by replacement offers the fastest means of returning aircraft to serviceability, but is often not feasible for structural repairs. Alteration of components is necessary when they cannot be removed, or if no spares are available.

Aircraft maintenance manuals document some standard kinds of repairs, but new repairs must be designed when none of these applies. Repair design and authorisation is an important and potentially time-consuming activity, which will often be performed while an aircraft is kept grounded.

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6 Frequently, the damage observed has been found and repaired previously on some other aircraft. In this case, the previous repair design can be reused. When doing so, it is essential to ensure that the repair design is entirely compatible with the newly discovered damage, structural configuration, environment, etc.

7 Previously known as Special Repair Authority (SRA).

8 Admittedly, most repairs will only be applied to a single aircraft (at least initially), so the significance of any errors is limited to that one aircraft; errors in scheduled maintenance requirements can affect the whole fleet (until the error is discovered). However, when airworthiness is concerned, even risking a single aircraft represents high stakes.

9 Repairs for damage noticed during major servicings can often be designed, approved and incorporated without extending the length of the servicing. In such cases, repair design and approval is not on the critical path, and therefore not subject to the same pressure.

The requirement for, and urgency of, unscheduled maintenance increases significantly during a contingency. These issues are discussed in Chapter 15.

Chapter 9
Modification and Configuration

INTRODUCTION

Most forms of maintenance (scheduled and unscheduled) aim to retain or restore the equipment to its normal condition, so that its performance remains unchanged to the maximum extent possible. However, the third form of maintenance, modification, aims to alter the configuration of the equipment to effect some form of improvement. This chapter outlines reasons for incorporating modifications, and means of managing this.

REASONS FOR MODIFICATION

Capability Enhancement

Modifications are frequently generated to improve the capability of equipment. This improvement may take the form of enhanced performance of an existing capability, or the introduction of a new capability (eg. to allow the equipment to perform a new role, or to perform an old role better).

Reliability or Maintainability Enhancement

When an item of equipment is observed to be particularly unreliable or expensive to maintain, there are several strategies that may be adopted to rectify the problem:

a. improve the effectiveness of preventive maintenance;

b. replace the equipment with a more reliable alternative; or

c. modify the equipment (ie. change its physical configuration) to improve its reliability.

The feasibility and cost-effectiveness of each of these alternatives should be compared to determine the best course of action.

Unreliability of safety-critical components equates to airworthiness risk, and this category of modifications is pursued with greatest priority.[1] Triggers to initiate such modifications are defects observed in RAAF equipment, or advice from the manufacturer or other operators.

1 The relationship between airworthiness and criticality is discussed on p. 56.

Unfortunately, the RAAF does not pursue reliability modifications to the ideal extent, especially when availability or cost-effectiveness are the maintenance goals being compromised. Contributing factors include:

a. Unreliability cannot be easily detected by existing management systems. Computer systems do not identify and flag signs of poor reliability (such as low MTBF, excessive maintenance effort, excessive procurement levels, etc). Unreliability is generally only noticed when an operating or maintenance agency becomes aware of repetition. This problem can be rectified by 'smarter' computer systems, and may require additional manpower to be directed to reliability analysis.[2]

b. Much more management effort is required to develop and obtain approval and funding for a modification than to accept overmaintenance and excessive procurement levels. Staffing a modification consumes considerable management effort; procedures to evacuate failed equipment for maintenance or to procure additional items are virtually automatic, being extensively computer-driven and requiring only routine approvals by logistics staff. Rectification of this problem could be achieved by streamlining the modification process, and increasing the accountability of logistics managers for overmaintenance/overprocurement (effectively reducing the expedience of these suboptimal means).[3]

MODIFICATION MANAGEMENT

Fleet-wide Incorporation

The normal way to manage modification incorporation is to require that the modification be applied to all aircraft of the appropriate type. Each modification order specifies the timescale within which the fleet must be modified (often by specifying at which servicing it is to be incorporated).

This approach allows all aircraft to share the same basic configuration baselines; the only differences between aircraft in a fleet are caused by the progressive incorporation of modifications.[4] Aircraft are essentially interchangeable, allowing maximum flexibility in operation and maintenance convenience.

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2 The 'Maintenance Engineering Analysis Candidate Identification' (MEACI) computer application (being proposed by HQLC) aims to monitor the effectiveness of scheduled maintenance programs by assessing failure data, item condition at maintenance, etc. As a bonus, items that would benefit from modification will also be identified by this approach.

3 Many of these problems were identified in a UK study on unreliability in defence equipment, (Report of the MOD(AFD)/MOD(PE)/SBAC/EEA Working Group on Ways of Securing Improved Reliability in RAF Equipment, July 1984). Unreliability is estimated to cost the UK Ministry of Defence about one billion pounds per year (LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993, paragraph 29).

4 Sometimes, individual aircraft configurations vary significantly within a fleet, so that certain modifications either need not, or cannot, be applied to all aircraft of the same type.

Generally, fleet-wide incorporation is the only reasonable option for modifications intended to enhance reliability or maintainability.

'Fitted For but Not With'

When a modification is for a capability that is not immediately required, some parts of the modification can be incorporated initially, with the remainder of the modification to be incorporated when circumstances require it. This approach is known as 'fitted for but not with' (FFBNW). For example, aircraft may be procured with internal wiring and structural attachments required for certain equipment; however, the equipment itself may not be procured at the time.

This strategy is applicable to capability enhancement modifications. Some types of operational equipment may not be procured initially, but the aircraft will be fitted for, but not with, that equipment.

The main advantage of the 'fitted for but not with' approach is the cost saving. The procurement of expensive operational equipment can be deferred until it is needed (if ever). Only equipment actually needed for roles encountered 'in anger' needs to be procured. When equipment is procured, the latest such equipment can be obtained, which is more likely to permit interoperability with allies.

However, there are significant disadvantages to this approach:

a. Aircrew are denied the opportunity of training with the equipment during peacetime, and maintenance personnel are likewise unable to gain experience in its maintenance.

b. Existing documentation (such as checklists, and aircrew and maintenance manuals) will generally not document the use and maintenance of the equipment.

c. The installation of the equipment will often be done in haste at the onset of a contingency. This can cause lower standards of workmanship with consequent impact on reliability. Perhaps more significantly, the aircraft must be removed from service prior to the contingency for such modification incorporation, and may not be available as soon as is operationally desirable. Aircraft availability is a high priority during the work-up period before a contingency to permit increased and specific training to be undertaken.

d. There is a risk that the pre-installed infrastructure (eg. wiring, plumbing, attachments) may not actually be fully compatible with the equipment finally fitted. This can occur due to updates to the equipment to be fitted between the time of procurement of the aircraft and the final realisation of the FFBNW capability. Organisational and policy changes can also render the FFBNW effort nugatory.[5]

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5 These last two issues are further discussed (with examples) in Chapter 17.

Partial Fleet Modification

Many of the disadvantages of the 'fitted for but not with' approach can be at least partially alleviated by fitting the equipment to a subset of the fleet. Aircrew may gain experience on the equipment when flying the aircraft fitted with it; procedures for its use can be properly determined and documented in advance of fleetwide incorporation; and there is greater assurance that the infrastructure installed in aircraft not fitted with the equipment will be compatible with the equipment.

The main disadvantage of partial fleet modification is the need to carefully manage the diversity of aircraft configurations that may occur across the fleet. There is greater cost involved than 'fitted for but not with', and there is still a need to incorporate the modification fleetwide at the onset of a contingency (although this should occur somewhat more quickly).

Partial fleet modification and 'fitted for but not with' can be used in parallel. Some aircraft may be fully modified, and the remainder of the fleet fitted for but not with the equipment. The RAAF will be taking this approach with certain items of equipment for the new C-130J Hercules fleet.

Non-Standard Modifications

Non-Standard Modifications (NSMs) can be used when a modification is only to be applied to a single aircraft, such as when installing instrumentation on an aircraft for a particular set of trials. The approval process for NSMs differs from other types of modifications. NSMs are used extensively by Aircraft Research and Development Unit (ARDU).

SPECIAL TECHNICAL INSTRUCTIONS

Special Technical Instructions (STIs) can be used to issue engineering directives of a more urgent nature. A common use of STIs is to institute an inspection of all components of a certain type, to determine their condition with regard to a recently discovered failure mode.

STIs should preferably not be used to alter the configuration of equipment. This should be managed by other means, such as Requests for Deviation/Requests for Waiver or modification orders. However, occasionally STIs will be issued which effect configuration changes for reasons of expedience. Such STIs must be carefully managed, akin to modifications.

SUMMARY

Modifications may be undertaken to enhance equipment capability, or to improve reliability or maintainability. Modifications in the latter category may enhance any of the maintenance goals, such as airworthiness, availability and cost-effectiveness; however, current RAAF information systems and management processes tend to limit the use of modifications to improve availability and cost-effectiveness.

Modifications can be fully incorporated fleet-wide, partially incorporated ('fitted for but not with'), fully incorporated on a subset of the fleet, or a combination of the latter two approaches. Over-reliance on the fitted for but not with approach can cause operational and maintenance difficulties.

Modification activity appropriate to contingency operations is discussed in Chapter 17.

Chapter 10
Maintenance Management

INTRODUCTION

Previous chapters have outlined means of determining the various kinds of maintenance requirements. Having determined the requirements, detailed planning and scheduling is necessary to ensure that the requirements are actually met, and are managed efficiently. This chapter deals with some of the methods used to manage maintenance requirements.

ON-AIRCRAFT MAINTENANCE MANAGEMENT

Maintenance of the aircraft as a whole (ie. on-equipment maintenance) has a direct impact on availability, as the aircraft cannot be flown while it is undergoing maintenance. There are two facets of aircraft servicing management: the overall management of the aircraft fleet as a whole, and the detailed management of the servicing of individual aircraft.

Periodic Servicing Concept

An important aim in scheduling aircraft maintenance is to achieve a regular flow of aircraft into and out of maintenance. This smooths out the maintenance workload (allowing a minimum number of people to be dedicated to such duties), and provides a fairly constant number of aircraft on-line (available for tasking).

For aircraft with periodic servicings,[1] a smooth flow of aircraft through maintenance is achieved by evenly distributing the servicings over time (see Figure 10-1). This is managed in practice by staggering the fleet's maintenance lives, so that aircraft with longer to wait for their next servicing have more maintenance life remaining. Where the maintenance life is measured in terms of usage (eg. airframe hours), perturbations in the smoothness of the stagger can be adjusted by varying the flying rates of individual aircraft.[2] Multiple stagger charts are frequently used to manage the various routine servicings (ie. servicings of different intervals).

1 Most of the RAAF fleet uses a periodic servicing concept.

2 This is only effective within limits: there is a maximum intensity with which any one aircraft can be tasked, which is often limited by the need to perform other (lesser) maintenance tasks. Extended periods of unscheduled downtime, such as for a major repair, can upset the stagger; in such cases, aircraft may need to exchange places ('leap-frog') on the stagger.

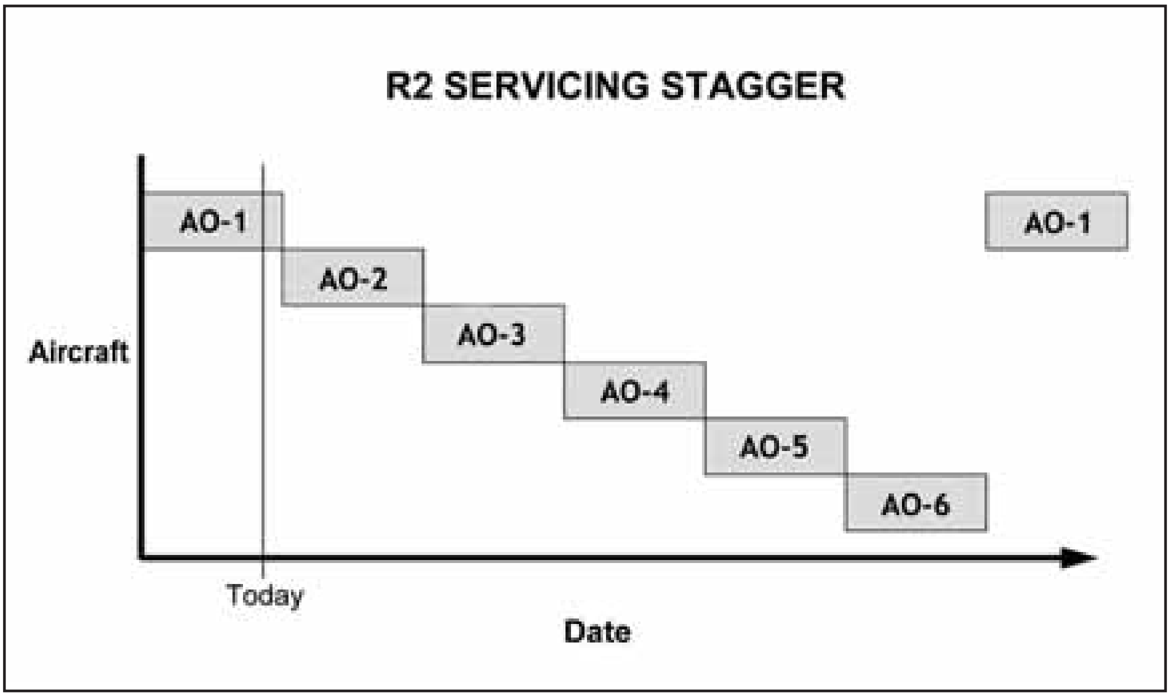

Figure 10-1: Aircraft Scheduled Servicing Stagger Chart

The Computer-Aided Maintenance Management (CAMM) system provides some assistance in stagger management. It monitors the maintenance lives, time to next servicing, and usage of each aircraft, and is able to show the flying rates necessary for each aircraft to maintain a smooth stagger.

Phased and Flexible Servicings

CAMM does not provide direct support for phased servicings, but can be used to manage them with some limitations.

CAMM has no capability to control flexible servicings at this stage. However, a specification for a system change to introduce this capability has been drafted.

Servicing Management

Scheduled servicings invariably include more than just scheduled maintenance, as there are significant efficiencies to be gained by performing as much maintenance work as possible during the one period of downtime. The requirement for unscheduled maintenance will be identified as a result of scheduled inspections performed, and some scheduled or unscheduled work may have been deferred to be performed until a more convenient time (such as a major scheduled servicing). Modifications are also frequently incorporated during scheduled servicings.

As a result, the duration of a scheduled servicing is usually somewhat longer than the minimum period necessary to perform the scheduled maintenance tasks alone.[3] Because the details of the unscheduled maintenance required cannot be accurately predicted in advance, and because of the need to incorporate modifications at the same time, a flexible management system is necessary to be able to efficiently manage an aircraft servicing.

Simpler servicings can be managed using standard paperwork systems to task, and coordinate, the sections and tasks necessary. More complex servicings are best managed using some form of Program Evaluation and Review Technique (PERT). A PERT chart shows the various tasks that need to be performed, and the relationships between them. Computer packages can be used to reschedule the tasks when confronted with unscheduled arisings, delays (such as late arrival of spares), resource (eg. manpower) constraints, etc.

Crucial to the PERT approach is the critical path. A maintenance task is on the *critical path* if it would cause the duration of the servicing as a whole to be extended if the task itself was extended or delayed. Other tasks are said to have some *slack*; they may be delayed or extended without causing the servicing as a whole to be extended. However, if such delays are too long, tasks previously not on the critical path may become on the critical path (possibly displacing some tasks previously on the critical path). The effect of delays, extensions or the addition of new tasks effectively causes the critical path through the network of tasks to change.

OFF-AIRCRAFT MAINTENANCE MANAGEMENT

Off-equipment maintenance of items will not affect aircraft availability—unless there are insufficient spare serviceable items in the maintenance pipeline. Efficient off-equipment maintenance will reduce the number of 'surplus' items that must be procured to minimise the probability of availability delays. The scheduling of off-equipment maintenance must be closely linked to the pipeline's requirements.

Another advantage of effective off-equipment maintenance scheduling is that it can result in a smoother maintenance workload (as with on-equipment maintenance scheduling).

The requirements for off-equipment maintenance scheduling are different to those for on-equipment maintenance. There are much closer parallels with the manufacturing industry, where component production schedules must be co-ordinated to ensure that the final product can be assembled with a minimum of delays. Accordingly, many RAAF and contractor deeper maintenance facilities use some variation of systems developed for industrial purposes.

3 Squadron Leader M.W. Cornwall, Squadron Leader G.D. Evans, Squadron Leader C.G. Wheaton, and Flight Lieutenant G.C. Saunders, DLDP AF91/7557 Pt 1 (14), *A Study of RAAF Aircraft Availability and Cost Factors*, Directorate of Logistics Planning and Development, 17 September 1991, shows that some 56 per cent of RAAF maintenance is unscheduled and 37 per cent is scheduled (the balance is modification/STI). It should therefore not be surprising that much, if not most, of a scheduled servicing consists of unscheduled work.

In the RAAF, there are currently three modern depot resource management systems in use, or under consideration. They are:

a. Manufacturing Resource Planning II (MRP II).[4] MRP II is a formal method for planning the allocation of all resources (manpower, parts, equipment, etc) of a manufacturing company.[5] It centres around a production schedule, which determines the timing necessary for each subprocess in a manufacturing (or maintenance) process.

b. Just-In-Time Management (JIT). JIT builds on MRP II, and aims to achieve significant and continuous improvement in performance by eliminating all waste of time and resources in the total business process.[6] JIT's production schedule aims to maximise the use of available capacity by delaying schedules until as late as possible (while still meeting deadlines).

c. Theory of Constraints (TOC). TOC is a synthesis of MRP, JIT, statistical process control methods, and elements of Total Quality Management (TQM).[7] It advocates a continual cycle of identifying and alleviating process constraints (similar to PERT's critical path), and managing process capacities according to the most constrained part of the process.

IMPROVING MAINTENANCE EFFECTIVENESS

In some circumstances, maintenance effectiveness can be improved by making non-standard alterations to the maintenance schedule, or by adopting tactics that can reduce the impact of delays in the receipt of necessary parts.

Maintenance Interval Extensions

Scheduled maintenance documentation specifies the life of the component at (or before) which it must be withdrawn from service for maintenance. It is often convenient to extend the maintenance interval on one or more items on a particular aircraft as a one-off dispensation. Examples include:

a. A particular aircraft may need to be flown overseas or on deployment for an extended period, during which a scheduled servicing will become due.

b. A component may be due for its scheduled maintenance, however the aircraft to which it is fitted is nearly due for a servicing of its own. Delaying the component's

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4 In some sources, MRP stands for *Material Requirements Planning*.

5 *Manufacturing Excellence Course Book*, David W. Buker (Australasia) Pty Ltd, Artarmon NSW, 1991, p. 1-5.

6 loc cit.

7 E.M. Goldratt and J. Cox, *The Goal*, North River Press, New York, 1986.

servicing to align it with that of the aircraft will avoid the downtime necessary to remove the component.

Extensions can often be granted because the risk of failure does not increase dramatically as soon as the specified life is reached. Maintenance intervals are often conservative (ie. shorter than necessary) because of the difficulties in determining the exact optimum policy, and because of the need to group individual tasks into discrete servicings.

The increased risk of failure can be balanced with the operational or maintenance benefit that would result from approving the interval extension. Logistics Management Squadrons are responsible for evaluating and approving most maintenance interval extension requests; small extensions of non-critical items can be approved by unit Senior Engineering Officers.

Carried-Forward Unserviceabilities

Carried-Forward Unserviceabilities (CFUs) are similar to maintenance interval extensions, but they apply to *unscheduled* maintenance. As soon as damage requiring repair is discovered, the aircraft or component is considered unserviceable. However, repair may be deferred until a more convenient time if the damage is unlikely to cause an accident, or get significantly worse, in the meantime.

Unit engineering staff perform the assessment and authorisation of CFUs.[8]

Cannibalisation

Cannibalisation involves removing a serviceable component from one aircraft (or higher assembly) and fitting it to another, to make the latter serviceable. This may be worthwhile when the first aircraft was to be grounded for an extended period (such as a servicing or repair), and the second aircraft was in need of a component that could not be obtained through the supply system within the timescale required. Cannibalisation allows at least one of the aircraft to be made serviceable faster, and thus provides an improvement in availability.

However, the price of improved availability is increased maintenance effort. The work involved in removing the cannibalised part from one aircraft and fitting to the other could have been avoided if a spare part had been available through the supply system. However, because of the unpredictable nature of demands on the supply system, there will always be some possibility that items will not be available when required. In these circumstances, cannibalisation offers a means of delivering aircraft from maintenance with less delay than would otherwise have resulted.

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8 The approval of CFUs is a technical airworthiness responsibility, the authority for which must therefore derive from Headquarters Logistics Command. However, there is no documented delegation or guidelines on the application of CFUs at this time.

An extension of the cannibalisation concept is the ‘Christmas tree’ or ‘hangar queen’ aircraft. One aircraft is used to supply parts to many others, and so all of the other aircraft’s unserviceable components become consolidated against the one airframe. This practice again allows availability to be maximised in the face of spares delays, but can result in the ‘Christmas tree’ aircraft being grounded for extended periods of time, as it cannot be returned to service until all of the delayed spares are finally delivered. If an aircraft is kept on the ground for too long, some forms of degradation can occur, eg. to seals and other components that benefit from the lubrication they receive in service. This degradation further compounds the difficulties in returning the aircraft to service, and increases the inefficiency of the process. The use of a ‘Christmas tree’ aircraft is therefore best restricted to shorter timeframes, aircraft procured for especially the purpose, or aircraft that could not otherwise be made airworthy. If necessary, a second aircraft can become a ‘Christmas tree’ after the first is returned to service.

Because of the inefficiency of the cannibalisation process it is strictly controlled, with only certain unit personnel authorised to approve cannibalisations.[9] Regular reports on cannibalisation rates are available from the Maintenance Analysis and Reporting System (MAARS).

The incidence of cannibalisation can be reduced by increasing holdings of spare items, to minimise the likelihood of a demand peak reducing spares holdings to zero. However, holding excess stocks ‘just in case’ also costs money (and other resources), and is another form of inefficiency. A balance must be struck between the levels of surplus stocks and the frequency of cannibalisation.

Fly-Away Kits

Maintenance efficiency and effectiveness are very dependent on the availability of necessary spare parts, tools and equipment. When an operational unit deploys, they take with them a Fly-Away Kit (FAK), which should contain all the spares, tools and ground support equipment considered necessary to support the deployment for a period of 30 days.[10] It effectively takes the place of the supply pipeline system during the deployment (or the first part thereof).

Determination of the optimum contents of FAKs is very difficult. The contents should cover requirements for any scheduled servicings that are to be performed, and also provide for any unscheduled maintenance that may be required. The size of FAKs is constrained by the space that can be made available on transport aircraft or vehicles supporting the deployment.

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9 DI(AF) LOG 2-17, *Transfer of Components between Aircraft or other Technical Equipment*, 11 November 1992.

10 DI(AF) LOG 7-5, *Flyaway Kits*, 9 December 1992.

11 OVR and OVP are introduced on p. 23.

Any inadequacies in the contents of the fly-away kit can result in aircraft being grounded. Additional spares may need to be delivered to the deployment, parts may need to be repaired on deployment that normally would not be, or deployed aircraft may need to be exchanged with non-deployed aircraft, depending on the circumstances.

The FAK is the primary form of Operational Viability Resources (OVR) used in support of maintenance in the RAAF.[11] FAKs should be stocked to permit *contingency* (as opposed to exercise) operations for the duration of the OVP specified in the CPD. Failure to do so effectively means that preparedness requirements probably cannot be met.

SUMMARY

The management of on-aircraft maintenance for an aircraft fleet is usually effected by the use of a stagger chart (or equivalent). This is simplest for periodic servicings, and most difficult for flexible servicings. Within individual aircraft servicings, the PERT method provides a way to flexibly and efficiently integrate the requirements for scheduled and unscheduled maintenance, and modification incorporation.

Different methods may be used to manage off-aircraft maintenance tasks, since the indirect impact of off-aircraft maintenance on availability allows further efficiency gains to be pursued. Modern methods for depot-type production management include MRP II, JIT and TOC.

A number of management expedients may be adopted to increase the efficiency and/or effectiveness of maintenance. These include maintenance interval extensions, CFUs, cannibalisation, and the provision of fly-away kits (FAKs).

Many of the processes described in this chapter have particular applicability to, or need to be adapted to suit, contingency maintenance requirements. These issues are discussed in Chapter 23.

Chapter 11
Factors Affecting Maintenance Requirements

INTRODUCTION

Chapter 6 listed four goals of the maintenance function: high airworthiness, high missionworthiness, high availability, and high cost-effectiveness. In addition, the time dimension was accounted for by the terms mission generation and preservation of the asset. Other factors, such as operational capability and flexibility, should also be considered when determining maintenance requirements.

This chapter discusses how the various operational and maintenance goals affect the maintenance requirements determination process. The goal is to determine general trends concerning the nature and amount of maintenance appropriate to each of the goals.

Definitions and Assumptions

The terms *scheduled maintenance* and *preventive maintenance* will be considered to be virtually synonymous in this chapter. Properly, scheduled maintenance consists of preventive and *surveillance* maintenance; the latter, in itself, has no preventive effect. However, properly used, surveillance maintenance will trigger preventive maintenance when necessary, and so the aim of all scheduled maintenance tasks is preventive.

Similarly, *corrective* maintenance is synonymous with unscheduled maintenance, even though it may be performed within (or simultaneously with) a scheduled servicing.

The discussion in this chapter focuses primarily on setting scheduled maintenance levels, and therefore applies mainly to items for which scheduled maintenance is appropriate and effective (see Chapter 7).

THE RELATIONSHIP BETWEEN SCHEDULED AND UNSCHEDULED MAINTENANCE

The maintenance function can vary performance against the various goals by adjusting the balance between scheduled and unscheduled maintenance for each component in an aircraft. Different goals usually require a different balance for at least some components. The nature of the relationship between scheduled and unscheduled maintenance is therefore the key to understanding how to maximise performance against any one goal, or how to achieve a balance between various conflicting goals.

The aim of performing *scheduled* maintenance is to reduce the number of failures that occur; this also avoids having to perform some *unscheduled* maintenance.[1] Because of the probabilistic nature of failures, no amount of scheduled (preventive) maintenance can ever entirely remove the possibility of failure in service (see Figure 11-1[2]). By performing scheduled maintenance frequently (ie. before the time since last maintenance gets too high), the probability of failure can be kept low, effectively chopping off the centre and right-hand-side of the graph. However, *as soon as* the item is used in service, there is some possibility of failure. The graph shows that the only way to totally avoid any possibility of failure is to perform scheduled maintenance at a life of zero; ie. continually!

Increasing the amount of *scheduled* maintenance will generally reduce the frequency of failures. Therefore, a balance needs to be struck between the amount of scheduled maintenance undertaken, and the number of failures that occur (and hence the amount of unscheduled (corrective) maintenance required).

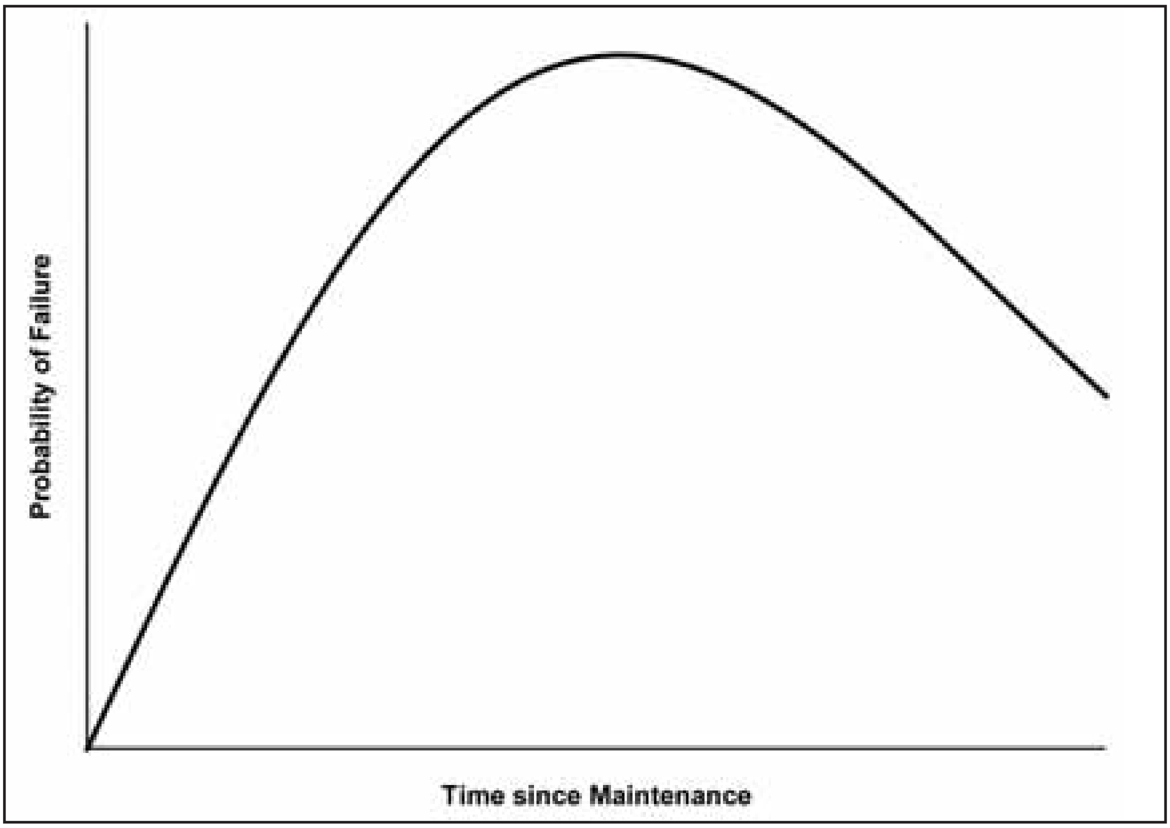

Figure 11-1: Failure Probability Density Function

1 Of course, it also reduced the risk of aircraft accidents and failed missions.

2 Figure 11-1 depicts a 'Probability Density Function'. It shows the probability of an item failing, against the item's age since last (effective) maintenance action. This particular graph corresponds to a very strong wear-out failure pattern (ie. predominantly long-life failures). The reduction in probability of failure on the right-hand-side of the graph does not indicate that the items are getting more reliable, but that most have already failed at an earlier time, and so only a small proportion of items survive long enough to fail at a great age. See also Annex A.

If no scheduled maintenance is performed, all maintenance work will be unscheduled, ie. performed in response to failures.[3] However, for many components, scheduled (preventive) maintenance is desirable; in such cases, the amount of unscheduled maintenance required is reduced compared to what would be required if no scheduled maintenance were to be performed.[4]

The amount of scheduled maintenance can be varied, either by increasing its frequency, by adding extra tasks (to prevent more failure modes), or by adding more thorough tasks. Up to a point, performing more scheduled maintenance reduces the amount of unscheduled maintenance. At some stage, further reductions in the amount of unscheduled maintenance do not occur. Furthermore, an excess of scheduled maintenance often results in an increase in unscheduled maintenance due to maintenance errors, 'infant mortality' of newly fitted components, etc—this is referred to as *over-maintenance*.

The general relationship between the amount of scheduled maintenance and the amount of unscheduled maintenance is shown at Figure 11-2.

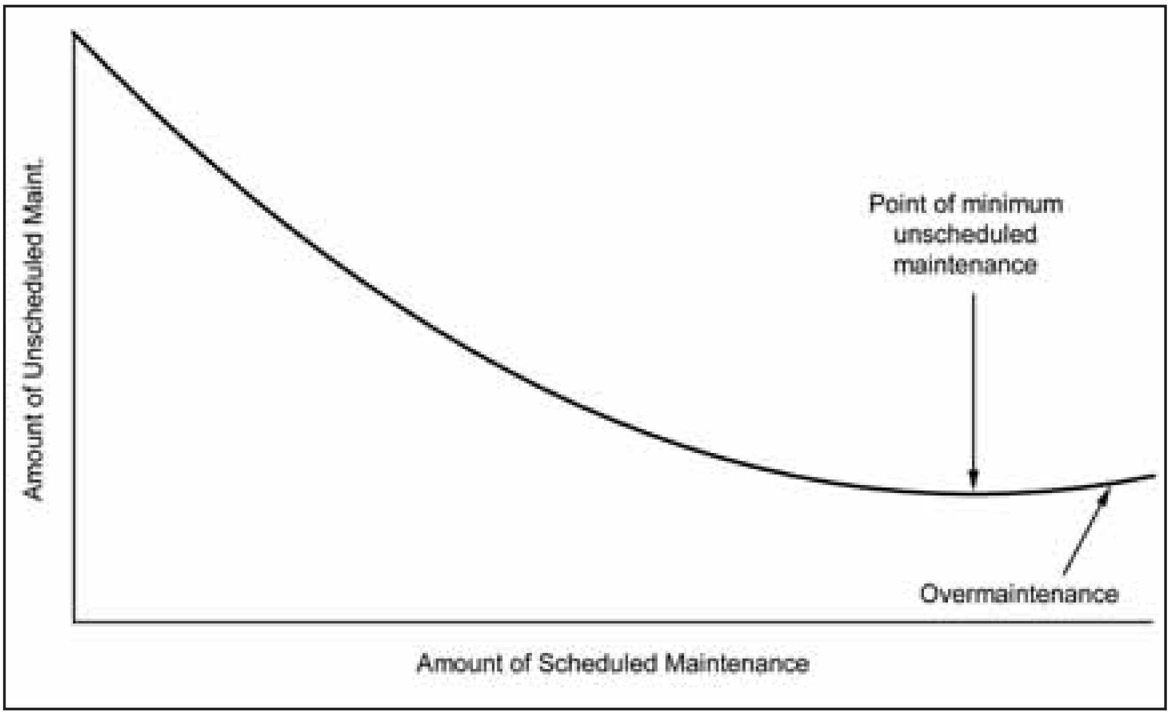

Figure 11-2: Unscheduled vs Scheduled Maintenance[5]

3 Sometimes this is the appropriate maintenance policy to adopt for an item. The issues that need to be considered to determine whether an item should be (preventively) maintained are discussed in Chapter 7.

4 The 'amount of unscheduled maintenance' includes cases where items are discarded and replaced, not just cases where items are repaired. The term will be more precisely (and variously) defined when used to draw specific conclusions later in this chapter.

5 This graph is loosely based on I. Bazovsky, *Reliability Theory and Practice*, Prentice-Hall, New Jersey, 1961, Figure 20.1. However, both axes have been inverted, and some account for the effect of overmaintenance has been included.

The relationship shown in Figure 11-2 applies generally to components where scheduled maintenance is justified. Because many components in an aircraft justify scheduled maintenance, the graph also represents the relationship that may be expected for an aircraft taken as a whole (ie. for all components combined).

This general relationship can be used to determine how to maximise performance against some of the conflicting goals of a maintenance program; ie. how to maximise airworthiness, missionworthiness, availability or cost-effectiveness.

AIRWORTHINESS

Individual Components

Airworthiness is maximised by minimising the probability (risk) of failures of safety-critical components occurring in service. A version of Figure 11-2 is therefore required where the 'amount of unscheduled maintenance' is measured in terms of the number of failures of safety-critical items that occur in service (Figure 11-3). The point of maximum airworthiness corresponds to the maximum amount of scheduled maintenance, short of the onset of over-maintenance problems.

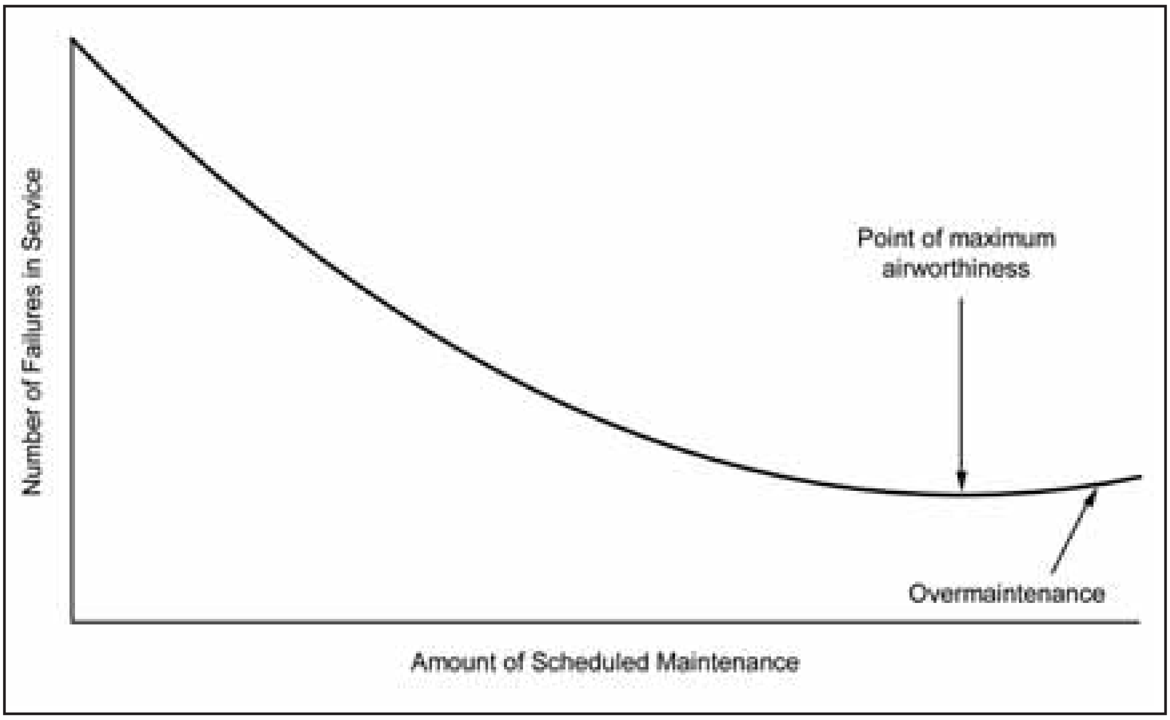

Figure 11-3: Failures vs Scheduled Maintenance

Whole Aircraft

The airworthiness risk to the aircraft as a whole depends on the risk of failure of individual safety-critical components. Some safety-critical components are more likely to have catastrophic results if they failed compared to other safety-critical components. For each component, a criticality rating can be estimated which takes into account the seriousness of failure and its frequency of occurrence.[6] The airworthiness risk to the whole aircraft is the sum of all the criticality ratings for all safety-critical items.[7]

The airworthiness risk to the aircraft is obviously minimised by minimising the individual components' criticality ratings. The component's effect (seriousness) of failure is largely determined by the aircraft design; however, the frequency of occurrence of failure can be influenced by the amount of scheduled maintenance.[8] Therefore, to maximise airworthiness, the amount of scheduled maintenance that minimises the number of failures in service for every safety-critical component should be adopted.[9]

The most important components to 'get right' are those with the highest criticality rating, and for which scheduled maintenance is most effective. A 'maintenance criticality rating' could be assigned for each item (or failure mode), being the product of the effectiveness of scheduled maintenance[10] and the failure criticality rating (itself the product of failure effects and frequency).

Roughly 20 per cent of aircraft maintenance-managed items are rated as safety-critical.[11]

MISSIONWORTHINESS

The maintenance considerations necessary to maximise missionworthiness are equivalent to those for airworthiness, except that the focus becomes mission-critical items, rather than safety-critical items.[12]

Roughly 30 per cent of aircraft maintenance-managed items are rated as mission-critical.[13]

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6 This approach is Failure Modes, Effects and Criticality Analysis. See p. 50.

7 Properly, safety-critical *failure modes*. Non-safety-critical failure modes of otherwise safety-critical items do not adversely affect airworthiness, and should not be counted.

8 ...assuming that the component either wears out or has a usefully long failure detection period; see Chapter 7.

9 More accurately, the amount of maintenance that minimises the frequency of occurrence of safety-critical failure *modes* should be adopted.

10 That is, how sensitive the item's failure rate is to changes in scheduled maintenance policy.

11 The RAAF's current means of assigning criticality can result in safety-critical items being rated as mission-critical if they possess sufficient redundancy. Therefore, the actual percentage of items that are truly safety-critical will be somewhat higher than this estimate.

12 Actually, failure *modes*, not items.

13 The RAAF's current means of assigning criticality can result in safety-critical items being rated as mission-critical if they possess sufficient redundancy. Therefore, the actual percentage of items that are truly mission-critical will be somewhat lower than this estimate.

AVAILABILITY

When considering airworthiness, the amount of unscheduled maintenance was equated to the risk of component failure. When considering availability, the amount of downtime (lost availability) incurred as a result of maintenance (both scheduled and unscheduled) must be considered.

Individual Components

Aircraft availability is most directly affected by the downtime associated with maintenance.[14] A variant of Figure 11-2 is therefore necessary that measures the 'amount of unscheduled maintenance' in terms of impact on aircraft availability. The vertical axis in this case should be the number of hours of downtime[15] required annually to restore the aircraft to serviceability.

In many cases, the aircraft will be restored to serviceability by simply replacing the failed component with a serviceable spare. In this case, the time required to do so is the only cost to availability. The actual time taken to effect repairs has no direct impact, and should not be considered.[16] (The impact of spares delays should ideally be included at this stage, as these will effectively increase downtime.[17])

To permit comparison between the downtime due to scheduled and to unscheduled maintenance, the horizontal axis must be the same as the vertical axis: the number of hours of downtime[18] required annually to perform maintenance. Figure 11-4 shows these adaptations to Figure 11-2.

Figure 11-4 does not indicate the maintenance policy that gives maximum availability (for this item). The point of minimum downtime due to *unscheduled* maintenance will *not* be the overall minimum, since there is also some downtime due to *scheduled* maintenance that needs to be considered. It is necessary to create a graph based on Figure 11-4 that shows the *total* amount of downtime due to maintenance (both scheduled and unscheduled).

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14 Squadron Leader M.W. Cornwall, Squadron Leader G.D. Evans, Squadron Leader C.G. Wheaton, and Flight Lieutenant G.C. Saunders, DLDP AF91/7557 Pt 1 (14), *A Study of RAAF Aircraft Availability and Cost Factors*, Directorate of Logistics Planning and Development, 17 September 1991, shows that 88 per cent of aircraft unavailability is attributable to maintenance activity.

15 *Not* manhours of work required.

16 A more detailed approach would consider the impact on availability that results from the need to allocate resources to maintain a maintenance pipeline for repairs.

17 The relationship between maintenance policy and supply delivery performance is complex; an appropriate method to study the interaction of such systems is *System Dynamics*: see Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994, Chapters 9 and 10.

18 *Not* manhours of work.

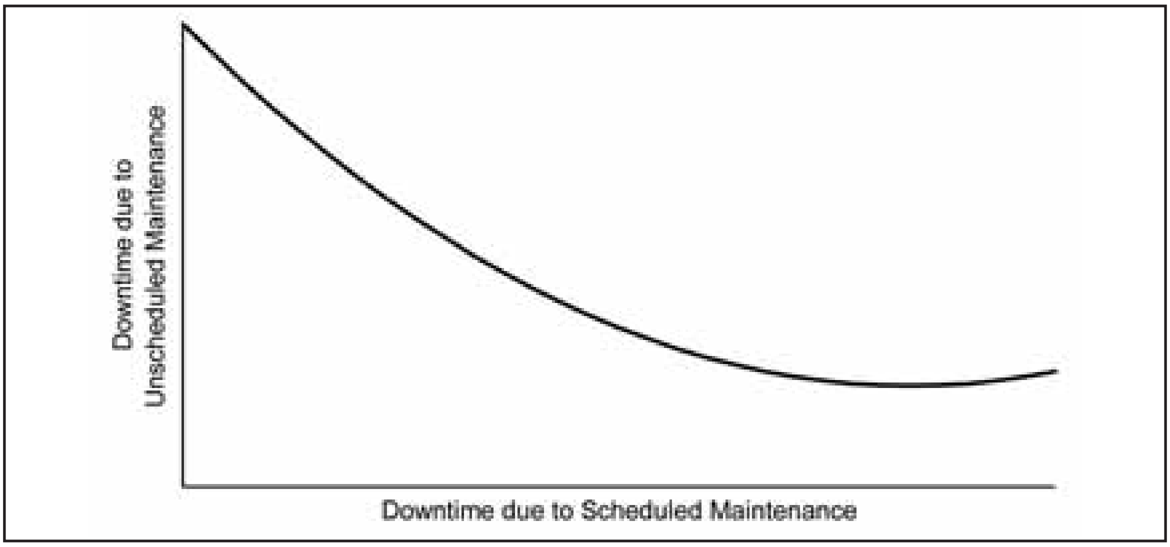

Figure 11-4: Unscheduled Downtime

Figure 11-5 is the same as the previous Figure except that the vertical axis has been generalised to become simply 'downtime'. The single line on Figure 11-4, representing unscheduled maintenance, is drawn as a dashed line in Figure 11-5. The effect of scheduled maintenance is represented as a continually increasing dotted straight line (since this is the parameter on the horizontal axis[19]). 'Total' is the sum of the scheduled and unscheduled contributions to downtime (solid line).

The point at which the minimum (total) downtime occurs is marked on Figure 11-5 ('point of maximum availability').[20]

The point of maximum availability is somewhat to the left of the point at which the minimum downtime due to *unscheduled* maintenance occurs. This is because the imposition of additional scheduled maintenance does not result in significant reductions in unscheduled maintenance in this part of the graph (the unscheduled maintenance curve is fairly flat). Accordingly, a policy to maximise availability (for this item) results in accepting a level of unscheduled maintenance (ie. in-service failures) somewhat greater than the absolute minimum level achievable.[21]

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19 A graph where the horizontal and vertical axes plot the same parameter (eg. x versus x) must always be a line like this. It is equivalent to plotting the equation y=x. The reason that the line is not at a 45° angle is that the scales on the axes are different.

20 Downtime can result from other causes, eg. spares shortages. However, all else being equal, this point corresponds to maximum availability.

21 Because the axes on the graph here represent availability loss rather than the number of failures in service (as in Figure 11-3), the point of minimum unscheduled maintenance does not necessarily represent the point of minimum risk (or maximum airworthiness). However, there will be a close relationship between the two measures (availability loss due to unscheduled maintenance, and number of in-service failures), so the two points should roughly coincide. This issue is discussed in more detail later in this chapter.

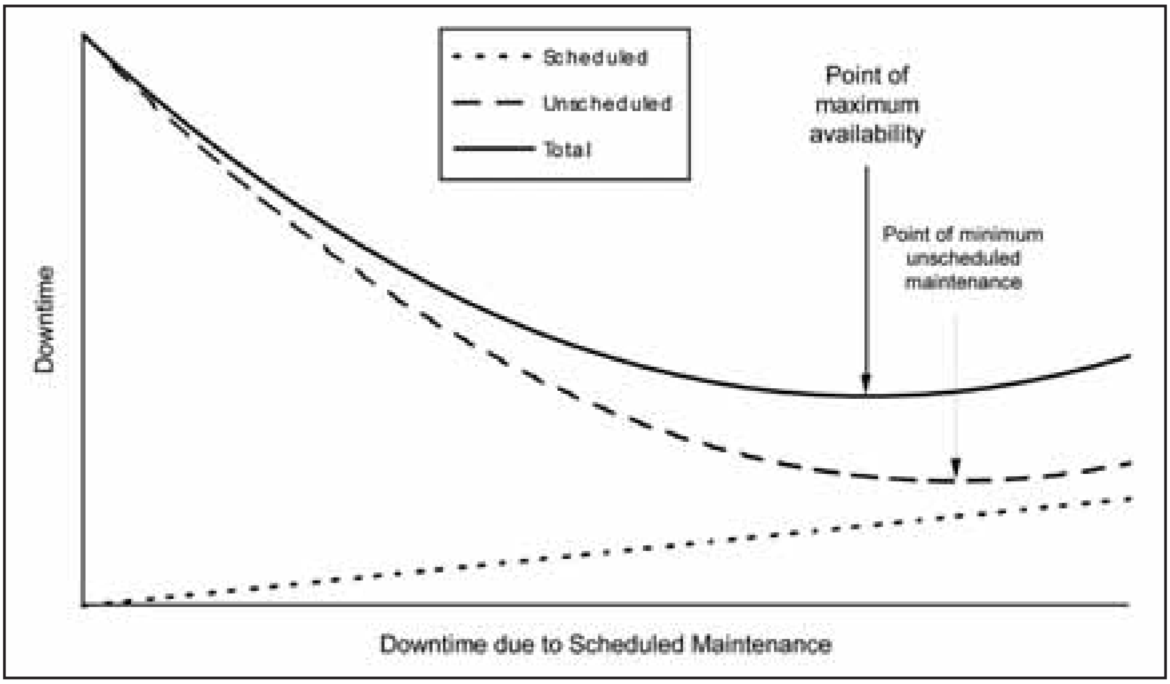

Figure 11-5: Downtime

There is increased risk in accepting a level of unscheduled maintenance greater than the minimum. Unscheduled maintenance arises as a result of failure (or other unsatisfactory condition). If the component is safety-critical, failure may result in the loss of the aircraft. Such aircraft attrition reduces fleet availability, so the saving in maintenance downtime may not equate to optimum availability overall—a case of sub-optimisation.

Other failures may be of mission-critical components, and failure may result in aborted or unsuccessful missions. The 'availability' of aircraft that are not reliably capable of executing missions is also undesirable, and is another case where minimising downtime due to maintenance can result in sub-optimisation.

Another reason why the point of minimum maintenance downtime may not correspond to maximum availability is the effect on the supply system. The supply requirements for scheduled maintenance are more predictable, to the extent that standard 'bills of material' are being constructed for several scheduled maintenance tasks performed within the RAAF. This more predictable usage allows better determination of stockholding levels, and increases the probability that demands can be satisfied from existing stocks. Unscheduled maintenance requirements generally arise from item failure; the parts needed to repair an item, and any other items that may also have failed as a consequence, are much less predictable. Moreover, the timing of failures is basically random, whereas the timing of scheduled requirements can be predicted in advance. Spares delays are therefore more likely for unscheduled maintenance, which will adversely affect availability. It is even possible that the increase in spares delays could outweigh the reduction in total 'hands-on' maintenance time achieved by minimising total, as opposed to unscheduled, maintenance.

However, between the point of minimum *unscheduled* maintenance and the point of minimum *total* maintenance, the increase in unscheduled maintenance is slight. Furthermore, the impact of increased unscheduled maintenance on in-service reliability can be minimised by judicious choice of the scheduled maintenance tasks that are deferred or dropped. Scheduled tasks that are performed on items to prevent failure modes that are neither safety-critical or mission-critical may be considered discretionary, and may be dropped or deferred with little risk to airworthiness or missionworthiness. (Such tasks are often performed because it is frequently more cost-effective to avoid a failure than to repair one.)

For the sake of simplicity, the adverse effects of the small increase in unscheduled maintenance will be neglected. Maximum availability will be assumed to occur at the point of minimum total maintenance downtime.

Whole Aircraft

Aircraft downtime consists of downtime associated with scheduled servicings and that associated with unscheduled arisings. Aircraft scheduled servicings comprises both scheduled and unscheduled maintenance (the latter either detected during, or deferred until, the servicing). As a result of these complex relationships, there is no simple way to translate individual component downtime into aircraft downtime.

For scheduled servicings, maximum availability for an aircraft as a whole is achieved by minimising the duration of the servicing. This is done by minimising the duration of those maintenance tasks which are on the servicing's *critical path*.[22] This is an iterative process, since minimising the duration of those tasks initially on the critical path may cause other tasks to then occur on the (new) critical path. These should then be minimised, potentially placing yet other tasks on the critical path, which should be minimised, and so on. This process should continue until the duration of all of the tasks on the (final) critical path have been minimised.

Thus, determination of which components should have their maintenance policy adjusted to minimise downtime depends on the organisation of the servicing.

The situation for unscheduled arisings is somewhat simpler, since generally only a single task needs to be done at any one time. Minimum unscheduled downtime for the aircraft is achieved by minimising the incidence of unscheduled maintenance for all of its components. This may be overly conservative, since some unscheduled maintenance may be deferred until a more convenient time when the task may not impact availability to the same extent.

Many components are maintained or repaired off-aircraft. The impact of this work on aircraft availability will be limited to the time taken to remove the component and replace the component with a spare (assuming one is available). Accordingly, the downtime associated with such tasks should be the removal and refit time, not the component's turn-around time (TAT) or time to make serviceable (TMS).

22 See p. 85.

A simplifying approximation is to assume that minimising the total downtime of all components will minimise the downtime of the aircraft as a whole. This assumption errs slightly on the side of too much unscheduled maintenance, since many scheduled tasks will not affect aircraft downtime as they will not be on the servicing's critical path. Accordingly, some slight bias towards component scheduled maintenance requirements should be introduced to minimise aircraft downtime. To permit comparisons between maintenance policies later in this chapter, the assumption that minimum total component maintenance equates to maximum aircraft availability will be adopted.

COST-EFFECTIVENESS

Individual Components

Scheduled maintenance for a component is cost-effective when the following conditions are met:[23]

a. the component exhibits a wear-out failure pattern (or a long failure detection period);

b. the cost of repairing a failure or replacing the item exceeds the cost of a scheduled servicing for the component; and

c. the scheduled servicing is effective in reducing the probability of failure of the item (ie. 'resetting' its life).[24]

To illustrate how maintenance cost varies with the amount of scheduled maintenance, the relative cost of repairing a failure (maybe by replacement) compared to the cost of performing a scheduled servicing must be estimated. There are a number of factors that should be taken into account when estimating maintenance costs:

a. component (and subcomponent) replacement costs, where necessary;

b. cost of hands-on maintenance;

c. transportation costs (including evacuation from the area of operations);

d. inventory holding costs (eg. warehousing);

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23 Cost here includes all aspects that can be converted into a dollar value (regardless of how difficult that may be).

24 *Relcode Reliability and Replacement Analysis Using the Weibull Distribution*, Albany Interactive Pty Ltd, Victoria, 1991, p. 85, lists the first two points (except for mention of the failure detection period) as they apply to a simple 'maintain-by-replacement' policy. The third condition is necessary to generalise from a replacement policy to a maintenance policy.

e. cannibalisation costs; and

f. cost of downtime (lost availability).[25]

The last-mentioned item here is particularly difficult to quantify in the military environment. Commercial operations such as airlines are able to cost down-time based on lost revenue, ie. cancelled flights. Delayed flights can also cause paying customers to turn to the competition—permanently, if the airline gets a reputation for unreliability. Airlines find that the cost of unavailability and mission failure swamps the material and labour costs of repairing a failure. As a result, airlines are typically much more zealous than the military in pursuing modifications to enhance reliability.[26]

What is necessary is a graph similar to Figure 11-5, but with maintenance cost on the vertical axis. To do this, the Figure 11-2 graph can be modified (yet again), but instead of representing the *amount* of unscheduled maintenance on the vertical axis, the *cost* of unscheduled maintenance should be plotted (Figure 11-6). The shape of the cost curve and the amount curve will be similar, since the cost of maintenance is roughly proportional to the amount.

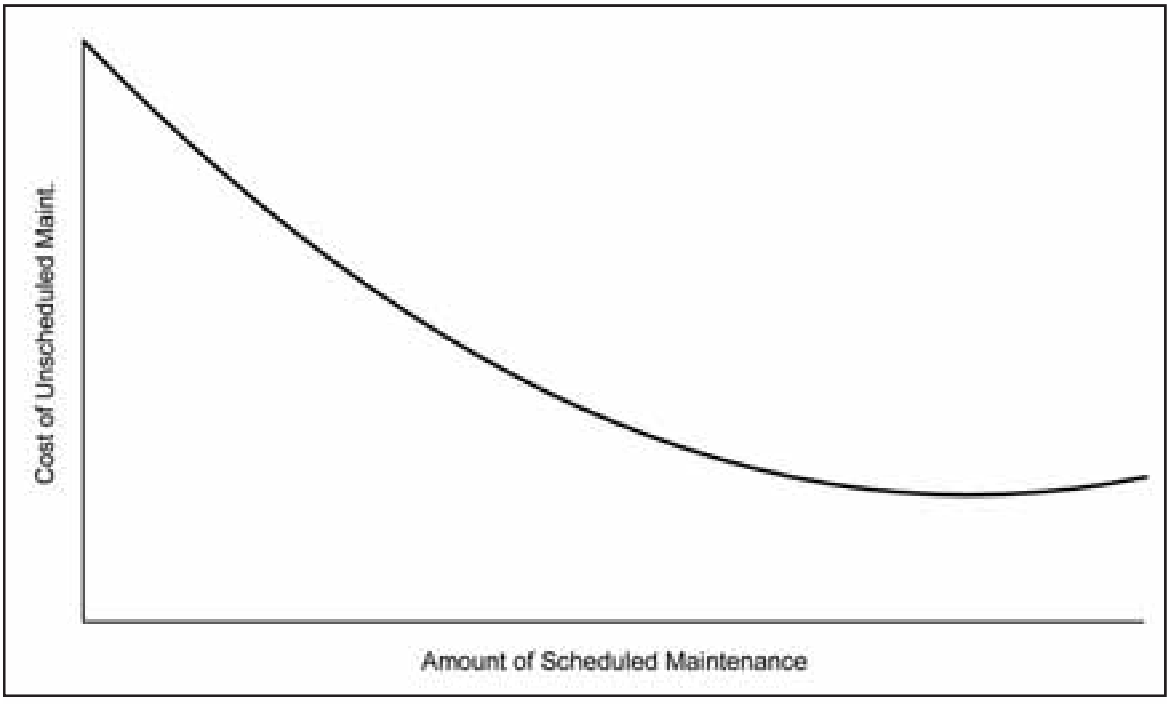

Figure 11-6: Cost of Unscheduled Maintenance

25 This list is adapted from *Relcode Reliability and Replacement Analysis Using the Weibull Distribution*, loc cit., p. 72. It is also important to consider the costs of rectifying any secondary damage resulting from failure.

26 Report of the MOD(AFD)/MOD(PE)/SBAC/EEA Working Group on Ways of Securing Improved Reliability in RAF Equipment, July 1984, pp. 13–18.

The vertical axis of this graph can be generalised to become *cost of maintenance*, and the cost of scheduled maintenance can be represented as a straight line by analogy with Figure 11-5[27]. Finally, the total maintenance cost can be calculated by adding the scheduled and unscheduled components together (Figure 11-7).

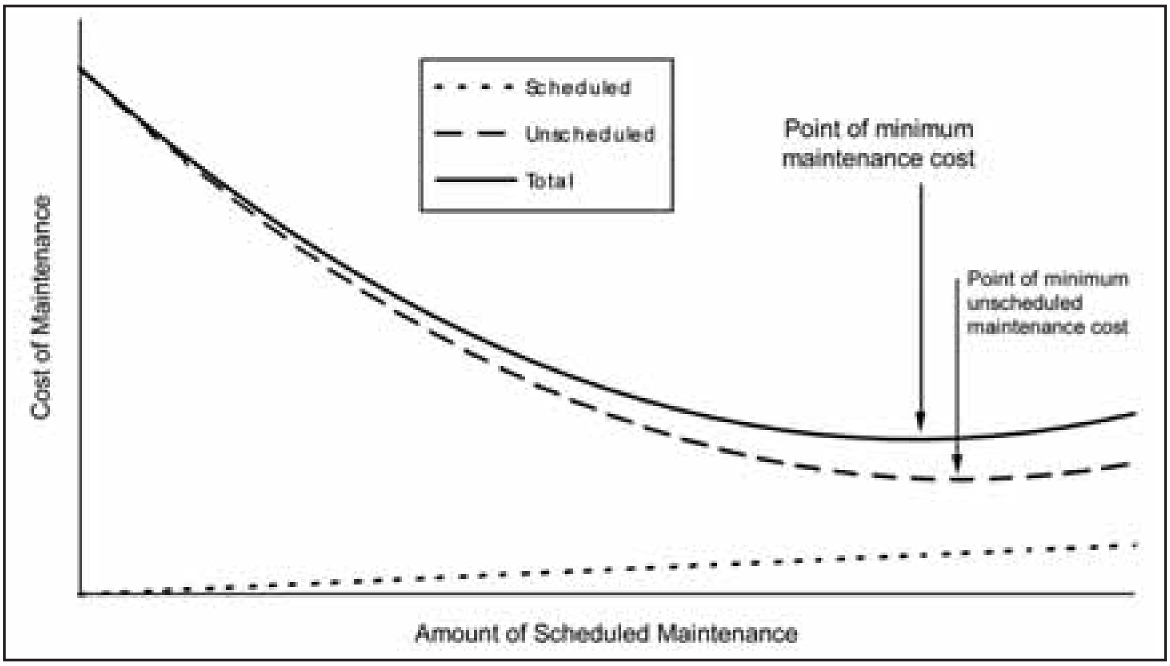

Figure 11-7: Maintenance Costs

The significant difference between the cost graph (Figure 11-7) and the downtime graph (Figure 11-5) is that, when calculating the 'cost of maintenance' curves, the cost of scheduled maintenance and the cost of unscheduled maintenance are factored in. Generally, unscheduled maintenance is more expensive per unit 'amount', since repair work more frequently involves component replacement, major rectification, secondary damage, inconvenient timing, etc; whereas scheduled maintenance generally involves cheaper restorative processes performed at more convenient times. Accordingly, the 'unscheduled' curve will be relatively higher when costs are considered, and the 'total' curve will more closely follow the 'unscheduled' curve as a result of this.

The amount of scheduled maintenance that minimises total maintenance cost can be read off Figure 11-7. As with the availability graph, maintenance cost will be minimised at some point to the left of the minimum amount of unscheduled maintenance; ie. there will be more failures occurring in service under a minimum-cost maintenance policy than would occur under a minimum-risk policy.

27 The cost of scheduled maintenance will be proportional to the amount of scheduled maintenance, hence the straight line. The gradient of the line will be a function of the cost of maintenance per unit amount (eg. cost per manhour).

Whole Aircraft

The maintenance cost for the whole aircraft is minimised by minimising the maintenance cost of all of its components.

However, not all components will have an impact on the overall cost of maintenance to the same extent. The most important components to 'get right' will be those which have high maintenance costs,[28] and for which changes in the amount of preventive maintenance result in large changes in maintenance cost.

MISSION GENERATION AND ASSET PRESERVATION

Mission generation tasks aim to ensure sufficient airworthiness, missionworthiness and availability *in the short term*. Maximising the mission generation aspects of a maintenance plan is therefore achieved by endeavouring to maximise the airworthiness, missionworthiness and availability goals for those tasks that are effective in the short term.[29]

The best guide to determining those tasks that are effective in the short term is the maintenance interval for the tasks. Short maintenance intervals will generally be adopted when degradation is rapid.

Conversely, asset preservation aims to ensure sufficient airworthiness, missionworthiness, availability and cost-effectiveness *in the long term*. Tasks that are effective in the long term for these goals are effective asset preservation tasks. Such tasks will generally have longer maintenance intervals, since more frequent performance of the task would not significantly improve reliability. If it did, the task would most likely be a mission generation task.

COMPARISONS

A policy of maximising airworthiness and/or missionworthiness will require the greatest amount of scheduled maintenance (on relevant components), since the aim is to reduce unscheduled arisings to a minimum.

Beyond this, it is difficult to make further comparisons. This is because, when considering airworthiness, missionworthiness, availability and cost-effectiveness in the preceding sections, the measure of the 'amount of maintenance' (from Figure 11-2) was varied in each case. Table 11-1 summarises the results.

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28 This will be a product of the frequency of arisings, and the cost per arising.

29 It is not actually possible to fully optimise a maintenance program for all of these three goals, since maximum airworthiness/missionworthiness and maximum availability are actually conflicting requirements. This will be expanded on later in this chapter.

Goal	Measure of 'Amount of Maintenance'	Relevant Items	Most Important Items
Airworthiness	Number of in-service failures[30]	Safety-critical only[31]	Failure effect significance x failure frequency x sensitivity to maintenance
Mission-worthiness	Number of in-service failures[32]	Mission-critical only[33]	Failure effect significance x failure frequency x sensitivity to maintenance
Availability	Amount of aircraft downtime required[34]	All	Downtime per arising[35] x frequency of arisings x sensitivity to maintenance
Cost-effectiveness	Cost to maintain / repair	All	Cost per arising x frequency of arisings x sensitivity to maintenance

Table 11-1: Summary of Factors Affecting Goals

To account for the mission generation/asset preservation distinction, a third dimension should be added to Table 11-1. Relevant airworthiness, missionworthiness and availability tasks that are effective in the short term will contribute to mission generation.[36] All tasks that are effective in the long term will contribute to asset preservation.[37]

Simplified Comparison

Because the measure of 'amount of maintenance' is not consistent between the graphs for the various goals, direct comparisons on the optimum amount of scheduled maintenance cannot be made. Comparisons can only be made by making some assumptions about the relationships between the measures used in each case.

30 This measures unscheduled maintenance only.

31 Including components with airworthiness implications but having sufficient redundancy, which are misleadingly labelled mission-critical in the RAAF system.

32 This measures unscheduled maintenance only.

33 Excluding components with airworthiness implications but having sufficient redundancy, which are misleadingly labelled mission-critical in the RAAF system.

34 Removal and replacement time only, for items maintained off-aircraft.

35 Taking into account whether the maintenance task is on a servicing critical path, slack time of other tasks, etc.

36 ...ie. those tasks satisfying the criteria in the rightmost two columns of Table 11-1 which have short maintenance intervals.

37 ...ie. those tasks satisfying the criteria in the rightmost two columns of Table 11-1 (regardless of maintenance goal) having long maintenance intervals.

The simplest assumption to make is that the various measures of 'amount of maintenance' are proportional. That is, the number of failures in service is proportional to the downtime required for their rectification, and is also proportional to the cost incurred. This allows Figures 11-5 (availability) and 11-7 (cost-effectiveness) to be directly compared.

The shape of the unscheduled maintenance curve is the same in both graphs, and the scheduled maintenance 'curve' is a straight line in both graphs. The only difference involving these two pairs of lines is their relative significance (height up the vertical axis); because the cost of unscheduled maintenance is greater than the cost of scheduled maintenance, the unscheduled maintenance curve assumes more significance when costs are considered (Figure 11-7), when compared to the scheduled maintenance line.

A result of this is that the 'total' curve more closely follows the unscheduled maintenance curve in the cost graph (Figure 11-7) than it does in the downtime graph (Figure 11-5). As a consequence, the point of minimum *total* maintenance cost is nearer to the point of minimum *unscheduled* maintenance cost (which is also the same point as the minimum unscheduled maintenance *downtime* on Figure 11-5, as the curves are the same shape). The significance of this is that *more scheduled maintenance is necessary to maximise maintenance cost-effectiveness than to maximise availability*. Therefore, the greatest amount of scheduled maintenance is necessary to maximise airworthiness and missionworthiness; the least amount of scheduled maintenance is necessary to maximise availability; and an amount of scheduled maintenance between these two extremes is appropriate to maximise cost-effectiveness.[38]

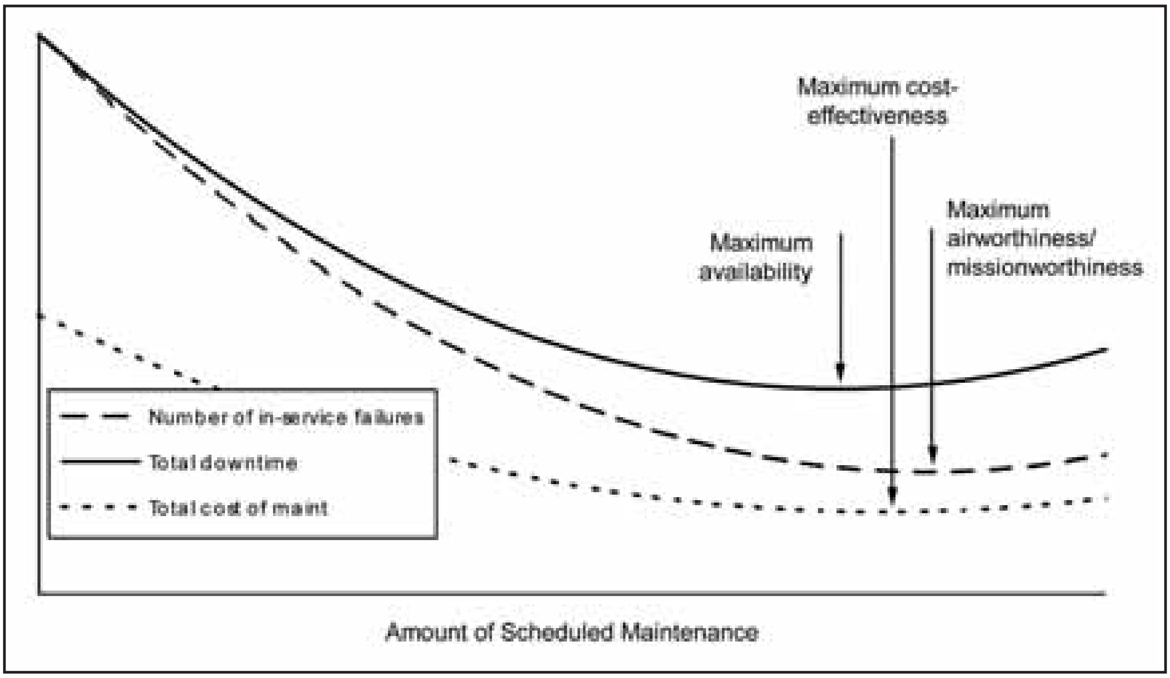

Figure 11-8: All Maintenance Goals

38 This is only true within the limitations of the assumptions stated earlier.

Figure 11-8 illustrates the relationship by combining the relevant curves from previous graphs. Maximum airworthiness/missionworthiness corresponds to the minimum number of in-service failures (from Figure 11-3); maximum availability corresponds to minimum total downtime (from Figure 11-5); and maximum cost-effectiveness corresponds to minimum total cost of maintenance (from Figure 11-7).[39]

Exceptions

The above comparisons assume that all measures of 'amount of maintenance' may be equated. However, there are many circumstances where this is not the case.

The failure of mission-critical and non-critical components can have no effect on airworthiness. Therefore, a policy of maximising airworthiness (alone) does not require that such components be preventively maintained at all.[40] Similarly, a policy of maximising missionworthiness (alone) does not require non-critical items to be preventively maintained.

The cost-effectiveness result relies on the generalisation that repairs are more costly than preventive maintenance. For cheap components, it can be more cost-effective to let them fail and then replace them, rather than attempt to avoid failures by preventive maintenance.[41] In this case, the cost curve *increases* as the amount of scheduled maintenance increases, so that the optimum amount of scheduled maintenance to maximise cost-effectiveness is none.

Another significant variation occurs for components that are generally maintained off-equipment (ie. removed from the aircraft for maintenance or repair). The downtime associated with removal is usually low, whereas the maintenance costs may be very high.

Multiple Maintenance Goals

In practice, the overall aim of the maintenance function at any point in time will generally consist of a mixture of *all* of the four goals (airworthiness, missionworthiness, availability, and cost-effectiveness). The level of emphasis on individual goals will vary depending on the circumstances at the time.[42]

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39 The meaning of the vertical axis on this Figure depends on the curve under consideration, as indicated by the key on the Figure. Unfortunately, it is generally impossible to cause the curves' minimum points to coincide at the same amount of scheduled maintenance, due to the fundamental tradeoff between the level of risk and the amount of scheduled maintenance. Therefore, it is necessary to select a maintenance policy (amount of scheduled maintenance) that best suits the relative priorities of the various maintenance goals.

40 A policy of maximising airworthiness alone makes no sense in practice, since an aircraft that is not reliably capable of executing any missions is of little use.

41 Although more cost-effective, this approach may jeopardise airworthiness, missionworthiness, and/or availability (depending on the criticality of the component).

42 These emphases are discussed in the next chapter.

However, the various goals cannot all be satisfied simultaneously: different levels of scheduled maintenance are appropriate in each case. Generating a maintenance program that achieves its aim requires establishing levels of scheduled maintenance for each component that represent tradeoffs between the individual goals.

When considering the appropriate maintenance policy for an item, the degree of emphasis afforded each of the goals should depend on the relative importance of that goal. In addition, the relevance of the goal for that item, and the significance of the item's impact on that goal, should be considered (ie. the two rightmost columns of Table 11-1). For example, the airworthiness goal can be ignored when considering a non-critical component, but must be taken into account when considering a safety-critical component. Likewise, a component that has little impact on availability, but has high maintenance costs,[43] should have its maintenance policy biased towards the point of minimum maintenance cost for that item (unless there is a very strong need for high availability—at all costs). Many other such conclusions can be drawn from Table 11-1; the important point is that the policy adopted should be influenced by the relative emphases of the various maintenance goals, and the nature and behaviour of the item.

The significance of mission generation/asset preservation is also relevant. Where mission generation is a high priority, tasks that benefit mission generation should be considered more favourably; tasks that hinder mission generation[44] should be disfavoured; and vice versa.

Aggregation

All of the above results apply to single components considered in isolation. Individual maintenance policies should be determined for each item, based on the criteria outlined above. The maintenance program for the aircraft as a whole will be basically the aggregation of these policies.

Because of the complexities and numbers of exceptions in the considerations for individual items, it is difficult to conclude generalisations about the levels of scheduled maintenance corresponding to each of the maintenance goals for an aircraft overall. However, the following relationships hold:

a. An emphasis on airworthiness will require additional preventive maintenance on safety-critical items, and so will increase the overall level of scheduled maintenance.

b. An emphasis on missionworthiness will require additional preventive maintenance on mission-critical items, and so will increase the overall level of scheduled maintenance.

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43 This situation could occur for an item that requires extensive off-equipment maintenance, but which is quickly removed from the aircraft.

44 For example, a long interval and long duration task will confer little benefit in the short term (as degradation will occur only slowly), but its impact on availability in the short term may be significant due to the scheduled downtime required.

c. An emphasis on availability will require the lowest levels of scheduled maintenance on all items (and in many cases, no scheduled maintenance at all). This will reduce the overall level of scheduled maintenance.

d. An emphasis on cost-effectiveness will require levels of scheduled maintenance between the maximum (airworthiness) level and the minimum (availability) level, for those items where repair cost exceeds maintenance cost.

SERVICING CONCEPT

The means by which individual maintenance tasks are grouped into servicings can have a significant effect on maintenance goals.

Availability

The grouping of scheduled maintenance tasks into servicings carries with it an inherent inefficiency, as the intervals at which items are actually maintained will be the *servicing* intervals, rather than the ideal intervals for the individual tasks. Generally, tasks are placed into servicings with a shorter maintenance interval. For example, if the ideal maintenance interval for a particular task is 120 hours, it may be placed in a 100-hourly servicing.[45] This reduces the risks inherent with undermaintaining the item, but the resulting overmaintenance has an adverse effect on availability and cost-effectiveness.

The flexible servicing policy does not suffer this inefficiency, as individual tasks are not grouped into servicings, and so may be performed at their ideal intervals.

A further inefficiency in grouping tasks into servicings is that any components installed between servicings (eg. to replace failed components) will have their maintenance lives out of step with the servicing cycle. When the servicing becomes due, such components will not have been used for long enough to justify performing maintenance tasks on them. However, if their maintenance tasks are not performed during the servicing, the tasks will become due at some stage thereafter, when maintenance may not be as convenient. The flexible servicing concept avoids this source of inefficiency by managing each component's maintenance requirements individually.

Against these benefits of flexible servicings, flexible (and phased) servicings can require unnecessary duplication (or replication) of tasks required to prepare the aircraft for maintenance, including obtaining access to internal areas. This duplication is a source of inefficiency which is not present in the periodic servicing concept. Whether this effect outweighs the other efficiency gains in a phased or flexible concept depends largely on the ease of access to aircraft structure and systems. A combined periodic/flexible approach can

45 The 100 hour figure may be dictated by a large number of other tasks that need to be performed at about that interval, and which could not be safely extended to 120 hours.

be adopted to attempt to obtain the benefits of both systems, with periodic-style servicings used where more time-consuming access is required.

A flexible servicing concept can improve availability, as many maintenance tasks can be performed between missions (eg. overnight), and so the need to withdraw the aircraft from service for extended periods is reduced. The impact on availability will be limited to whatever delays to missions result from tasks that cannot be completed in between missions (plus inevitable unscheduled arisings).[46] Additionally, there may also be a need for infrequent periodic-type servicings to perform larger tasks that cannot be efficiently packaged into flexible task groups. A flexible servicing concept is often adopted for control tower equipment, ground radars, etc, where very high levels of availability are paramount.[47]

Conversely, the periodic concept does not require any scheduled maintenance to be performed between servicings (which are much more infrequent than flexible servicings). Aircraft availability is therefore not interrupted at all—until a scheduled servicing becomes due, or the need for unscheduled work arises.

Cost-Effectiveness

The efficiency considerations described above (overmaintenance resulting from packaging, tasks getting out of step, and duplicated access tasks) also affect cost-effectiveness.

In addition, periodic servicings can result in a spasmodic workload, especially if the aircraft fleet size is so small that there is not a continual stream of aircraft into and out of maintenance. If maintenance personnel cannot be productively employed during the periods of low workload, they are effectively being paid to wait for the next servicing. A phased or flexible approach does much to smooth out the workload, permitting more continual utilisation of a smaller maintenance team.

Airworthiness and Missionworthiness

The choice of servicing concept does not greatly affect airworthiness or missionworthiness. In all cases, tasks are done at about the interval required. There may be some slight airworthiness benefit to periodic servicings, as the packaging inefficiency generally results in tasks being performed somewhat more frequently than is absolutely necessary. Moreover, the long duration of periodic servicings tends to take some pressure to meet deadlines off maintenance personnel, who will then perform tasks more thoroughly. Also, any work identified as a result of surveillance tasks (eg. the removal of corrosion) is more likely to be undertaken at the time, rather than be deferred. However, these effects should be minimal, and airworthiness/ missionworthiness considerations should not affect the choice of servicing concept.

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46 With the increasing capability for, and emphasis on, night-time missions, the opportunities to perform flexible servicings without disrupting operations must reduce.

47 Actually, the usual approach taken in the RAAF is closer to a phased concept, but the phases are kept small to minimise ‘downtime’.

Mission Generation and Asset Preservation

The choice of servicing concept does not affect the mission generation or asset preservation properties of a maintenance program. The choice of individual *tasks*, rather than their grouping, determines the effectiveness of the maintenance program over time.

OPERATIONAL FACTORS

Airworthiness consists of operational and technical aspects.[48] Technical aspects are those which are primarily controlled by engineering functions; operational aspects are controlled by the manner of usage of the aircraft. This latter category includes operational restrictions (such as limiting the severity with which flight manoeuvres may be performed), the rate of effort, mission profiles, and the environment in which the aircraft is operated and based.

In some regards, compromises can be achieved between the two aspects of airworthiness. The most obvious relationship is between the rate of effort and the amount of maintenance required. A less apparent example is the imposition of operational restrictions, which can result in a reduction in the maintenance effort required to assure airworthiness. Changes to operating procedures can also go some way towards ameliorating the adverse effects of harsh environmental conditions.

Multi-role aircraft also have another element of flexibility in this regard. Different mission types (roles) will often have different impacts on the aircraft; one role may require a harsh load spectrum (accelerating fatigue damage), whereas another role may require operations in a more corrosive environment. By carefully allocating specific aircraft to particular roles, the condition of the fleet overall can be kept more consistent, which minimises the need for additional maintenance.

Rate of Effort

The frequency of many maintenance tasks will be based on aircraft usage (eg. flying hours, rounds fired, landings, etc) rather than elapsed time. This is appropriate where the failure mode(s) that the maintenance task is trying to prevent is a function of usage rather than simply time. Increasing the aircraft's rate of effort (rate of usage) accelerates the onset of usage-related failure modes, hence the appropriate maintenance tasks must be performed more frequently.[49]

This does not apply to tasks that correspond to failure modes that are not affected by usage.[50] Therefore, when contemplating the impact of a change in rate of effort on a maintenance

48 DI(AF) OPS 2-6, *Airworthiness Certification in the RAAF*, 1 April 1991, paragraph 2.

49 *ADF Reserve Stockholding Policy Implementation Guidance*, December 1993, p. 38.

50 Corrosion is a significant example of this: to a large extent, the rate of corrosion degradation is independent of the aircraft's rate of effort, and depends mainly on elapsed time, the environment, and preventive measures (such as protective coatings).

program, it is important to be able to distinguish between those tasks which are usage-related and those which are not. The increase in maintenance effort required will *not* be simply proportional to the increase in rate of effort; the factor by which the maintenance effort must increase will also be a function of the proportion of tasks that are usage-related.

The reliability of some systems may improve with increased usage, as familiarity with the operation and maintenance of the system increases.[51]

When grouping tasks into servicings, some assumption must be made on the rate of effort. This allows usage-dependent and time-dependent tasks to be placed into the one set of servicings.[52] The interval for the resulting servicings can be stipulated in terms of either elapsed time or aircraft usage—or preferably both. The important point is that a servicing set thus obtained is appropriate *only for the rate of effort on which it is based*.[53] To continue to use a servicing set unaltered after a change of rate of effort must result in some amount of over-servicing or under-servicing, unless the servicing does not contain a mixture of usage-based and time-based tasks.

Operational Restrictions

Operational restrictions commonly take the form of a limitation on the manoeuvre loads that the aircraft can be subjected to, and are usually specified in terms of the maximum permissible acceleration for certain kinds of manoeuvre. Some manoeuvres may be forbidden altogether. The imposition of operational restrictions for technical reasons usually arises from Aircraft Structural Integrity (ASI) considerations.[54]

Imposing restrictions of this kind reduces the extremes of load that will be experienced by those parts of the aircraft structure that carry the load during the kinds of manoeuvre to which the restriction applies. This means that those components experience a less severe load spectrum; Figure B-1 on page 306 shows that this will delay the fatigue degradation process.

The benefit of delayed fatigue degradation depends on the Aircraft Structural Integrity philosophy being used to manage the aircraft. If the aircraft (or affected components) are managed by a safe-life philosophy, the reduced load spectrum means that the aircraft (or

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51 *ADF Reserve Stockholding Policy Implementation Guidance*, p. 38.

52 The alternative would be to have two sets of servicings: one being usage-based, the other being time-based. To carry this approach further, usage-based tasks could be further separated into different sets of servicings based on the different usage measures (aircraft hours, rounds fired, landings made, etc). The servicing set would become impracticably unwieldy to manage if this approach were taken to its extreme. In many cases, the resulting ‘servicings’ would consist of one (or few) tasks, reminiscent of the flexible servicing concept.

53 A *servicing set* is the full set of servicing schedules for an aircraft (ie. all of its on-aircraft maintenance policies).

54 ASI is discussed in Annex B.

components) do not need to be withdrawn from service as soon. This can permit an extension to the planned withdrawal date for the aircraft.

If the aircraft (or components) are managed by a safety-by-inspection philosophy, the effect of the reduction in the rate of fatigue degradation is that necessary structural inspections need not be performed as frequently. This reduces the maintenance workload, which will save maintenance costs and usually improve availability. If the operational restrictions are to be in force for an extended period of time, the aircraft servicings can be repackaged to take maximum advantage of the extended inspection intervals.[55]

A reduced load spectrum will also result in less damage occurring in practice. As a result, repair or replacement workload will be reduced, with consequent benefits to availability and cost. Moreover, virtually all structural repairs degrade the durability of the structure and so are detrimental to the preservation of the asset.

If operational restrictions are removed, the engineering benefits disappear. This can mean that relevant safe-life components will need to be withdrawn from service sooner (possibly including the whole aircraft), and that safety-by-inspection components must be inspected more frequently to retain assurance of aircraft structural integrity (with consequent impact on downtime required and maintenance costs). The whole servicing package may need to be revised to take into account the reduced removal or inspection intervals. Repairs to fatigue-related damage will be required more frequently.

Mission Mix and Profiles

Most aircraft are capable of performing a number of different roles; moreover, specifically 'multi-role' aircraft are most desirable to compensate for low numbers of aircraft and thus reduce defence costs.[56] Different aircraft roles make different demands on the aircraft structure (ie. apply different load spectra), and on the aircraft systems which are required to be serviceable. The most significant effect from a maintenance viewpoint is that the different load spectra translate to different fatigue lives, for the same reason that operational restrictions influence fatigue lives.

In practice, this is managed by assuming fixed proportions of the various types of mission that will be flown. This mission mix allows an overall load spectrum to be derived, and maintenance requirements (component retirements and inspections) are based on this. However, any significant variations to the mission mix may mean that the load spectrum on which the maintenance requirements are based is no longer representative of reality. A new load spectrum should be derived based on the new mission mix; the fatigue consequences of this should then be determined, giving revised maintenance requirements; and the entire servicing set may need to be repackaged.[57]

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55 This has been done for the RAAF F-111C fleet.

56 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, pp. 69, 80.

57 Done properly (and with routine priority), this sequence of processes would take over 12 months.

A single mission type may be performed in different ways; eg. different altitudes, different stage lengths, different flying habits, etc. These variations can also result in changed load spectra, requiring that a typical mix of profiles must be assumed when calculating fatigue behaviour. If the mission profile mix changes significantly, the fatigue calculations may again be invalidated.

Changes to the mission mix and profiles also affect failure modes other than fatigue. For example, if the average sortie duration is significantly reduced, undercarriage components will undergo considerably greater usage per flying hour. Undercarriage component inspections and maintenance may well be 'packaged' in a servicing which is nominally based on flying hours or calendar time; given the increased undercarriage usage, the undercarriage components will require servicing before the aircraft's scheduled servicing becomes due. This effect leads to inefficiency in the servicing packaging (or over-maintenance or under-maintenance). If such problems are common, and the changed operating profile is to be used for some time, repackaging of the aircraft's servicing set is appropriate.

Environment

The environment in which the aircraft is based and operated can have a significant effect on the maintenance tasks found necessary. The main environmental factors are sand and dust, foreign object damage, temperature, humidity/moisture, and salt.[58]

Environmental problems may be addressed by:

a. incorporating appropriate modifications,

b. providing extra ground support equipment,

c. introducing additional maintenance tasks, and/or

d. adopting changed operating procedures.

Even with all of these measures in place, there may still be a significant degradation of the reliability of some systems. Additional surveillance maintenance may be appropriate for systems with hidden functions, and increased corrective maintenance will be necessary. Appropriate additional scheduled maintenance tasks include additional cleaning, and pre-existing tasks such as engine overhauls may need to be conducted more frequently. Requirements for replacements of affected components will be increased.

58 Annex E describes the possible effects of the environment on aircraft in some detail.

SUMMARY

For many components, there is a tradeoff between the amount of scheduled maintenance undertaken and the number of failures that will occur (and hence the amount of unscheduled maintenance required). Adjusting the amount of scheduled maintenance is a way of 'controlling' the frequency of failures, and this balancing can be used to adapt a maintenance program to different goals.

Maximum airworthiness requires a maximum amount of scheduled maintenance on safety-critical components, to reduce the number of in-service failures of these items to a minimum. Similarly, maximum missionworthiness requires a maximum amount of scheduled maintenance on mission-critical components.

Maximum availability requires a lesser amount of scheduled maintenance. This is particularly true for those components maintained on-aircraft which are on a servicing critical path.

The appropriate servicing concept to maximise availability depends on the maintainability of the aircraft. An aircraft with convenient maintenance preparation and access should use a flexible servicing policy to maximise availability; otherwise, a periodic concept should be used. Periodic maintenance may also be most appropriate for aircraft fleets to be operated on deployment for extended periods with minimal deployed maintenance capability (although higher availability could be achieved by using flexible servicings and additional deployed maintenance personnel).

Maximum cost-effectiveness requires no scheduled maintenance at all for items which are cheap to repair or replace. For other items, an amount of scheduled maintenance approaching that required to minimise the frequency of failures is appropriate.

The phased maintenance concept can be the most cost-effective, potentially providing a steady workload while avoiding the duplicated preparation and access requirements of a flexible maintenance concept. For large fleets, periodic servicings will achieve the same (or better) results.

Airworthiness and missionworthiness are the only two maintenance goals which are fully compatible (both requiring a maximum amount of scheduled maintenance on relevant items). The amount of maintenance required to maximise availability is somewhat less, and the amount required to maximise cost-effectiveness is somewhere in between. Thus, a compromise must usually be struck between the various maintenance goals.

Mission generation emphasises maintenance tasks with shorter intervals, but still requires a compromise between airworthiness, missionworthiness and availability. Asset preservation emphasises longer interval tasks, but again requires tradeoffs between the other maintenance goals.

All else being equal, increasing a fleet's rate of effort will result in increased maintenance requirements (but not a proportional increase). To properly adapt a maintenance program to a different rate of effort may require that the servicing schedules be repackaged.

The imposition of operational restrictions permits a relaxation of maintenance requirements; conversely, the removal or relaxation of operational restrictions will generally require increased maintenance. If the changes are significant, repackaging may be appropriate. Changes to the fleet's mission mix and mission profiles, and changes to the environment in which the fleet operates, may also require changes to the maintenance program.

There are a large number of complicating factors and exceptions which make it impossible to develop a simple and accurate model for relating goals to maintenance requirements. However, the basic conclusion is that maximum availability requires less scheduled maintenance than is required to maximise airworthiness or cost-effectiveness. However, maximising airworthiness in this manner will reduce the levels of airworthiness and cost-effectiveness achieved.

The next chapter discusses the changes to maintenance priorities that may be expected during a contingency; Chapter 13 then applies the principles described above to establish the types of changes required to adapt a maintenance program to contingency circumstances.

Part 3

Preparedness and Maintenance

Chapter 12
Contingency Maintenance Goals

INTRODUCTION

Chapter 6 introduced the four main goals possible for a maintenance program: airworthiness, missionworthiness, availability, and cost-effectiveness. The means by which a maintenance program may be varied to improve the extent to which it meets particular maintenance goals were discussed in the previous chapter. The relationship between operational, environmental and maintenance factors was also described.

The prevailing strategic circumstances have a significant effect on the emphasis placed on the various maintenance goals. This chapter outlines the emphases appropriate for peacetime and during a contingency, and describes the changes likely to be required to a maintenance program as a result. The use of contingency maintenance during the Gulf War is also briefly surveyed.

Definition

Although the term ‘maintenance’ includes unscheduled maintenance (ie. repair work), ‘contingency maintenance’ usually refers only to *scheduled* maintenance performed during a contingency. An important subset of unscheduled maintenance during a contingency is *Battle Damage Repair*, which is discussed in Chapter 15.

POLICY ON MAINTENANCE GOALS

An ideal maintenance program would give good results in all of the maintenance goals; ie:

a. a high level of airworthiness,

b. a high level of missionworthiness,

c. a high level of availability,

d. highly cost-effective, and

e. a high degree of asset preservation.[1]

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1 The requirement for mission generation is effectively taken care of by the provision of airworthiness, missionworthiness and availability.

However, there are conflicting requirements between these goals; the conflict often centres on the appropriate scheduled maintenance requirements to adopt. Airworthiness, missionworthiness, cost-effectiveness and asset preservation generally benefit from a greater amount of scheduled maintenance than is required to maximise availability.[2]

Because of such conflicts, the maintenance program can only be optimised to suit one set of goals (or, more correctly, one set of *emphases between* the various goals). When strategic circumstances dictate that the emphases between the goals should change, the maintenance program should also change to an optimum for the new set of emphases. The differences between peacetime and contingency priorities for maintenance are outlined in many ADF documents; the relevant material is surveyed in the following sections.

It is useful to distinguish between 'contingency' versus 'combat' circumstances. Contingency circumstances would prevail for the duration of potential conflict; combat circumstances exist during actual engagements or when evacuating aircraft or personnel.[3] The distinction is useful as it allows determination of relative priorities in greater detail, and permits the establishment of a more flexible framework for maintenance policy. In the discussion below, combat maintenance will be considered to be a special case of contingency maintenance; provisions applicable to contingency maintenance are also applicable to combat maintenance unless otherwise stated.

Availability and Mission Generation

Availability is given particular emphasis during contingency operations.[4] During combat operations, the need for maximum availability is further increased.[5]

This is equivalent to an emphasis on mission generation,[6] although this term also implies a sufficiently high level of airworthiness and missionworthiness to give a high probability of successfully completing missions.

Availability goals may be derived from the CDF Directive on ADF Preparedness (CPD) and Air Command Operational Preparedness Directive (ACOPD) targets for the number of aircraft required to be available, and guidance on mission frequencies and profiles.[7] Thus, a direct relationship between preparedness and availability exists.

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2 This is a significant oversimplification. For a more complete explanation, see Chapter 11.

3 DI(AF) AAP 7038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, paragraph 734. Chapter 3 outlines recent thoughts on the nature of short-warning conflict, which includes a distinction between contingency and conflict. Interestingly, the aforementioned maintenance publication's distinction predates this work by several years.

4 LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993; DI(AF) OPS 5-9, *Paramount Procedures*, 1 April 1982, paragraph 1; DI(AF) LOG 13-7, *Contingency Maintenance and Battle Damage Repair of Technical Equipment*, draft, 28 February 1994, paragraph 1; and DI(AF) AAP 7001.038-1, paragraph 733.

5 DI(AF) AAP 7001.038-1, paragraph 748.

6 LD93-20656 Pt 1, op cit.

7 CPD and ACOPD goals are described in Chapter 4.

Operational Flexibility and Performance

Although not a maintenance goal as such, there can be a very close relationship between operational flexibility and performance, and maintenance measures.[8] During a contingency, it is highly desirable that aircraft be permitted to operate with as few flight restrictions as possible, and in whatever environment is necessary. If flight restrictions are removed, the maintenance program may need to be adjusted accordingly.[9]

Safety and Airworthiness

Safety (airworthiness) is given particular emphasis during peacetime.[10]

It is never desirable to operate aircraft with low levels of safety (poor airworthiness). Accordingly, airworthiness continues to be important during a contingency, although somewhat reduced standards may be acceptable depending on the circumstances.[11] During combat operations, further reductions in airworthiness are acceptable,[12] in the interests of achieving maximum availability.

The need to avoid aircraft losses due to structural or equipment failure is heightened for a relatively small air force such as the RAAF.[13] This is an important aspect of attrition management.

Missionworthiness

Intuitively, it would seem appropriate for missionworthiness to be somewhat less important during peacetime than during a contingency. However, ADF policy does not appear to suggest that this is the case, or that missionworthiness should be increased during a contingency. The assumption appears to be that peacetime maintenance practices will provide sufficiently high levels of missionworthiness, and that the same levels will suffice for contingency operations.[14]

During combat operations, some reduction in missionworthiness is acceptable,[15] given the need to further maximise availability. Obviously, a careful balance must be struck here: the availability of aircraft with poor missionworthiness can result in ineffective operations, and merely risks aircraft and aircrew. However, a small decrease in mission reliability may be an acceptable price to pay if the increase in availability is large.

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8 See p. 113.

9 DI(AF) LOG 13-7, paragraph 2.

10 ibid., paragraph 1; and DI(AF) AAP 7001.038-1, paragraph 735.

11 DI(AF) OPS 5-9, loc cit.; DI(AF) LOG 13-7, loc cit.; and DI(AF) AAP 7001.038-1, paragraph 735.

12 DI(AF) AAP 7001.038-1, paragraph 736.

13 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, paragraph 4.49.

14 DI(AF) AAP 7001.038-1, paragraph 735, refers to retaining high levels of mission reliability.

15 ibid., paragraph 736.

Preservation of the Asset

Preservation of the asset is strongly emphasised during peacetime.[16] During a contingency, such long-term considerations become secondary to more immediate concerns, which are best served by increased availability, operational flexibility and performance.[17]

Cost-Effectiveness

Cost-effectiveness is also a peacetime pursuit.[18] During a contingency, additional funding could be expected to be made available, from additional allocations to Defence, and/or by rearranging the existing defence program. Accordingly, the emphasis on cost-effectiveness can be reduced during a contingency.[19]

Priorities

Availability (mission generation), and operational flexibility and performance are accorded increased emphasis during a contingency. Conversely, safety (airworthiness), missionworthiness, preservation of the asset, and (particularly) cost-effectiveness may be given less emphasis compared to peacetime priorities.

EXPEDIENTS PERMITTED DURING CONTINGENCY

Various ADF documents provide guidance or grant waivers to assist in maximising contingency maintenance performance. The main issues are discussed below.

Relaxed Serviceability Criteria

An example of the reduction in safety standards is a relaxation of serviceability criteria.[20] Thus, an item may be deemed serviceable for contingency use when its condition would render it unserviceable for peacetime use. This is a pervasive concept which underlies many of the other permissible expedients, such as battle damage repair and reduced levels of maintenance.

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16 LD93-20656 Pt 1, op cit.; DI(AF) LOG 13-7, paragraph 1; and DI(AF) AAP 7001.038-1, paragraph 733. Preservation of the asset is somewhat similar to *attrition management* (DI(AF) AAP 1000, p. 65), except that the latter emphasises minimising losses due to aircraft accidents and battle damage, whereas asset preservation aims to minimise usage-related degradation. Since the rate of such degradation is very slow, asset preservation may be de-emphasised during a contingency; however, attrition management is always crucial.

17 DI(AF) AAP 7001.038-1, loc cit.; and DI(AF) AAP 1000, paragraph 10.39.

18 LD93-20656 Pt 1, op cit.; DI(AF) LOG 13-7, loc cit.; and DI(AF) AAP 7001.038-1, loc cit.

19 DI(AF) LOG 13-7, loc cit.; and DI(AF) AAP 7001.038-1, loc cit.

20 DI(AF) OPS 5-9, loc cit.; DI(AF) LOG 13-7, paragraph 1; ADFP4, Operations Series, *Mobilisation Planning*, First Edition, draft, 1994, paragraph 434; and LD93-20656 Pt 1, op cit.

An important application of this principle is that the standard to which maintenance is performed may be relaxed, when this is justified to meet operational requirements. This practice should be carefully controlled, to avoid an unacceptable drop in reliability which could adversely affect availability, airworthiness or missionworthiness.

The option to relax serviceability criteria also has application to the determination of Carried Forward Unserviceabilities (CFUs). Components whose condition would be unacceptable for continued use in peacetime may be documented as a CFU, with the appropriate maintenance to be conducted at a more convenient time (possibly even after the contingency).

Reduced Levels of Maintenance

A reduction in the overall amount of maintenance (and particularly scheduled maintenance) is expected.[21] If required, all Deeper Maintenance (DM) may be deferred for the duration of the contingency[22] (DM is here interpreted to mean maintenance aimed at achieving preservation of the asset). This is entirely consistent with the findings of Chapter 11, which shows that the optimum level of maintenance required to maximise availability will be somewhat less than that required to maximise airworthiness, missionworthiness and cost-effectiveness.

During combat, *all* scheduled maintenance may be deferred, if necessary.[23]

All maintenance associated with Aircraft Structural Integrity (ASI)[24] may be deferred, although the deferral of usage monitoring should be a last resort.[25] Thus, all inspections performed solely for the purpose of structural integrity assurance may be deferred, if necessary. It may not be prudent to automatically drop all structural inspections, however: an inspection that frequently finds damage that could jeopardise flight safety in the short term should normally be retained, to meet the goal of providing adequate airworthiness.

Battle Damage Repair

Battle Damage Repair (BDR) may be used for unscheduled maintenance, when appropriate.[26] BDR encompasses techniques that are relatively quick to apply and which may be undertaken in deployed conditions. As a result, BDR may significantly enhance availability; however, peacetime standards of safety and durability may not be achieved. BDR is covered in more detail in Chapter 15.

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21 DI(AF) LOG 13-7, paragraph 10; and DI(AF) AAP 7001.038-1, paragraph 734.

22 DI(AF) AAP 1000, loc cit.

23 DI(AF) AAP 7001.038-1, paragraph 748.

24 See Annex B.

25 DI(AF) ENG 5-2, *Aircraft Structural Integrity Management*, 20 December 1993, paragraph 32. Usage monitoring permits estimation of the amount of fatigue damage accrued by the structure. This information is necessary when transitioning the aircraft back to peacetime standards of airworthiness.

26 DI(AF) LOG 13-7, op cit.

Compensatory Maintenance

The removal of flight restrictions (or the extension of the operating envelope or authorisation of non-standard flight manoeuvres) may be required to maximise operational flexibility and performance. Doing so may make the adoption of additional maintenance desirable.[27] Such maintenance would generally be surveillance maintenance, with an aim of detecting any adverse effects resulting from the more severe usage. This would allow problems to be rectified before an aircraft accident could occur, or before the damage reached a stage where major repairs became necessary, requiring that the aircraft be removed from service for a considerable period.

A likely form of damage to result from the relaxation of operational restrictions is fatigue. BDR techniques may be used for the rapid (albeit short term) repair of fatigue damage.

The imposition of additional maintenance may well adversely impact availability. A three-way compromise is required between the desirability of removing flight restrictions, the need for maximum availability, and the desirability of a high standard of airworthiness.

Environmental Maintenance

The Area of Operations (AO) in which contingency operations may take place could have adverse effects on aircraft. Additional or changed maintenance requirements may be able to minimise adverse effects, with a consequent increase in the availability, airworthiness and missionworthiness than may otherwise have been achieved.[28] The main forms of additional maintenance that may be required are:

a. inspections for stone and sand damage, foreign object damage, and battle damage;

b. improved or more frequent cleaning;

c. improved or extra orifice covers;

d. improved or more frequent lubrication;

e. application of protective coatings;

f. Early Failure Detection (EFD) methods, such as vibration monitoring;[29] and

g. improved cockpit (and systems) cooling.

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27 ibid., paragraph 10.

28 loc cit.; and DI(AF) AAP 7001.038-1, paragraph 741.

29 See p. 52.

The effects of many forms of environmental degradation can be reduced by the incorporation of appropriate modifications.[30] Changed aircraft Standard Operating Procedures (SOPs) may also help to ameliorate adverse effects.

Annex E discusses forms of environmental damage and appropriate remedies in some detail.

Flexibility

The uncertainty of war requires maintenance policy to be sufficiently flexible to adapt to changing or unforeseen contingency requirements.[31] Increased flexibility in the management of contingency maintenance is provided by:

a. permitting greater delegations of authority to be made (or assumed, if necessary);[32]

b. authorising the adoption of non-standard, and possibly undocumented, procedures;[33] and

c. reducing normal supervision requirements.[34]

To facilitate the best use of this flexibility, appropriate procedures and provisions should be established and documented during peacetime.[35] Such guidance will allow commanders to exercise their freedom more confidently and with a higher likelihood of successful results.

Risk Management

Underlying all the expedients that may be adopted during a contingency is the need to carefully manage the associated risks, including:

a. the risk of failing to achieve military objectives due to:

   (1) insufficient availability caused by excessive maintenance, or

   (2) inadequate mission reliability caused by insufficient maintenance; or

b. the risk of aircraft accidents arising from insufficient maintenance.

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30 For examples, see p. 186.

31 DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraph 5e.

32 DI(AF) OPS 5-9, paragraph 7; DI(AF) LOG 13-7, paragraph 15; DI(AF) ENG 2-4, *Configuration Management of Technical Equipment*, 20 December 1993, paragraph 12; and DI(AF) AAP 7001.038-1, paragraph 743.

33 DI(AF) OPS 5-9, paragraphs 1 and 12.

34 DI(AF) LOG 6-4, *Supervision and Inspection of Aircraft Maintenance Operations*, 11 March 1993, paragraph 10.

35 DI(AF) LOG 13-7, paragraph 10.

Lesser 'risks' include the possibility of unnecessarily degrading the Life Of Type (LOT) of the aircraft, and unnecessarily consuming funds or resources.

A caveat underscoring the adoption of any contingency variation is that it must be *necessary*. Peacetime procedures and delegations are to be adhered to unless doing so would jeopardise the successful completion of operational objectives.[36]

The determination and documentation during peacetime of options for contingency maintenance will further reduce the risk associated with the adoption of such procedures.

CASE STUDY: CONTINGENCY MAINTENANCE DURING THE GULF WAR

The USAF did not significantly reduce maintenance requirements during the Gulf War. Some servicings were reduced in scope, but even intermediate level servicings (eg. the F-15's 200-hourly servicing) were still performed on schedule.[37]

Similarly, USN aircraft were generally maintained in accordance with peacetime schedules, except that depot maintenance was deferred so long as the deferral 'did not prevent mission completion'.[38] In other words, greatly reduced deeper maintenance servicings were undertaken.

Other air forces made greater use of contingency maintenance. The RAF used contingency servicings and modified NATO maintenance schedules for in-theatre maintenance of the Tornado F.3 fleet.[39] Aircraft were rotated back to the UK for more major servicings.

The Canadians also utilised contingency maintenance for their Hornet fleet, and rotated aircraft back to Canada for more major servicings. However, in hindsight, the Canadians believe that they adopted contingency maintenance servicings too readily, and should have continued with the use of peacetime schedules for as long as possible.[40]

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36 DI(AF) OPS 5-9, paragraph 12; and DI(AF) AAP 7001.038-1, paragraph 737.

37 Murray Hammick, 'Report from the Front: AMUs Underrated in USAF's Success', *International Defence Review*, 5/1991, pp. 451–452. In this example, the availability of the fleet fell to *below* peacetime levels, because the increased flying rate meant that more aircraft were undergoing servicings concurrently. The USAF had the luxury of having a great number of aircraft available in-theatre; this meant that the availability of individual aircraft was not paramount, and continuing with these servicings avoided the possibility of reduced reliability in subsequent months.

38 Department of Defense (USA), *Conduct of the Persian Gulf War*, April 1992, Appendix F, p. F-65.

39 Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, p. 245.

40 STLO NAVAIR 79/2/Air Pt 2 (61), *F/A-18 Persian Gulf Operations – Canadian Forces Engineering/ Logistics Lessons Learned*, STLO NAVAIR, 10 July 1991.

An example of enhancing operational performance is the uprating of USAF F-15C engines during the Gulf War. To improve the reliability and longevity of the engines, they are normally restricted to 96 per cent of their maximum thrust; however, this restriction was lifted during the Gulf to permit better aircraft performance.[41]

Caution must be exercised when interpreting Gulf War practices. The great superiority of the coalition forces, and the fact that the coalition countries' homelands were not under threat, meant that peak availability was not required (although the levels attained were certainly high). In the face of a major threat to national sovereignty, even greater operational effort may be required than that evinced during the Gulf War; this may encourage greater use of contingency maintenance expedients to maximise availability.

SUMMARY

Although high performance in all of the maintenance goals is always desirable, tradeoffs are required between them. Different emphases are appropriate between peacetime and contingency, and these give rise to different maintenance programs. Availability and operational performance and flexibility become much more important during a contingency; airworthiness and missionworthiness are still highly desirable but may be downgraded if necessary; and asset preservation and cost-effectiveness assume significantly lower priority during a contingency.

Maximum performance of the maintenance function given these goals can involve the use of various expedients, such as a relaxation of serviceability criteria, reduction in the amount of maintenance, the use of Battle Damage Repair, and greater flexibility in procedures and delegations. Conversely, additional maintenance may need to be undertaken to permit greater operational performance and flexibility, and for operations in adverse environmental conditions. The changes required to adapt a peacetime maintenance program to contingency needs are discussed in the next chapter.

Significant variations in the use of contingency maintenance may be observed from the Gulf War. The Canadian Force and RAF adopted contingency maintenance schedules to a greater extent than American forces.

41 Hammick, 'Report from the Front'.

Chapter 13
Contingency Scheduled Maintenance
What Do We Need To Do?

INTRODUCTION

Chapter 11 discussed how the various maintenance goals and constraints should alter the nature of the maintenance program; the goals and constraints appropriate to maintenance in a contingency were discussed in Chapter 12. This chapter builds on both of these, and develops a theoretical approach to determine the changes that should be made to a scheduled maintenance program to adapt it for contingency use.

OVERVIEW

The changes required to a peacetime maintenance program can be considered in three stages:

a. adaptation of maintenance tasks in the existing program,

b. addition of new tasks appropriate to a contingency, and

c. task packaging.

ADAPTING EXISTING TASKS

The requirements (or rather, emphases) for a maintenance program alter during a contingency. Availability becomes paramount; the importance of other maintenance goals is reduced (especially cost-effectiveness and preservation of the asset). Generally, maximum availability for a component is achieved with a level of scheduled maintenance somewhat less than the level required to optimise any other maintenance goal (airworthiness, missionworthiness, cost-effectiveness, or preservation). Accordingly, consideration should be given to a reduction in the amount of scheduled maintenance for every component.[1]

1 The exception is where failure modes may be more frequent as a result of changed usage and environment (discussed later).

The amount of scheduled maintenance given to an item can be reduced by:

a. performing abbreviated tasks at the existing intervals,

b. increasing task intervals, and/or

c. deferring task(s) until the cessation of the contingency.

The desirability of adjusting an item's maintenance policy to attempt to increase availability is affected by:

a. the probability that the item *will* affect availability,

b. the extent of the item's potential impact on availability,

c. the likely effectiveness of maintenance as a means of reducing or avoiding the impact, and

d. the consequences of an increase in unscheduled maintenance.

Probability of Impact on Availability

When considering the desirability of reducing the amount of scheduled maintenance for an item, some indication of the item's criticality *from an aircraft availability viewpoint* is useful. Many maintenance tasks will not have a direct impact on aircraft availability, and to reduce the performance of such tasks may unnecessarily compromise some other goal for little useful gain.

The standard engineering concept of criticality is not useful here. The criticality rating normally used in aircraft maintenance requirements considerations assesses an item's impact on airworthiness or mission-worthiness, but not availability.

An 'item importance hierarchy' can be constructed, which indicates how directly various categories of items can affect aircraft availability (Figure 13-1). The development and implications of this diagram are discussed at Annex F. The basic conclusions are:

a. The aircraft itself is the most critical component from an availability point of view; any maintenance work performed on the aircraft must directly affect availability.

b. The impact of component maintenance on availability can be buffered by the existence of spares holdings for the component.

c. The criticality of components reduces with increasing 'depth' within the physical build structure of the aircraft, due to the existence of spares holdings for items above it in the hierarchy.[2]

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2 The physical build structure is the hierarchy of components in an aircraft, indicating which component is fitted to which.

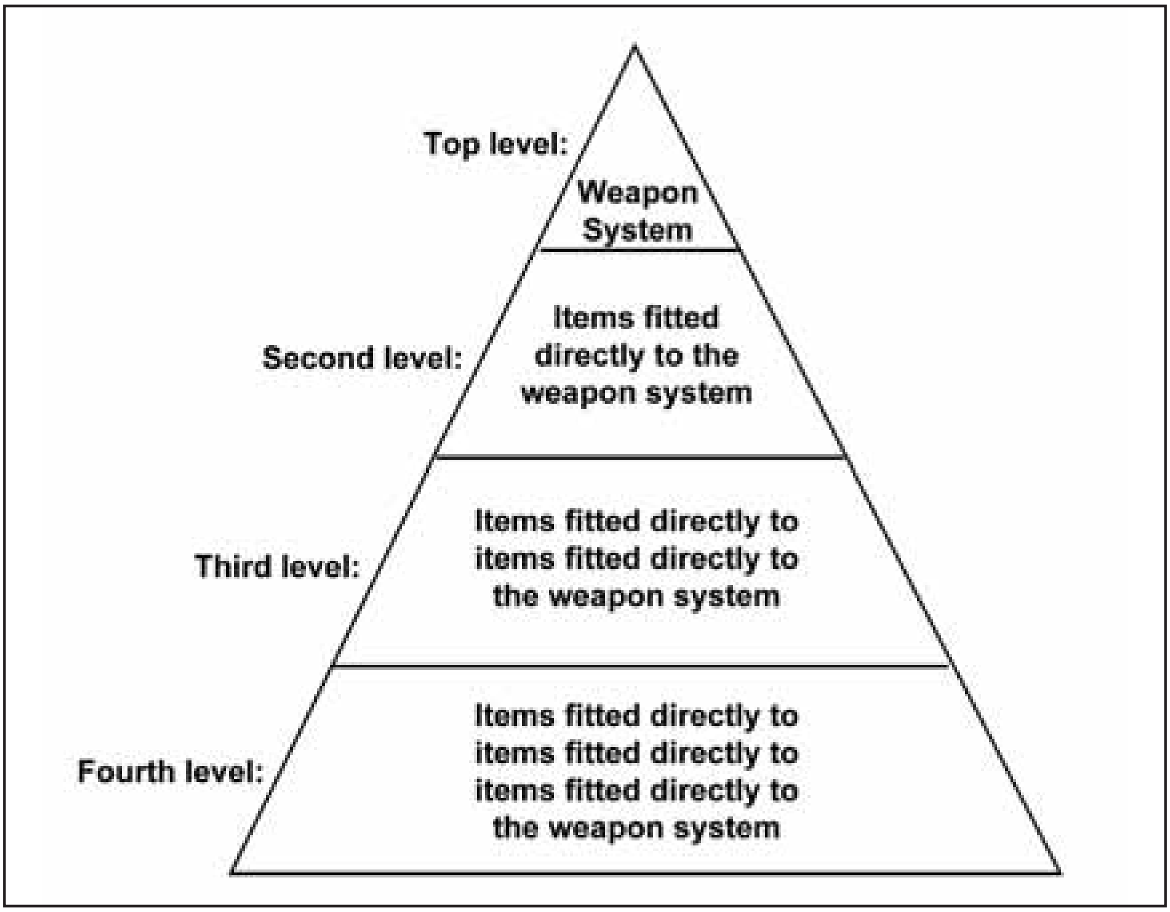

Figure 13-1: Item Importance Heirarchy

The position of an item in the item importance hierarchy indicates the *potential* for an item to affect availability; it measures how 'exposed' or 'vulnerable' it is, based on the shielding effect provided by spares holdings. The other major factor that influences the potential for impact is the adequacy of spares holdings. At the top level of the hierarchy (maintenance performed directly on the aircraft), spares holdings means holdings of spare aircraft—which will generally be zero.

The simplest application of the item importance hierarchy is that the amount of *on-aircraft* maintenance must be reduced as the highest priority. However, this does not mean that the production (including scheduled maintenance and repair) of subassemblies need not change during a contingency. Increased demand rates will require increased maintenance throughput to keep spare serviceable items in the pipeline. If pipeline capacity is not increased to match demand rates, supplies of spares will be exhausted, and the component may then directly impact availability (depending on the existence of spares for items higher up the hierarchy).

Extent of Impact on Availability

Having established the *potential* (or probability) for an item to impact on availability, the extent of the possible impact should be assessed. Factors include:

a. whether the item needs to be fitted or serviceable for the aircraft to be able to perform all of its roles and essential functions;

b. the frequency of maintenance arisings (frequent arisings can affect availability more often);

c. the speed with which items can be repaired or serviced (items that may be turned around quickly will have less impact on availability); and

d. the extent of other delays in the maintenance pipeline (eg. transportation time, administration time).

Air Command Operational Preparedness Directives (ACOPDs)[3] indicate what aircraft systems are required to be serviceable for various roles. This data, coupled with knowledge of the item's criticality to the successful functioning of the system, provides detailed information on the mission essentiality of the item.

When considering items at the top level of the item importance hierarchy (ie. whole aircraft), considerations concerning the existence of spares and the performance of the maintenance pipeline are simplified (albeit more critical). The extent of the impact on availability is the product of the frequency and duration of maintenance.

Sensitivity to Maintenance

Even if it is highly likely that an item will affect availability, and the extent of the impact could be serious, it does not automatically follow that the item's maintenance requirements should be adjusted. If availability is greatly affected by adjustments to the maintenance program, changes should certainly be considered. If, however, changes to the maintenance program have little effect on availability, such changes are much less worthwhile. This property could be called the sensitivity of item availability to maintenance.

Figure 13-2 shows how downtime is affected by changes to (scheduled) maintenance requirements for an item with availability that is highly sensitive to maintenance.[4] A reduction in the amount of scheduled maintenance (ie. scheduled downtime) results in a relatively small increase in the amount of unscheduled maintenance (unscheduled

3 See p. 31.

4 This Figure and the next are somewhat simplified versions of graphs presented in Chapter 11. In the present context, the relationship between scheduled and unscheduled maintenance is depicted as linear (a straight line); this makes it easier to see why total downtime varies depending on the 'response' of unscheduled maintenance to a reduction in scheduled maintenance. However, presenting the graphs as linear means that there is no point at which downtime is minimised; the graphs in Chapter 11 are more realistic in this regard.

downtime). Consequently, there is a significant reduction in the total amount of downtime; ie. availability is significantly improved.

Figure 13-3 shows a similar graph, but for an item whose availability is relatively unaffected by changes in the amount of scheduled maintenance. A reduction in the amount of scheduled maintenance is accompanied by an increase in unscheduled maintenance of similar magnitude, so that the overall reduction in maintenance downtime is small. In this case, the small gain in availability may not be worth pursuing: the large increase in unscheduled maintenance may significantly reduce airworthiness or missionworthiness; the undesirability of these effects may well outweigh the benefit of the small increase in availability. Availability improvements should be sought for items that do *not* display a rapid increase in unscheduled maintenance before looking at items where the benefits are more marginal.

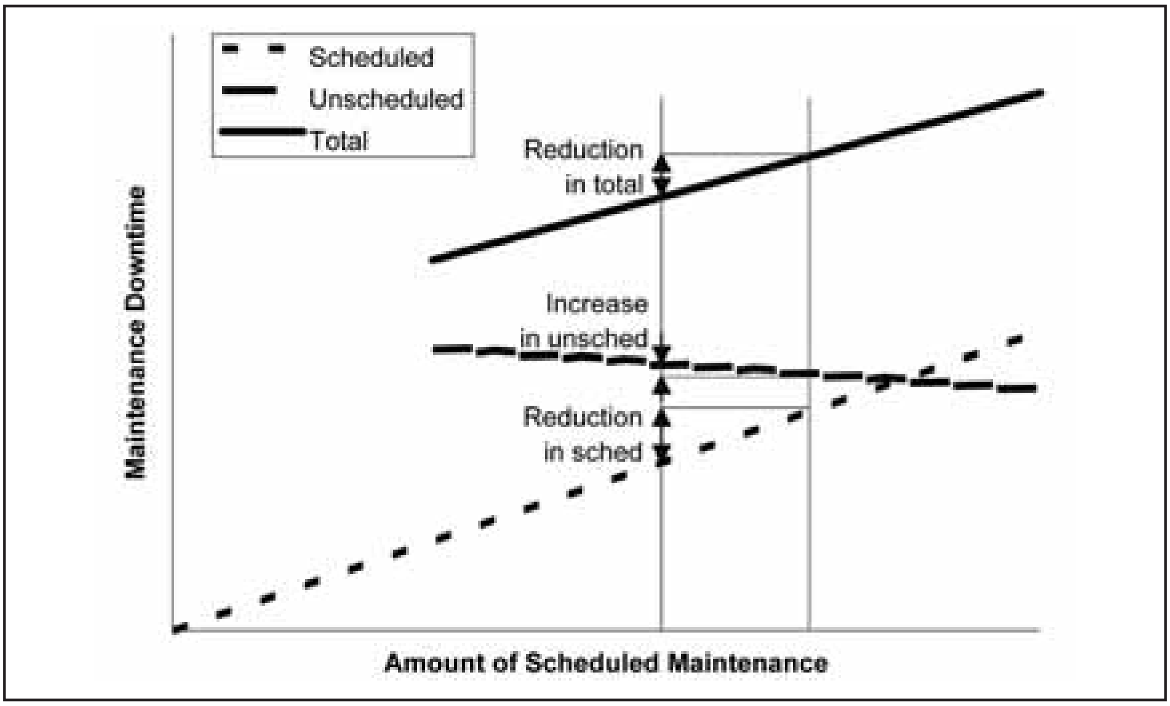

Figure 13-2: Downtime vs Scheduled Maintenance – High Sensitivity Item[5]

5 *Low sensitivity* and *high sensitivity* refer to the sensitivity of *availability* to scheduled maintenance changes; not the sensitivity of hazard or unscheduled maintenance. This is why the larger increase in hazard is marked *low sensitivity*: increased hazard will result in more unscheduled maintenance, which will largely dissipate the advantage gained by extending the scheduled maintenance interval.

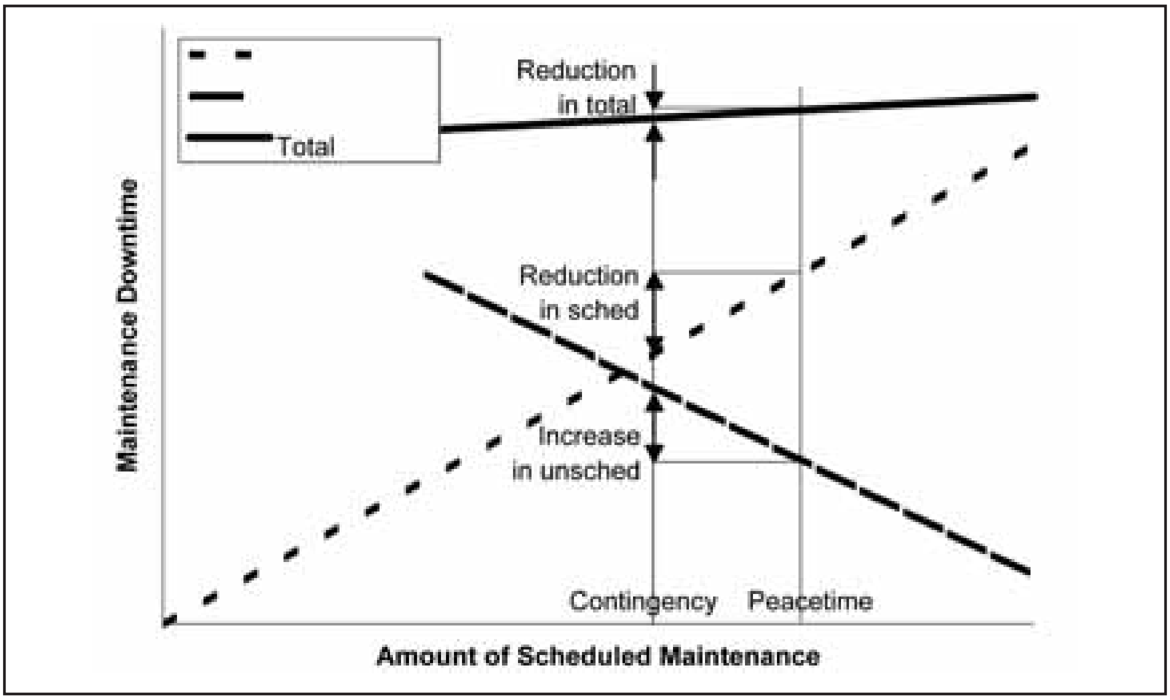

Figure 13-3: Downtime vs Scheduled Maintenance – Low Sensitivity Item

Determining an item's sensitivity to maintenance in practice is difficult. Items with a strong wear-out failure pattern are likely to exhibit a significant increase in unscheduled maintenance requirements if scheduled maintenance intervals are extended (assuming that the intervals were set correctly in the first place). Thus, the overall maintenance downtime may not be greatly reduced (if at all). Conversely, a component with only weak wear-out will not exhibit dramatically increased unscheduled maintenance requirements given a scheduled maintenance interval extension, and so larger savings in downtime are more likely to result.

Determining the nature of an item's failure pattern (eg. suddenness of wear-out) can be achieved by statistical analysis of failure history, eg. by fitting a Weibull distribution.[6] One of the Weibull parameters directly indicates the significance of wear-out. Figure 13-4 shows two Weibull distributions corresponding to items with different wear-out trends.

In addition to the nature of the failure mode itself, the effectiveness of maintenance tasks in delaying failure should also be considered. If the task can do little to correct the condition which causes failure, a significant number of failures will occur even when the task is performed frequently (this will also affect the nature of the Weibull curve). Accordingly, extending the task interval will have less of an adverse effect on reliability than may otherwise have been expected.

6 See p. 299.

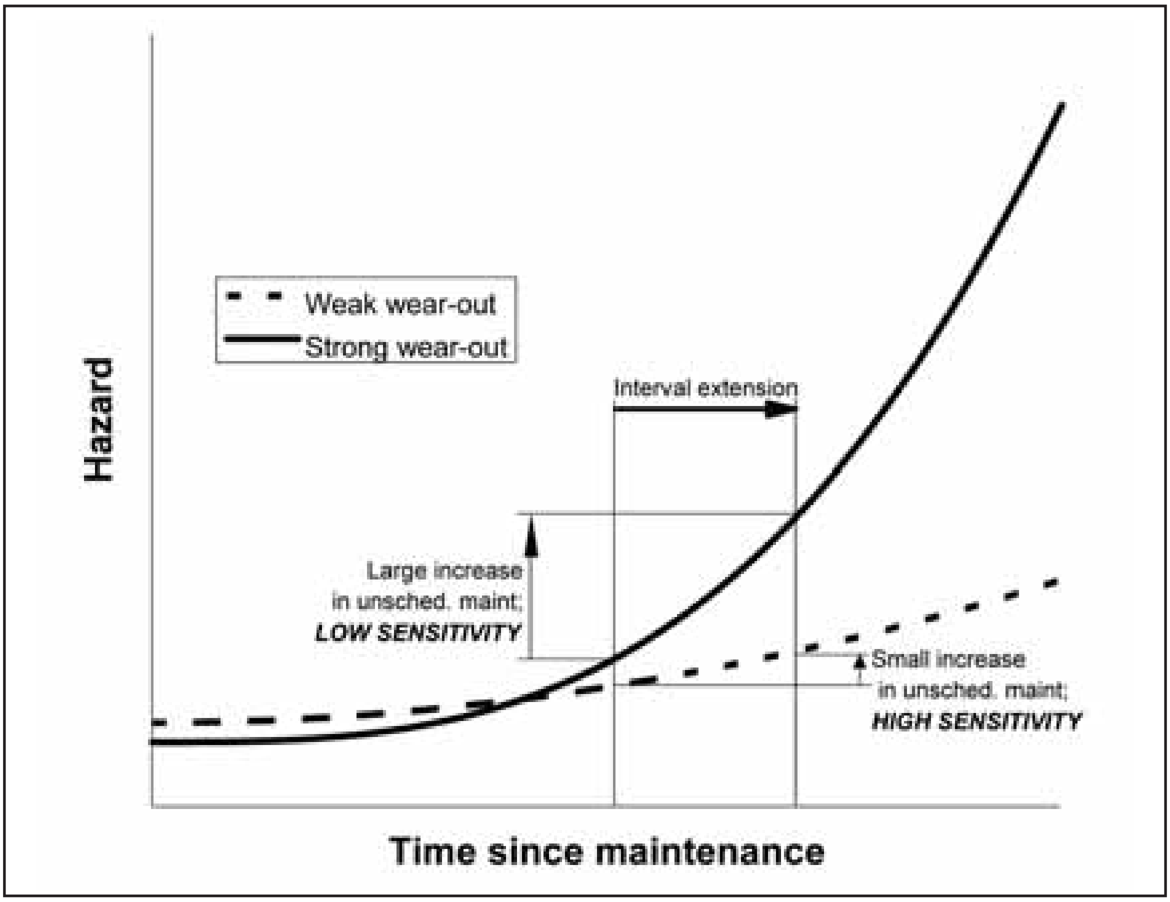

Figure 13-4: Weibull Wear-out Comparison

Consequences of Increased Unscheduled Maintenance

If scheduled maintenance requirements are relaxed, unscheduled arisings will generally increase. This can mean a reduced level of airworthiness or mission reliability, increased maintenance cost and/or reduced preservation of the asset. The nature of the impact depends on the item's criticality; the likelihood and severity of the impact must be assessed and balanced against the expected availability benefit.

Aircraft Structural Integrity

When necessary, tasks included in a maintenance program only to provide assurance of structural integrity may be deferred.[7] This can mean deferring inspections for items managed by a safety by inspection philosophy, or deferring component replacements for items

7 This is implied in DI(AF) ENG 5-2, *Aircraft Structural Integrity Management*, 20 December 1993, paragraph 32. This interpretation is shared by HQLC ASI managers.

8 The downtime saving (and hence availability increase) will be greatest for aircraft managed using safety by inspection, since the maintenance requirements are greater under this philosophy.

managed on a safe-life philosophy.[8] To demonstrate the use of the criteria discussed above, they will be used to assess the possible benefits and risks of the deferral of ASI tasks.

Probability of Impact on Availability. Structural integrity tasks often involve inspections of aircraft structure (sometimes requiring the use of Non-Destructive Inspection techniques[9]). Virtually all such inspections are of the aircraft structure,[10] which represents the top level of the item importance hierarchy; therefore, any reductions in maintenance downtime equate to direct improvements in availability. If the inspections are on the servicing critical path, downtime savings will accrue.[11]

Extent of Impact on Availability. Often, such inspections are required for areas of the aircraft that cannot be easily accessed, so structural integrity tasks can require significant downtime when performed. Even though the inspections are generally not required to be performed very frequently, a potentially significant increase in availability can be achieved.[12]

Sensitivity to Maintenance. Damage is actually found relatively infrequently, so the increase in unscheduled maintenance resulting from the deferral of structural integrity tasks would be slight; ie. availability is highly sensitive to maintenance requirements. Accordingly, a reduction in scheduled requirements will result in a significant saving in downtime (albeit with some increase in risk).

Consequences of Increased Unscheduled Maintenance. The consequences of unscheduled arisings are most severe. An undetected structural flaw can have catastrophic results; the only mitigating factor here is that the incidence of such arisings will generally be most infrequent.[13] Where specific structural integrity tasks are known to find damage relatively frequently, such tasks should generally be retained (although possibly at an extended interval).

Exploiting the Sustainability Period

A significant difference between contingency and peacetime circumstances is that a contingency is a *time limited situation*.[14] Peacetime maintenance schedules are developed on the assumption that the serviceability level of the aircraft must be retained virtually

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9 See p. 310.

10 Exceptions include inspections of the F-111 wing structure, which are performed with the wing removed from the aircraft. Since spare wings may be held, they are not at the top level of the item importance hierarchy, but the second level. As a result, there should be significantly less need to defer such inspections.

11 See p. 85.

12 The exact amount could be determined by rescheduling the servicing using PERT, see p. 85.

13 Many structural inspections have *never* detected any damage during the life of the aircraft (at least in RAAF service); the probability of damage arising during the relatively short duration of a contingency is slight. (Changed operating profiles may, however, invalidate this reasoning.)

14 DI(AF) AAP 7001.038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, paragraph 733.

indefinitely (to the maximum extent possible).[15] Peacetime is thus considered to be steady-state; however, a contingency can be treated as a dynamic scenario.

The CDF Directive on ADF Preparedness (CPD)[16] provides an indication of the duration of possible contingencies for each serial listed. The relevant figure is called 'sustainability resources', and indicates how many days' usage of supplies should be available to support the serial.[17] This figure can be assumed to be the Sustainability Period, which can be used to fine-tune the maintenance program to maximise availability for the required duration.

The methods required to exploit the time-limited nature of a contingency are quite different to the standard methods used for peacetime maintenance requirements determination. If peacetime methods alone are used to determine contingency maintenance requirements, the maximum possible availability would probably not be attained—even given the changed emphases on availability, airworthiness, etc. It is therefore important to appreciate the advantages that are offered by exploiting the time-limited nature of contingencies. Annex G shows why the use of a dynamic model can yield increased availability without allowing airworthiness (etc) to drop to unacceptable levels; the following paragraphs provide an overview.[18]

A reduction in the amount of scheduled maintenance performed on an item (eg. a transition from a peacetime to a contingency maintenance program) will not result in an *immediate* increase in the amount of unscheduled maintenance. Rather, the item will become *gradually* less reliable, until a new equilibrium is established between the amounts of scheduled and unscheduled maintenance. However, for some period of time, the reduction in the amount of scheduled maintenance will exceed the increase in unscheduled maintenance required, and so the overall maintenance burden, and hence downtime, will be reduced compared to peacetime levels. Figure 13 5 illustrates this.

At some point, the amount of unscheduled maintenance may well increase by a greater amount than the saving in scheduled maintenance. From this point onwards, availability will be *less* than could have been achieved if the maintenance program had been left unchanged. It is therefore necessary that the period of increased availability be of similar duration to the sustainability period.

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15 A notable exception is the Aircraft Structural Integrity safe-life philosophy, which requires that the component (or aircraft) be discarded after a certain amount of usage. See p. 306.

16 See Chapter 4.

17 The measure is *not* actually a period of time, so much as a quantity of supplies. While this interpretation may be useful for supply-related planning, it does not provide the necessary guidance for maintenance purposes. S. Craig Moore, J.A. Stockfisch, Matthew S. Goldberg, Suzanne M. Holroyd, Gregord G. Hildebrandt, 'Measuring Military Readiness and Sustainability', RAND, Santa Monica, 1991, p. vi, is critical of readiness and sustainability measures that are expressed (solely) in terms of stockpiles of materials, and which fail to cover engineering and maintenance preparedness.

18 There are many simplifying assumptions and approximations in the summary provided here; Annex G expands on some of these, but still only outlines the principles and some traps. Further work needs to be done to produce a procedure for exploiting the finite nature of the sustainability period in a methodical manner.

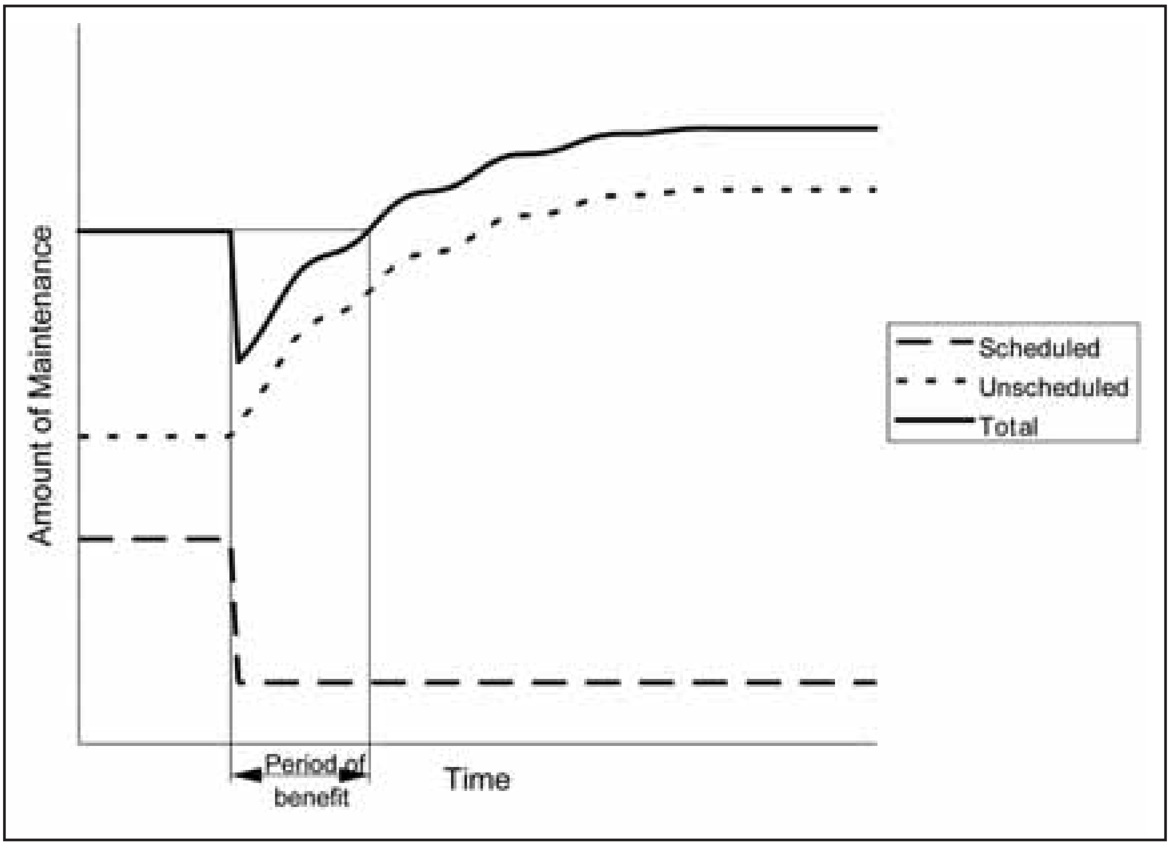

Figure 13-5: Transient Reduction in Maintenance

The important issue then becomes: how quickly will a component's unreliability increase after a reduction in scheduled (preventive) maintenance? The rate of increase of unreliability will be a function of the design of the item, the nature of its failure modes, and the way in which it is used. The (peacetime) scheduled maintenance interval will provide some indication of the rapidity with which the need for unscheduled maintenance would increase. If a component is maintained often, this will be because it will not remain sufficiently reliable for very long; if a component only needs scheduled maintenance infrequently, the rate at which unscheduled maintenance increases will be more gradual. All else being equal, the duration of the period of increased availability will be proportional to the peacetime maintenance interval. Moreover, the duration will be of the same order of magnitude as the peacetime interval; eg. if a component is maintained every few days during peacetime, a reduction in scheduled maintenance could only be of benefit for a few days; if the component only needs scheduled maintenance every few years during peacetime, the potential period of benefit would be of similar duration.

This suggests that tasks with peacetime scheduled maintenance intervals of similar (or greater) duration to the sustainability period are candidates for possible interval extensions during a contingency. The proportion of longer-interval maintenance required on an aircraft will influence the amount of increased availability that may be achieved by this approach. Conversely, shorter sustainability periods admit the possibility of extending the intervals of more frequently maintained components (as well as components with longer intervals); ie. a greater percentage of maintenance overall may be extended. Thus, availability for shorter duration conflicts can be greater than that for longer conflicts. Another application of this observation is that maintenance requirements could be adapted for short surges (or combat periods) during a longer contingency, to provide additional availability when it is most needed.

There is an obvious risk in this approach: the required sustainability period cannot be predicted with great accuracy during peacetime. If the contingency 'overruns' the anticipated duration by a considerable margin, those components for which maintenance was reduced when exploiting the finiteness of the sustainability period will become ever more unreliable. If the increasing unreliability cannot be tolerated, additional preventive maintenance effort may be required to attempt to reduce unreliability to acceptable levels. This amounts to a surge in maintenance requirements, with a consequent drop in availability. It would be beneficial to continually adjust the expected sustainability period during the contingency based on changing fortunes, and to make changes to the maintenance program as these updates become available. Achieving this in practice would require that those tasks (including deferred tasks) which depend on a certain sustainability period assumption can be easily identified.

On-Condition Maintenance

An alternative to simply extending component preventive maintenance intervals is to move to on-condition maintenance (surveillance maintenance).[19] In some respects, this is a compromise between extending preventive maintenance intervals and retaining peacetime intervals. Surveillance maintenance (eg. inspections, use of test equipment) can replace preventive maintenance tasks at the same intervals.

A time saving will accrue since the inspections will generally be quicker to perform than the preventive tasks. Little extra risk (to airworthiness, etc) should result if the inspections provide a high confidence of detecting conditions that warrant preventive (or corrective) maintenance. If further time savings are required, the inspection interval can be extended beyond the peacetime maintenance interval (with a corresponding increase in risk of failure).

Not only can time (and hence availability) savings accrue from the use of on-condition maintenance, but the GSE requirements can also be reduced. It may be feasible to deploy the required test equipment, but not the preventive or corrective maintenance GSE required; thus, in the extreme, the use of an on-condition policy can defer the need for the aircraft to be rotated back to a maintenance base.[20]

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19 *ADF Reserve Stockholding Policy Implementation Guidance*, HQADF Logistics Division, December 1993, p. 38.

20 Wing Commander Gary Waters and Squadron Leader David Pasfield, *Imperatives for Air Force Logistics Preparedness*, DLDP AF89/2202 Pt 2 (22), Canberra, 1992, p. 21.

In addition to application to existing peacetime tasks, on-condition maintenance can be used for newly-introduced contingency maintenance tasks, such as inspections for the detection of environmentally-related damage. This approach was used extensively in the Gulf War, ranging from unassisted visual inspection of aircraft surfaces for damage (including battle damage), through to assisted inspections of engine components[21] and vibration monitoring of bearings.[22]

ADDITION OF CONTINGENCY MAINTENANCE TASKS

Although the primary goal of a contingency maintenance program is to maximise availability, it is generally necessary to add some new maintenance tasks, and to increase the frequency of some existing tasks, when adapting a maintenance program for contingency use. This can be necessary to allow for increased operational flexibility and performance (eg. the removal of flight restrictions or the adoption of a changed mission mix), or to minimise the adverse effects of operations in adverse environmental conditions.[23]

Annex E describes the maintenance tasks that may be necessary to combat environmental degradation.

Although additional tasks may be added to the *scheduled* maintenance program as a result of these considerations, the *overall* amount of maintenance may well be reduced. This is because *unscheduled* maintenance may increase significantly if preventive steps are not taken, especially concerning environmental effects: sand and temperature damage can result in significant reductions in reliability, requiring unscheduled maintenance (repair) and degrading mission reliability.

A failure to adequately atone for increased operational demands may well result in reduced airworthiness. Although additional scheduled maintenance may adversely impact availability, airworthiness must still be maintained at an adequate level.

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21 *Operation Scimitar/Friction – CF-18 Maintenance*, Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, Section 4, Enclosure 2.

22 Murray Hammick, 'Sea Kings in Sand', *International Defence Review*, 5/1991, pp. 453–455. Vibration monitoring is a part of the normal peacetime maintenance program for Sea Kings; however, it was found useful in detecting damage caused by the desert environment.

23 See also p. 124.

TASK PACKAGING

On-aircraft maintenance tasks are generally grouped into servicings to provide increased efficiency and to simplify maintenance management. Contingency requirements may justify the adoption of a different servicing concept for the aircraft, and will very probably require repackaging of the contingency maintenance tasks into a new servicing set.

Servicing Concept

During a contingency, the aircraft may be operated from a site some considerable distance from established maintenance facilities. Moreover, the daily pattern of aircraft usage may differ considerably between peacetime and contingency. As a result of these changes, the servicing concept used during peacetime may not be the best choice for contingency operations.

If the aircraft can be made available for maintenance for a few hours every day without impacting operations, and if the aircraft's maintenance tasks can be performed discretely, a flexible servicing concept may be best, with the maintenance tasks being performed on deployment to the maximum extent possible.[24] If maintenance tasks can be programmed between operational requirements, scheduled maintenance need have virtually no impact on availability,[25] hence making most efficient use of limited fleet sizes. Also, aircraft can remain at the deployed site for longer or indefinitely (depending on the exact format of the maintenance package and the need for major repair work). Thus, the need to ferry and rotate aircraft is reduced; this becomes more beneficial as the distance between the deployed site and the maintenance base increases. However, since most (or all) on-aircraft scheduled maintenance will be performed on deployment, the number of maintenance (and other support) personnel present on deployment, and the amount of ground support equipment required, is large: an obviously undesirable situation.[26] The flexible servicing concept is also the most difficult to manage.

The periodic servicing concept is at the other end of the spectrum. Maintenance tasks are aggregated into large servicings to the maximum extent possible. If operational requirements are so demanding that flexible maintenance tasks could not be undertaken between sorties, or if the aircraft is not suited to a flexible servicing concept, the periodic concept is probably the next best alternative during a contingency. The relative infrequency of periodic servicings makes it more feasible to perform the servicings away from the Area of Operations, by rotating aircraft to and from the deployment. Aircraft undergoing periodic (normally called routine) servicings will not be available for operations during maintenance

24 DI(AF) AAP 7001.038-1, paragraph 745.

25 The truth of this statement depends on the definition of availability adopted. The aircraft can be always available *when required by the operators*, although there is downtime for maintenance in between operational requirements.

26 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, p. 151; and DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraph 21.

(except in emergencies); overall fleet availability must suffer, with consequent impact on operations unless commitment of the full fleet is not required. However, between servicings, aircraft availability will be higher than could be achieved using a flexible servicing concept;[27] hence, the periodic servicing concept is best suited to short but intensive conflicts. The need to deploy maintenance personnel and equipment is also minimised, if few servicings are to be performed on deployment.

The phased servicing concept does not appear to offer any significant advantage during a contingency. The main benefit of phased maintenance is the efficient use of maintenance resources arising from a more even distribution of maintenance workload. The availability of aircraft in a small fleet is also more constant (albeit lower than could be achieved under a periodic concept). However, aircraft operated from a remote site must be ferried back for maintenance significantly more frequently than would be required under a periodic servicing concept. Phased maintenance may be appropriate during a contingency for a small fleet of aircraft that is not required to operate from remote bases for extended periods, such as a small fleet of strategic transport aircraft.

A composite servicing concept would appear to offer advantages in some situations. All maintenance that will not be performed on deployment should be grouped into periodic servicings: this minimises the frequency with which aircraft must be rotated from the area of operations to undergo maintenance. Where the aircraft's usage and maintainability justifies it, the maintenance to be performed on deployment should be managed using the flexible concept; this would minimise the impact of maintenance on operations, maximising availability. Thus, the combination of flexible and periodic concepts can offer increased availability over any one concept alone, and offers greater flexibility when determining what level of maintenance should be performed on deployment.

It is probably undesirable to change servicing concepts for an aircraft between peacetime and contingency. Lack of familiarity with contingency maintenance schedules was identified as a significant problem during *Desert Storm*;[28] this problem could be minimised by minimising the differences between peacetime and contingency schedules.[29] The difference between the schedules will be most significant if different servicing concepts are used. However, if the same concept is to be used, and if *different* concepts are optimum for peacetime and contingency use, a decision must be made as to whether an optimum peacetime schedule will be adapted for contingency use, or vice versa.

27 DI(AF) AAP 7001.038-1, loc cit.

28 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, paragraph 407.

29 Trialling and exercising with contingency maintenance schedules is another means of reducing this problem; see p. 156.

Repackaging

Even if the same servicing concept is used for both peacetime and contingency maintenance schedules, it will probably be desirable to 'repackage' the servicings; ie. adopt different servicing intervals and/or migrate individual maintenance tasks between the (new) servicings.

During a contingency, many longer interval tasks should be deleted from the maintenance program altogether. Many other tasks should be performed at longer intervals than in peacetime. As a result, servicing intervals should generally extend.[30]

The majority of maintenance tasks that must be added to the maintenance program will be required for environmental reasons, and will generally have very short intervals. Many tasks (such as the fitting and removal of seals and covers) are appropriate for inclusion into flight servicings; other tasks (eg. cleaning, checks for degradation) may be performed on a daily or weekly basis.[31]

Even if individual task intervals are not changed, the increased rate of effort expected during a contingency may justify repackaging. A servicing consists of a group of tasks which are expected to fall due at about the same time. The intervals of some of these tasks will be calendar time based (eg. elapsed days); other intervals will be measured in terms of usage (eg. airframe hours, rounds fired, landings, etc). The grouping of tasks into servicings requires assumptions about how quickly such usage accrues; ie. the rate of effort. If the rate of effort changes significantly, the tasks will not fit neatly into the same groups.[32]

Another motivation for repackaging contingency maintenance servicings is the possible absence (or reduction) in Aircraft Structural Integrity (ASI) tasks. For aircraft managed using a safety by inspection philosophy, such tasks may virtually determine the intervals of many servicings, and may comprise a significant percentage of the maintenance program.[33] The absence of (some of) these tasks removes a constraint in the way that non-ASI tasks may be packaged. Different intervals may be readily adopted to re-optimise the maintenance program in the absence of ASI tasks.

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30 Paradoxically, they may be performed more frequently. If the servicing interval is increased by 50 per cent (from say 200 to 300 flying hours), but the rate of effort doubles, the servicing must be performed more often in terms of calendar time. According to one source, this effect led to a *reduction* in F-15 availability during *Desert Storm* (Murray Hammick, 'Report from the Front: AMUs Underrated in USAF's Success', in *International Defence Review*, 5/1991, pp. 451–452).

31 DI(AF) AAP 7001.038-1, paragraph 742, recommends that such tasks not be included in the contingency scheduled maintenance program, but be managed via Unit Maintenance Orders (UMOs). However, this approach would complicate the maintenance management process. Since a lack of familiarity with contingency maintenance schedules has been identified as a problem, and that a possible move to a flexible servicing concept will further complicate maintenance management, such a distribution of maintenance requirements between documents should be avoided.

32 DI(AF) AAP 7001.038-1, paragraph 740.

33 See p. 310.

OFF-AIRCRAFT MAINTENANCE

The Need for Off-Aircraft Contingency Maintenance

Because off-aircraft maintenance is performed on items that are not at the top level of the item importance hierarchy, holdings of spare items can reduce the need to introduce contingency maintenance. Ideally, if spares holdings are sufficient to cover the increased usage rates expected for the duration of a contingency, there will be no need to accelerate the maintenance phase of the maintenance pipeline: airworthiness, missionworthiness, cost-effectiveness and preservation would not need to be sacrificed to meet availability targets (although there is a cost overhead in holding large numbers of spares).

However, there will not be sufficient spares held to fully buffer all components from possible impact on availability. Because of the complexity of maintenance pipelines, predicting the relationship between maintenance performance and aircraft availability is considerably more complex than for on-aircraft maintenance.[34]

Component Contingency Maintenance Options

There are two basic strategies that can be used to improve the availability of a component: reduce the frequency of maintenance arisings, or reduce the time taken for each (the Turn Around Time – TAT). Unfortunately, the RAAF does not have a system in place that monitors the progress of components through the maintenance pipeline in the general case. It is therefore not easy to determine what percentage of the TAT is comprised of hands-on maintenance (Time to Make Serviceable – TMS). A figure of 20 per cent seems consistent with the limited information available,[35] the rest of the TAT comprising transportation and delays awaiting the next step. This means that compressing the maintenance phase of the TAT (eg. by the use of overtime, multiple shifts, or cut-down servicings) can only result in a small increase in availability; eg. halving TMS would only reduce TAT by about ten per cent. Much greater improvements to component availability could be made by reducing the transportation and delay components of TAT—and this could be done without detriment to maintenance standards, and hence component reliability.[36]

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34 Principles and approaches to this problem are discussed in Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994. The analysis technique of *System Dynamics* is commended as a means of modelling the complexity of this domain.

35 LG8/4540/9/219 Pt 10 (22), Visit Report – East Sale, Richmond and Edinburgh, 23 June 1993, provides examples of 12.5 and 25 per cent (admittedly on problematic components). Maclean, *Preparedness and Repairable Item Management*, p. B-16, relates a case where TMS is less than 12 per cent of TAT. The general feeling of supply staff seems to be that TMS is 'a minor part' of TAT. It would be reasonable to expect that TMS would constitute a larger percentage of TAT where the maintenance requirements are greater (eg. longer servicings), since the transportation and delay overheads should not change appreciably.

36 US Gulf War practices support this argument: 'Desert Express' was used to expedite the transportation of components into the theatre, as transportation delays were recognised as a major problem. Component production times were also reduced, but the effectiveness of this is not generally considered to be as significant (United States General Accounting Office, *Operation Desert Storm – The Services' Efforts to Provide Logistics Support for Selected Weapon Systems*, September 1991, pp. 4, 30–31).

A component contingency maintenance strategy that would be more effective is to reduce the arising rate by increasing scheduled maintenance intervals (but not to the extent that increased unscheduled arisings negate the advantage). In this case, items enter the pipeline less frequently, and so not only is the TMS 'saved' for every non-arising, but the transportation and other delays are not incurred either. Therefore, halving the arising rate would roughly double the availability of the component.[37] Adopting increased servicing intervals is therefore a much more effective component contingency maintenance strategy than reducing TMS. Of course, a true Integrated Logistics Support (ILS) approach would consider *both* strategies, and the inter-relationship between them.[38]

The RAAF's approach to increasing maintenance pipeline performance during a contingency appears to focus on the latter tactic (reducing TMS). This can achieve some gains in pipeline performance with little direct effect on component reliability. However, if greater component availability is required, a change to maintenance policy should be considered (even though the side-effects may be more drastic). Contingency maintenance policies for critical components should be established during peacetime (as they should be for on-aircraft maintenance).

Determining Component Contingency Maintenance Policies

Having determined that off-aircraft contingency maintenance is indeed necessary for a particular component, many of the abovementioned considerations apply; ie. the consequences of reduced reliability must be balanced against the increase in availability; advantage may be taken of the limited duration of the sustainability period; and on-condition maintenance may be considered as an alternative to scheduled preventive maintenance.

There will also be a need to introduce additional off-aircraft maintenance tasks for some items. For example, additional inspections or tests may be necessary to reduce environmental degradation of components such as engines.

The duration for which off-aircraft contingency maintenance is required for a component depends on the 'health' of its maintenance pipeline. If additional spares are acquired part way through a contingency, it may be possible to return to peacetime maintenance schedules (except for environmental additions). To permit this, a clear management link must be established between the state of the component's pipeline and its maintenance policy, so that a change to one can trigger a change to the other.

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37 This is a significant oversimplification; many other factors should be considered.

38 ILS is introduced on p. 39. A more complete discussion of these issues can be found in Maclean, *Preparedness and Repairable Item Management*.

SUMMARY

Adapting a peacetime scheduled maintenance program to contingency use requires the adaptation of existing tasks, addition of new tasks, and/or repackaging of servicings.

Existing tasks should be evaluated with a view to reducing scheduled maintenance commitments. This can be achieved by abbreviating the task, and/or by performing it less frequently (or not at all). A set of criteria can be established to assist in this decision. One of these criteria requires assessing the likelihood that maintenance on the item will impact on availability; an item importance hierarchy can be drawn that provides general guidance in this regard. The desirability of adjusting an item's maintenance policy also depends on how the servicing is conducted.

A further increase in availability may be achieved by exploiting the limited duration of the sustainability period. Some scheduled maintenance tasks may be deferred with few implications in the short term; doing so increases availability until the component's reliability declines.

Greater use of on-condition maintenance can also increase availability, with little detriment in the longer term.

Tasks may need to be added to the maintenance program to account for increased operational flexibility, changed aircraft usage, and/or environmental degradation.

The ideal servicing concept for the aircraft during a contingency may differ from its ideal peacetime concept. Given the undesirability of radically changing maintenance procedures during the transition to wartime, a single concept should be used and adapted as required. Choice of the single best servicing concept should therefore consider both peacetime and contingency goals. A composite servicing concept, using flexible and periodic servicings, would seem to offer maximum availability and flexibility in many circumstances. Regardless of the servicing concept chosen, repackaging of the servicings is likely to be highly desirable to re-optimise it for contingency use.

Some components maintained off-aircraft may need contingency maintenance policies. The most effective form of such policies involves extending the maintenance intervals rather than reducing or expediting task durations. Close coordination between maintenance pipeline managers and maintenance requirements determination analysts is necessary to properly manage this process.

Planning issues associated with the determination of contingency maintenance requirements are discussed in the next chapter. Chapter 16 discusses considerations appropriate to the determination of how much maintenance to perform on *deployment*. Contingency maintenance requirements should also influence the determination of which maintenance tasks may be performed by industry (discussed in Chapter 19).

Chapter 14
Preparing for Contingency Maintenance

INTRODUCTION

The previous chapter discussed the considerations necessary to produce a contingency scheduled maintenance program. This chapter addresses some of the management issues concerning the development and validation of such programs.

PREPARATION DURING PEACETIME

Development Timescales

Developing a full maintenance program for an aircraft is a time-consuming task. Reviewing an existing (peacetime) maintenance program takes between two and eight manyears—even when there are no fundamental changes to the relative priorities of maintenance goals, or changes to the aircraft's usage.

Generally, a contingency maintenance program could not be created within the timescales indicated in CPD readiness notice figures.[1] Necessary contingency maintenance schedules must therefore be drafted during peacetime. Doing so permits validation of the program, and allows the timely establishment of arrangements for industry contingency maintenance support.[2] Development of contingency maintenance requirements should preferably be completed as a part of core capability development;[3] thereafter, peacetime and contingency maintenance requirements should be developed and maintained in parallel throughout the life cycle of the equipment.

Current RAAF practice is to develop only peacetime maintenance schedules during the acquisition phase. In-service management staff in HQLC have developed contingency maintenance schedules for some fleets, but these are minimum modifications of the peacetime schedules, and predate the promulgation of policy and guidelines for the determination of contingency maintenance requirements.

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1 DI(AF) LOG 13-7, *Contingency Maintenance and Battle Damage Repair of Technical Equipment*, draft, 28 February 1994, paragraph 9; and DI(AF) AAP 7001.038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, paragraph 737.

2 LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993, paragraph 56.

3 DI(AF) LOG 13-7, paragraph 14.

Weapon Systems

Not all fleets in the order of battle will need to have contingency maintenance schedules prepared for them; of those that do, the urgency with which contingency maintenance schedules may need to be invoked will vary. Contingency maintenance programs should be prepared in advance for all weapon systems (including ground-based equipment) that are 'expected to be involved in the direct support of combat or other contingency operations, and assessed as critical to the success of those operations'.[4] This will include all operational (as opposed to support) aircraft.[5]

More rigorous criteria can be derived by reference to the CPD. Not all aircraft fleets are given serials in the CPD; any aircraft not mentioned is not expected to be critical to the success of contingency operations, and therefore should not need a contingency maintenance program.[6] Of the fleets listed in the CPD, those with the greatest shortfall between peacetime availability and required contingency availability are prime candidates for the production of contingency maintenance programs.[7]

Not all aircraft fleets will be equally amenable to availability increases by the use of contingency maintenance. The basic criterion determining this is the amount of maintenance that could be removed from peacetime schedules (without resulting in unacceptably poor reliability). All else being equal, fleets with relatively little maintenance performed during peacetime will not yield availability gains as large as fleets with extensive peacetime maintenance requirements. Likewise, maintenance schedules with little 'surplus' peacetime maintenance performed in the pursuit of airworthiness, cost-effectiveness, and asset preservation cannot be pared back to the same extent as more 'conservative' schedules.

FLEXIBILITY

Unpredictability and Variability of Contingencies

The major disadvantage of preparing contingency maintenance schedules during peacetime (other than the resource commitment) is that the exact nature of the contingency cannot be known with any certainty. With the advent of the CPD, some planning assumptions are now documented; ACOPDs provide additional information. As neither of these sources (yet) provides any indication of possible areas of operations, higher level strategic guidance and Contingency Plans must be consulted for this information. These sources describe a range

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4 ibid., paragraph 7.

5 DI(AF) AAP 7001.038-1, paragraph 737.

6 However, some consideration should be given to the development of contingency maintenance schedules for training aircraft, even if they are not mentioned in the CPD. During longer contingencies (possibly beyond the scope of the CPD), increased aircrew recruitment and training will probably be undertaken.

7 The CPD does not specify required availability levels; however, this information may be deduced from ACOPD requirements.

of possible scenarios for which contingency maintenance programs could be developed. Unfortunately, it is not feasible to develop a separate maintenance program for every possible scenario; generally, the most demanding CPD serial should be selected as the basis for maintenance plans.

A contingency that actually arises may not closely match the CPD serial that was selected as the basis for maintenance planning (or any other CPD serial, for that matter). Accordingly, the maintenance schedules must be easy to adapt to other possible scenarios.[8] Even within a single contingency, one fixed set of maintenance requirements will not always be optimal. Often, the operational commander will need to make decisions on the tailoring of the maintenance program to meet immediate requirements; the maintenance program should be presented in such a way that the operational commander is effectively presented with a range of options, preferably with an indication of the benefits and risks associated with each.[9]

An explicit example of the need for such flexibility is the distinction between contingency and combat maintenance.[10] Combat maintenance will consist of a subset of contingency maintenance tasks, possibly with increased task and servicing intervals. This information should be clearly documented in contingency maintenance schedules, so that it can be quickly and safely invoked by the operational commander should the need arise. Without this guidance, arbitrary decisions on maintenance tasks may be made, which could have greater adverse side effects, and may not achieve the increased availability sought for the duration required.

Endurance

A measure of the achievable sustainability duration at any point in time may be termed *endurance*. Ignoring on-aircraft maintenance, endurance will be limited by the available stockholdings of spares, and will be significantly influenced by activity level. Such knowledge would allow operational commanders to make tradeoffs between activity level (eg. rate of effort) and endurance.[11] The SUSMOD computer application being developed within HQLC could form the prototype of such a system.[12]

It should be possible to identify those components which are likely to most constrain endurance; ie. the poor performers (or 'bad actors'). Having done so, logistics actions can be taken to improve the endurance of these components. In addition to supply-related

8 HQLC DCOE/4000/49/MRU Pt 2 (9), *Impacts on Logistics Command Functions in a Contingency*, COFS-LC, 16 December 1992, predicts such an increase in 'reliability analysis' during a contingency.

9 DI(AF) LOG 13-7, paragraph 10; and DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraph 5e.

10 See p. 120.

11 Discussion with Group Captain P. Hayes, SOPB AHQ, 6 October 1994.

12 SUSMOD is introduced on p. 33.

measures, such actions may include the adoption of increased maintenance intervals or cut-down servicings (ie. component contingency maintenance).[13]

Data Storage

A flexible means of documenting contingency maintenance requirements would involve the use of a database that linked assumptions (such as sustainability period, required rate of effort, status of supply pipelines) to outcomes (such as maintenance policies for individual tasks, and possibly maintenance packaging concept). Whenever any of the assumptions changed, the database would immediately indicate which outcomes were invalidated. This would avoid the need to review the whole maintenance program whenever the situation changed, which would not be feasible. The database should also be indexed by other parameters which could assist in rapidly assessing the impact of a proposed change, such as item criticality, lifing units, and justification for maintenance task (eg. structural integrity, cost-effectiveness, etc).

The logical repository for these data would be in the Weapon System DataBase (WSDB);[14] specifically, within the CAPLOG-hosted Logistic Support Analysis Record (LSAR).[15] This database will already contain much of the required information.[16] Some additional fields and access methods may be necessary, but should not be of any greater magnitude than the changes currently being made to the basic CAPLOG suite to adapt it for in-service RAAF use.

Limited Scope of CPD

Whenever the CPD is used as the basis for planning, the limited scope of the document must always be considered. Maintenance programs developed for CPD serials may not be optimal for use in major conflict or for multinational operations (eg. peacekeeping). These scenarios may differ significantly in the duration of the conflict or operation (sustainability period), required aircraft availability and usage pattern, and distance from maintenance bases. Flexibility in the presentation and data storage of contingency maintenance information would facilitate its adaptation to scenarios not covered by CPD serials.

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13 See p. 143.

14 RAAF Engineering Planning Team, *Blueprint 2020 – Engineering the Future*, Departmental Publications, Canberra, 1993, p. 10-5.

15 See p. 62.

16 Some necessary information may not be held in the LSAR itself, but may reside in a separate database that supports a Reliability-Centered Maintenance (RCM) application, also to be hosted on CAPLOG. Plans for the acquisition and integration of a separate (but integrated) RCM tool are proceeding at the time of writing. There is also considerable overlap between these systems and the Maintenance Engineering Analysis Candidate Identification (MEACI) system—see p. 78.

MAINTENANCE PERFORMANCE MEASUREMENT

There are virtually no systems in place to measure maintenance performance in terms of operationally-focused goals, such as availability and airworthiness.[17] The usefulness of such systems for assessing contingency performance would be limited at any rate; peacetime measures do not provide a direct indication of contingency performance. However, data on the performance of a peacetime maintenance program would provide a good basis for assessing the expected effects of incremental changes made to such a program, eg. when adapting it to contingency use.

Measurement of maintenance performance during exercises would also be of value, but the artificial nature of most exercises from a maintenance viewpoint limits the conclusions that could be drawn from such measurements.

Monthly Maintenance Reports (MMRs)

Monthly Maintenance Reports (MMRs) record the availability of all aircraft in a fleet as at 0930 hours every working day. This information provides a statistical sample ('snapshot') of fleet availability. Reasons for unavailability are codified, with categories such as scheduled maintenance, unscheduled maintenance, modification, spares shortages, etc. The sampled nature of the data provides opportunities for the results to be manipulated; eg. by not declaring aircraft to be unserviceable until after 0930 hours. In addition, the MMR database figures do not add up accurately: in some cases, only 80 per cent of available time is accounted for; in other cases, 170 per cent is accounted for![18] Despite these problems, MMR data still provides the best indication of availability and attribution of downtime.

Aircraft Availability Tracking and Reporting System (AATARS)

AATARS is a computer-based system that avoids many of the limitations of the MMR. It records the continual changes in aircraft availability throughout the day, thus reducing the possibility of manipulating the data, and ensuring that all time is accounted for (and no more).

AATARS is more closely linked to the CPD than previous approaches. It records which CPD roles each aircraft is capable of performing. However, AATARS will not record mission reliability. This information can be obtained from aircrew reports[19] or from maintenance databases such as the Computer-Aided Maintenance Management system (CAMM) and the Maintenance Analysis And Reporting System (MAARS).

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17 LD93-20656 Pt 1, paragraph 27.

18 Squadron Leader M.W. Cornwall, Squadron Leader G.D. Evans, Squadron Leader C.G. Wheaton, and Flight Lieutenant G.C. Saunders, DLDP AF91/7557 Pt 1 (14), *A Study of RAAF Aircraft Availability and Cost Factors*, Directorate of Logistics Planning and Development, 17 September 1991.

19 Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994, p. 3-9.

Maintenance Management and Supply Systems

Various RAAF maintenance management computer systems also collect some data that can be used to assess maintenance performance. In addition to supporting the collection of MMR data, CAMM records data on component failures and maintenance tasks performed. Summaries of this data are passed to MAARS for historical recording; MAARS can provide printouts that can be used to assess performance in reliability-related areas such as airworthiness and missionworthiness.

Maintenance cost and timing data are not collected to the same extent. This limits current ability to assess maintenance cost-effectiveness. A more serious limitation, when considering contingency performance, is that a breakdown of component turn-around time is not available; ie. it is not possible to assess how much time an item spends in transit, waiting for manpower or spares, or in work. This information would allow determination of the most effective areas for attention if it became necessary to speed up maintenance pipeline performance to improve availability.

MODELLING CONTINGENCY MAINTENANCE PERFORMANCE

It is highly desirable to be able to predict the maintenance performance that could be achieved during a contingency. There are two general ways in which this can be done:

a. predicting performance by the use of simulations and other models, and

b. conducting trials in which contingency maintenance schedules are used in practice.

Logistic Support Analysis (LSA)[20]

Logistic Support Analysis (LSA) includes tools that can be used to predict maintenance performance in general terms. However, the current lack of a fully integrated, powerful Reliability Centered Maintenance (RCM) capability restricts this use of LSA: detailed RCM analysis is necessary to quantify the reliability that may be achieved under a particular maintenance program. Without this capability, LSA estimates of contingency availability may be based on contingency levels of scheduled maintenance, but *peacetime* levels (or *guessed* contingency levels) of reliability (and hence unscheduled maintenance). This leads to an underestimation of downtime, and hence an overestimation of availability.

The level of component reliability is critical to the determination of availability (as well as airworthiness, etc). Component reliability figures must be provided before ‘higher level’ performance can be modelled; for this reason, reliability figures are mandatory inputs to

20 LSA was introduced on p. 62.

tools such as OPUS 9 and LOGCAS. Preferably, data on the change in reliability over time given changes in scheduled maintenance requirements (eg. from peacetime to contingency) should be provided, to more accurately model the behaviour expected for the duration of a contingency. RCM, possibly augmented by statistical methods such as Weibull analysis, can be used to ascertain these data—although not easily.

The ability to assess levels of scheduled and unscheduled maintenance allows estimation of the availability that may be achieved (as well as spares requirements). The component reliability and maintenance data in the LSA can be 'rolled up' to provide an indication of the availability that may be expected for the aircraft overall.

In addition, reliability figures provide an indication of the possible effect on airworthiness and missionworthiness that may result. Cost-effectiveness may also be calculated from these data, and knowledge of maintenance costs. The level of asset preservation is indicated by the level of reliability expected in the longer term.

Optimal Utilisation of Spares 9 (OPUS 9)

CAPLOG's implementation of LSA also includes a spares assessing tool, OPUS 9. OPUS 9 is a *steady-state* model; ie. it does not attempt to model changing conditions over time; all conditions are assumed to be stable. This includes the rate of effort, component reliabilities, repair times, etc. As a result, OPUS 9 cannot be used to realistically assess logistics performance in a changing environment, such as the transition from peacetime to contingency.[21]

OPUS 9 bases its calculations on the aircraft's build structure, component reliabilities, component replacement costs, maintenance and transportation durations, and spares holdings. Multiple bases, maintenance venues and storage depots can be modelled. Given this data, OPUS 9 can forecast the aircraft availability resulting from the specified input data. OPUS 9 does not explicitly distinguish between scheduled and unscheduled maintenance requirements, although the effect of this can be achieved if necessary.

OPUS 9 can be used to determine the availability that would result from a change in maintenance policy (eg. the adoption of contingency maintenance), although the resulting levels of reliability must first be estimated by other means. However, since the model is steady-state, it can provide no indication of how long it would take before the contingency maintenance equilibrium is reached.[22] Moreover, the possible benefits of exploiting transient

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21 However, OPUS 9 does have a 'surge' function, whereby different rates of effort and levels of scheduled maintenance may be specified. However, the system remains steady-state, in that it cannot model *transitions* from one state to another.

22 Squadron Leader Chris Wheaton, 'Logistics Performance Measurement', *The Logbook*, June 1993, pp. 37–39. Anecdotal evidence indicates that a new equilibrium is reached after about 90 days; ie. after a change in input variables, the performance of the logistics system would oscillate for about 90 days before settling down again (to a different level of performance). OPUS 9 could not predict what would occur during the 90 day period.

effects (such as the limited duration of the sustainability period[23]) could not be assessed using OPUS 9.

OPUS 9 is not a simulation, but is deterministic:[24] it solves relevant equations to determine its output.

Logistic Capability Assessment (LOGCAS)

Logistic Capability Assessment (LOGCAS) can provide a more detailed estimate of aircraft availability throughout a contingency. LOGCAS is a computer model which can simulate a particular contingency. Unlike LSA and OPUS9, LOGCAS is *dynamic*; ie. it attempts to model how conditions change over time. Contingency planning requires such an approach, so that work-up and surge can be more accurately modelled, as well as attempts to exploit the finiteness of the sustainability period. As a result of this more precise way of modelling logistics performance, greater availability could be achieved for the same level of logistics cost by more optimal allocation of resources (spares and maintenance effort).[25] HQLC is currently evaluating a LOGCAS tool for possible incorporation into CAPLOG: a Swedish package called *Availability Simulation of Total Operational Resources* (ASTOR).

Despite being a logistics simulation (as opposed to a wargaming simulation), LOGCAS requires considerable operational data to be specified, including a detailed flying program listing what sorties should be executed, when, and from which base. Operational and training sorties can both be accommodated. Individual aircraft and bases are modelled.[26]

Logistics inputs are not as detailed as those used in LSA. Aircraft scheduled servicings can be modelled in reasonable detail, including the servicing interval and tolerance, the mean and standard deviation of the servicing duration, and the reduction in aircraft reliability if a servicing interval is unduly extended. Major aircraft subassemblies can also be modelled, in terms of their reliability (which is normally assumed constant), spares holdings, and the location and duration of maintenance activities. Maintenance manpower capacities can be specified for each base and trade group.

Obtaining the necessary inputs for LOGCAS will be problematic. The CPD and Operational Preparedness Directives (OPDs) do not specify detailed flying programs, although OPDs indicate typical sortie types, durations and frequencies. A detailed flying program is not

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23 See p. 136.

24 *Determinism* does not mean that the model does not take probabilities into account; rather, it means that the same set of inputs are guaranteed to produce the same outputs—there are no random elements in the calculations. This is to be contrasted with 'Monte Carlo' models such as LOGCAS, which use random numbers to determine such things as servicing durations, component failures, etc. As a result, non-deterministic models will seldom generate the same results even if inputs are held constant. Several runs are therefore required to assess the consistency and variation in the results.

25 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, paragraph 10.33; and Cornwall *et al*, *A Study of RAAF Aircraft Availability and Cost Factors*, p. 35.

26 However, all aircraft must be of the same type.

normally available until an Air Tasking Order (ATO) is drafted, which is not until an actual contingency is imminent. Current planning documents (CPD and OPDs) can be said to specify requirements at the *strategic* level; LOGCAS requires tactical level inputs. This void can only be filled by making assumptions about a plausible flying program; it would be unfortunate if the responsibility to do this falls to logisticians rather than operational staff.

The logistics data required will need to be extracted from various sources and manipulated for input to LOGCAS. Some data may require adjusting to adapt it from peacetime measurements to wartime expectations.[27] This will be a time-consuming and cumbersome process, until all required data can be extracted directly from CAPLOG.[28]

Maintenance policies (servicing intervals) can be changed at any time during a LOGCAS run, so the effect of a transition from peacetime to contingency maintenance can be assessed. However, management of a maintenance stagger will not be attempted, so there is some risk that the model's prediction of availability will suffer as a result of not attempting to forecast and avoid maintenance workload peaks.

Since it is possible to specify the maintenance capacity of each base, LOGCAS can be used to assess the improvement in availability provided by performing servicings at deployed sites, compared with ferrying aircraft from the AO for maintenance.

With this data, LOGCAS attempts to 'generate' sorties to meet the specified requirements. Aircraft are subject to maintenance downtime for both periodic and unscheduled work; replacement components are drawn from spares holdings as required; spares are maintained or repaired according to the pipeline specified for them. If necessary to meet the flying program, scheduled servicings will be deferred up to the specified tolerance.

LOGCAS can show how aircraft availability varies over the duration of the contingency, as well as monitoring the levels of spare components and manpower over time. By varying inputs to LOGCAS, the effect on availability of changed levels of component reliability, maintenance downtime, spares holdings (etc) can be estimated.

For each aircraft type, there are generally a number of CPD serials, and so different operational requirements. The most demanding of these should be analysed, preferably using a most likely flying program and a worst-case flying program. This would allow determination of confidence levels of attaining these scenarios (eg. it is *x* per cent likely that the average program can be met, but only *y* per cent likely that the worst-case program could be achieved).

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27 Maclean, *Preparedness and Repairable Item Management*, p. 8-4.

28 Gary Waters, *Line Honours – Logistics Lessons of the Gulf War*, Air Power Studies Centre, Canberra, 1992, p. 91. The basic CAPLOG LSAR will not contain all of the data necessary. It will therefore need to be augmented, either by acquiring and storing all of the necessary data, or by obtaining additional data when required from other sources via networking.

It is desirable to analyse more CPD serials than just the most demanding one. This would allow determination of the optimum amount of maintenance to deploy in each case, and the need to invoke contingency maintenance schedules.

LOGCAS (and other models) cannot attempt to accurately simulate all of the variables that can influence availability and logistics performance (eg. personnel ingenuity and motivation). Also, the interpretation of probabilistic models can also be difficult. Accordingly, there remains a need to conduct actual trials of logistics performance to validate the theoretical results obtained from modelling exercises.[29]

TRIALLING CONTINGENCY MAINTENANCE

Ideally, contingency maintenance programs should be validated in practice to ensure that the expected levels of availability can be achieved and sustained.[30] Only then should the increase in availability so provided be factored into operational plans and preparedness assessments.[31] However, there are very significant problems involved in realistically and fully trialling a contingency maintenance program.

Advantages

The major benefit of trialling a contingency maintenance program is to ensure that the required levels of availability and reliability are actually met; ie. that the contingency maintenance program meets its goals. If not, the program (or the goals) can be adjusted. Maintenance performance data thus gained can also be used in operational planning and preparedness assessments.

Lack of familiarity with contingency maintenance schedules is potentially a significant problem.[32] Regular usage of contingency maintenance schedules during peacetime would help to reduce the severity of this problem; in this case, short but more frequent periods of contingency maintenance would be effective. Alternatively, command-post exercises could be used to familiarise maintenance management personnel with the contingency maintenance schedules; this could be done during work-up, and would not have undesirable side-effects on the aircraft. The duration of contingency servicings could be estimated from this kind of exercise, but no additional information about the reliability of the aircraft would be obtained.

29 Maclean, *Preparedness and Repairable Item Management*, p. 8-5.

30 Squadron Leader R.P. Lewis, *An Essay on Sustainability*, paragraph 49.

31 DI(AF) LOG 13-7, paragraph 11.

32 The Canadian Forces found this to be the case during the Gulf War; *Operation Scimitar/Friction – CF-18 Maintenance*, Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, Section 4, Enclosure 2.

A third benefit of trialling contingency maintenance would be to more realistically assess maintenance interoperability with regional allies[33] and possible multinational alliance partners. The feasibility of host nation support could also be assessed in this manner.[34]

The need for contingency maintenance programs to be evaluated by the RAAF depends on the origin of the program, and its applicability to the RAAF environment. For example, a foreign-sourced program which has not been significantly changed, and which accords well with the RAAF environment, need not be trialled by the RAAF for the purpose of estimating the fleet availability resulting from the program. However, trials would still be beneficial in providing familiarity with the revised schedules, and for assessing interoperability and support options.

Duration of Sustainability Period

The reliability of an aircraft does not instantly change as a result of the adoption of a different maintenance program. The change is gradual, taking years for the full effects of the new program to be felt. Unfortunately, this means that using contingency maintenance schedules for only a short duration will provide little indication about what level of availability can be achieved *in the longer term*. Similarly, environmentally-related problems will often not surface during relatively short exercises.[35]

The only way to observe the long-term effects of operating on contingency maintenance schedules is to actually use them for the duration of the sustainability period. Unfortunately, it is not feasible to conduct an exercise in the normal manner for the duration of the longest sustainability period listed in the CPD. However, it would be possible to maintain some aircraft on contingency maintenance schedules for extended periods while operating from their normal base.[36] This practice would establish the lower levels of reliability that would result from the reduction in scheduled maintenance, but would not assess the effectiveness of the environmental adaptations made to the maintenance program, or the effectiveness of manpower under combat conditions.[37]

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33 LD93-20656 Pt 1, paragraph 21.

34 Host nation support is discussed on p. 240.

35 US forces in the Gulf experienced some unexpected environmentally related problems; in some cases, the reason that the problems were not foreseen was that exercises in similar environments had been of too short a duration for such problems to develop (United States General Accounting Office, *Operation Desert Storm – The Services' Efforts to Provide Logistics Support for Selected Weapon Systems*, September 1991, p. 44).

36 There would be some managerial difficulties with this, including maintenance management on CAMM, and implications for the repair pipeline and spares assessing processes.

37 Group Captain E.P. Holzapfel, 'What is Logistics?', *The Logbook*, June 1994, pp. 45–47 suggests creating separate logistics challenges (exercises) to test logistics' ability to sustain operations for extended periods in remote localities.

For typical short duration exercises, many supplies are prepositioned,[38] and aircraft maintenance scheduling is adjusted to ensure that minimal maintenance is required for the duration of the exercise. These expedients, which are effective only in the sort term, serve to ensure that maintenance effectiveness is *not* currently trialled on exercise.[39] The USAF conducts special logistics exercises to verify some aspects of maintenance performance, but even these are of very limited duration.[40]

Disadvantages of Contingency Maintenance

The increase in availability provided by contingency maintenance programs is bought at a price. Airworthiness, cost-effectiveness and preservation can be expected to decline when contingency maintenance is adopted.

The reduction in airworthiness should be slight, since a high level of airworthiness is also a priority during a contingency (albeit of reduced importance). However, any increased risk may be difficult to justify. A criterion that could be adopted would be to follow the precedent of aircraft operational practices: if flight envelope and manoeuvre restrictions are lifted during an exercise, this indicates a willingness to accept higher levels of risk.

A relaxation of aircraft structural integrity tasks during an exercise may not be consistent with CAS' responsibility to assure the airworthiness of RAAF fleets; however, contingency maintenance schedules may depend strongly on the absence of such tasks for their effectiveness.[41] In general, it would not be possible to trial a 'watered-down' version of the contingency schedules, as the amalgamation of peacetime and contingency tasks may well result in a maintenance program significantly less efficient than the standard peacetime program.

A reduction in cost-effectiveness should be less of a problem—as long as resources are available to cover the additional expense. An area of difficulty here is in arranging, and funding, civilian overtime. A realistically long test of contingency maintenance capabilities may involve the need to accelerate and streamline servicings performed by contractors or defence civilians,[42] or provide additional contracts to lessen the load. In addition to contingency maintenance aircraft servicings, increased repair arisings (of aircraft and subcomponents) would also result.

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38 loc cit.

39 This is not to say that these practices should be discontinued. They both have the potential to benefit contingency performance, and therefore should be trialled. The shielding of support functions during operationally-oriented exercises is discussed in G.F. Matecko and Major Clifford R. Borofsky, USAF, 'Solving the Wartime Combat-Support Manpower Equation', *Airpower Journal*, Fall, 1989, pp. 75–85; and by Holzapfel, 'What is Logistics?'.

40 See p. 260.

41 This would be particularly true of the F-111, where the aircraft structural integrity tasks basically provide the framework for the peacetime maintenance program.

42 Matecko and Borofsky, 'Solving the Wartime Combat-Support Manpower Equation'.

The Practicality of Trials

It would not be necessary to fully trial the contingency maintenance program during every exercise. The program only needs to be validated once during the lifetime of the aircraft (unless major modifications or role changes may invalidate it). Also, it is not necessary to commit all aircraft of a fleet to a contingency maintenance trial; however, one or two aircraft may be insufficient as the results would not be statistically significant (the chance of a random event profoundly affecting the outcome would be too great).

There would be some benefit to trialling contingency maintenance as a command post exercise. While this would not assess the impact of the contingency maintenance schedules on availability or reliability, it would at least serve to give maintenance managers some familiarity with the new schedules.

Given the possible side-effects of contingency maintenance, it does not seem feasible to exercise a contingency maintenance program for the duration required to fully validate it. Estimation of the longer-term reliability implications of the program must be left to analytical means, and environmental considerations will need to be forecast based on history and judgement. However, it remains important to provide maintenance personnel with some familiarity with the program, and to assess the reduction in *scheduled* maintenance. This can be done by regular use of contingency maintenance schedules for short periods, such as during operational exercises.[43] This appears to be the most realistic option.

SUMMARY

Because of the timescale required to develop contingency maintenance programs, they should be developed during peacetime. Weapon systems listed in the CPD should be given priority for this work.

Because of the unpredictability of wartime, and the consequent need to retain maximum flexibility, information required to develop or revise maintenance policies should be easily accessible. Currently, the data are spread across many different information systems; integration is required to make the extraction and use of the data seamless.

Existing maintenance performance measurement systems are generally very weak at measuring performance against maintenance and operational goals. Again, increased scope and integration of information systems is required. The same is true for the implementation of maintenance modelling tools. Various systems can be used to assess the likely effects of contingency maintenance, but most require detailed maintenance and reliability information as input data. The tools required to provide this information (statistical analysis, RCM, and LSA) are currently largely disparate, and do not integrate with the modelling tools (OPUS 9

43 If necessary, only a few aircraft need be subject to contingency maintenance; however, this would limit the opportunities for maintenance personnel to gain experience with the new schedules.

and LOGCAS). In addition, OPUS 9 is limited to modelling steady-state scenarios, and LOGCAS is dependent on the provision of a representative flying program.

Once developed, contingency maintenance schedules should be trialled in practice, to verify that it achieves its goals and to provide maintenance personnel with some familiarity with the new schedules. However, there are significant problems with trialling contingency maintenance for the duration required to fully validate it, including airworthiness risk. A compromise solution is to use contingency maintenance schedules on operational exercises.

Chapter 15
Battle Damage Repair

INTRODUCTION

Battle Damage Repair (BDR) is the name commonly given to contingency unscheduled maintenance, when relaxed standards are applied to effect structural (and other) repairs. This chapter describes the nature, benefits and implications of BDR, and the implementation of BDR in the RAAF.[1]

SCOPE OF BDR

BDR is a form of contingency maintenance that aims to return damaged mission capable aircraft or technical equipment to a minimum state of missionworthiness in the shortest possible time using the minimum of resources.[2] Despite its name, BDR techniques (when authorised) may be applied to any damage incurred during a contingency, regardless of its cause. Thus, BDR may be used to repair damage caused by ground incidents and maintenance errors, as well as damage sustained in combat. BDR should be thought of as *repair of damage during battle*, rather than merely *repair of battle damage*.

Unlike peacetime repairs, BDR aims to achieve one more flight from the aircraft. Preferably, this flight should be an operational sortie, but if the aircraft cannot be restored to an adequate standard for this, a ferry flight to move the aircraft to a rear base for further repairs can be undertaken. If necessary, inspections of the repaired area can be undertaken after every flight (or few flights), to verify that the aircraft remains capable of continuing in service. In this way, 'one more flight' may become many more flights, hopefully to the extent that the aircraft will not need to be removed from service for better repairs for the duration of the contingency (or until a suitable servicing at which better repairs may be effected).

BDR techniques may be used to repair damage that is otherwise repairable by standard Structural Repair Manual (SRM) techniques, but it can also be used to repair damage not covered by SRM repairs, and which would normally require a Request for Waiver/Request for Deviation (RFD/RFW). In either case, BDR techniques should only be employed when operational requirements necessitate. Having BDR as an option provides the operational

1 Chapter 8 provides an overview of general unscheduled maintenance issues.

2 DI(AF) LOG 13-7, *Contingency Maintenance and Battle Damage Repair of Technical Equipment*, draft, 28 February 1994; Air Force Capability Proposal No. 6044, *Battle Damage Repair Capability for the RAAF*, draft, July 1994.

commander with additional flexibility in balancing the competing operational and maintenance priorities.

Generally, BDR is mainly required for aircraft structure. Damaged aircraft systems can normally be repaired by replacing the damaged components; the components can then be repaired in due course. While this practice will maximise availability, it places significant demands on the supply system to be able to provide replacement components on deployment at short notice. Moreover, many components are not subject to high usage rates during peacetime, and therefore may not be provisioned to allow for battle damage usage rates. This is a situation where contingency usage rates cannot be accurately forecast by scaling up peacetime levels.

BENEFITS OF BDR

Principles

The need for BDR is consistent with the shift in emphasis in the goals of maintenance discussed in Chapter 12. The peacetime priorities of airworthiness, missionworthiness, and preservation of the asset encourage the completion of thorough repairs which aim to restore the structure to its original strength and endurance (to the maximum extent feasible).[3] Likewise, any damaged systems are restored to their full capabilities.

However, the emphasis on availability during a contingency encourages more expedient repair methods to be applied. The acceptance of higher risk (including possibly reduced airworthiness) permits the use of repairs which may not be as effective as peacetime repairs, and the time-limited nature of contingency scenarios means that repair endurance is not as critical. It may be necessary to make a tradeoff between repair quality and timeliness; if the latter is particularly critical, some operational limitations may need to be negotiated to permit flight with a less-than-ideal repair. In addition, only those systems required *for the next sortie* will normally be repaired.

An additional motivation for adopting alternative repair techniques is the often limited nature of facilities and materials available on deployment, and the desire to minimise deployment manpower levels. Furthermore, BDR techniques may be used to repair damaged components when replacement items are not available.

BDR in Practice

Predictably, the frequency with which aircraft repairs are required increases significantly during conflict. For every aircraft lost in combat, three to five aircraft will return with battle

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3 In this context, *endurance* refers to the durability of the repair; ie. how long it is expected to last. Frequently, fatigue or other failure mechanisms can cause repairs to fail prematurely, even though the repair may have the static strength of the original structure. Fatigue is discussed in Annex B.

damage. During the Falklands War, *all* of the RAF's Harrier aircraft were damaged at some stage, and were repaired using BDR techniques.[4]

During the latter stages of World War II, some 35 per cent of aircraft being issued to flying squadrons were not new, but repaired aircraft. About one-quarter of the strength of the RAF was devoted to the repair of damaged aircraft.[5]

The USAF employed BDR extensively during the Vietnam War. A lesson learned from this experience is the benefit of repairing as much equipment *in theatre* as resources will permit. In this spirit, the USAF has established regional centres in Europe and the Pacific region to handle component repair, and even corrosion control. Host Nation Support arrangements are in place to provide further regional support.[6] The expeditionary nature of the US forces increases the benefits to be obtained from strong local support.[7]

The RAF Jaguar and Tornado squadrons that deployed during the Gulf War were initially intended to be self-sufficient in their BDR capability. However, soon after their arrival it was decided to provide enhanced BDR capability in-theatre by setting up a 'deep repair facility'. Personnel from RAF Support Command were formed into additional BDR teams and deployed to the Gulf.[8]

The USAF approach to BDR fundamentally includes the projection of a 'heavy' (deeper) maintenance capability into the field. Unlike the UK (and embryonic Australian) approaches, the USAF has teams to perform BDR which are independent of the operational units. Forty-two of these teams (called Combat Logistics Support Squadrons – CLSSs) deployed to the gulf.[9] Each CLSS BDR team consisted of between five and 34 members, including an aeronautical engineer and airframe and engine technicians. In addition to performing BDR, these teams also performed depot-level modifications in the field, and assisted other deployed units with their maintenance duties when not required for BDR.[10] Furthermore, CLSSs inspected every aircraft after every sortie to detect any battle damage, since aircrew

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4 Squadron Leader A.R. Jury, 'Aircraft Battle Damage Repair: An Effective Force Multiplier', *Air Clues*, November 1992, pp. 410–414.

5 op cit.

6 Major General Edward R. Bracken, 'Vietnam Logistics: Its Meaning for Tomorrow's Air Force', *Air Force Journal of Logistics*, Fall, 1986, pp. 18–21.

7 Host Nation Support is discussed in Chapter 20; general considerations for determining how much maintenance to perform on deployment are discussed in Chapter 16.

8 Jury, 'Aircraft Battle Damage Repair'.

9 CLSSs also contain personnel to provide additional supply and packaging support in-theatre, known as Rapid Area Distribution Support (RADS).

10 Michael Self and Edward Kozlowski, *Air Force Logistics Command Operations in Desert Storm*, USAF HQ AFLC/XPOX, July 1991, p. 10.

were generally unaware that their aircraft had been hit unless major damage had been sustained.[11]

The USAF found that its A10 Thunderbolt fleet was particularly susceptible to battle damage, as a result of the low-level missions they flew.[12] Of the 144 A10s used during DESERT STORM, about 70 suffered some form of battle damage. Of these, 24 sustained significant damage, but only one could not be returned to service by the local USAF BDR teams.[13] Damage successfully repaired included two A10 aircraft with most of their tail sections shot away, and one which lost much of one wing. Another A10 required a wing change as a result of damage sustained—this was performed in the field within eight days, including the time required to locate and transport a replacement wing from the US.[14]

The USAF also used BDR techniques to repair some components that were in short supply during *Desert Storm*.[15] Normally, the need for off-aircraft BDR is avoided by adopting a repair-by-replacement strategy.

BDR Studies

BDR was also instrumental in the 1973 Yom Kippur War. Using BDR techniques, the Israelis had some 60 per cent of their aircraft available for combat at the war's end; had BDR not been used, less than ten per cent of the fleet would have been available.[16]

The results of an RAF study of the effectiveness of BDR are shown at Figure 15-1. The study considers the availability of a fleet of fighter/ground attack type aircraft used in a short conflict. After some ten days of combat, only ten of the original 70 aircraft would be available if BDR techniques were not used. However, if BDR were to be employed, about 35 aircraft would be available at the same point in time.[17] The intensity of conflict assumed in this study is doubtless greater than the RAAF would expect to face in short-warning conflict, and so the significance of the benefit of BDR is greater than the RAAF could expect in more probable scenarios. However, the intensity of combat in multinational operations—such as the Gulf War—may be significantly greater.

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11 Captain Jack Cooley, USAF, *USAF Combat Logistics Support Squadron Briefing*, Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, Section 4, Enclosure 7; Minutes of the Operation *Desert Storm* Lessons Learned ABDR Conference, Wright-Patterson AFB OH, 24–28 June 1991, paragraph 9c.

12 Cooley, *USAF Combat Logistics Support Squadron Briefing*.

13 Jury, 'Aircraft Battle Damage Repair'.

14 Self and Kozlowski, *Air Force Logistics Command Operations in Desert Storm*.

15 Minutes of the Operation *Desert Storm* Lessons Learned ABDR Conference, paragraph 24.

16 Jury, 'Aircraft Battle Damage Repair'.

17 op cit.

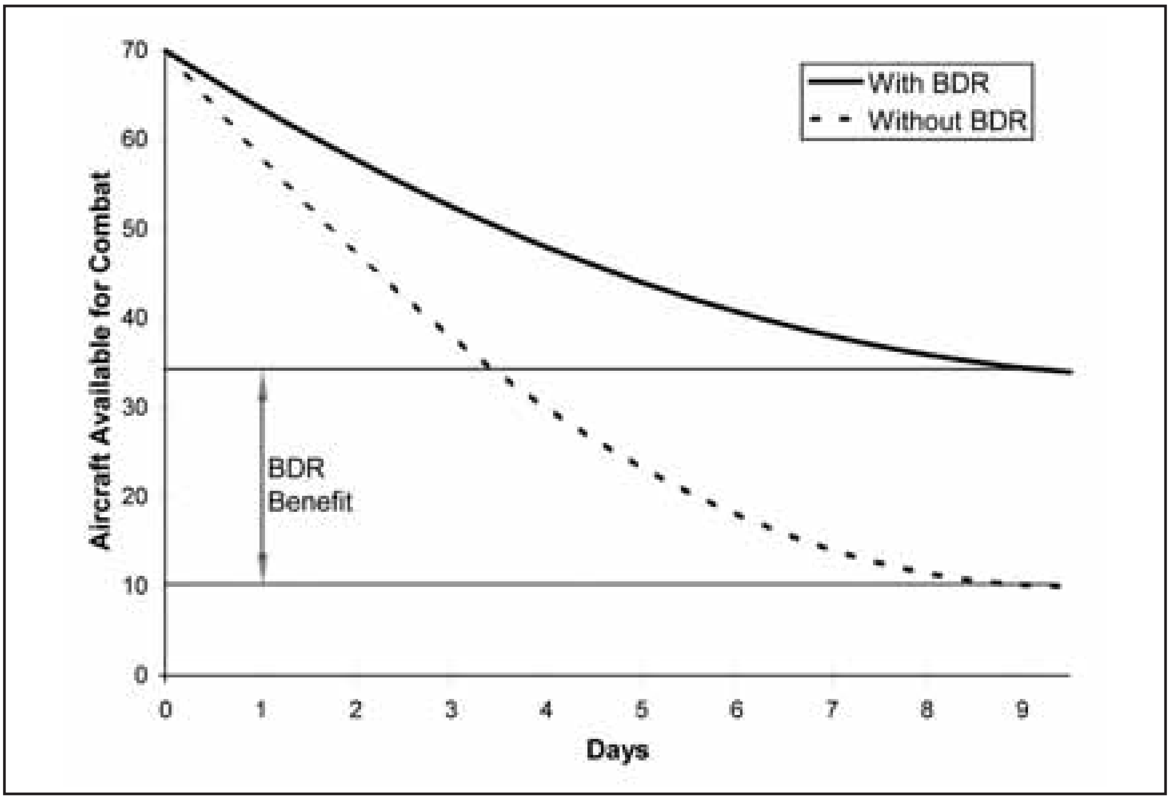

Figure 15-1: Effectiveness of BDR[18]

Clearly, BDR can achieve very significant increases in availability compared to what may be achieved otherwise. BDR can help to ensure that specified availability goals can be met for the duration required; ie. BDR applies to the *sustainability* aspect of preparedness.

IMPLICATIONS OF BDR

Manpower and Training

Adequate training in BDR techniques is crucial for BDR to achieve its aim. Without sufficient training, the pursuit of increased availability would result in ad hoc improvisation and corner-cutting, often leading to repairs that are either not adequate (meaning excessive risk), or are unnecessarily time-consuming (reducing availability more than is necessary).

Three roles are required to effect BDR:

a. Assessors determine what structure and systems have been damaged, and the extent of the damage. If the damage is within the limits for a standard repair to be applied, the assessor may adapt such a repair and authorise its application.

18 Based on Jury, 'Aircraft Battle Damage Repair', Figure 1.

b. Engineers are only required if the damage is not covered by a standard repair. The engineer must determine the necessary repairs or waivers, and may need to propose limitations to capability (such as flight restrictions).

c. Technicians perform the necessary repair work.

Developing sufficient expertise in these areas takes considerable time—significantly longer than the available warning time for short-warning conflict. Therefore, development of a BDR capability cannot be deferred until a threat becomes imminent, but at least some level of BDR capability must be retained during peacetime.[19]

Since BDR will not be used in practice during peacetime, realistic continuation training must be provided so that trained personnel remain current.[20] This is best achieved by developing and applying repairs on aircraft hulks used as training aids. Both the RAF and USAF use this approach.

History has shown that tradesmen with deeper maintenance experience make the best BDR technicians as they possess in-depth knowledge of the aircraft.[21] Furthermore, more significant repairs become indistinguishable with deeper maintenance capabilities, such as wing changes.[22] The USAF found that the depot maintenance experience of their BDR teams was 'irreplaceable' and 'paramount to ... success'.[23]

Validation

The potential benefits of BDR should be taken into account when estimating preparedness levels. However, the expected gains should first be validated through practical exercises and evaluation programs.[24] To minimise the expense of this, such validation could be performed as an adjunct to BDR continuation training exercises.

Engineering Approval

As with repair standards, peacetime engineering approval processes emphasise airworthiness, cost-effectiveness and preservation at the expense of availability, by requiring rigorous analysis and endorsement by multiple agencies. To maximise the benefits of BDR, a cut-down engineering approval process must be adopted that can provide rapid approval of proposed repairs.

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19 Air Force Capability Proposal No. 6044, op cit.

20 In general, using BDR techniques on operational aircraft during peacetime is not feasible, since increased airworthiness risk (and reduced preservation of the asset) are side-effects of the streamlined BDR procedures and techniques.

21 Jury, 'Aircraft Battle Damage Repair'.

22 Minutes of the Operation *Desert Storm* Lessons Learned ABDR Conference, paragraph 4.

23 Cooley, *USAF Combat Logistics Support Squadron Briefing*.

24 DI(AF) LOG 13-7, paragraph 11.

Tooling, Materials and Publications

Tooling, materials and repair publications must be tailored for each unit and weapon system. As with personnel training, the provision of these resources must be undertaken during peacetime. Naturally, the equipment and tooling provided must be commensurate with the level of damage intended to be repaired by the deployed BDR personnel; if DM-type repairs are intended to be carried out in-theatre, DM-type equipment and tooling will be required.[25]

Given the potential delays caused by the need to design and approve repairs and new techniques, standard BDR techniques and repairs should be determined and documented to the maximum extent feasible during peacetime. This information, as well as aircraft stressing information and data on material and fastener properties, should be available to be deployed with unit engineering staff.[26]

Documentation

Because of the possible interaction between repairs, it is necessary to document the location and nature of all BDR applied. Any repairs required in the vicinity of previously repaired areas must be designed accordingly. A computer database may be used to record repairs.[27]

After the conclusion of a contingency, aircraft must be returned to peacetime levels of airworthiness (etc) to the maximum extent possible. This may involve applying stronger and/or more durable repairs than were effected using BDR techniques. To facilitate this, all instances of BDR must be documented to allow the repairs to be assessed at a later date.

BDR methods may need to be applied to removable components, as opposed to aircraft structure, in some cases (such as spares delays). Items thus repaired must somehow be identified and tracked separately within the supply system, since they may not possess the safety margins or durability of other items maintained to peacetime standards.[28] Without such segregation, there is a possibility that an item repaired to BDR standards may be issued during peacetime as a 'normal' component, resulting in a possible airworthiness hazard.

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25 Cooley, *USAF Combat Logistics Support Squadron Briefing*.

26 Minutes of the Operation *Desert Storm* Lessons Learned ABDR Conference, paragraph 11.

27 'AWACS Battle Damage Assessment', *FASTRACK*, British Aerospace Defence, Warton, Lancashire, June 1994, pp. 28–29.

28 Minutes of the Operation *Desert Storm* Lessons Learned ABDR Conference, paragraph 24.

BDR IN THE RAAF

Scope

RAAF policy is to possess a BDR capability for aircraft fleets and equipment expected to be involved in combat (or direct support thereof), and assessed as critical to the success of operations.[29] Emphasis is being given to the F-111, F/A-18, C-130 and P-3 fleets. Concurrently, Army is introducing BDR capability for the Blackhawk and Iroquois fleets.[30]

Organisation

The RAAF is not large enough to justify the creation of specialist BDR units, like USAF CLSSs. Rather, selected personnel in operational units will be trained to be able to perform BDR duties. This also ensures that the BDR capability is deployable, which will further enhance the ability to provide quick turnaround of damaged aircraft. (Of course, when the damage sustained is beyond the capability of deployed maintenance resources, deeper maintenance will be required to effect repairs.)

A disadvantage of integrating BDR into operational squadrons is that squadron tradesmen will have to divide their time between mission generation and BDR duties. RAF experience with this arrangement is that priority will generally be given to mission generation, and that BDR may lapse.[31] This is understandable, given the immediacy of benefit possible from turning serviceable aircraft around. The balancing of these competing priorities represents a challenge to unit management. Some RAAF units have nominated personnel to have primary responsibility for BDR.[32]

Although the RAAF does not intend to provide deploying units with deeper maintenance BDR capabilities, some supplementation of operational units with personnel from DM units is foreseen. For their part, DM units are expected to maintain a greater depth of expertise in BDR techniques.[33]

The diminishing amount of deeper maintenance (DM) conducted within the RAAF gives some cause for concern. The RAAF's BDR capability will be constrained if an insufficient number of personnel can be given DM experience, since this experience significantly enhances the individual's ability to perform BDR. Although Manpower Required in Uniform (MRU) considerations can provide a means of checking the decline of DM in the RAAF, the required links are not yet in place. Moreover, the Commercial Support Program (CSP)

29 DI(AF) LOG 13-7, paragraph 7.

30 Air Force Capability Proposal No. 6044, op cit.

31 Jury, 'Aircraft Battle Damage Repair'.

32 Personnel seconded from Deeper Maintenance units would be well suited to this role.

33 DI(AF) LOG 13-7, paragraph 13.

predates MRU, and the commercialisation of DM for several weapon systems is already *fait accompli*.[34]

Contractors performing RAAF DM should also have responsibility for maintaining an appropriate level of BDR capability. The likelihood of contractors developing such experience coincidentally, as a byproduct of their primary maintenance duties, should be assessed. If their BDR capability is unacceptably low, some means of supplementing this must be found, either by specifying additional contractual requirements or by identifying an alternative source of BDR capability for the affected weapon system.[35]

Where DM capability exists within the RAAF for a weapon system, personnel streaming practice is to rotate personnel between operational and DM venues for the one weapon system. In this way, most tradesmen will obtain some DM experience on the weapon system.

Training and Exercises

Training of BDR personnel will be conducted at base level, rather than centrally. This encourages the tailoring of BDR training to suit the local weapon system(s). Continuation training, consisting of applying BDR to aircraft hulks, is to be conducted annually.

Authorisation

Normally, approval to adopt BDR techniques will be given by Headquarters Logistics Command, although operational commanders may assume this authority if circumstances warrant it.[36]

There are no changes planned to the peacetime engineering authorisation levels for the approval of repair designs during a contingency. However, streamlined communication and design approval systems are expected to speed up the approval process. In addition, emphasis on providing training, data and design tools to unit engineers may permit some limited delegation of authority for repair design approval to deployed engineers.[37] The ability to design and approve a repair using only deployed manpower would significantly increase the responsiveness of the approval process, and hence improve the effectiveness of BDR as a whole. Accordingly, such delegation of authority should be granted to the maximum extent possible.[38]

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34 MRU and CSP are discussed in Chapter 19.

35 The feasibility of contacting for a company to retain a *capability* is questionable. There is some analogy with the requirement for contractors to maintain some expansion capacity—see p. 227.

36 DI(AF) LOG 13-7, paragraph 15.

37 ibid., paragraphs 17–18.

38 RAAF Engineering Planning Team, *Blueprint 2020 – Engineering the Future*, Departmental Publications, Canberra, 1993, paragraphs 9.19g, 9.64.

SUMMARY

BDR aims to return damaged equipment to a minimum state of missionworthiness in the shortest possible time. This is consistent with a shift in emphasis from peacetime maintenance priorities to increased availability.

BDR has been used extensively from World War II to the Gulf War. Low-flying aircraft appear to be particularly susceptible to battle damage. Studies have shown that very significant increases in availability, or extensions to sustainability, can be achieved using a BDR program.

BDR requires a considerable training investment, both for initial and continuation training. Realistic continuation training typically involves applying repairs to aircraft hulks. DM experience significantly increases the effectiveness of BDR, and the decline of DM in the RAAF will limit the level of BDR capability that can be achieved. Moreover, contractors performing DM on RAAF aircraft should also possess a deeper BDR capability, or other arrangements must be made for this.

A streamlined engineering approval process is required, to ensure that the potential availability improvements made possible by BDR are not negated by tardy design approval. To this end, maximum delegation of authority to deployed personnel should be effected.

A means of recording the location of BDR on aircraft, and of tracking components which have had BDR applied, is necessary to contain airworthiness risks.

Chapter 16

Maintenance on Deployment

What Do We Need To Do On Deployment?

INTRODUCTION

Contingency operations may need to be conducted from a deployment site, which may be distant from the normal maintenance facilities. It is therefore necessary to consider which maintenance tasks should be performed on deployment, and which tasks can be performed remotely.

Chapter 13 explained the issues to be considered when determining what scheduled maintenance tasks should be performed during a contingency. However, not all contingency maintenance tasks will need to be performed on deployment. Theoretically, aircraft Logistic Support Concepts (drafted as a part of the acquisition process) address contingency maintenance issues, including what maintenance capabilities should be deployable. However, in practice, this aspect is seldom covered. Moreover, very little doctrine or policy guidance exists that provides any basis for the development of this aspect of contingency maintenance.

This chapter outlines considerations that should influence the determination of how much maintenance should be performed on deployment.

CRITERIA

Impact on Operations

Maintenance arrangements should be structured to support operations. During a contingency, this predominantly means maximising availability. Accordingly, those tasks that offer the greatest availability increase when performed on deployment should be prime candidates for consideration for performance on deployment.

The item importance hierarchy provides some guidance on this issue.[1] On-aircraft tasks generally have the most direct impact on availability; the directness of impact of lower-level components decreases with increasing 'depth' within the build structure. The existence of spare components (when available) serves to provide a buffer between component maintenance and aircraft availability.

1 See Annex F.

Considering on-aircraft maintenance, the impact on availability will be the product of the servicing duration[2] and the servicing frequency. Generally, the more frequently performed servicings offer the greatest benefit to performance on deployment, and are also easier to perform on deployment due to less demanding resource requirements (manpower, skills, equipment, etc). Fortuitously, the less frequent servicings are the most amenable to reductions in scope, increases in interval, or deferral; this effect minimises the duration and/or frequency with which aircraft must be absent from the AO.

The same considerations apply to unscheduled maintenance, eg. battle damage repair: the more frequently required tasks offer the greatest availability gains when performed on deployment. Accordingly, the more commonly expected types of repair should be considered for performance on deployment.

Off-aircraft maintenance is generally less critical than on-aircraft maintenance. The exception occurs when there are insufficient spare items held to give a high probability that a replacement item will be available when required. In this case, the turn-around time (TAT) for maintenance on the item must be faster: avoiding the need to transport the item to and from the area of operations can contribute significantly to a reduction in TAT. In the extreme case, where there are no spare items, time spent transporting items equates directly to lost availability (unless cannibalisation is used).[3]

Another aspect of this situation is that delays in the maintenance pipeline, eg. for transportation, create a need for additional components within the pipeline to retain the required number of serviceable assets. Greater delays (eg. longer pipelines) require more such 'delay' spares. Where additional spares cannot be obtained, the pipeline must be kept as short as possible. The shortest possible pipeline will be when the off-aircraft work is performed deployed. (Note that this will create a need for pipelines to be established to the deployed site for items required to repair or maintain such components, such as replacement sub-assemblies and consumable items.)

Therefore, perhaps surprisingly, the adequacy of spares holdings and resupply capability (combined with other considerations) should be a determinant of the desirability of deploying selected component maintenance capabilities. Since the adequacy of spares holdings can change rapidly, decisions on which components most need deployed maintenance cannot be made far in advance of the deployment. Also, the longer-term prognosis of the spares situation should be taken into account when deciding whether to deploy the corresponding maintenance capability or not.

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2 Including aircraft ferry time, if necessary.

3 In fact, the *entire* TAT contributes directly to lost availability. However, the 'hands-on' maintenance element of TAT must be performed regardless, whether it is done on deployment or remotely. If the maintenance is performed on deployment, only the transportation component of TAT is minimised, enhancing availability.

As with on-aircraft maintenance, frequently performed component maintenance tasks tend to offer the greatest improvement to availability when performed deployed, since the amount of transportation time avoided is greatest.

The above considerations are based on the relationship between availability and maintenance *downtime*. A more subtle relationship is between availability and maintenance *responsiveness*. Having maintenance elements present on the deployed site simplifies communication and coordination, and provides the maintenance elements with greater visibility of operational requirements and priorities. Short lulls in operational activity can be utilised by maintenance personnel, cannibalisation can be more effectively employed, and availability surges can be more easily and quickly achieved.[4] The maintenance tasks that have the most direct effect on availability from a downtime viewpoint also need to be the most responsive: a further justification for the forward deployment of these capabilities.

Intensity of Operations

The intensity of the contingency has an effect on the amount of maintenance that should be deployed. For a smaller contingency (ie. a less demanding CPD serial in terms of the number of aircraft required), the need for maximum fleet availability is less. Not all aircraft would be required for contingency operations, so more maintenance could be performed from bases remote to the area of operations. When a deployed aircraft became due for maintenance, a replacement aircraft could be provided to replace it.

As the number of aircraft required for operations (and related training) increases, the need for high availability increases. There will be fewer, or no, spare aircraft. Delays incurred by rotating aircraft (and critical components) to and from the area of operations will have an increasing impact on availability; therefore, greater maintenance resources should be deployed forward to minimise such inefficiencies.[5]

Area of Operations

The location of the area of operations also has an effect on the level of maintenance that should be deployed. The most obvious relationship is the distance that aircraft and components would need to be transported if they require maintenance that is not provided at the deployed site. If relatively short ferry flights can be used to rotate aircraft to and from the deployment, there is little need for the deployed site to be highly autonomous. Similarly, if quick, reliable lines of supply exist for the evacuation and replenishment of components, the deployment need not be as autonomous in performing off-aircraft maintenance. Physical

4 Major Kenneth L. Privratsky, 'Comparing US and Soviet Maintenance Practices', *Army Logistician*, September–October 1986, pp. 7–9.

5 DI(AF) AAP 1000, *The Air Power Manual*, Air Power Studies Centre, Canberra, 1990, paragraph 10.135. This situation arose for US forces during the Vietnam conflict, where the gradual escalation of operations generated increased maintenance requirements, which provided increased motivation for greater in-country facilities and manpower (Major General Edward R. Bracken, USAF, 'Vietnam Logistics: Its Meaning for Tomorrow's Air Force', *Air Force Journal of Logistics*, Fall, 1986, pp. 18–21).

distance is not the only influence: the speed and ease with which it may be traversed, and the existence of local (and cooperative) transportation infrastructure will also effectively shorten supply lines. The vulnerability (potential for interdiction) of supply lines is also a factor, with greater levels of deployment self-sufficiency becoming more desirable when supply lines are vulnerable.

US (and Soviet) military doctrine stresses the need for 'maintenance assets to be pushed as far forward as possible consistent with the tactical situation to repair inoperable and damaged technical equipment and to return it to the battle as quickly as possible'.[6] This doctrine of 'forward support maintenance' is intended to maximise availability by minimising maintenance pipeline distances.[7] US forces must adopt this approach in view of their desire for 'global reach'. Since Australia's strategic guidance does not share this expeditionary focus, ADF maintenance capabilities will generally not need to be deployed as extensively. However, although expeditionary capabilities are not enjoined, the narrow concept of 'continental defence' is explicitly repudiated: Australia must have the military capability to prosecute operations anywhere within the region.[8]

The most likely area of operations for the ADF is identified as the North and North-West of the continent. This area justifies the deployment of some measure of maintenance resources above the minimum, due largely to the lack of infrastructure in the region. However, the distance from this area of operations to existing maintenance bases can be relatively quickly covered by most operational aircraft types, so the need to perform extensive on-aircraft maintenance on deployment is not great, unless the scale of the contingency demands the maximum possible level of availability.

Operations outside Australia can present a significantly different situation. As the distance from the mainland increases, the desirability of greater maintenance autonomy increases. This is most likely to occur when involved in multinational operations, which can occur in any part of the world (although preference will be given to regional assistance). In this case, supply lines are often artificially lengthened due to cumbersome administrative arrangements.[9]

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6 US Field Manual 100-10, *Combat Service Support*, quoted in Privratsky, op cit.

7 Department of Defense (USA), *Conduct of the Persian Gulf War*, April 1992, Appendix F, p. F-61. This has been cited as a significant contributing factor to US success in the Gulf War (ibid., p. F-67). During the Vietnam War, the USAF found that local repair of aircraft was not just more ffective than ferrying aircraft back to continental USA, but it was also more economical (Bracken, op cit.).

8 *Defending Australia*, AGPS, Canberra, 1994, p. 15. Even Australia's region should not mark the geographical limits of Australia's military capabilities; the ADF must also be able to mount operations 'in other parts of the world'.

9 For example, spares required by the RAAF detachment of three C-130 Hercules in Somalia were shipped via London. Partially as a result of this arrangement, the deployment was required to become more self-sufficient than was intended: various maintenance expedients had to be authorised by the detachment commander to allow operational requirements to be met (source: discussions with the deployment Senior Engineering Officer).

The preoccupation with the defence of the North and North-west of the continent represents a non-conservative assumption in some regards. It requires a lower level of logistics mobility than would be required to support operations further afield—such as assisting regional allies and providing contributions to peacekeeping forces. However, these latter operations appear more likely than the defence of Australia in the near term.[10] History shows that military operations are regularly required in areas not planned for; a non-conservative assumption in this regard could prove limiting in Australia's ability to rise to such other challenges.

The level of risk present at the deployed site also affects the determination of how much maintenance to deploy. As the level of risk at the deployed site increases, it becomes more desirable to minimise the size of the deployment. This is particularly true where civilian personnel are used.[11] A maintenance venue on which many combat elements depend is a lucrative target.

If the deployment base is well equipped with facilities, fewer resources will need to be deployed to achieve a greater level of self-sufficiency. If the deployment is to a bare base, additional equipment would need to be transported; since transportation space would be at a premium, the feasibility of achieving the same degree of maintenance self-sufficiency is reduced.

Similarly, the availability of alliance partner support, local infrastructure or host nation support will also reduce the need for maintenance to be performed at the deployed site. Such other local or regional capabilities can be used to provide quicker turn-around times than could be achieved by ferrying aircraft or freighting components to and from normal peacetime maintenance venues. Tapping into such external support may require some measure of commonality or interoperability.[12] Various agreements, such as Closer Defence Logistics Support Agreements (CDLSAs), have been established to facilitate the use of local or regional support.

Mobility

The mobility of deployed units is reduced by the presence of collocated maintenance resources (manpower and equipment). Therefore, high levels of local maintenance capability are not desirable when mobility is a major requirement (eg. when the AO is particularly large, or there is a significant level of risk at the deployment site).

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10 Wing Commander Gary Waters, 'The Gulf War and Logistics Doctrine', *RAAF Supply*, March 1992, pp. 37–41.

11 See p. 214.

12 For example, during the Korean War, support for No 77 Squadron's Mustang fleet benefited considerably from the local US logistics system. However, when the squadron re-equipped with the British Meteor, this source of supply was of little use, and the RAAF had to develop its own organisation to undertake aircraft maintenance and supply requirements (David Wilson, *Lion over Korea*, Banner Books, Canberra, 1994, p. 168).

A compromise arrangement can be adopted, where maintenance resources are moved *closer* to the operational elements, but are not *collocated with* them. This means that the operational elements can be more mobile, while regional maintenance support is still available.[13]

Duration of Contingency

During a longer contingency, it becomes more practical to deploy further maintenance capabilities forward, since more opportunities for transportation will exist after the initial deployment surge. However, maintenance capabilities should not be deployed forward just because they *can* be; the need for increased airworthiness should always be the driving factor, and constraints such as the level of risk at the AO must always be considered.[14]

Deployability

The deployability of maintenance capabilities must also influence the decision to deploy. The portability, bulkiness, weight, ruggedness and packaging of equipment, and the need for special facilities such as clean rooms, will be significant criteria.

This is somewhat of a 'chicken-or-the-egg' issue. Preferably, those maintenance capabilities that need to be performed on deployment should be determined during the acquisition process, based on criteria such as the task's impact on operations. If there is significant benefit in performing the task on deployment in any identified scenario, the capability should be procured and established to be deployable. Unfortunately, peacetime practice is often to ignore this issue: if deployment of the equipment is not needed to support a two-week exercise, the equipment is often firmly fixed in place.

Size of Deployment

Deployment bases may be within the AO or Main Support Area (MSA),[15] and will almost certainly be under greater threat from attack than the home base. This presents some risk to deployed personnel and equipment. In addition, increased deployed capability will require increased capacity (and complexity) of component pipelines and Lines of Communication (LOC) from deployed sites to home bases (and possibly other maintenance venues as well). These pipelines and LOC are also vulnerable; they, and the deployment sites, will require protection and possibly redundancy. In part, this protection and redundancy will require logistics resources (manpower) to effect, which will reduce the productive capacity or

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13 This is an example of 'cascading' levels of deployment, further discussed on p. 180.

14 For example, after several years of aircraft operations in the Vietnam War, local commanders started to demand increased local maintenance capability. The delays incurred by continual rotation of aircraft and components between deployed sites and more distant maintenance venues meant that operational requirements could not always be met (Bracken, op cit.). When it became clear that a quick solution to the Vietnam situation was not going to be found, the additional benefit of increased availability resulting from local maintenance was deemed to outweigh the disadvantages of greater deployment sizes, etc.

15 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, paragraph 10.10.

require a further increase in deployed resources.[16] If the requirements for the protection of bases and pipelines is too great, or if bases are attacked or pipelines interdicted, deployed maintenance capability may be less effective than that which could be provided from a remote but secure site with simple, robust pipelines and LOC.

The level of risk at the deployed site is an important parameter when deciding the size of the deployment. As stated previously, the higher the level of risk, the smaller the deployment should be. Furthermore, additional complications arise with the employment of civilians in areas of high risk.

Cost

Financial resources should present less of a constraint during a contingency than is the case during peacetime. However, some costs associated with deployed maintenance capability will be incurred during peacetime. For example, deployable equipment will often need to be more rugged or compact than a stationary installation; suitable packaging will be required; additional equipment may need to be procured to provide redundancy or duplicated capability at the home base; and sufficient transportation capacity must exist.[17] Moreover, any deployable capability should have its deployability exercised from time to time; this would constitute a significant cost and inefficiency during peacetime.

During a contingency, cost may be incurred in the transportation of deployment personnel and goods (this will be most noticeable if infrastructure transportation is utilised). Operating and maintaining deployed equipment will also increase costs.

APPLICATIONS

The above criteria can be used to assess various strategies that may be adopted for performing maintenance in support of deployments.

Aircraft Rotation

A decision needs to be made regarding the level of on-aircraft maintenance that should be performed on deployment. The content of contingency servicing schedules (if used) should be determined before this decision can be made. Other major issues will include the required level of availability, expected duration of the contingency, the area of operations, and so on.

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16 ibid., paragraph 10.11. The use of civilians in the AO further exacerbates this situation, since better protection must be afforded, and civilians can take no part in base defence duties (see Chapter 19).

17 Civilian infrastructure support could be used for the transportation of maintenance equipment. Contingencies large enough to warrant extensive deployed maintenance probably also justify the use of civilian infrastructure.

A tradeoff exists between the frequency with which aircraft need to be rotated from the deployed site and the level of maintenance capability required to be deployed. If little maintenance capability is deployed, only the simpler, most frequent servicings can be performed locally—in the extreme case, only flight servicings (before flight, after flight, and turn around). Whenever any more substantial servicing becomes due, or any significant repair becomes necessary, the aircraft must be flown from the deployed site (if possible) and should preferably be replaced by another. As the deployed maintenance capability increases, the need for this rotation becomes less frequent as more complex servicings can be conducted on site. In the extreme, aircraft would never have to leave the AO since all maintenance tasks could be performed locally.

The Gulf War shows evidence of both approaches. The US forces were largely self-sufficient, being able to perform almost all of the maintenance required in-theatre. Aircraft Maintenance Units (AMUs) deployed with USAF squadrons, which include aircraft and component (including engine) intermediate-level maintenance capabilities.[18] By contrast, the RAF and Canadian contingents were not as self-sufficient, and rotated their aircraft back home for servicings and modifications beyond the capability of the deployed units.[19]

The requirement for availability should initially drive the determination of how self-sufficient the deployment should be. If required availability levels can be achieved with frequent aircraft rotation, then there is little benefit in deploying extensive maintenance capability. However, if aircraft rotation impacts on required availability, additional deployed maintenance capability should be considered.

The rotation of aircraft effectively requires spare aircraft in the fleet; ie. aircraft not required for operations or operational training. These spare aircraft are used to cover the requirements to ferry aircraft to and from the deployment, in the same way that spare components are needed in a maintenance pipeline to allow for transportation time. For a less demanding CPD serial, the whole of the fleet will not be required to deploy or undertake related duties; in this case, more frequent aircraft rotation is feasible and the deployment need only undertake the simplest, most frequent servicings and repairs. However, for the most demanding CPD serials, the loss in availability caused by frequent aircraft rotation would be unacceptable, so the more major servicings and repairs must be conducted deployed to minimise the frequency of rotation.

In between these extremes lies a continuum of possibilities, balancing availability and deployment size. While many options could be planned for (eg. perform R1s only on deployment, R1s and R2s only, R1s to R3s, etc), this multitude of alternatives would probably overwhelm the planning process. Moreover, it would not be possible to exercise

18 Murray Hammick, 'Report from the Front: AMUs underrated in USAF's Success', *International Defense Review*, 5/1991, pp. 451–452.

19 Sir Kenneth Hayr, 'Logistics in the Gulf War', *RUSI Journal*, Autumn, 1991, pp. 14–19; STLO NAVAIR 79/2/Air Pt 2 (61), *F/A-18 Persian Gulf Operations – Canadian Forces Engineering/Logistics Lessons Learned*, STLO NAVAIR, 10 July 1991.

and validate all of these possibilities. Accordingly, it would probably be more expedient to plan for, and trial, relatively few cases; eg. a minimal deployment, a highly self-sufficient deployment, and possibly an intermediate position if it offers distinct advantages.

The duration of the deployment is also directly relevant. Regardless of the required availability, if the deployment is to be very short, longer interval servicings would not assume great significance since few would arise during the contingency. Those which do arise could probably be deferred for the duration required. Only servicings or tasks that can be expected to arise frequently during the contingency can have a major impact on availability, and hence be worthy of consideration for performance on deployment.

Component Removal versus On-Aircraft Maintenance

In some cases, a decision needs to be made about whether a component should be removed from an aircraft for maintenance or whether it should be maintained while still fitted to the aircraft. A common variation to this issue is in fault-finding: often, diagnosing a defective component is easier using the aircraft systems to recreate the problematic circumstances. However, this practice requires that the whole aircraft be dedicated to maintenance, whereas removing and replacing the components that are in need of maintenance (or suspected of causing problems) can free the aircraft for operations.

Other issues here include the time taken to remove and replace components, the existence of spares, and the probability that the defective components in a system can be correctly identified. Aircraft Built-In Test Equipment (BITE) or Automatic Test Equipment (ATE) can play a major role here.[20]

For some aircraft types (such as the Hornet), systems simulators exist that allow components to be tested in realistic conditions when removed from the aircraft, which permits effective off-aircraft fault-finding (assuming the errant components can be identified on the aircraft correctly). Such equipment is usually fitted with many aircraft components, to provide a realistic environment. This creates a temptation to cannibalise components from the simulator. While this practice could produce additional serviceable aircraft in the short term, the effect in the long term could be to require that all fault-finding be conducted on the aircraft, significantly degrading availability (which may well impact on aircrew training capacity).

Removal of components for maintenance provides the option of fault-finding, repairing or maintaining the components either at the deployed site or elsewhere; on-aircraft maintenance strongly encourages the work to be performed deployed. Accordingly, to minimise deployment size, off-aircraft maintenance is to be preferred to on-aircraft maintenance whenever there is a reasonable choice. Technology that facilitates off-aircraft maintenance, such as BIT/BITE, WSSFs and system simulators, can therefore serve to reduce deployment size as well as improve availability. Modern aircraft also emphasise

20 Wing Commander Gary Waters and Squadron Leader David Pasfield, *Imperatives for Air Force Logistics Preparedness*, DLDP AF89/2202 Pt 2 (22), Canberra, 1992, p. 21.

design strategies that better support off-aircraft maintenance, such as modularity, ease of access, and ease of component removal.

Cascading Levels of Deployment

The requirements described above require that a compromise decision be reached for each maintenance capability, balancing criteria such as availability with the desire to minimise deployment size. The emphases of the various criteria will vary in each case, with some capabilities clearly needing to be collocated with combat elements, and other capabilities best left in situ. In between will exist some maintenance capabilities that would provide worthwhile performance benefits if placed closer to combat elements, but which should not be placed on the front line.

ADF doctrine supports this continuum of deployment sites. Necessary logistics elements may be deployed to the AO (or JFAO[21]). Behind the AO can be multiple support areas, which can contain further logistics elements. Lines of communication exist between the *support areas* and the AO. Support areas may be separated from the AO by a land or sea gap;[22] in any case, the geographic separation from the AO provides greater security in support areas, making the establishment of more substantial maintenance capabilities in these areas more feasible. Support areas that are fundamental to the operational effort are called Main Support Areas (MSAs).[23]

An example of this approach is the (draft) logistics support concept for the F/A-18.[24] Any or all of the bare bases in the North or North-West of Australia could be within the AO; squadrons deployed to these sites would bring with them the maintenance elements necessary to provide the required availability. RAAF Base Tindal would function as the MSA.[25] The existing maintenance capabilities at Tindal may be augmented from resources at Williamtown, and would support all of the (other) deployments in the AO (as far east as RAAF Base Scherger). Williamtown would continue to perform its peacetime role as the principal hub of the Hornet maintenance support network.

Progressive Deployment

Maintenance capabilities need not all be deployed simultaneously (were that even possible). Logistics elements may be deployed pre-emptively (ie. before the arrival of combat elements) where the level of risk is low. However, if combat elements need to be deployed simultaneously to protect the build-up, those maintenance capabilities necessary to directly

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21 Joint Force Area of Operations, ADFP1, Operations Series, *Doctrine*, 1993, Glossary.

22 ADFP1, paragraph 2021.

23 loc cit.; also DI(AF) AAP 1000, paragraph 10.10.

24 *Logistics Support Concept – TFG Hornet Contingency Operations*, Draft B, SOLDEV AHQ, September 1994.

25 Tindal may also be within the AO; this does not violate the definition of MSA. Tindal would still provide additional logistics support to other AO deployments under normal circumstances.

support combat operations in the short term will need to be deployed first.[26] Thereafter, further maintenance elements may be progressively deployed to support a longer or more intensive contingency, as dictated by changing circumstances.

Planning Assumptions

Most deployment planning should be based on CPD serials, and assume likely AOs identified in strategic guidance and Contingency Plans.[27] This ensures that the requirements for short-warning conflict are planned for, as well as those other roles covered by CPD serials.

However, some roles of the ADF, such as peacekeeping and the defence of Australia in major conflict, are not covered by CPD serials. These scenarios may differ significantly from CPD-type scenarios in that the area of operations may be remote from Australia, and the intensity and duration of conflict may be greater. All of these criteria should influence decisions on the amount of maintenance to deploy. Therefore, maintenance planning based exclusively on CPD serials may not adapt well to cover non-CPD situations.

Some additional planning should be undertaken to ensure that peacekeeping operations can be supported. Maintenance constraints could well be the limiting factor in sustaining a RAAF peacekeeping contribution, since the distances to the deployment could be considerable, requiring either extensive aircraft rotation or substantial deployed maintenance capability (or substantial reliance on other forces or infrastructure). In reality, the effect of the maintenance constraint is likely to be a limitation in the size or duration of the RAAF contribution.

Planning for major conflict is justifiably accorded a lower priority, given the long warning time expected before such a contingency. The demands of a major conflict will generally require substantial deployed maintenance capabilities, although the levels appropriate to the more demanding CPD serials may suffice in many cases.

It may be that several different concepts for deployed operations need to be developed for each weapon system, corresponding to (significantly) different scenarios.

SUMMARY

Many factors should be considered when deciding what level of maintenance to perform on deployment. The potential impact on operations is a most important issue, and argues primarily for frequently performed on-aircraft maintenance tasks to be performed deployed. Off-aircraft maintenance may need to be performed deployed if spares holdings are inadequate.

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26 ADFP1, paragraph 2014.

27 This is the case with the draft *Logistics Support Concept – TFG Hornet Contingency Operations*, op cit.

Greater deployed maintenance capabilities are appropriate for more intense, longer or more isolated contingencies. Other factors include the need for mobility, nature of the area of operations, allowable size of deployment, and cost.

The need for particular maintenance strategies, such as rotating aircraft and components away from the deployment for maintenance, or establishing cascading or progressive levels of deployed maintenance capability, can be evaluated using these criteria.

The determination of the maintenance capabilities which may need to be performed on deployment has a significant bearing on the level of industry support that may be considered (discussed in Chapter 19), and is also a consideration when deciding organisational issues (discussed in Chapter 21).

Chapter 17
Contingency Modification and Configuration

INTRODUCTION

Invariably, extensive aircraft modification activity accompanies the onset of a contingency. This chapter provides examples and suggests processes to improve the management of this task.

Modifications are effectively configuration changes. Some broader configuration management issues arise from consideration of modification (and other) requirements; these are also discussed in this chapter.

MODIFICATION

Examples from the Falklands War

Many of the aircraft modifications undertaken for the Falklands conflict were completed within days or weeks, when similar modifications undertaken during peacetime might have taken years. Some of the modification programs effectively introduced new roles for aircraft: the RAF Harrier GR.3 was designed as a ground-attack aircraft, but was adapted to perform air-to-air and maritime roles as well. Modifications included the capability to carry the AIM-9 Sidewinder missile. Shipboard capability was also introduced, which required mechanical alterations and avionics installations. Further modifications were necessitated by the change in operating environment; for example, drain holes and improved sealing were applied to minimise the effect of the corrosive salt water. The GR.3 modifications took four weeks to complete.[1]

Surprisingly, Harrier aircraft did not have adequate defensive and ECM protection prior to the conflict. Harriers had to be fitted with chaff and flare dispensers to provide some protection from radar and heat-seeking missiles. The initial RAF solution was somewhat crude; a better solution was delayed until US aid to Britain for the campaign was approved. A more challenging modification was the design of an ECM pod ('Blue Eric') for the Harrier. In peacetime, such a project would take at least two years; during the campaign, nine pods

1 Captain Joseph F. Udemi, USAF, 'Modified to Meet the Need: British Aircraft in the Falklands', *Airpower Journal*, Spring, 1989, pp. 51–64.

were produced, thoroughly flight tested, and delivered within 15 days of identification of the requirement. Despite this, the equipment was never used in combat. Interestingly, the rapidity of the modification process meant that the cost of developing the modification was considerably less than would have been the case during peacetime.[2]

The RAF was on the verge of retiring its fleet of Vulcan bombers at the onset of the Falklands campaign. However, the aircraft were pressed into service after the installation of electronic countermeasures (ECM) systems and appropriate navigation equipment to permit long-range over-water flights. Further modifications were made to the Vulcan to allow it to carry anti-radiation missiles (used to attack radar installations).[3]

Victor tanker aircraft were also fitted with improved navigation systems.[4]

The long logistics lines from Great Britain to the Falklands (and the main support base on Ascension Island) necessitated modifications to the Hercules aircraft to improve its range. Initially, internal fuselage-mounted fuel tanks from previous aircraft types were installed into the Hercules cargo bay; this modification was completed within a few days. Thus modified, the Hercules could fly from Great Britain to Ascension Island non-stop—a distance of some 6500 km. A better, longer-term solution involved the provision of in-flight refuelling, since this did not reduce the aircraft's payload capability. A contractor modified the first aircraft for in-flight refuelling within ten days.[5]

The RAF also modified six C-130 aircraft to become in-flight refuelling tankers. The first of these extensive modifications was completed within 38 days, but another four weeks were required to iron out initial problems. As a result, the conflict was over before these aircraft could see operational service.[6]

RAF Nimrod maritime reconnaissance aircraft were also modified to give them an in-flight refuelling capability. This modification was performed within two weeks; a further week was required to alleviate resulting aerodynamic instability problems by installing 'finlets' near the aircraft's tail. To provide some measure of defensive capability, Nimrods were modified to carry the Sidewinder air-to-air missile. The Harpoon anti-shipping missile was also fitted.[7]

A capability missing from the British order of battle was Airborne Early Warning (AEW). Previous AEW aircraft had been retired from service without replacement. Extensive modifications to two Sea King helicopters were undertaken to equip them for this role.

2 ibid.

3 ibid.

4 ibid.

5 ibid.

6 ibid.

7 ibid.

Unfortunately, these aircraft were not available in time to help prevent the loss of British ships from surprise air attacks.[8]

The cooperation of industry was absolutely fundamental to the timeliness of modifications; for example, British Aerospace delivered the first Harrier GR.3 transponder modification kit within eight days of the request. Ferranti developed and delivered a portable system for aligning the GR.3's inertial navigation-attack system (INAS) for carrier operations within 18 days—after initially estimating a six-month lead time based on peacetime priorities. (Unfortunately, the latter system was not a total success, with teething problems limiting its usefulness until after the campaign was over.) The design of an interface for the ECM pod to the Harrier was completed by Marconi within five days; the first nine pods were manufactured within four days.[9]

Also noteworthy is the speed with which modifications were approved during the Falklands campaign. A number of very significant modifications, such as adapting the Harrier GR.3 to carry the AIM-9 Sidewinder, were approved within one day. Normal design approval and funding processes were short-circuited to achieve the required expedience; the possibility of some reduction in safety and cost-effectiveness must be expected as a result.[10]

Another contributing factor to the speed with which the Harrier Sidewinder modification was effected was that some design work had been previously performed for this modification, but peacetime funding had not been approved. The same is true for the Hercules in-flight refuelling and Sea King AEW modifications.[11]

Examples from the Gulf War

Over 300 modifications were made to the RAF fleets for the Gulf War. The need for so many modifications was due in part to the expectation that RAF fleets would be committed to a European, rather than Middle Eastern, theatre of war.[12]

The RAF's GR.1 derivative of the Tornado was subject to 18 modifications and 13 Special Trial Fits (STF) on average. For example, leading edges and weapon pylons were fitted with Radar Absorbent Material (RAM) and Surface Wave Absorbent Material (SWAM); improved Identification-Friend-or-Foe (IFF) equipment, jam-resistant radios, larger fuel tanks, and buddy-buddy air-to-air refuelling capability were all provided. During the war, the aluminium Tornado taileron leading edges were replaced with nickel-chromium ones,

8 ibid.

9 ibid.

10 ibid.

11 ibid.

12 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding RAAF Logistics Command, 20 September 1991–18 October 1991, paragraph 405.

after firing of AIM-9 Sidewinder missiles was found to cause pitting of the original leading edges.[13]

A desert camouflage paint scheme was also applied to RAF Tornado and Jaguar fleets. The Jaguars were also modified by the installation of electronic countermeasures equipment, enhancements to the radar warning receiver and cabin conditioning, and the provision of night vision goggle capability and jam-resistant radios.[14]

RAF Buccaneer aircraft also received updates to the radar warning receiver; jam-resistant radios and Identification-Friend-or-Foe (IFF) equipment were installed; and chaff and flare capability was activated.[15]

Lynx helicopters underwent various modifications, depending on the service operating them. These included improved radar and electronic support measures, and infra-red jammers. Missile approach warning systems were fitted to Chinook and Puma helicopters.[16]

A common theme was the incorporation of new or improved weapons capabilities. Modifications were applied to improve Tornado missile capabilities, and over-wing pylons were fitted to allow the Jaguar to carry Sidewinder missiles.[17] RAF Chinooks were fitted with flash-suppressors for their mini-guns, and chutes to prevent spent cartridges from entering the rotor arc.[18] Lynx helicopters were variously fitted with machine guns and TOW missile thermal image sighting systems with night vision goggle capability. This latter combination provided a full night-fighting capability.[19]

A further modification was found necessary to allow the safe use of helicopters at night in this way, after four helicopters were lost during night training missions. Downwards-facing infra-red lights were installed on helicopter skids; if both lights illuminated the ground, the pilot knew the helicopter was too low.[20]

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13 Wing Commander Gary Waters, 'The Gulf War and Logistics Doctrine', *RAAF Supply*, March 1992, pp. 37-41; and Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, p. 25.

14 Waters, 'The Gulf War and Logistics Doctrine'; and Waters, *Gulf Lesson One*, pp. 25, 41.

15 Waters, *Gulf Lesson One*, p. 245.

16 ibid., p. 139.

17 ibid., pp. 25, 41.

18 Waters, 'The Gulf War and Logistics Doctrine', pp. 37–41.

19 Waters, *Gulf Lesson One*, p. 269.

20 ibid., p. 139.

Aircraft engine capabilities were improved on at least two fleets. Tornado engine power was increased by the introduction of low pressure compressors,[21] and the USAF F-15 Eagle engines were uprated.[22]

Many modern aircraft systems are software controlled. This can provide additional flexibility, as the systems can be reprogrammed (ie. modified) to adapt to different threats or environments. For example, the RAF Tornado radar warning receiver was updated with information on the threats expected to be encountered; other software upgrades were also applied.[23]

Both US and Canadian forces updated software systems in-theatre, using quite different approaches. The Canadians deployed a team into the Gulf who were vested with sufficient engineering authority to undertake and approve modifications to the Hornet electronic warfare software on site.[24] By contrast, US aircraft software modifications were always developed and tested in the US. Initially, updates were applied by transporting magnetic or punched computer tapes to the Gulf, where deployed maintenance staff would load the changes to the aircraft systems. Later, a direct secure communications link was provided so that software engineers in the US could directly modify the deployed aircraft's software without the need to transport any physical media.[25] Both the Canadian and final US methods provided very responsive approaches to software modification; interestingly, neither country was willing to risk the delays incurred by the need to transport media from home.

Many modifications performed during the Gulf War were in response to environmental problems. An example is scratching and pitting of the glass window of the Low Altitude Navigation Targeting Infrared for Night (LANTIRN) system, used on F-15E and F-16C/D aircraft. Carbon-coated windows were found to have superior ability to withstand sand damage. Twenty sets were delivered to the Gulf by the commencement of *Desert Storm*, permitting more reliable ability to attack targets at night.[26]

In a similar vein, Tornado cockpit canopies were modified to avoid thermal distortion problems.[27] Lynx helicopters were fitted with improved engine cooling systems.[28]

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21 ibid., p. 245.

22 Murray Hammick, 'Report from the Front: AMUs Underrated in USAF's Success', *International Defence Review*, 5/1991, pp. 451–452.

23 Waters, *Gulf Lesson One*, p. 25.

24 STLO NAVAIR 79/2/Air Pt 2 (61), *F/A-18 Persian Gulf Operations – Canadian Forces Engineering/Logistics Lessons Learned*, STLO NAVAIR, 10 July 1991.

25 Department of Defense (USA), Conduct of the Persian Gulf War, April 1992, Appendix F, p. F-64.

26 United States General Accounting Office, *Operation Desert Storm – The Services' Efforts to Provide Logistics Support for Selected Weapon Systems*, September 1991, p. 45.

27 Waters, *Gulf Lesson One*, p. 25.

28 ibid., p. 269.

Helicopters were particularly susceptible to environmental problems due to prolonged operations at low altitude. For example, sand erosion of Sea King rotor blades was reduced by the application of a protective tape to main and tail rotor leading edges.[29] Helicopter engines required a significantly reduced mean time between overhauls as a result of sand ingestion, which was partially alleviated by modifications such as the installation of particle separators.[30] This modification program was not complete by the time hostilities commenced.[31]

Also incomplete was a program to improve the life of C-141 undercarriage struts, which deteriorated rapidly apparently as a result of sand ingress. A strut cover was designed but no installations were completed by the cessation of the conflict.[32]

As in the Falklands conflict, several relevant modification programs had been initiated during peacetime but had not been completed due to funding restrictions, and a focus on the European theatre. Such modifications included actions to circumvent anticipated problems with operations in the hot, sandy desert environment.[33] For example, a modification to alleviate sand ingestion problems with the UH-60 helicopter Auxiliary Power Unit was proposed in 1981, but cancelled because 'there was no user requirement...'. Helicopter rotor blade problems were also foreseen, but the corresponding modification was not implemented.[34] Many RAF Tornado modifications incorporated for the Gulf War had been planned for future incorporation, notably as part of mid-life upgrade programs.[35]

Although the need for some modifications was foreseen before the war, other problems were unexpected. In part, this was because exercises in similar environments were of such short duration that the problems observed during the Gulf War did not develop.[36]

While the incorporation of many pre-existing (peacetime) modifications can be deferred for the duration of a contingency, others cannot. Approximately half of the aircraft rotated out of the Gulf region by the Canadian Forces were rotated out due to the need to incorporate time-dependant critical modifications.[37] In this regard, modification work presented as great

29 Murray Hammick, 'Sea Kings in Sand', *International Defense Review*, 5/1991, pp. 453–455. The tape on the rotor blades had to be frequently replaced, for example, after rain. It could be debated whether this process was a modification, a recurring ('special') servicing, or even the replacement of a consumable (eg. new oil for old).

30 Waters, *Gulf Lesson One*, p. 139.

31 United States General Accounting Office, *Operation Desert Storm*, p. 5.

32 ibid., p. 45.

33 ibid., p. 5.

34 ibid., p. 43.

35 Waters, *Gulf Lesson One*, p. 139.

36 ibid., p. 44.

37 STLO NAVAIR 79/2/Air Pt 2 (61), loc cit.

a constraint as scheduled servicings. Similarly, the RAF chose to rotate its aircraft back to the UK for the incorporation of many environmental modifications.[38]

Peacekeeping in Cambodia

The ADF sent a detachment of Blackhawk helicopters to Cambodia in 1993, as a part of the United Nations peacekeeping force. The aircraft required the installation of ECM equipment to afford adequate defensive capability. Three of the four modifications required the installation of 'fitted for but not with' equipment. Although this expedited the installation of the new equipment, there were still problems; eg. electrical looms failing continuity checks.[39]

A modification for the incorporation of a missile warning receiver was developed from scratch by ARDU within six days. In addition, ARDU was requested to manufacture the six modification kits required for incorporation on the deployed aircraft. Despite the rapidity of the modification design work, installation of the new equipment had to be performed on the aircraft in Cambodia.[40]

The lack of aircrew familiarity with the newly installed items of equipment served to decrease the advantage intended to be provided by the new equipment.[41] Delays in installing the modifications also meant that the deployed aircraft did not have the appropriate ECM protection during the early part of the operation.

CONTINGENCY MODIFICATION MANAGEMENT

Reasons for Modification

The majority (and most substantial) of the modifications described above were motivated directly by operational requirements. New offensive capabilities were provided in many cases, usually by modifying aircraft to be able to accept new weapons. Defensive systems, such as ECM, flares, chaff, RAM and SWAM were also commonly added; in many such cases, the need for additional defensive systems (in particular) suggests a lack of forethought during peacetime. Unavoidably, many systems had to be updated to match the threats encountered.

In both the Falklands and Gulf wars, the AO was not that expected by the UK, USAF and coalition forces. This necessitated the provision of appropriate navigation equipment for the

38 Sir Kenneth Hayr, 'Logistics in the Gulf War', *RUSI Journal*, Autumn, 1991, pp. 14–19.

39 Discussion with Group Captain N. Schmidt, DTA-LC, 22 June 1994.

40 RAAF Engineering Planning Team, *Blueprint 2020 – Engineering the Future*, Departmental Publications, Canberra, 1993, p. 5-17.

41 Discussion with Squadron Leader J. Adams, AIRREG1, 22 June 1994.

Falklands campaign, and larger fuel tanks or air-to-air refuelling capability were added to some fleets in each of these campaigns. Paint schemes were also changed appropriately.

In some cases, aircraft were adapted to perform new roles; this gave rise to both offensive and defensive modifications.

Many modifications were found necessary to *indirectly* support operations, by maintaining reliability and availability at acceptable levels. Environmental modifications come into this category; again, the need for many of these modifications arose because the AO was not that expected.

Reliability and Maintainability

Most of the examples discussed above are modifications intended to provide additional capability, or to adapt a weapon system to its environment. However, there is another significant motivation for performing modifications: improvements to reliability and maintainability (R&M).[42] Improved reliability means that maintenance arisings will occur less frequently; improved maintainability means that less downtime will be required per arising. Both of these effects equate to increased availability.

However, the effect of improved reliability and maintainability is not limited to availability improvements. The need for deployed maintenance capabilities can be reduced, and those capabilities still needed on deployment may be performed with less manpower or equipment. Modifications to improve reliability and maintainability are therefore clearly helpful in meeting preparedness goals. Improvements in component reliability of between two and ten times are sometimes achievable; maintainability can be improved up to fourfold.[43]

When a contingency is imminent, virtually all modification activity will be oriented towards capability improvements and environmental adaptation, much of which could not be forecast before the exact nature of the threat and AO became known. Therefore, R&M enhancements must generally be wrought during peacetime. Happily, R&M also assists in meeting peacetime maintenance goals such as airworthiness and cost-effectiveness, so there is some motivation for R&M improvement during peacetime. However, some shortfalls in contingency-related goals (such as insufficient availability or excessive deployment size) may be redressed by modifications that would not be justified on other grounds. Some 'artificial' priority must therefore be afforded to such modifications during peacetime, as they are unlikely to be accommodated immediately before or during a contingency.

A significant disincentive to the processing of R&M-enhancing modifications is the difficult and time-consuming nature of the modification development and approval process. It is quicker and easier to require aircraft to be serviced more frequently, or to buy additional

42 The emphasis here is on the avoidance or rectification of *predictable* failure modes, rather than modifications to deal with *unexpected* failure modes which occur during a contingency.

43 AF Pamphlet 800-7, *The USAF R&M 2000 Process*, Department of the Air Force, Washington, 1 January 1989, *passim*.

spares, than it is to staff a modification proposal.[44] The lack of visibility and accountability for maintenance costs also contributes to this situation; the formation of Logistics Management Squadrons may help to redress this situation. The adoption of performance measures other than direct cost is also germane; measures such as achieved availability and reliability need to levied against logistics managers to the same extent as expenditure on spares and modifications, servicing durations, etc. Unbalanced emphasis on performance measures can lead to suboptimisation, and hence poorer performance overall.

Urgency

Modification design, approval and incorporation will be among the first, and therefore most urgent, contingency management tasks.[45] The need to have necessary modifications incorporated should *precede* the deployment of aircraft, whereas many other activities need not be completed until *after* aircraft have deployed. This will reduce the need to rotate aircraft away from the AO.

Some necessary modifications will be already ‘in the pipeline’ before a contingency; these need only to be expedited. The need for certain other modifications cannot be foreseen, especially those required for unexpected threats or extreme environments. A rapid development, approval and incorporation capability must exist for modifications in this category. In between these two categories lies a third category: modifications developed in peacetime but subsequently not approved. In many instances, these apparently wasteful situations enabled the rapid incorporation of complex modifications during wartime. Based on this observation, a deliberate strategy could be established whereby potentially useful modifications are developed and (possibly) trialed during peacetime, then held ‘on the shelf’ until an appropriate contingency warrants their incorporation.[46] This arrangement parallels many of the advantages and disadvantages of the ‘fitted for but not with’ concept, offering savings in time and money during peacetime, but sacrificing operator effectiveness and risking teething and incompatibility problems during a contingency.[47]

Design and Approval

A rapid modification approval process is necessary to support contingency operations. There are many examples of the approval of complex modifications within 24 hours during a contingency. The RAF found that the collocation of operational, engineering and procurement staffs was helpful in this regard during the Gulf War. The creation of RAAF Weapon System Logistics Management squadrons, and their collocation with operational

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44 A major UK study found that this effect was contributing significantly to the unreliability of UK military equipment (Report of the MOD(AFD)/MOD(PE)/SBAC/EEA Working Group on Ways of Securing Improved Reliability in RAF Equipment, July 1984, pp. 13–17, 13–18).

45 Waters, *Gulf Lesson One*, p. 257; and HQLC DCOE/4000/49/MRU Pt 2 (9), *Impacts on Logistics Command Functions in a Contingency*, COFS-LC, 16 December 1992.

46 Waters, *Gulf Lesson One*, p. 136.

47 ‘Fitted For But Not With’ is discussed on pp. 79 and 196.

staffs, will permit the same economies—as long as dependence on external agencies can be kept to a bare minimum.[48] When preparing for the Cambodia deployment, Army LMSQN found itself hampered by a lack of autonomous engineering authority; the squadron's collocation with other engineering organisations in Melbourne at the time helped to limit the impact of this.[49]

For the RAAF, much of the contingency modification development work would fall to ARDU. However, ARDU does not possess engineering approval authority for the incorporation of modifications fleet-wide,[50] as its modification capability arises as a byproduct of its primary role of flight test and evaluation. The need for remote approval of ARDU-developed modifications could be a cause of delays in the modification process. Further, ARDU's modification development resources would need to be augmented for the unit to be able to perform a significant amount of modification development work on behalf of other agencies. During a contingency, this augmentation could come from LMSQNs (at least in part).[51] Without this increased capacity, LMSQNs must either develop their own modifications (requiring replication of ARDU's design infrastructure and raising concerns over the sustenance of small, isolated design cells), or outsource more modification work (eg. to DSTO, OEMs or DACs).[52]

The RAF's modification development unit (Central Trials and Tactics Organisation (CTTO)—analogous to the RAAF's ARDU) could not cope with all of the modification requests received during the Gulf War. This facility moved to 24-hour a day operations to support modification development for the Falklands conflict. Previous planning had expected some CTTO personnel to augment deploying units at the onset of conflict; however, during the Gulf conflict, it was CTTO which needed augmentation. The demands on ARDU during

48 Such external agencies may include Original Equipment Manufacturers (OEMs), AFO, AHQ, and Centres Of Expertise (COEs). DI(AF) AAP 7001.051 Section 1 Chapter 3, draft, includes some of these in the (peacetime) design approval process.

49 Captain Rob Crowe, 'Army LMSQN's Provision of Logistics Support for Operation *Gemini*', *The Logbook*, September 1994, pp. 19–23.

50 Discussion with Group Captain N. Schmidt, DTA-LC, 22 June 1994.

51 RAAF Engineering Planning Team, *Blueprint 2020*, pp. 5–16, 5–18. A disadvantage of transferring technical staff from LMSQNs is that many LMSQNs are integrating technical and supply responsibilities to form true logistics teams. Removing engineers from such organisations reduces their ability to manage the non-technical responsibilities that would *not* be transferred to ARDU. Moreover, other agencies are considering using LMSQN engineers to augment operational squadrons on deployment. There seems to be some risk of double-counting LMSQN resources, and leaving LMSQNs ill-equipped to perform their own important contingency roles.

52 The RAAF's need for, and capability in, repair design is frequently underestimated. Well over 100 structural repairs are designed annually by the RAAF for the F-111 fleet alone. This work is now performed within LMSQNs (albeit with greater reliance on other agencies than has been the case in the past). This permits LMSQNs to retain some design capability which can be applied to modification work, and also behoves LMSQNs to maintain an adequate design control system.

RAAF involvement in conflict can be expected to be similar; certainly, ARDU personnel cannot be made available to bolster other units, at least at the onset of a contingency.[53]

During the Gulf War, requests for modifications increased all the more once aircraft were in-theatre.[54] The combination of unexpected environment and threat probably contributed to this situation. These circumstances are most likely to arise in the performance of multinational operations.

The ability to modify software-controlled systems can provide a quick and effective means of tailoring these systems to meet local conditions and threats. However, this can only be done expediently if the software source code is acquired (or is quickly accessible), and indigenous capability to maintain the code is retained.[55] In many ways, this is analogous to (or a special case of) obtaining sufficient technical data (eg. design calculations, technical drawings) to permit the local design of modifications to structural and mechanical components, although these can be more readily 'reverse engineered' in the absence of technical data.[56]

RAAF Deeper Maintenance units have a responsibility to provide a capability for the rapid development and incorporation of modifications.[57] With the progress of the Commercial Support Program (CSP), the RAAF's in-house Deeper Maintenance base is shrinking; for some weapon systems, no in-house capability will be retained.[58] CSP contracts are unlikely to specify the requirement to provide a rapid modification development capability (such a vague requirement would be difficult to specify in any case). As a result, the RAAF can expect to find itself more dependent on contractors for modification development, although the contractors may not have the infrastructure in place to quickly assume this role. Establishing a network of Design-Approved Contractors (DACs) for each weapon system would go some way towards alleviating this potential problem.

Incorporation

The incorporation of modifications does not provide an instant solution. Work-up time is required for crews to gain familiarity with, and confidence in, newly installed items of equipment. Modifications made to the Tornado F.3 for the Gulf War probably doubled the navigator's workload; additional training, and extended sorties during *Desert Shield*, were

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53 Waters, *Gulf Lesson One*, p. 268; and discussions with Group Captain N. Schmidt, DTA-LC, 22 June 1994.

54 Waters, *Gulf Lesson One*, p. 245.

55 ibid., p. 268.

56 *Reverse engineering* is the process of deducing the internal workings of a system by studying its performance and behaviour.

57 DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraph 38.

58 The PC-9 trainer aircraft is an example. If this aircraft were to take on the additional role of light ground attack, the need to appoint an agency to take on contingency modification responsibility becomes more acute. The decision to retain no in-house DM capability should probably be rethought in the face of aircraft role changes.

necessary to ensure the effectiveness of the new equipment. Even then, the best procedures for the use of new equipment were often not determined until the 'second or third iteration after fitment'. This learning curve can be shortened by the use of facilities such as ARDU to exhaustively test new equipment and support operational squadrons.[59]

Moreover, newly installed equipment frequently suffers from production and installation problems. Once again, a facility such as ARDU can be invaluable in the rectification of such problems.[60] Similarly, hastily fitted equipment is not always well integrated with existing systems; for example, the F-15 jammer would occasionally generate a false alarm on the aircraft's radar warning receiver.[61]

The expected theatre of war is a factor in determining the extent of modifications necessary. If operations are to be conducted in theatres for which few preparations have been made, substantially increased modification requirements are to be expected. The main application of this lesson could be in supporting multinational operations, where aircraft could potentially operate from anywhere in the world (although more substantial contributions are likely to be within Australia's region). The suitability of a fleet's modification state for deployment to a given theatre may be a determinant of the forces to be deployed.

A recurring theme arising from the frenetic pace of contingency modification activity is the need for a strong indigenous capability.[62] The use of high technology equipment further increases the need for this emphasis.[63] Australian involvement in the research, development, and production of weapon systems would help to provide the knowledge, skills and equipment necessary for an indigenous modification capability.[64] This will require appropriate Defence investment in Australian industry; in the interests of retaining an indigenous capability, such investment may be defensible in some cases where the local industry is not internationally competitive.[65]

Limitations

Some modifications attempted are far too extensive for the nature of the contingency. If it seems likely that a modification cannot be effected within sufficient time for it to provide operational benefit, it may be better to deploy the aircraft unmodified rather than suffer

59 Waters, *Gulf Lesson One*, pp. 257–258.

60 ibid., pp. 258, 298.

61 ibid., p. 269.

62 Udemi, 'Modified to Meet the Need'; RAAF Engineering Planning Team, *Blueprint 2020*, pp. 2-3, 5-2; and *Strategic Review 1993*, AGPS, Canberra, 1993, p. 52.

63 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, p. 150; and Waters, *Gulf Lesson One*, p. 300. Other implications of technology are discussed in Chapter 18.

64 *Defending Australia*, AGPS, Canberra, 1994, p. 135.

65 *Strategic Review 1993*, p. 72. See also Chapter 20.

additional downtime to no avail. Of course, accurately forecasting the duration of a contingency is not easy.

Some modifications simply cannot be achieved within required timescales, despite limitless expedients, enthusiasm and ingenuity. In such cases, there can be no substitute for preparedness.[66]

CONFIGURATION MANAGEMENT

Configuration Baselines

The process of modifying an aircraft fleet to a new configuration (eg. for a particular contingency) is greatly simplified if all aircraft in the fleet share a common modification baseline; ie. all aircraft are essentially of the same configuration, having the same basic set of equipment installed and modifications incorporated.[67] Non-standard combinations of equipment and modification state can require individual attention when a new modification is designed and incorporated, to avoid possible undesirable interactions between the new modification and the pre-existing configuration.[68]

Software

Software configuration management requires careful consideration to ensure that contingency requirements can be met. In general, a safe practice is to follow the software configuration managed by the OEM or major operator. However, this process may not be sufficiently responsive in a contingency, should Australia identify the need to incorporate software modifications to adapt equipment to a new threat or environment. Some indigenous capability for software modification, and hence software configuration control, is therefore desirable.

However, a mixture of locally developed and externally provided software updates is a dangerous mix: interactions between different modifications can have unintended side-effects. While the practice of incorporating locally developed modifications is defensible (and even desirable) during a contingency, the software may need to be subsequently demodified after the contingency to return it to a configuration compatible with the chosen configuration

66 Udemi, 'Modified to Meet the Need'; and Crowe, 'Army LMSQN's Provision of Logistics Support for Operation *Gemini*'.

67 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding RAAF Logistics Command, 20 September 1991–18 October 1991, loc cit.; and STLO NAVAIR 79/2/Air Pt 2 (61), op cit.

68 For example, at one time, of the four RAAF RF-111C aircraft, there were three different modification states of the cockpit alone! The adoption of processes to control fleet modification baselines in an orderly manner was a significant part of the engineering management redirection in Logistics Command in 1992; procedures for achieving this are documented in aircraft Configuration Management Plans (CMPs).

management authority. The alternative is to take full responsibility for software configuration locally, which complicates the incorporation of modifications developed elsewhere.

Fitted For But Not With

A commonly used configuration strategy is 'fitted for but not with' (FFBNW).[69] Although the intention of this practice is to permit the absent capability to be installed at short notice, there are many instances where this strategy has not worked. For example, when attempting to incorporate FFBNW equipment on Australian Blackhawk helicopters to allow deployment to Cambodia on Operation *Gemini*, ARDU found that electrical looms failed continuity checks.[70] This kind of problem is virtually unavoidable, since it is not practical to regularly test the ongoing serviceability of the FFBNW equipment in the aircraft prior to modification.

Physical incompatibility and functional integration problems between new equipment and existing systems are difficult to predict; unless the FFBNW capability is trialed on at least one platform, the risk of incompatibility remains.

Even though FFBNW should permit the rapid incorporation of new equipment when required, the absence of the equipment during peacetime denies aircrew the opportunity to gain familiarity with the equipment. Having the equipment installed is one thing; being able to use it, and use it well, is quite another. This problem can be avoided (to some extent) by fully incorporating FFBNW capabilities on some percentage of the fleet; aircrew can obtain some experience with the equipment when flying the fully modified aircraft, and the correct operation of the installation can also be verified. Although this practice is contrary to the goal of maintaining a common configuration baseline, the advantages make it highly desirable. A similar approach is where FFBNW equipment is installed on some aircraft of another fleet (eg. RAAF C-130J FFBNW capabilities are currently installed on some C-130H aircraft).[71]

As the ADF force structure is based on low level contingencies, the configuration of ADF assets usually corresponds to a low level of threat; FFBNW is often used to provide some capability to upgrade equipment to a higher threat environment.[72] While long warning times are expected before higher threats are encountered in the defence of Australia, the same is not true of contributions to multinational operations. For example, the use of FFBNW has been

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69 FFBNW was introduced on p. 79.

70 Discussion with Group Captain N. Schmidt, DTA-LC, 22 June 1994.

71 Discussion with Wing Commander C. Nolan, ILS Manager C-130J Project, 6 July 1994.

72 Levels of conflict are discussed on p. 12.

73 The Parliament of the Commonwealth of Australia, Joint Committee on Foreign Affairs, Defence and Trade, *Stockholding and Sustainability in the Australian Defence Force*, Australian Government Publishing Service, Canberra, 1992, p. 58. The ships were fitted for, but not with, air defence systems; however, this capability eventually materialised in the form of an Army regiment, leaving the ships poorly protected.

identified as a potential problem with the deployment of ADF ships into the Gulf region, possibly serving as a limiting factor on the number of ships that could be deployed.[73]

Some items of equipment can take years to procure. If the procurement leadtime exceeds the readiness notice period, FFBNW cannot be relied upon to provide such equipment during a contingency. Procurement leadtimes will not necessarily reduce in the lead-up to a contingency, since other air forces may also be seeking the same equipment at the same time.

Interoperability

Common configuration of equipment with allies offers advantages during coalition warfare (eg. during multinational operations or if involved in major conflict for the defence of this country). In addition to operational benefits, maintenance facilities can be shared,[74] host-nation support becomes more feasible,[75] spare assets can be traded, etc. While the greatest benefits are achieved by operating identical aircraft types and configurations, benefits would also accrue from the use of common (or similar) aircraft components, GSE and systems.[76]

From an operational viewpoint, the need for such interoperability becomes more significant when a coalition partner is the US or UK. In such cases, contributions of smaller coalition partners are only feasible and worthwhile when a significant degree of interoperability exists with the larger partner.[77]

Since regional engagement is a strong theme in current strategic guidance, interoperability with regional countries is also desirable.[78] The emphasis is on operational rather than logistics interoperability. In theory, interoperability should not be a significant influence on equipment acquisition decisions, although the criterion may be considered when the cost penalty is small, or if value for money also increases.[79] In practice, interoperability is a most important consideration due to the need for ADF fleets to be able to work in with allied fleets, possibly for the defence of Australia.

Interoperability *within* the ADF is also an important goal.[80] From a logistical viewpoint, the operation of common components between the Services permits Single Service Logistics Management (SSLM), which yields increased efficiency and flexibility of support.

Multinational operations potentially provide the greatest challenges for interoperability, since United Nations operations may make alliance partners of almost any countries.

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74 Waters, *Gulf Lesson One*, p. 138.

75 Host Nation Support is discussed on p. 241.

76 *Strategic Review 1993*, p. 47.

77 Waters, *Gulf Lesson One*, p. 286.

78 *Strategic Review 1993*, p. 40.

79 ibid., p. 48.

80 ibid., p. 66.

The UN proposes to maintain details of the equipment that member countries (including Australia) may be willing to make available for UN operations. The UN can then initiate efforts to ensure the interoperability of the equipment types listed.[81]

SUMMARY

Frenetic aircraft modification activity accompanies contingency operations. Most such modifications are for the incorporation of additional or improved offensive and defensive capabilities. Other common enhancements are in navigation capabilities and range extension. Modifications are also needed to minimise the impact of adverse environmental conditions.

The scramble to incorporate contingency modifications is exacerbated by a lack of forethought concerning contingency requirements (ie. too much peacetime emphasis), and an element of surprise when the enemy turns out to be someone and somewhere other than expected. There are disadvantages to the incorporation of modifications at the onset of a contingency, including initial unreliability, aircrew unfamiliarity, and a reduction in availability.

Modifications aimed at enhancing reliability and maintainability are also of benefit to contingency operations, yielding improved availability and reduced support requirements. Such modifications must be pursued during peacetime, even though the main motivation in some cases will be the contingency priority of availability. Unfortunately, there are many disincentives to the staffing of such modifications, including cumbersome processes and limited and uneven logistics performance measures.

Some modifications required specifically for contingency incorporation could be designed and approved (up to a point) during peacetime. This would greatly expedite modification incorporation when necessary, possibly making otherwise infeasible modifications realistic.

Rapid design and approval of modifications will be required during a contingency. Relevant strategies include streamlining of procedures, collocation of relevant personnel, the avoidance of non-essential agencies, and maximum delegation of authority. Strong indigenous capability must exist, including software capability. ARDU's role (and capacity) would be most important. Where no in-house DM capability exists, contractors must provide a modification capability.

Rapid fleet modification is facilitated if all aircraft share a common configuration baseline to the maximum extent possible. The 'fitted for but not with' strategy can also help to speed incorporation, but suffers from many problems, and must therefore be employed with great care (if at all).

81 Robert Grey, 'Strengthening UN Peacekeeping Operations: The Secretary General's Proposals', paper delivered to the seminar *Peacekeeping at the Crossroads*, Canberra, 21–24 March 1993, p. 7.

Contingency operations and logistics are simplified if aircraft and equipment are interoperable with allies, neighbours and between the services. Aircraft configurations should be managed with this in mind.

Chapter 18
Technology

INTRODUCTION

One of the imperatives for the RAAF is the achievement of a qualitative edge, which requires the selective employment of high technology equipment.[1] This is primarily to achieve increased operational effectiveness, but the use of technology also has implications for the maintenance of the equipment. This chapter outlines the relationship between technology and maintenance.

THE NEED FOR ADVANCED TECHNOLOGY

High technology should be applied selectively.[2] The use of high technology can reduce manpower requirements, increase operational performance, and reduce costs of ownership.[3] Often, these criteria are in conflict with one another: for example, while technology can often improve operational capability and obviate the need for additional equipment by permitting multiple roles to be performed by the one platform, there is often an increase in manpower, life cycle cost, and complexity. Even though the high cost of advanced technology (both to procure and operate) may result in less equipment being procured, the additional capability afforded by sophisticated systems often outweighs the disadvantage of smaller fleet sizes.[4]

The vast size of Australia's area of military interest virtually necessitates the application of some amount of advanced technology to provide adequate defence.[5] Modern technology can confer many operational advantages, including night and all-weather capabilities; improved munitions; missile defence; expanded flight envelopes; stealth; electronic surveillance, communications and defences; and space-based systems.[6]

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1 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, p. 65.

2 *Strategic Review 1993*, AGPS, Canberra, 1993, p. 47.

3 *Defending Australia*, AGPS, Canberra, 1994, pp. 21, 125.

4 DI(AF) AAP 1000, p. 36.

5 *Defending Australia*, p. 115; and *Strategic Review 1993*, p. 48.

6 USAF Air Force Manual 1-1, Volume II, *Basic Aerospace Doctrine of the United States Air Force*, March 1992, p. 201; and James P. Coyne, *Airpower in the Gulf*, Air Force Association, Virginia, 1992, p. 113.

A conclusion drawn from the Gulf War is that the advanced technology employed in the allied weapon systems contributed significantly to the allies' success.[7]

Maintaining a technological edge has traditionally been an important part of Australia's defence posture, but the growth of regional economies and technological skills reduces the margin.[8] Even so, it is possible to have too much technology: technology which far exceeds the operational capability of would-be adversaries merely restricts fleet sizes, is overly expensive, and unnecessarily burdens the logistics system.[9] The need should determine the level of technology required, balanced with considerations of cost and supportability.

THE IMPLICATIONS OF TECHNOLOGY

Technology and Complexity

There is an unfortunate nexus between technology and complexity.[10] Advanced technology is often dependent on complex interactions between a multitude of components to achieve its effectiveness. While some of these components can be combined, effectively reducing the overall parts count, it remains generally true that sophisticated systems rely on a larger number of components and connections than older, simpler systems.[11] All else being equal, a higher parts count equates to lower system reliability.[12]

Reliability

RAAF doctrine states that technological developments have increased the reliability of modern aircraft.[13] While the reliability of individual components may be improved, the increased complexity of weapon systems as a whole tends to dissipate this advantage. Certainly, admirable mission-capable rates were sustained during the Gulf War; this has been ascribed in part to improved levels of reliability of modern aircraft (although other relatively recent innovations, such as modularity and built-in test and diagnostic equipment, could achieve the same trend despite poor reliability).[14]

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7 Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, pp. 278, 281.

8 *Strategic Review 1993*, p. 41.

9 DI(AF) AAP 1000, p. 46.

10 ibid., p. 59.

11 The classic example of the aggregation of discrete components into one is the integrated circuit ('silicon chip'). A single chip can contain the equivalent of millions of discrete electronic components.

12 See p. 44.

13 DI(AF) AAP 1000, p. 149.

14 Murray Hammick, 'Report from the Front: AMUs Underrated in USAF's Success', *International Defence Review*, 5/1991, pp. 451–452.

There appears to be no clear evidence that the use of high technology brings with it an increase in overall reliability. The nexus between technology and complexity generally means that there are more components required to achieve the intended function; all else being equal, this means reduced reliability. However, various design and manufacturing techniques can mitigate this tendency, such as redundancy, use of higher reliability components (such as integrated circuits), etc.

Prior to the Gulf War, there was some concern that the investment in high technology by the US military might be misguided, as the reliability of such systems was expected to suffer by comparison with simpler systems in a combat environment. In practice, although there were some problems, the reliability of the high technology equipment did not suffer to the extent feared by its critics.[15] However, this is not to say that high technology is *more* reliable than simpler, more robust systems.

High technology equipment is most likely to exhibit poor reliability early in its life; reliability is expected to significantly improve throughout the first few years of the system's operation. For example, USAF F-111 reliability (measured in terms of mission-capable rates) increased from 43 per cent in 1978 to 73 per cent in 1987.[16] This initial unreliability can be expected to have various manifestations, including significantly higher cannibalisation rates and a high proportion of 'false failures'.[17]

Many new high technology systems were fielded for the first time during the Gulf War, and teething problems were indeed present. The lengthy build-up period permitted the exorcising of many problems before the onset of hostilities, and civilian contractors deployed to the Gulf region were relied upon extensively to rectify problems and attain reasonable availability from the new systems.[18] The practicality of this latter expedient may have been tested if the allied bases had been less secure from attack than proved to be the case. Regardless, the use of advanced technology, and especially newly introduced advanced technology, carries with it the need for some level of in-theatre Development, Test and Evaluation (DT&E) capability.[19] Such a capability is also useful in facilitating modifications to high technology equipment to adapt it to the local environment or threats.[20]

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15 Coyne, *Airpower in the Gulf*, p. 175.

16 United States General Accounting Office, *B-1B Parts Problems Continue to Impede Operations*, July 1988, p. 46. Note that, at the time of its introduction, the F-111 was a high-technology aircraft. The document referred to expects even more dramatic variations in reliability for higher technology aircraft, such as the B-1B.

17 ibid., pp. 47, 51. A false failure occurs when a component is removed from the aircraft when initial test results indicate that it has failed, but subsequent testing reveals otherwise. In CAMM/MAARS terminology, these are 'no fault found' arisings.

18 Waters, *Gulf Lesson One*, p. 267.

19 loc cit.

20 See Chapter 17 for examples of such modifications.

The complexity of modern weapon systems can also render them fragile.[21] Not only does complexity contribute to this situation, but the pursuit of maximum performance from a weapon system encourages the use of small margins of safety and very tight manufacturing tolerances. These factors can result in a system not being particularly damage tolerant, in that the smallest deviation from design conditions can result in unserviceability. Since such deviations will occur in practice—particularly during contingency operations—fragility equates to reduced reliability, and hence availability.

The adverse relationship between technology and reliability can be controlled by a conscious effort to improve reliability and maintainability at the design stage. This is a most important facet of Integrated Logistics Support (ILS).

Support

Technological improvements can improve the maintainability of weapon systems.[22] Built-in test equipment can help to quickly identify the system or component that needs replacing; the more specific the fault diagnosis is, the quicker the repair can be effected. Moreover, accurate diagnosis can mean that spares holdings of higher-level assemblies can be reduced, since these should need to be replaced less frequently. This reduces the cost of maintaining reserve stocks, and permits generally easier storage and handling of the spares (lower-level components will be smaller, cheaper and more rugged).[23]

Modular design allows errant components to be quickly and easily changed, even in remote localities. Repair of removed components is necessarily more complex, but the ability to perform a maximum amount of maintenance off the aircraft means that such repairs need not affect availability (spare parts permitting), and can be performed well away from the area of operations. This latter issue is particularly important for the maintenance of complex systems, which frequently requires sophisticated and expensive equipment and advanced skills.[24] Although it is generally desirable to keep such capabilities out of the area of operations, some lengthening of supply pipelines and lines of communication will result, reducing the responsiveness that may otherwise have been achieved.

Even front-line maintenance on advanced technology equipment requires the use of complex test equipment, which must be deployed with the aircraft. For the Gulf War, the USAF deployed dozens of sets of aircraft test equipment.[25] With centralised maintenance performed to a large extent during peacetime (for reasons of economy), there is a tendency

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21 Major General Edward R. Bracken, USAF, 'Vietnam Logistics: Its Meaning for Tomorrow's Air Force', *Air Force Journal of Logistics*, Fall, 1986, pp. 18–21.

22 DI(AF) AAP 1000, loc cit.

23 Karen W. Tyson, Stanley A. Horowitz, Peter Evanovich, D. Graham McBryde, Mitchell A. Robinson, Barbara Junghans, and Mei Ling Eng, *Weapon Reliability and Logistic Support Costs in a Combat Environment*, Institute for Defense Analyses, Virginia, August 1989, p. ES-4.

24 DI(AF) AAP 1000, loc cit.

25 Department of Defense (US), *Conduct of the Persian Gulf War*, April 1992, Appendix F, p. F-62.

to procure only the minimum amount of test equipment needed to support such centralised operations. However, during a contingency, this equipment may be needed to support multiple deployments as well as aircraft operations from non-deployed sites. It is important that such equipment procurements be based on the aircraft's operational concept, rather than on peacetime arrangements and cost saving measures.

Many of the items of test equipment used on deployment equal the complexity of the aircraft itself. Even though much deployed maintenance on advanced technology aircraft involves component replacement, considerable skill is needed on the part of maintenance staff to diagnose the appropriate component to change. The need for such specialists on deployment is undesirable, as it reduces manpower flexibility and may necessitate increased deployment manpower. In addition, the extended training times required to generate maintenance personnel of the required skill levels can result in increased Manpower Required in Uniform (MRU),[26] since the rotation pool cannot be augmented by training and qualifying new recruits to the same extent.[27]

Conversely, the ability of built-in test and diagnostic equipment, as well as external automatic test equipment, can allow problems to be diagnosed on aircraft with which maintenance staff are relatively unfamiliar. This provides some additional flexibility amongst technical staff, and contributed to the high availability levels achieved during the Gulf War.[28] To some extent, no longer does the aircraft have to be mastered, but its test equipment does.

Many aircraft electronic components (as well as ground-based test equipment) need to be periodically calibrated. Rather than rotate such components back to the US for calibration during the Gulf War, a mobile calibration facility was deployed into the Gulf region.[29] This is consistent with the US practice of striving for a greater degree of self-sufficiency on deployment than Australia desires. The extremely long logistics pipelines from the US to the Gulf encouraged a great deal of self-sufficiency; regardless, without such deployable capabilities, the ADF must expect that increased transportation capacity will be required to handle the movement of equipment for calibration (and other maintenance activities). Moreover, additional items may need to be present in the logistics pipeline to atone for delays incurred by transportation.[30]

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26 See Chapter 19.

27 AHQ 3020/13/TECH Pt 1 (20), *Report of the Working Party to Consider TFG CMR and Associated Maintenance Issues*, 16 May 1993, p. C-1.

28 Hammick, 'Report from the Front'.

29 Department of Defense (US), *Conduct of the Persian Gulf War*, p. F-63.

30 Another option is to defer some calibration activities. The need to consider this will depend on the intensity of the conflict and the location of the contingency; its feasibility will be a function of how quickly and severely items are known to drift out of calibration, and how significant such errors would be on aircraft operations.

In many instances, repair of highly complex components (eg. circuit cards) is not cost-effective, so the need for maintenance is supplanted by the need for additional stocks or procurement.

A direct consequence of poor reliability is an increased dependence on the 'support tail' to provide replacement components and repair defective ones. Such support services require facilities, power, support equipment, etc. In the pursuit of maximum availability, a strong temptation exists to deploy as much of this support as possible, which can make the deployment base an even more lucrative target. In addition, the mobility of the fleet is reduced.

USAF doctrine warns that technological advances may require additional support infrastructure.[31] The trend for defence forces investing in high technology to require increased numbers of support personnel may be observed in defence forces of all sizes,[32] and the Gulf War further demonstrates technology's strong dependence on complex and comprehensive support systems.[33] Australian strategic guidance acknowledges that modern, more capable equipment generally costs more to operate than older designs.[34]

For the most part, industry will be required to take the lead in providing advanced technology equipment, and for providing the deeper levels of support. However, there is a risk that long term relationships between defence and industry could lock Defence into obsolete technology; the onus is therefore on Defence to be a well informed customer, which will require some in-house 'internal technological advice structure'.[35]

Another consequence of the procurement of high technology equipment is that it tends to make Australia more reliant on overseas agencies for the support of the equipment. Specifically, the retention of an alliance relationship with the US for the provision of technology is an important facet of Australia's defence posture.[36] A conscious effort is required to develop local industry to be able to undertake the maintenance of high technology equipment.[37]

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31 USAF Air Force Manual 1-1, Volume II, loc cit.

32 This observation was expressed by the then Minister for Defence Science and Personnel, the Hon. Mr Gordon Bilney, quoted in Christopher Jay, 'The Navy gets most of the Gravy', *Financial Review*, 20 May 1992, p. 37.

33 Waters, *Gulf Lesson One*, p. 300. Interestingly, RAAF doctrine claims that the use of high technology permits a *simplified* support infrastructure and tends to *reduce* the level of logistic support required (DI(AF) AAP 1000, p. 149).

34 *Defending Australia*, pp. 60, 69, 148; and *Australia's Strategic Planning in the 1990s*, AGPS, Canberra, 1989, p. 25.

35 RAAF Engineering Planning Team, *Blueprint 2020 – Engineering the Future*, Departmental Publications, Canberra, 1993, p. 5-3, quoting from Defence Policy and Industry, *Report to the Minister for Defence Prepared under the Direction of the Parliamentary Secretary to the Minister for Defence, the Hon Roger Price MP*, Canberra, 1992.

36 *Strategic Review 1993*, p. 39.

37 DI(AF) AAP 1000, p. 150; and *Defending Australia*, pp. 115, 130.

This requires transfers of technology and intellectual property; Defence has an important responsibility to foster this process through international agreements and contracting practices.[38]

Australia's desire for interoperability with regional neighbours and allies[39]—most notably, the US—will encourage Australia to keep up with the technology used by these countries. This, in turn, will tend to make Australia more dependent on the US for the support of the technology.

A further cost of technology is in training.[40] High technology systems are often more complex to operate, necessitating that additional training be provided to operators. In addition, the maintenance and repair of such equipment at the component level also requires more highly trained personnel; this dependence on increased training militates against the maintenance of high technology componentry within the ADF, and certainly on deployment. Strategies such as modular design, repair by replacement, and built-in test capabilities all serve to work around this situation, but some increased reliance on industry support will generally result from the use of high technology equipment.

Cost to Procure

Sophisticated weapons and systems are more expensive to procure than lower technology equipment.[41] A trend observable across defence forces of all sizes is that the size of the order of battle reduces as the technology acquired increases.[42] A balance between technological quality and numbers of equipment must therefore be struck.[43]

Another consequence of the increased cost of higher technology is that fewer items are often procured for resupply; however, the items may be consumed just as quickly during a contingency as lower technology items. This places an extra burden on the logistics system to more carefully manage the fewer assets available, which includes an increased emphasis on maintenance to ensure reliability.[44] Additionally, the increased reliability of individual components results in smaller spares holdings,[45] which further reduces the buffer available to cover surges in demand.

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38 *Defence Logistics Strategic Planning Guide 1991*, p. 20.

39 *Strategic Review 1993*, p. 47.

40 Squadron Leader R.P. Lewis, *An Essay on Sustainability*, p. 9.

41 *Defending Australia*, p. 147.

42 This observation was made by the then Minister for Defence Science and Personnel, the Hon. Mr Gordon Bilney (quoted in Jay, 'The Navy gets most of the Gravy'). See also DI(AF) AAP 1000, p. 36.

43 *Strategic Review 1993*, p. 48; and DI(AF) AAP 1000, pp. 46, 65.

44 Wing Commander Gary Waters, 'The Gulf War and Logistics Doctrine', *RAAF Supply*, March 1992, pp. 37–41; and Waters, *Gulf Lesson One*, p. 271.

45 DI(AF) AAP 1000, p. 149.

This problem is even further compounded by reduced industry capability to surge. Smaller order quantities mean lower production rates; this limits the ability to rapidly expand production to meet a sudden increase in usage occasioned by a contingency. The cost of ensuring that industry maintains sufficient surge capability is significantly increased for high technology items. Achieving surge levels within required timescales is also made more difficult by smaller industrial capacity. Technology further exacerbates this problem by compressing the timescales within which conflict can break out (reduced warning time/ readiness notice, or increased intensity).[46]

These issues should be taken into account when deriving reserve stockholding levels; it could well be that the lower resupply rate and longer lead times could require greater reserve stocks to be held—at a significantly increased cost over more quickly procured, lower unit cost (but less capable) items.

The increasing complexity of high technology weapon systems can result in the need to stock and maintain a larger number of different types of components (albeit possibly smaller quantities of each).[47] This can be potentially costly, requiring the establishment of additional maintenance venues or contracts, increased documentation and technical data, etc.

The combination of increased procurement and support costs for high technology equipment means that technology represents a considerable investment. If the defence budget is static or shrinking, there can be a retarding effect on the acquisition of technology; the severity of the retarding effect is increased in smaller countries (such as Australia) that must rely on external sources for technology, when compared to countries with a stronger indigenous technological base such as USA and Japan.[48]

SUMMARY

This chapter may appear to paint a bleak picture of technology. This is because technology generally creates additional logistics demands. It is undeniable that the use of advanced technology can confer significant operational advantages. However, the cost of obtaining such advantage must be considered: potentially increased procurement and support costs, fewer assets, the need to deploy complex test equipment and skilled personnel, a longer and

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46 Charles W. Groover, paper delivered to the American Defense Preparedness Association, *Defence Readiness and Requirements Symposium*, 24–25 September 1980; and *Strategic Review 1993*, p. 41. During the Gulf War, the Canadian Forces found that a last-minute infusion of funds was not able to buy their way out of spares shortages (STLO NAVAIR 79/2/Air Pt 2 (61), *F/A-18 Persian Gulf Operations – Canadian Forces Engineering/Logistics Lessons Learned*, STLO NAVAIR, 10 July 1991). Spare capacity must be planned for, or spare components procured, during peacetime.

47 DI(AF) AAP 1000, loc cit.

48 The Minister for Defence Science and Personnel, The Hon. Mr Gordon Bilney (quoted in Jay, 'The Navy gets most of the Gravy'). As stated on p. 201, high technology equipment can be more cost-effective than existing equipment or lower technology solutions; however, it cannot be procured unless the capital is available to do so.

larger logistics tail, greater dependence on industry and overseas, and reduced industrial surge capability.

It should not be surprising that the ADF's 'tooth to tail' ratio is decreasing over time, when 'tooth' is measured simply by the number of operational personnel. The acquisition of advanced technology will generally be associated with fewer items of equipment (hence fewer operators), but increased support requirements (manpower and dollars). The proper way to assess the 'tooth-to-tail' ratio must be in terms of the *capability* of the ADF. If the increased level of capability does not outweigh the increase in the support tail, there is indeed a problem. Conversely, any attempt to return 'tooth-to-tail' ratios to levels achieved when operating lower technology equipment must result in current equipment being under-supported. This may be manifested in inadequate spares support, low reliability, poor logistics responsiveness, inflexibility and/or poor sustainability.

Chapter 19

In-House Maintenance and Industry Support

What Do We Need To Do In-House?

INTRODUCTION

There are advantages and disadvantages to performing maintenance within the ADF (using either uniformed or civilian personnel). With the relatively recent introduction of new maintenance concepts and the Commercial Support Program (CSP), this issue is most topical.

This chapter briefly discusses the advantages and disadvantages of the use of Service, Defence civilians and contractors for the performance of Defence work, focusing on maintenance work to be performed during a contingency. As a result, this chapter builds on previous chapters on contingency maintenance (Chapter 13), and maintenance on deployment (Chapter 16). The concepts of core/non-core and operational/deeper maintenance are described, and their relevance to the maintenance function is examined. Lastly, some practical issues concerning industry support during a conflict are discussed.

ADVANTAGES AND DISADVANTAGES

Flexibility

The use of military infrastructure permits greater flexibility and freedom of action than can be achieved through civilians.[1] Moreover, permanent forces provide greater flexibility than reserves.[2] Uncertainty is an unavoidable attribute of war;[3] flexibility is therefore enjoined by the ADF as a principle of war.[4] It is crucial that required levels of flexibility be retained

1 HQADF OL DA 178/91, OPS 89/29038, *Logistics Considerations for the Defence of Australia*, A/DGOL, 23 July 1991, p. 11; RAAF Engineering Planning Team, *Blueprint 2020 – Engineering the Future*, Canberra, July 1993, p. 8-6; and Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, Canberra, 1991, p. 7. The latter states that the military will perform a wider range of tasks than civilian employees.

2 Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, p. 255.

3 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, p. 6.

4 ibid., p. 13.

in those aspects of logistics most directly supporting operations. This flexibility provides responsiveness to operational needs by the ability to quickly adapt to changing requirements, and by offering surge capacity.[5]

Even during peacetime, the use of uniformed manpower demonstrably provides greater flexibility. For example, when the responsibility for Caribou R2 and R3 servicings was temporarily transferred to a civilian contractor, servicing dates had to be more-or-less fixed. This denied the squadrons the flexibility to adjust servicing dates to cater for variations in flying rates and restricted their ability to generate surges. In addition, the reduced number of uniformed personnel reduced the manpower pool available that could be diverted onto unscheduled maintenance (repairs), cannibalisation, etc. These restrictions had a significant effect on aircraft availability—equivalent to the loss of two aircraft from the Caribou fleet.[6]

Similarly, there are indications that the RAF's contracting of C-130 'second line' maintenance has resulted in a reduction in the ability to handle fluctuating throughput.[7]

Contractor performance was generally considered to be satisfactory during the Gulf War, with both good and bad performers. There are many examples of companies providing what was requested of them (including development and modification work) without receiving one page of paperwork in advance.[8] Deliveries against many existing contracts were hastened, and the majority of contractors were able to respond. Interestingly, more than 80 per cent of these did so at no additional charge.[9] Conversely, at least one company appeared to be reticent to move to wartime throughput rates.[10]

RAF second and third line maintenance support which had been civilianised was deemed to be successful during the Gulf War, with all personnel (including civilians) providing 'unswerving support far beyond the normal terms of employment'.[11]

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5 Lieutenant Commander Saad, 'The In-house versus Subcontract Decision for Aircraft Component Maintenance', *Naval Engineering Bulletin*, September 1993, pp. 67–72.

6 Group Captain McDougal, 'HQOC Staff Visit Findings and Trends', paper delivered at the *1986 Logistics Seminar*.

7 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, p. 6-4.

8 James P. Coyne, *Airpower in the Gulf*, Air Force Association, Virginia, 1992, p. 37. Other examples of positive cooperation are to be found in Coyne, pp. 122–3.

9 United States General Accounting Office, *Operation Desert Storm – The Services' Efforts to Provide Logistics Support for Selected Weapon Systems*, September 1991, p. 31.

10 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, p. 4-2.

11 Paul Jackson, 'Third Line, First Rate', in *RAF Yearbook Special – Air War in the Gulf*, Bristol, UK, 1991, pp. 75–76, quoted in Waters, *Gulf Lesson One*, p. 264. A possible source of motivation in many cases was the possibility of winning follow-on contracts.

The perceived inflexibility in the use of contractors is not entirely attributable to the contractors themselves. Defence contracting procedures must be flexible to respond to variations in contingency needs.[12] Expedited procedures were certainly employed during the Gulf War—procedures which would have been illegal during peacetime, such as 'authorising' contract work without paperwork. The ability to move to more flexible arrangements would certainly be expedited by the existence of documented contingency contracting procedures. Courses in contract procedures should include exercises in the use of contingency provisions.

Economy

The major advantage to the use of commercialisation and civilianisation is the cost saving. Civilians are estimated to be 20 to 25 per cent cheaper than military personnel, as a result of the combined effects of salaries, superannuation, housing, removal expenses, freedom from military 'diversions', and other factors. In addition, the private sector is more focused on economy because of the profit motive; they are also able to adopt more efficient work practices as they are not constrained by traditional military or public sector approaches.[13]

Overseas experience verifies the economy of commercialisation: commercialisation programs in the UK are estimated to have saved between 24 and 31 per cent; a US estimate is 35 per cent.[14]

Defence money saved through increased commercialisation can be redirected into other defence programs to increase the effectiveness of the ADF.[15] Predominantly, this means the acquisition of capital equipment as originally envisaged by the Government in 1987,[16] but not subsequently funded to the levels required.

Although the use of civilians is more efficient during peacetime, it may not necessarily be so during wartime. Although financial matters are de-emphasised during wartime, there is another issue: the need to protect any civilians deployed to AOs. Not only can civilian staff not be used for base defence, but the safety of civilians must be assured to the maximum extent possible.[17] This may require additional facilities and military manpower to effect.

Expansion Base

Increased reliance on civilian industry can allow a more effective increase in capacity during contingencies, since the total capacity of industry far exceeds that of the ADF.[18] Effort can

12 DI(AF) AAP 1000, p. 153.

13 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, loc cit.

14 loc cit.

15 ibid., p. 6.

16 *The Defence of Australia*, AGPS, Canberra, 1987.

17 These issues are further discussed below.

18 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, loc cit.

be redirected from commercial ventures to defence-related work.[19] The effectiveness of this would be greatly enhanced by prior industry experience in defence work (as well as other factors, such as the strength of industry's technological RDT&E base, and the extent of the threat).

Range of Skills

In some areas, commercialisation can offer greater capabilities and skills than could be retained within Defence.[20]

Civilians in the Area of Operations

The legalities of deploying civilians into an Area of Operations are currently being debated. *Protocol 1 Additional to the Geneva Convention* (ratified as law by Australia) places an onus on *both* sides to take all reasonable precautions to avoid the loss of civilian lives. This has implications for the legality of employing civilians in an AO which may be subject to attack.[21]

Until recently, the interpretation of the Protocol has been that civilians should not be present in the AO unless absolutely necessary. This carried with it the obligation to make defence plans in peacetime so that it was not essential to have civilian support in the AO.

More recent interpretation of the Protocol is more liberal, and reduces the requirement to plan to avoid the need for civilians in the AO. Civilians may now form a part of a combat force in an AO as long as their presence is deemed to be essential to the military effort. The Protocol levies responsibility on the military to provide appropriate protection for civilians in this situation (eg. if necessary, the provision of bomb shelters).[22] Civilians in an AO are not permitted to undertake combat tasks (such as base defence).[23] 'Civilian' in this context applies equally to contractors and Defence civilian employees.[24]

However, it would be an invalid interpretation of the Protocol to plan for all roles in an AO, other than actual combat, to be performed by civilians. The use of civilians in the AO should

19 'A New Environment for Industry', *Defence Industry and Aerospace Report*, 8 June 1990, pp. 1–9.

20 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, loc cit.

21 ADFP4, Operations Series, *Mobilisation Planning*, First Edition, draft, 1994, p. 3-3. Some countries get around this by insisting that civilians are also Reserves, and can thus be called up in a contingency. Reserves are deemed to be military personnel, so the protection obligations of the Geneva Convention Protocol would not apply.

22 Attorney-General's Department 94544236, *Use of Civilians in an Area of Operations*, 12 May 1994. The need to provide some form of self-defence or survival training could also be considered.

23 HQADF Preparedness Briefing, 12 May 1994.

24 Attorney-General's Department 94544236, op cit.

be limited to cases where military personnel cannot be readily used, such as in providing specialist skills.[25]

Existing Australian law provides no power to compel civilians to deploy to, or remain in, an AO (short of conscription). A contractor who refuses to honour contractual obligations requiring a presence in the AO may be in breach of contract, but it is unlikely that a court would issue a specific performance order to compel the contractor to complete the contract.[26]

Regardless of the legalities, in-theatre civilian support during the Gulf War was considerable. British Aerospace (BAe) contractors already in Saudi Arabia provided technical support for the RAF deployment, and some 1000 US contactors deployed to the Gulf to perform maintenance and modifications on their equipment.[27] The BAe contractors were under no contractual obligation to remain in the country during the war, but showed a willingness to help.[28] Newly fielded systems required very significant levels of support from the civilian sector in-theatre—even on-board, in the case of the J-STARS aircraft.[29]

If the Gulf War is a reliable and legal precedent, it seems that civilians have a definite niche in deployed maintenance. However, the lack of threat to allied bases during the conflict suggests that any conclusions drawn in this regard must be treated with considerable caution.

Deployability

Uniformed personnel are more deployable than defence civilians or contractors. Thus, a strong military force is capable of sustaining operations at a greater distance from home, as more of the support infrastructure (such as maintenance) could be deployed or moved forward. Wrigley acknowledges that increased reliance on commercial support would deny governments the option of sizeable deployments to distant theatres; (only) 'token involvement' in distant regions could be mounted.[30] This bodes poorly for increases in ADF involvement in multinational peacekeeping operations, at a time when requests for ADF contributions are becoming ever more frequent.

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25 Attorney-General's Department, *Use of Civilians in Areas of Operations*, 26 August 1994.

26 loc cit.

27 Wing Commander Gary Waters, 'The Gulf War and Logistics Doctrine', *RAAF Supply*, March 1992, pp. 37–41; and Waters, *Gulf Lesson One*, p. 251. USAF aircraft maintenance was performed largely in-theatre, whereas the RAF rotated their aircraft back to the UK for larger servicings. A factor that apparently contributed to the RAF decision was that more of its second and third line maintenance had been civilianised, and union and political problems were expected if attempts were made to move these operations into the Gulf. Since the USAF retained more military personnel in the ILM of its front-line aircraft, it had additional flexibility to deploy this capability. No statistics are available to allow comparison of the two maintenance strategies (in-theatre versus rotate home), although the in-theatre option is likely to offer increased availability at the expense of larger deployments and greater cost.

28 Waters, *Gulf Lesson One*, p. 262.

29 ibid., p. 238. Even on-board the aircraft, there was little risk to the contractors.

30 Bill Pritchett, 'Arguments Must be Tested', *Asia-Pacific Defence Reporter*, October 1990, pp. 36–37.

Industrial Disputes

The Wrigley report acknowledges that civilianisation renders the Government more vulnerable to having military operations blocked by factional or union interests. Industrial strikes and trade union embargoes were directed against ADF operations during World War II and the Korean and Vietnam wars.[31]

Wrigley suggests the possibility of disallowing such behaviour, but the subsequent Inter-Departmental Committee (IDC) review seems to indicate that this would not be possible, and emphasised means to *resolve* such problems rather than attempting to prohibit them. The review suggests that unions can be expected to cooperate in times of threat to Australia.[32] While this premise has not been recently tested, past events indicate that it might not hold for operations in support of regional allies or multinational security operations. Both of these are defined roles of the ADF, and the latter is clearly an area of significantly increasing emphasis.

A related issue is the use of overseas companies to perform maintenance on RAAF equipment. Overseas unions may disagree with Australian military activities, and would not be so motivated to cooperate in the absence of any direct threat to their homeland.

COMMERCIAL SUPPORT PROGRAM

The Commercial Support Program (CSP) arose from the Wrigley review, and aims to improve overall defence capability by exploiting many of the advantages of commercialisation discussed above, including:

a. more economical performance of support functions, leading to savings which can be redirected;[33]

b. increased Defence access to skills and capabilities not able to be retained in-house; and

c. more effective increase in capacity in times of emergency.[34]

The disadvantages and problems with commercialisation discussed in the preceding section effectively form constraints on the extent of CSP. Criteria to assist the determination of which tasks can be subject to commercialisation have been developed: 'core' activities are

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31 DI(AF) AAP 1000, *The Air Power Manual*, Air Power Studies Centre, Canberra, 1990, p. 218; and Commander Ward Hack, 'Good Reasons for Caution', *Asia-Pacific Defence Reporter*, October 1990, pp. 25–28.

32 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, p. 17.

33 Savings from CSP are generally redirected into the procurement of capital equipment, although commercialisation savings could also be used to augment operating costs.

34 *Commercial Support Program (CSP) Manual*, Fourth Edition, June 1994, pp. 2–3. Other advantages are listed therein; those quoted above are the most relevant to preparedness and maintenance.

those which are so integral to the operational effectiveness of the ADF that performance by other than Defence personnel would diminish or jeopardise their effectiveness.[35] Non-core activities are those 'which are *clearly* not part of Defence's organisational core, and which are not integral to the support and sustainment of core...'.[36] Core activities may not be offered for commercialisation; non-core activities may be offered for commercialisation as long as the commercial option is cheaper than in-house performance, and the uniformed manpower need not be retained in-house as part of Manpower Required in Uniform.

CSP and Preparedness Planning

The IDC report is unclear on whether commercialisation should be permitted to affect preparedness or not. It explicitly states that commercialisation should have *no* impact on preparedness,[37] but elsewhere says that 'commercialisation can be managed to *minimise* any impact by including performance specifications deriving from preparedness criteria in the contract negotiations'.[38] This latter statement would suggest that even non-core tasks can have *some* relationship with operational effectiveness, and that some (operational) impact resulting from commercialisation may be allowable.

Wrigley's original concept involved greater reliance on the use of reserve forces ('Militia') for the defence of Australia. Regular forces were to be prepared to deal with 'constabulary' tasks that might arise at short notice. Other low-level threats were assumed to have a six-month warning period, and the Militia were seen to play an important role in such scenarios.[39] Therefore, post-CSP, the RAAF should not expect to be able to handle more significant tasks without reliance on reserves. This makes it more important to plan for the mobilisation and incorporation of reserves into operational plans than was previously necessary. Such planning would be assisted by an indication of which CPD serials are deemed 'constabulary', and should be achievable using only permanent RAAF members, and which serials (if any) should be planned for using reserve members.

As discussed above, Wrigley stated that a consequence of the commercialisation he envisaged (ie. CSP) was that governments would be denied the option of sizeable deployments to distant

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35 ibid., Glossary.

36 loc cit. Author's italics. The word 'clearly' suggests that, when in doubt, an activity should be considered to be core.

37 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, paragraph 47. This criterion is a part of the 'Tier 1' definition (paragraph 54), which includes aircraft ILM and DLM, and aircraft engine overhaul (Attachment C).

38 ibid., paragraph 44 (see also paragraph 75). Author's italics.

39 Wrigley's assumptions about the nature of low-level conflict disagree with the Government guidance at the time and subsequently. Wrigley ignores the possibility of anything but trivial short-warning threats (Professor P. Dibb, *The Strategic Priorities for Australian Industry*, AGPS, Canberra, November 1992, p. 16). Since CSP is based on assumptions that do not agree with preparedness requirements, it is plausible that CSP may compromise the attainment of preparedness goals. Care must therefore be undertaken to reassess relatively early documents such as the Wrigley report and IDC review in light of more recent preparedness goals, CSP Manual and MRU guidance.

theatres. A lesson from recent military actions (eg. the Falklands and Gulf Wars) is that 'logistics requirements will be for operations in areas not planned for.'[40] Moreover, recent strategic guidance expresses the desirability of Australian involvement in multinational security operations, primarily—but not solely—in our own region.[41] The demands for such involvement can only be expected to grow.[42] Logistics shortcomings have already been identified as a constraint to the timely deployment of peacekeeping forces,[43] and this constraint is likely to be amplified by CSP. While CSP may be compatible with the defence of Australia, it is not so compatible with multinational security operations, and it is an unfortunate piece of timing that rapid expansion in both areas is occurring simultaneously.

Once the RAAF has transferred a capability to industry under CSP, it will not recontest that capability when the CSP contract expires.[44] This leads to the possibility that, over time, *all* capabilities identified as suitable to test under CSP will be transferred to industry. Thus, RAAF manpower plans should not assume the existence of any successful in-house options; more reliable means must be taken to ensure that sufficient uniformed manpower and skills exist for necessary tasks.[45]

Operational Maintenance and Deeper Maintenance

The terms *operational maintenance* (OM) and *deeper maintenance* (DM) were initially adopted to attempt to clarify the application of core/non-core to maintenance capabilities. In general terms, the implications of CSP for maintenance are as follows:[46]

a. OM required on deployment is *not* subject to CSP;

b. DM is generally subject to competition; and

c. some DM capacity may be retained in-house to provide a sufficient manpower base to cover Manpower Required in Uniform (MRU) requirements that cannot be otherwise met from OM or Reserve personnel. MRU is discussed in Annex H.

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40 Waters, *Gulf Lesson One*, p. 238.

41 *Strategic Review 1993*, Departmental Publications, Canberra, 1993, p. 16.

42 ibid., p. 75.

43 Senator Gareth Evans, Minister for Foreign Affairs and Trade, opening address at the United Nations seminar *Peacekeeping at the Crossroads*, Canberra, 21–24 March 1993.

44 Discussion with Wing Commander P.D. King, SOCA-LC, 23 June 1994.

45 This is the role of Manpower Required in Uniform (MRU), discussed in Annex H. Current RAAF MRU policy excludes positions corresponding to successful in-house options from contributing to other MRU categories (AF 91/33925 Pt 4 (46), *Development of Manpower Required in Uniform (MRU) – Situation Report*, DGPRM-AF, February 1993, Annex B).

46 DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraph 23 (paraphrasing the Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*).

The definitions of OM and DM are therefore most significant in determining which maintenance tasks should be offered for commercialisation. Unfortunately, clear definitions do not exist.[47] OM has been characterised by the following traits:

a. core;

b. mission generation;

c. deployable;

d. direct effect on operations;

e. Air Command responsibility; and

f. low resource demands (in terms of manpower size, skill levels, specialised equipment and facilities, etc).[48]

Conversely, DM has been characterised by:

a. non-core;

b. asset preservation;

c. non-deployable;

d. indirect effect on operations;

e. Logistics Command responsibility; and

f. higher resource demands.[49]

Unfortunately, these criteria do not always arise simultaneously, and are seldom clear-cut in their own right. This has lead to significant differences of opinion over the classification of certain maintenance tasks. To some extent, these difficulties have arisen because the origin of the terms, ie. the 'bigger picture', has been forgotten. OM and DM were first coined in 'RAAF 2000', to try to provide a basis to distinguish between core and non-core maintenance.[50] Since the RAAF 2000 attempt has not been totally successful, it is therefore necessary to take a step back from OM and DM towards the original core/non-

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47 Probably, clear definitions *could* not exist. There is no black-and-white distinction between maintenance tasks in the manner needed; maintenance tasks are better visualised as a continuum.

48 This last criterion is particularly problematic. High technology aircraft are often reliant on Automated Test Equipment (ATE), which is used at flight-line level and deploys with the aircraft. Unavoidably, the use of such equipment requires significant skill and experience. (Department of Defense (US), *Conduct of the Persian Gulf War*, April 1992, Appendix F, p. F-62.)

49 *RAAF 2000 – Our Flight Plan for the Future*, September 1991, paragraphs 305a, 307a; DI(AF) LOG 2-1, paragraph 17.

50 *RAAF 2000 – Our Flight Plan for the Future*, paragraph 307a.

core definitions. The rightful resting place of maintenance tasks (in-house versus contractor) should be determined on the basis of core/non-core, rather than OM/DM.

CORE AND NON-CORE

Precursors to CSP

The genealogy of core/non-core may be traced from the Wrigley report. Wrigley did not use the terms as such, but distinguished between combat, combat-related and support functions. Support functions were to be the emphasis for commercialisation.[51]

The Report of the IDC on the Wrigley Review refined this breakdown into four categories:[52]

a. operations (not subject to commercialisation),

b. operational support (generally not subject to commercialisation),

c. functional support (subject to commercialisation 'with caution'), and

d. defence infrastructure (subject to commercialisation).

CSP Definitions

The current descriptions of core and non-core appear in the CSP Manual. Before attempting to describe core and non-core activities, the CSP Manual outlines four factors which indicate whether an activity should be core:[53]

a. Combat. Combat basically means committing 'acts of violence'.[54]

b. Combat-related. Combat-related duties are in support of combat duties, and are performed in close proximity to the combatant. There is a risk of injury due to possible acts of violence by the enemy (ie. combat-related work must be performed within an AO). Moreover, personnel nominally performing combat-related tasks could be called upon to perform combat tasks, such as base defence.[55] Any maintenance tasks performed on deployment will fall into this category.

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51 A.K. Wrigley, *The Defence Force and the Community – A Partnership in Australia's Defence*, AGPS, Canberra, June 1990.

52 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, p. 8 and Annex B.

53 The *CSP Manual* actually describes *three* factors, grouping 'combat' and 'combat-related' together. They are separated here for clarity.

54 *CSP Manual*, paragraph B13.

55 ibid., paragraphs B13–B14.

c. Essential Combat Support. Essential combat support duties include military command and combat training. Support activities on which operational elements depend (such as providing weapons and ammunition) are also critical to the operation and sustainability of combat forces, *but may not necessarily be core*.[56] Since an aircraft is a weapon in the same way that a rifle is a weapon, maintenance tasks directly related to the supply of aircraft (eg. on-aircraft contingency maintenance) should fall into this category (with the exception of tasks performed on deployment, which fall into the 'combat-related' category).

d. Department of State. Department of State considerations include (legal) responsibility, accountability or public interest, etc.[57]

Using these factors, and following the IDC Review of Wrigley fairly closely, the CSP Manual defines four 'core activity classification bands':[58]

a. Operational: 'combat' and 'combat-related'. Core (requiring uniformed personnel).[59] Because they are combat-related, any maintenance tasks performed on deployment will fall into this category, and hence must be core.

b. Operational support: 'essential combat support' and 'department of state'. Primarily core, but with some potential for civilianisation. Personnel may be required to engage in combat. The activity may be closely related to the direction and control of combat, and may require specific military skills or training. If on-aircraft contingency maintenance is deemed 'essential combat support', it would fall into this category.

c. Functional support: training and support which does not require military skills, and is generally commercial or administrative in nature. Such activities may be core or non-core, and are usually not directly related to combat or combat-related operational activities. Core functional support activities may be appropriate for civilianisation (as opposed to commercialisation). Non-core functional support activities are suitable for commercialisation.

d. Defence-related Infrastructure: fixed base support outside AO. Non-core. These activities have a direct equivalent within the community, and are not amenable for performance on deployment or in an AO. They are appropriate for commercialisation.

56 ibid., paragraphs B16–B20.

57 ibid., paragraphs B29–B32.

58 ibid., paragraph B51.

59 The CSP conclusion that these categories are core appears to be based largely on legal grounds. Much of the interpretation of the relevant legal articles described above postdates the CSP definitions, and so it is possible that the CSP position on civilians on deployment may need to be adjusted.

The Status of Maintenance

These definitions clarify the position of some aspects of maintenance. Any maintenance that may need to be performed on deployment is core, and must be performed in-house.

Unfortunately, the status of all other maintenance tasks is unclear. Maintenance activities with a *direct* impact on operations would appear to be 'essential combat support', hence 'operational support', hence probably (but not necessarily) core. Maintenance activities that are not *directly* related to operations fit best into the 'functional support' band, and are probably (but not necessarily) non-core.

The CSP guidance permits many exceptions in these areas, and clarification must usually be obtained by reference to the basic definitions of 'core' and 'non-core'. The essence of 'core' is that such activities must be '*integral* to operational effectiveness'; or '*integral* to the support and sustainment of operations'; the commercialisation of such activities could 'diminish or jeopardise operational effectiveness'. The key would appear to be the recurring use of the terms 'direct' and 'integral'. Unfortunately, these terms are subjective: how 'direct' is 'direct'? Maintenance activities which are deemed to be sufficiently directly related to operations should be classified as core essential combat support (regardless of whether they are performed on deployment or not). Activities without such a direct relationship should be classified as non-core.

Maintenance tasks may affect operations in many ways: most of the goals of maintenance are also relevant to operations, such as airworthiness, missionworthiness, etc. However, availability is the primary means by which maintenance may affect contingency operations. It therefore follows that those maintenance tasks that most affect availability have the most direct impact on operations, and are most likely to be considered core.

The issue of directness of impact on availability has been discussed previously. It is a most significant issue in determining contingency maintenance requirements,[60] and also in determining the amount of maintenance to undertake on deployment.[61] An 'item importance hierarchy' was derived in Annex F to help address these issues; it can also assist here. The main conclusions that may be drawn from the item importance hierarchy are:

a. The aircraft itself is the most critical component from an availability point of view; any maintenance work performed on the aircraft must directly affect availability.

b. The impact of component maintenance on availability can be buffered by the existence of spares holdings for the component.

c. The criticality of components reduces with increasing 'depth' within the physical build structure of the aircraft, due to the existence of spares holdings for items above it in the hierarchy.

60 See p. 130.

61 See p. 171.

Although still requiring subjective interpretation, this helps to clarify the issue. On-aircraft maintenance most directly affects availability; the adequacy of spares holdings and the 'depth' of an item within the build structure reduce the impact of the item's maintenance on availability.

Before driving this to a conclusion, one further consideration is necessary. Not all aircraft are equally important in their operational impact. Poor availability in VIP or trainer fleets will not jeopardise military operations to the same extent as poor availability in the fighter, strike or (probably) transport fleets. The USAF use a 'Mission Item Essentiality Code' (MIEC) to indicate the operational significance of weapon systems.[62] Hereafter, weapon systems that are of primary importance in completing operational goals will be referred to as 'critical'.[63]

Alternative Definitions

A definition of core maintenance can now be proposed: *core maintenance tasks are those contingency maintenance tasks performed directly on critical weapon systems or critical components thereof*. Non-core maintenance tasks would comprise *all maintenance tasks that would be deferred during a contingency, all maintenance tasks on non-critical weapon systems, and off-aircraft maintenance tasks on non-critical components*. 'Contingency maintenance' includes scheduled, unscheduled and modification aspects; 'critical components' are those components high up the item importance hierarchy (therefore probably LRUs and RIs) for which acute spares and resupply problems exist.

Note that it is not necessary to include the deployment issue, since this is subsumed in the broader definitions proposed: all deployed maintenance tasks should be performed directly on critical weapon systems or critical components thereof.[64]

If OM/DM is intended to align with core/non-core, as would seem to be the original intention, the above definitions should apply to OM/DM. However, not only does this disagree with current OM/DM guidance (eg. some core maintenance is non-deployable, but this would be categorised as DM), but it is counter-intuitive in some cases. For example, all maintenance (even flight servicings) on non-critical aircraft would be deemed DM because it is non-core. It seems best to decouple OM/DM from core/non-core, and use the core/non-core definitions for CSP determinations, rather than OM/DM. The OM/DM concept then becomes orphaned, having little significance in practice.

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62 TLO SMALC 4060/A08/204 Pt 4 (11), *Contracting Out of US Military Aircraft Maintenance – Lessons for Australia*, TLO SMALC, 28 March 1991.

63 A better system would provide greater resolution than simply critical/non-critical. The importance of aircraft should actually be a continuum; a criticality scale should acknowledge this. Such increased accuracy would allow better tradeoff decisions; eg. an aircraft that is 'just a bit critical' could be subject to more commercialisation than if it was simply deemed critical.

64 A side effect of this is that changes to the interpretation of the legal issues surrounding the employment of civilians in an AO do not require changes to the scope of core/non-core. The focus is no longer geographical, but is based on responsiveness, flexibility, etc.

Applications of the Definitions

On-aircraft maintenance of critical weapon systems will have the most direct impact on operations: when such an aircraft is removed from service to undergo maintenance, it is not available for tasking. Therefore, if any non-deployed maintenance is to be considered core, it should be on-aircraft contingency maintenance of critical weapon systems. The USAF and USN will not allow all aircraft DLM on its most critical (front line) weapon systems (as indicated by the MIEC) to be subject to commercialisation.[65]

The existence of a CPD serial for a capability indicates that the capability may be a core activity.[66] Most RAAF CPD serials effectively specify an availability target (although the greater detail in the ACOPDs is necessary to quantify this). Aircraft availability targets are directly affected by all on-aircraft maintenance (whether performed on deployment or not). This criterion further indicates that all on-aircraft contingency maintenance of critical weapon systems should be considered core.[67]

Could the commercialisation of this work diminish or jeopardise operational effectiveness?[68] Some loss in flexibility may result from such commercialisation (as per the examples given on p. 211). Of greater concern is the potential for industrial action to effectively remove aircraft from service. These considerations, if deemed significant enough, would further support the core classification of on-aircraft contingency maintenance of critical weapons systems.

The directness of impact of other maintenance tasks falls away rapidly. Where there are grave spares shortages (and poor prospects of resupply) of line replaceable units for a critical weapon system, maintenance on these may directly affect availability. However, during peacetime such situations may be viewed as transient, and maintenance on the item probably cannot be deemed to be core.

On-aircraft maintenance of non-critical weapon systems cannot be considered to be core, as the weapon system itself does not *directly* affect operations. Hence, all maintenance related to non-critical fleets is non-core.

Current CSP practice appears to be taking a somewhat simpler view than that argued above. The only criterion applied in practice seems to be maintenance deployability. All non-deployed maintenance, even on-aircraft maintenance, is often considered to be non-core (although this is currently being contested in some circles). Perhaps this should not be surprising, as the documents leading to CSP (ie. the Wrigley review and the IDC report

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65 TLO SMALC 4060/A08/204 Pt 4 (11), p. 10.

66 *CSP Manual*, paragraph B23.

67 If many spare aircraft are held (compared to CPD requirements), high fleet availability may not be required, and less flexible and responsive maintenance performance may be acceptable. In this case, on-aircraft maintenance could be deemed non-core. However, if the force development process performs correctly, no fleet should have such surplus aircraft, so this possibility is therefore academic.

68 This is another test of core/non-core.

thereon) permit this interpretation, and listed aircraft DLM as suitable for commercial testing.

Difficult Issues and Cases

The preceding discussion applies predominantly to the direct performance of scheduled maintenance. However, there are other 'peripheral' aspects of maintenance that further complicate the core/non-core decision, or require different reasoning.

An important issue seldom addressed during peacetime is that the relevant maintenance activities for core/non-core determination should be *contingency maintenance* (scheduled, unscheduled and modification). Any maintenance task that would be deferred for the duration of a contingency is non-core. However, the majority of peacetime servicings contain both tasks which would be deferred and those which would continue (ie. contingency maintenance). How can a core/non-core decision be made for such servicings? This question can only be answered by studying the contingency maintenance servicing schedules to determine a mapping between the peacetime and contingency servicings.

> '...the boundary between core and non-core activities is not immutable over time. Thus, changing strategic guidance ... may lead to redefinition of the boundary between what is core and non-core.'[69]

Changes introduced into the 1994 edition of the CPD include a most significant re-evaluation of sustainability periods. This should lead to a re-evaluation of contingency maintenance schedules, which in turn could lead to a review of the current allocations between core and non-core. However, there are no mechanisms in place for identifying changed strategic or CPD guidance and triggering a core/non-core review.

RAAF DM has broader responsibilities than day-to-day scheduled maintenance duties, including the repair and recovery of battle-damaged aircraft, and the rapid incorporation of modification work required for contingencies.[70] When a DM capability is commercialised, alternative arrangements must be made for these dormant contingency roles, such as transferring the responsibilities to another RAAF DM facility, or including the requirements in an appropriate contract. This latter approach could be complicated by the need for aircraft recovery and (occasionally) major BDR to be performed in the AO.

The categorisation of ARDU roles as core or non-core is not straightforward. The simple alignment of core with deployable would see ARDU's roles classified as non-core, but the very direct support that ARDU must provide to operations during a contingency argues for a core classification. Examples of the flexibility needed of ARDU have been described in Chapter 17; this also supports the retention of ARDU's flight test and modification development capabilities in-house. A draft Defence Instruction stipulates the requirement to

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69 *CSP Manual*, paragraph B8.

70 DI(AF) LOG 2-1, paragraphs 20, 38; and DI(AF) LOG 13-7, *Contingency Maintenance and Battle Damage Repair of Technical Equipment*, draft, 28 February 1994, paragraph 13.

maintain an in-house test and evaluation capability to provide the responsiveness required in contingency situations.[71]

In some cases, attempts to split functions into core and non-core are thwarted by sharing of facilities and capabilities. For example, some Hornet Automated Test Equipment (ATE) is used to support both operational maintenance and deeper maintenance. The use of such equipment must be carefully integrated in workshop job planning with other more capable equipment.[72] Splitting such shared capabilities into core and non-core could require duplication of the capability, which could destroy the cost-effectiveness of commercialisation. However, major USAF studies have indicated that the grouping of trades (etc) across OM/DM boundaries tends to reduce the capacity for intensive sortie production (ie. mission generation) and rapid deployment, as a result of less clearly focused management structures.[73] A tradeoff must be made between cost-effectiveness (integrated OM/DM) and operational effectiveness (duplicated capabilities).

INDUSTRY SUPPORT DURING CONFLICT

Given that defence is reliant on industry for the performance of some amount of maintenance, industry has a role to play in ensuring that CPD preparedness goals (particularly sustainability) can be met. Since most contractual arrangements are based on peacetime expectations, careful planning, coordination and cooperation are necessary to ensure that the ADF's contingency requirements can also be met. Specifically, Defence must determine and communicate its expectations for industry support during contingencies.

Contractual Obligations

The Interdepartmental Report on the Wrigley Review (which instigated CSP) appears to admit that commercialisation may have some operational impact. It speaks of *minimising* any impact by including appropriate performance specifications in contracts, which should be derived from preparedness goals.[76,77]

71 DI(G) LOG XX-X, *Defence Test and Evaluation Policy*, draft, 1994, paragraph 9.

72 AHQ 3020/13/TECH Pt 1 (20), *Report of the Working Party to Consider TFG CMR and Associated Maintenance Issues*, DENGPP-AF, 16 May 93.

73 Major Gene E. Townsend, USAF, 'Air Force Maintenance: Issues and Challenges for the Eighties', *Air Force Magazine*, January 1980, pp. 56–61.

74 ADFP4, p. 2-2; DI(AF) AAP 1000, Second Edition, p. 154; and Gary Waters (ed.), *Line Honours – Logistics Lessons of the Gulf War*, Air Power Studies Centre, Canberra, 1992, p. 89.

75 Defence Logistics Strategic Planning Guide 1991, HQADF, Canberra, 1991, p. 67.

76 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, pp. 8, 14. Author's italics.

77 ADFP4, p. 4-9.

Contractual clauses covering contingency requirements should specify the increased level of support expected during a contingency. This may take the form of greater supply priority for Defence work, or the establishment of higher rates of production.[78] To be meaningful, the requirement should be quantified; eg. Australian Defence Industries (ADI) is contractually bound to be able to surge to some specified factor greater than the previous year's output. Unfortunately, such quantification in contracts is rare, largely because contingency maintenance requirements have yet to be worked out in detail.

The USAF method of allocating workload (to USAF depots, contractors, etc) includes a concept of surge workload. Likely surge levels for the work package are defined, in terms of the percentage increase over peacetime rates that may be required during wartime. These have implications for wartime manpower levels and/or working routines. The USAF depots are required to indicate the additional manpower requirements they may need during wartime to meet the indicated surge levels of their work packages.[79] Presumably, contractors must do likewise, and must provide an undertaking that they can provide the required capacity.

Most current RAAF contracts contain few contingency provisions. Typical clauses include the following:

a. Defence may declare an emergency, and demand that the contractor's total effort be placed on defence work;

b. work may be transferred from the contractor to some other venue; and

c. uniformed personnel may supplement contractor staff in the event of a strike.

None of these provisions can guarantee any particular level of performance.

There are cases where contractual arrangements should be in place during peacetime even when *no* peacetime workload is contracted. An example is airline repair facilities, which may not be required by defence during peacetime, but which may be crucial during a contingency.[80]

Surge Capability

Generally, plans for the expansion and mobilisation of industry in times of conflict remain to be developed.[81] From a maintenance perspective, proper guidance can only be provided after determination of contingency maintenance and deployment requirements.

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78 *ADF Reserve Stockholding Policy Implementation Guidance*, HQADF Logistics Division, December 1993, p. 50.

79 TLO SMALC 4060/A08/204 Pt 4 (11), loc cit.

80 DI(AF) AAP 1000, p. 168.

81 *Defence Logistics Strategic Planning Guide 1991*, pp. 15, 67.

Further, processes to assess (and even exercise) industry's expansion and mobilisation capability need to be developed.[82] Some simple approaches are in place,[83] but these are largely passive and merely describe defence's requirements in broad terms, and monitor industry's capacity. There appears to be no detailed outworking of the implications of preparedness goals for industry, no measures to check industry's potential to rise to the occasion, and no system to correct shortfalls.

There are practical limitations to the provision of latent surge capacity. Spare manpower capacity cannot be retained in a specialised field if the peacetime throughput is insufficient to allow the retention of expertise.[84] Generally, any spare capacity is likely to take time to come fully on line, due to the need to provide additional manpower and/or training.[85] This transient response may require additional reserve stock to be held to cover the contractor's work-up time; however, this is not an option for on-aircraft maintenance. Flexible companies are likely to be able to retain greater surge capacity at less expense, as manpower can be diverted from other tasks.[86] Some encouragement for Defence contractors to diversify would therefore seem prudent, although the current economic downturn (and tightening in the Defence budget) should already provide sufficient impetus for this.

One means of bolstering industrial surge capacity is the procurement of selected items of equipment (such as machine tools) by Defence and placing these in contractor facilities. However, unless the contractor can find a peacetime use for the equipment, it is unlikely to be maintained, and, if unique, expertise in its use will not be developed.

Whether an industrial expansion base can be maintained during peacetime without government incentives is debatable. Government policy (understandably) plays down the need for incentives,[87] but many commentators see some form of support to be essential for an expansion base to be a reality.[88]

An example scenario is the need to have industrial pipelines 'primed' with semifinished materials and components for long lead-time items, which may otherwise not be available for up to two years.[89] These are known as Reduction Of Lead Time (ROLT) holdings, and represent a Defence investment in materials held in abeyance at contractors' facilities.[90]

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82 ibid., p. 15.

83 ADFP4, p. 4-6.

84 Discussion with Wing Commander P.D. King, loc cit.; and discussion with Mr Gordon Kennett, Director, Rosebank Engineering, 23 June 1994. Morale difficulties were also anticipated if underutilised personnel were to be retained.

85 *ADF Reserve Stockholding Policy Implementation Guidance*, p. 43.

86 Discussion with Mr Gordon Kennett, op cit.

87 RAAF Engineering Planning Team, *Blueprint 2020*, p. 5-5.

88 Waters, *Gulf Lesson One*, p. 238.

89 Colonel Orville M. Collins, USAF, 'Combat Sustainability and Reconstitution Warfare: The Missing Link in Air Force Basic Doctrine', *Air Force Journal of Logistics*, Summer, 1987, pp. 33–37.

90 *ADF Reserve Stockholding Policy Implementation Guidance*, pp. 3, 50.

Additional cost is incurred in the initial manufacture and storage of such wartime assets during peacetime. Without contractual obligations and incentives, it is most unlikely for a contractor to undertake such preparation. The example of a two-year delivery lead-time is extracted from a US source—how much more important will it be for Australia, where delivery of spares and raw materials from overseas may add further delays, to be industrially prepared?[91]

In some cases, premiums for the retention of surge capacity may be offset against the requirement for Defence to hold additional reserve stocks.[92] This logic is valid for the production and maintenance of components, but for major systems (such as whole aircraft), the option of procuring additional assets to cover a lack of surge maintenance capacity is most unlikely. In this case, there may be no ameliorating cost factor, and premiums may need to be justified on the basis of the need to provide contingency capacity alone.[93]

Industry's ability to surge is adversely affected by the use of advanced technology. For a variety of reasons, lower industry capacity is often associated with the production of high technology items; this reduces the ability to rapidly increase capacity.[94] In addition, the production or maintenance of high technology items requires the use of high technology equipment, which can take time to acquire: a vicious circle.

The use of high technology pushes up the cost of production and maintenance facilities, and any Reduction of Lead Time (ROLT) assets held to enhance sustainability. The need for some form of encouragement to provide surge capacity in high technology industries is therefore more acute.

Standard RAAF contracting practice does not include payment to retain surge capacity in suppliers for contingency purposes. Surplus capacity may arise as a result of forecast peacetime arising rates being lower than anticipated, but this results from the vagaries of statistical variation and estimation, and is not a good substitute for planned and documented contingency arising levels.

The difficulties of retaining industrial surge capacity can be avoided in cases where the ADF can use commercially available 'off the shelf' components, instead of military specification items which must be specially manufactured. Commercial products are also usually cheaper, so military specification products should be procured only when the commercial equivalent is unsatisfactory.[95]

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91 An example is F-111 hydraulic components, for which a definite usage-related demand trend exists. Overhaul (and repair) of these components requires materials which can only be obtained from the US, with a delivery time of two years. (Discussion with Mr Gordon Kennett, op cit.)

92 ADFP4, p. 4-7; and *ADF Reserve Stockholding Policy Implementation Guidance*, loc cit.

93 This issue further highlights the criticality of on-aircraft maintenance, and questions whether such maintenance should be considered to be non-core for critical weapon systems.

94 Discussed in Chapter 18.

95 Even the US military is now moving away from separate MIL-SPEC products.

Major Conflict

Current preparedness goals do not cover scenarios for major conflict (this is seen to be the purview of the force development process). However, the expansion capability of industry would be much more important (and more demanding) during higher levels of conflict.

There is a lack of planning for industry (and in-house) expansion for higher levels of conflict, largely because the longer warning time allows the planning process to be deferred, but also possibly as a consequence of the lack of specific goals as in the CPD. However, general preparedness concepts can still be applied: the required industrial build-up time should be less than the expected warning time for major conflict scenarios. If this is not the case, some excess industry capacity must be retained during peacetime, or industry's ability to expand must be accelerated.

A major study, commissioned by CDFS (now CDF) and the Defence Secretary in 1978, discussed many related topics.[96] A recurring theme was a disturbing lack of planning for expansion of the maintenance support base. The report specifically noted the need to plan for what amounts to a worst-case scenario.

The study also makes mention of the concept of *Reserve Capacity Maintenance*: 'a payment to certain Government factories and private companies to meet various costs incurred in maintaining a capacity to satisfy emergency defence needs, but which are not covered by receipts arising from current use of that capacity'. The application of this concept appears to have been replaced by a desire for industry to have sufficient expansion capacity by successfully tendering for peacetime defence work on commercially competitive grounds,[97] conversion from commercial activities,[98] and exports. However, there remains a need to ensure that these expedients are sufficient to ensure that an adequate industry expansion base, and surge capacity, exists.

SUMMARY

The use of defence civilians and contractors for military maintenance work has advantages and disadvantages. The major advantages are economy, larger expansion base, and larger range of skills; disadvantages include reduced flexibility and deployability, legal concerns with employment in high risk areas, and the possibility of industrial action.

Under Australian law, civilians cannot be legally compelled to deploy to, or remain in, the AO. If civilians are to be used in the AO, plans to provide sufficient safety and protection for them must be made.

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96 Department of Defence, Supply and Support Organisation, *Maintenance, Repair and Overhaul of Service Equipment*, January 1980.

97 *Strategic Review 1993*, p. 71.

98 'A New Environment for Industry', loc cit.

Increased use of civilians, eg. CSP, will reduce the ADF's ability to support distant deployments. This may reduce the options for ADF contributions to multinational operations. The risk of industrial disputes is also more likely to affect multinational operations rather than the defence of Australia. As a consequence of the downsizing associated with CSP, Reserve forces may be used more extensively to meet other than 'constabulary' tasks.

The concept of *core/non-core* indicates which tasks must be retained within Defence, and which may be tested under CSP. The main indicators of core tasks are the need for performance on deployment, and the directness of the relationship between task performance and operations. Subjective judgements are required for this latter consideration, and core/non-core category definitions permit exceptions in many situations making them difficult to apply.

The terms *operational* and *deeper maintenance* (OM and DM) were originally coined to reflect the application of core/non-core to the maintenance function; unfortunately, the existing definitions of OM and DM are somewhat unclear. The definitions should be based on core/non-core, but while deployability is relatively easily decided, the directness of the relationship between a maintenance capability and operations is more difficult to assess. The item importance hierarchy suggests that core maintenance tasks are those *contingency maintenance* tasks performed *directly on critical weapon systems* or *critical components* thereof. Non-core maintenance tasks would comprise all maintenance tasks that would be *deferred* during a contingency, all maintenance tasks on *non-critical weapon systems*, and *off-aircraft maintenance* tasks on *non-critical components*. OM/DM cannot be easily reconciled with these definitions, and remain problematic and of limited usefulness.

Since contingency maintenance tasks may be core but deferred tasks will be non-core, determining whether a peacetime servicing should be considered core or non-core is not straightforward. The issue does not currently arise since the RAAF does not yet have separate contingency maintenance servicing schedules. When commercialising a depot capability, the disposition of latent responsibilities such as aircraft recovery, modification and repair must also be considered. Moreover, there is no mechanism in place to re-evaluate core/non-core determinations in light of changes to the CPD.

Defence expectations of industry in a contingency must be determined and communicated during peacetime. This could take the form of contingency clauses in contracts, preferably specifying quantified goals for contingency performance. The determination of contingency maintenance requirements would be a prerequisite for this.

Industry's ability to surge to meet contingency requirements should be actively assessed, and shortfalls corrected. Measures that can be used to increase industry's ability to surge include the provision of additional equipment, and priming of maintenance pipelines with partially fabricated components. The need to provide financial incentives for industry to retain latent capacity is a disputed issue. All of these measures have limitations, so industry will always require some finite period of time to 'work up'.

Industry's role would be much increased during higher levels of conflict. Although warning times are greater in this case, some planning for industry expansion to meet these greater demands is highly desirable.

Chapter 20

Maintenance Self-Reliance

What Do We Need To Do In-Country?

INTRODUCTION

Australia's policy of defence self-reliance requires that some level of defence industry capability be maintained in this country. However, practicalities rule out the possibility of total self-sufficiency, and require Australia to concentrate on certain critical areas of capability.

This chapter discusses the need and priorities for indigenous maintenance capability, and mechanisms for acquiring overseas support when necessary.

SELF-RELIANCE

The Need for Self-Reliance

Other countries are the only practicable source for the supply of many defence items. This also applies to the maintenance of many advanced technology and high precision components. Unfortunately, there is some risk that overseas support may become less accessible and responsive during a contingency.[1] This includes foreign military logistics systems, such as the US Foreign Military Sales (FMS) system, if only because the system will not be able to sustain the higher rate of demands expected during a contingency.[2]

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1 LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993, paragraph 50; DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraph 27. There is debate concerning the level of war at which overseas support may become unreliable. *The Defence of Australia*, AGPS, Canberra, 1987, p. 68, sees overseas logistics support to Australia continuing during low-level conflict (although acknowledging the risk of inadequate response or even denial in other circumstances—p. 78). A later government review points out that no guarantees are made, and is generally critical of Australia's over-reliance on overseas agreements (Joint Committee on Foreign Affairs, Defence and Trade, *Stockholding and Sustainability in the Australian Defence Force*, AGPS, Canberra, December 1992, pp. 27–28).

2 HQLC DCOE/4000/49/MRU Pt 2 (9), *Impacts on Logistics Command Functions in a Contingency*, COFS-LC, 16 December 1992; and *ADF Reserve Stockholding Policy Implementation Guidance*, HQADF Logistics Division, December 1993, p. 44.

The possibility of reduced performance arises for a number of reasons. Most obvious is that overseas suppliers are less likely to empathise with the military aims of the Australian government than would local companies.[3]

A dependence on overseas sources brings with it the risk that overseas governments, companies or unions may disagree with Australia's military position, and may become uncooperative. For example, during the Vietnam War, Pilatus became unresponsive in supporting the Porter aircraft.[4] There is also a risk that overseas suppliers may have other priorities during Australia's hour of need, eg. if they are fighting the same enemy as Australia.[5] The possibility of interdiction of the supply routes into this country also exists.[6]

A supplier's responsiveness to ADF needs is also likely to be influenced by the dependence of the supplier on ADF custom. The ADF can therefore expect to exert more influence on local companies than on larger overseas suppliers.[7]

Australia's policy of Closer Defence Relations (CDR) with New Zealand effectively means that that country's defence industry is to be treated the same as indigenous Australian industry (with a few minor exemptions).[8] Hopefully, none of the potential problems outlined above could ever arise between Australia and New Zealand, since this arrangement makes Australia reliant on support from New Zealand during a contingency.[9]

Australia's alliance with the USA has always been fundamental to this country's security. However, with the end of the cold war, US forces are downsizing and the US presence and involvement in this part of the world is decreasing. The likelihood of direct US military involvement in Australia's region is thus diminished (or the threshold level of contingency for US involvement is increased), and the capability of the US military and defence contractors to support Australia is likely to wane. This suggests that Australia should aim for *increased* indigenous defence capability at a time when many other countries are reducing capability (in the absence of a threat which Australia never postured itself to face).[10]

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3 Local companies would be particularly well motivated if the defence of Australia was at stake.

4 RAAF Engineering Planning Team, *Blueprint 2020 – Engineering the Future*, Departmental Publications, Canberra, July 1993, p. 5-8.

5 *Strategic Review 1993*, Canberra, December 1993, p. 70.

6 ibid., p. 69.

7 *ADF Reserve Stockholding Policy Implementation Guidance*, p. 44.

8 *Strategic Review 1993*, p. 70.

9 For example, RAAF C-130 deeper maintenance is undertaken by Air New Zealand. C-130 maintenance has been identified as 'strategic priority 1' (see p. 222), but the extent of this dependence on NZ depends on the fate of C-130 deeper maintenance during a contingency, eg. if all current C-130 DM is deferred, the dependence will be limited to possible modifications, repairs and advice.

10 Professor P. Dibb, *The Strategic Priorities for Australian Industry*, AGPS, Canberra, November 1992, pp. 19, 21.

Limits to Self-Reliance

Local production to meet a relatively small ADF demand incurs cost penalties,[11] whereas overseas suppliers to larger markets can benefit from economies of scale. In many cases, increased local content may incur cost, time and performance penalties.[12] Although total self-sufficiency would be desirable, resource limitations and the desire for cost-effectiveness require that priorities for the development of indigenous capabilities be established.[13]

The ADF's reliance on advanced technology tends to increase Australia's dependence on overseas sources for the supply and support of defence equipment. The ADF can reduce this dependence by efforts to secure transfers of technology and intellectual property to local industry. International agreements and contracts provide a medium for this.[14]

There will always be a strong temptation to rely on the Original Equipment Manufacturer (OEM) for in-service support, particularly in design-related areas such as modification and repair. Maximum reliance on the OEM is probably the most expedient way to maximise such peacetime priorities as airworthiness. However, other issues may take centre stage during a contingency, such as responsiveness and flexibility. OEMs are generally overseas companies, and moreover have other concerns (such as profitability, freedom from litigation, support to other customers, etc). Too strong a reliance on OEMs could therefore *reduce* Australia's military effectiveness during a contingency.[15] Regardless, OEMs will probably remain the most knowledgeable source of design information, and so strong links to OEMs should be retained.[16] An appropriate self-reliant strategy would be to endeavour to *learn from* the OEM so that the ADF could assume greater independence should the need arise.

Priorities for Maintenance Self-Reliance

Although the widest possible indigenous industry support is desirable (where operationally acceptable and cost effective), some capabilities are more central to Australia's national interests and accord a higher priority. Critical capabilities include the ability to manufacture, maintain, repair, modify and adapt ADF equipment;[18] ie. every aspect of maintenance! Indigenous maintenance capability is seen as a higher priority than local supply of

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11 'A New Environment for Industry', *Defence Industry and Aerospace Report*, 8 June 1990, pp. 1–9.

12 *Strategic Review 1993*, p. 70.

13 DI(AF) LOG 2-1, paragraph 27.

14 *Defence Logistics Strategic Planning Guide*, Departmental Publications, 1991, pp. 20, 67.

15 RAAF Engineering Planning Team, *Blueprint 2020*, p. 9-7.

16 Once a weapon system has been fielded for some years, the lead operator may match the OEM's capabilities in some areas. There are cases where the OEM has transferred all design data, authoritative engineering drawings, etc to the lead operator, who effectively becomes a *de facto* OEM.

17 *Defence Logistics Strategic Planning Guide*, p. 17.

18 *Defending Australia*, AGPS, 1994, pp. 28, 115; *Strategic Review 1993*, pp. 52, 53, 66, 70; DI(AF) AAP 1000, *The Air Power Manual*, Air Power Studies Centre, Canberra, 1994, p. 154; and DI(AF) LOG 2-1, paragraph 27.

consumables—including ordnance.[19] Adequate in-country reserve stockholdings can reduce the impact of poor overseas supply responsiveness, but no such strategy exists for the provision of maintenance.[20]

The most detailed guidance currently available on the Defence priorities for Australian industry is the Price report, which emphasises the importance of deriving priorities for Australian industry from contingency sustainability and force expansion requirements.[21] The Price report anticipated that detailed guidance would arise from the sustainability and force expansion studies underway at the time (such guidance has yet to materialise). The report provides interim guidance on the capabilities thought to be most important, pending completion of the more detailed work within the Defence organisation.

The Price report loosely endorsed the approach taken and proposals made by Professor Paul Dibb in his contribution to the Price report.[22] Dibb identified three levels of strategic priority for Australian defence industry.[23] Table 20-1 extracts the maintenance, support and repair priorities from Dibb's submission.

PRIORITY 1	PRIORITY 2	PRIORITY 3
P3C Orion	F/A-18 (remainder)	F-111 (most)
C130 Hercules	F-111 (some)	
Caribou		
Blackhawk		
F/A-18 (One squadron at Tindal)		

Table 20-1: Strategic Priorities for Australian Defence Maintenance Industry[24]

Dibb's work is based on the strategic guidance available at the time, and also endeavours to factor in readiness notice, the expected intensity of fleet usage, and the need for surge: all considerations which determine the need for the increased responsiveness that could be provided by local industry.

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19 *Strategic Review 1993*, p. 70.

20 This is particularly true of *on-aircraft* maintenance. Sufficient spares holdings of repairable items (RIs) can reduce the need for local maintenance, but the expense of many RIs is likely to militate against the provision of surplus stockholding levels. There is a tradeoff between the cost needed to establish and support a local maintenance capability and the cost needed to retain additional reserve stockholdings.

21 Defence Policy and Industry, Report to the Minister for Defence Prepared under the Direction of the Parliamentary Secretary to the Minister for Defence, the Hon Roger Price MP, Canberra, 1992, p. 13.

22 Dibb, *The Strategic Priorities for Australian Industry*.

23 Even priority three indicates *some* emphasis, rather than no priority at all.

24 Based on Dibb, *The Strategic Priorities for Australian Industry*, Table 2. Dibb has since reconsidered the priorities appropriate to F-111 maintenance.

Dibb also observed that the ADF's reliance on maintaining a technological edge requires concentrated efforts to ensure that Australian industry keeps abreast of technology.[25] This is made more difficult by the effect of technology to drive acquisition and support overseas. In addition to being a significant force multiplier, technological applications are well suited to existing Australian industrial capabilities, and provide significant opportunities for export.

Table 20-1 does not distinguish between priorities that might exist *within* an individual aircraft type (eg. is it more desirable to maintain component A or component B in Australia?). The ubiquitous item importance hierarchy can have application here. In conjunction with the criticality of the weapon system, the item importance hierarchy can indicate the desirability of in-country support. Closely following the argument in the previous chapter,[26] on-aircraft maintenance of critical weapon systems can have the most direct effect on availability, and hence on operations. This category of maintenance is therefore the most critical for indigenous support.

The criticality of component maintenance reduces with the 'depth' of the component within the aircraft's build structure, and with the provision of adequate reserve stockholdings. Therefore, components well buried within an aircraft's structure (eg. sub-sub-subassemblies) may safely be supported overseas, since spares holdings for this item, and its 'parents', can buffer the impact of poor responsiveness. An exception is when component modification is required—no amount of spares can make up for a local capability to design and incorporate modifications to improve operational effectiveness.

Maintenance on any non-critical weapon system (or its components) is less of a priority for indigenous performance, since poor availability of non-critical weapon systems should not directly impact on operations.

Achieving Maintenance Self-Reliance

To acquire in-country maintenance capabilities for weapon systems that are manufactured overseas, procurement contracts should specify some measure of Australian industry involvement. The potential role of local industry should be a major consideration from the earliest stages of the force development process.[27] If local industry involvement is impracticable, an otherwise capable aircraft may be rendered unsupportable during a contingency.

The extent to which financial premiums need to be, or should be, paid to support an in-country capability is a vexed question.[28] However, the need to occasionally do so is

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25 Dibb, *The Strategic Priorities for Australian Industry*, p. 28. *Defending Australia*, p. 27, acknowledges that Australia will not be able to maintain a technological edge in all areas in the longer term.

26 See p. 214.

27 DI(G) LOG XX-X, *Principles for the Maintenance of Technical Equipment*, draft, 1994, paragraph 29.

28 Peter Robinson, 'The High Price of Peace', *Financial Review*, 20 May 1992, p. 35.

acknowledged in recent government guidance,[29] although commercially competitive contracting is understandably preferred.[30] Professor Dibb indicated the extent of premiums that he believed may be justified for each of the three priority levels he identified (see Table 20-1). Generally, no premiums would be justified for priority three requirements; and under ten per cent would be justified for priority two requirements. No limit was stated for priority one requirements, given the high strategic value of keeping this work in-country; however, the need for industry to attempt to undertake such work on a competitive basis was stressed. Any premiums paid should be within 'reasonable bounds'.[31]

The demands of the ADF are frequently too small to ensure that contractors can be kept viable by only relying on ADF custom.[32] Therefore, it is most desirable for ADF trade to be placed with companies whose viability does not depend exclusively on ADF business. Such companies may have significant interests in the civilian sector, or may be involved in exporting defence products or services.[33] The Government can play an active role in assisting companies to achieve their export potential.[34]

The Defence Industry Development (DID) program is able to foster self-reliance by issuing contracts to Australian industry to increase local capability to meet Defence requirements. In principle, DID has a specific focus on supply and through-life support aspects (although, in practice, there has been a strong bias towards development at the expense of supporting existing capital equipment).[35]

DID contracts will only be issued to provide financial assistance to industry to meet a priority Defence requirement. Capabilities developed by DID should not be restricted to any one project—funding, and any subsidies, required for a single project are the responsibility of that project. An important issue is that there should be *strategic* reasons for the development of an in-country capability; frequently, pragmatic or short-term considerations have taken priority over such contingency-related thinking. Unfortunately, the lack of agreement over what capabilities justify local industry encouragement causes problems; for example, a capability developed by DID may not be supported by follow-on Service contracts. Clear guidance on which areas of industry are of significant strategic value, and are thus worthy of both DID and Service support, are required to alleviate this problem.[36] Providing such guidance was one of the roles of the Price report (although its recommendations were intended to be superseded by more detailed Defence studies).

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29 *Strategic Review 1993*, p. 70.

30 *Defence Policy and Industry*, p. 25.

31 Dibb, *The Strategic Priorities for Australian Industry*, p. 62ff.

32 *Defending Australia*, p. 114.

33 *Strategic Review 1993*, pp. 27, 74; *Defence Policy and Industry*, p. 1.

34 *Defence Logistics Strategic Planning Guide*, loc cit.; and *Defending Australia*, p. 123.

35 Exports and International Programs Branch, *Review of the Defence Industry Development Program: Summary*, Department of Defence, November 1992, pp. xi–xii.

36 ibid., pp. xi, xiv, xv.

Normal Defence procurement practice is not well suited to establishing an Australian industry capability *in anticipation* of future demands. Even when a *current* demand is identified, the extensive project management capabilities required to establish a significant local capability often cannot be provided within the Defence procurement organisations. The role of DID also encompasses these requirements.[37]

The ease of use of foreign military logistics systems such as FMS also tends to militate against the development of Australian industry. It takes significantly less time to find a NATO stock number and process an FMS buy through the US services than it does to identify and assess an Australian company capable of performing the same work. A register of indigenous capabilities ('Local Military Sales'?) could go some way towards redressing this problem.[38]

OVERSEAS SUPPORT

International Agreements

Because of limitations in Australia's indigenous capability, and the risks associated with reliance on overseas sources, international agreements need to be in place to ensure the provision of support beyond Australia's capability or capacity, particularly during contingencies.[39] Moreover, *awareness* of the provisions available must be communicated to Service personnel and local industry.[40]

Australia has bilateral government-to-government agreements in place with the US and New Zealand. Even though these agreements have treaty status, they do not *guarantee* any particular level of support. Memoranda of understanding, which are not generally legally binding, are in place with a number of European countries and with Canada. These memoranda generally only apply to specifically nominated weapon systems. None of these international agreements specifically covers support for operations in the face of a major threat to Australia, or guarantees support if Australia's political position differs from that of the supplier nation. A 1992 government review expressed concern at the reliance being

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37 *Defence Policy and Industry*, p. 32.

38 This issue was highlighted in discussions with Mr Gordon Kennett, Director, Rosebank Engineering, 23 June 1994. Even though Rosebank Engineering is a local agent for a particular item, the RAAF placed an FMS order and procured the item from the parent company overseas. Had the order been placed locally, local manufacturing of the equipment would have established in-country expertise, spares, etc. Although Australian companies can be registered in the FMS system as being able to provide a particular NSN, the procedure is extremely cumbersome, which discourages its use.

39 DI(AF) AAP 1000, p. 151.

40 *Defence Logistics Strategic Planning Guide*, pp. 17, 99. Staff unfamiliarity with existing international logistics agreements was a problem for the Canadian Forces during the Gulf War (STLO NAVAIR, *F/A-18 Persian Gulf Operations – Canadian Forces Engineering/Logistics Lessons Learned*, TLO NAVAIR 79/2/Air Pt 2 (61), 10 July 1991).

placed on these agreements, to the detriment of indigenous capabilities and stockholding levels.[41]

International agreements must cover the full scope of military operations required of the ADF, rather than just concentrating on, for example, continental defence. The Canadian Forces had difficulties in obtaining support from the US during the Gulf War because existing Memoranda of Understanding only applied to support for operations in the North American region.[42] These problems persisted even though the US and Canadian forces were fighting beside each other!

Host Nation Support

Host nation support is assistance provided by a country that is hosting a military deployment from another country. In many ways it is analogous to infrastructure support, with the infrastructure being overseas military and civilian resources. Obviously, host nation support only applies to Australia in the event of significant Australian operations beyond our shores (or, conversely, if Australia should need to host other nations' operations). ADF reliance on host nation support is therefore not likely to be relevant for the defence of Australia, but may be appropriate if Australian forces are required to assist regional allies or participate in sizeable multinational peacekeeping operations.

The benefit of host nation support increases with increasing distance from home. Even the USAF obtains great benefit from host nation support.[43] During World War II, the USAF made extensive use of host nation support in the UK to perform depot level maintenance, and also for the incorporation of the many aircraft modifications continually called for.[44] As a result of its experience in Vietnam, the USAF has established contractual arrangements for host nation support in countries such as UK, Japan, Spain and Korea. These contracts include the provision of 'theatre-level' maintenance.[45]

By contrast, the RAAF seems to be very poorly prepared to utilise (or to provide) host nation support. There is a strong preference to either deploy all required logistics support from Australia, and/or to use long supply pipelines and maintain equipment in Australia.

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41 Joint Committee on Foreign Affairs, Defence and Trade, *Stockholding and Sustainability in the Australian Defence Force*, pp. 27–28. In effect, this is criticising earlier government guidance which claimed that the need for large-scale stockholdings was alleviated by the existence of agreements with the US (*The Defence of Australia*, p. 4). More recent guidance is more conservative on this issue (*Defending Australia*, p. 52).

42 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding RAAF Logistics Command, 20 September 1991–18 October 1991, p. 4-6.

43 J.A. Stockfisch, 'Linking Logistics and Operations: A Case Study of World War II Air Power', RAND, N-3200-AF, p. 53.

44 ibid., p. 50.

45 Major General Edward R. Bracken, USAF, 'Vietnam Logistics: Its Meaning for Tomorrow's Air Force', *Air Force Journal of Logistics*, Fall, 1986, pp. 18–21. Both the USAF and RAF relied heavily on host nation support during the Gulf War, but apparently not for the maintenance of technical equipment; Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, p. 241.

However, practicalities may well dictate that deployment sizes be limited, and unduly long supply pipelines may cause delays that translate to lost availability.

Host nation support does bring with it some problems, involving compatibility, interoperability and engineering and performance standards.[46] Vendors accredited to acceptable standards, such as the ISO 9000 series, would be more acceptable sources of host nation support.

Because it is not always feasible, host nation support should not be seen as an alternative to strategies such as the establishment of adequate indigenous maintenance capabilities, reserve stockholdings, prepositioning and caching, etc. For example, some measure of host nation support was contemplated for the deployment of ADF Blackhawks to Cambodia in 1993, but the local infrastructure was deemed inadequate.[47] However, where available, host nation support can work in parallel with other logistics expedients.[48]

The applicability of host nation support to the ADF is to be specified in a forthcoming HQADF Defence Instruction. More detailed guidelines for the implementation of host nation support, if not actual agreements to provide it, should be drafted. If nothing else, this would increase the awareness of this option, which would in turn simplify and speed its implementation when required. One planning strategy that would facilitate the implementation of host nation support is to perform and maintain a survey of local resources in potential areas of operations.[49] Of course, the most desirable form of preparation would be to have host nation support contract procedures in place during peacetime.[50]

SUMMARY

There are risks with the use of overseas contractors, which argues for the establishment and retention of some level of indigenous maintenance capabilities. Downsizing of foreign military industrial capacity may require increases in Australian self-reliance, to avoid reductions in the level of logistics support available to the ADF.

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46 LD93-20656 Pt 1, paragraph 20. An example of maintenance standards differences occurred with the need to calibrate communications equipment being used by the Australian contingent as part of the United Nations presence in Cambodia. The UN, who is responsible to fund such deployments, directed that a Singapore venue be used to calibrate the equipment when it became necessary. However, the Singapore agency was not compliant with the ADF-preferred ISO standard, and so alternative arrangements had to be made. Any additional costs incurred would have had to have been met by Australia.

47 Captain Rob Crowe, 'Army LM SQN's Provision of Logistics Support for Operation *Gemini*', *The Logbook*, September 1994, pp. 19–23.

48 Waters, *Gulf Lesson One*, p. 241.

49 Stockfisch, 'Linking Logistics and Operations', p. 50. Areas of interest for Australia could include allied nations in our own region, and areas of tension where Australian forces may be requested to contribute to a peacekeeping effort.

50 Waters, *Gulf Lesson One*, p. 241.

Maintenance self-reliance is made more difficult by the use of high technology equipment, and by the relatively small size of the ADF. Maintenance self-reliance (particularly regarding modification and repair) can be improved by efforts to *learn from* OEMs, rather than simply rely on them.

Indigenous maintenance capability is a higher strategic priority than the local production of consumables. The Price report provides interim guidance on maintenance priorities, but definitive guidance is intended to be provided by Defence studies. On-aircraft maintenance of critical weapon systems should be accorded the highest priority, with maintenance of these weapon systems' components which are in short supply being second priority. Other components, and all maintenance on non-critical weapon systems, are the lowest priority.

Indigenous capability may incur financial premiums, if the work cannot be performed competitively with overseas industry. Greater premiums could be justified for higher priority capabilities. The Defence Industry Development (DID) program can be used to assist in funding the establishment of indigenous capabilities; clearer guidance on the priorities for indigenous capabilities would allow better utilisation of DID. The ease of access to foreign military logistics systems tends to militate against the establishment of local capabilities.

Australia has a number of international logistics agreements in place. These agreements should support the full range of functions of the ADF, and an awareness of these agreements must exist if they are to be used in a timely manner. Similarly, host nation support could be used to provide maintenance support to the ADF in some situations; guidance for the use of host nation support by the ADF should be drafted.

Chapter 21
Organisational Options

INTRODUCTION

If any maintenance tasks are to be performed within the ADF (as opposed to contractor), options arise concerning the organisation for whom such maintenance elements should work, and the relationship between the maintenance elements and the operators.

This chapter discusses issues that should be considered when deciding organisational arrangements, and also evaluates various options for the control and management of maintenance elements within the Defence organisation. The main emphasis is on the control of maintenance work undertaken *within* the ADF (as opposed to contractors).

PREREQUISITE ISSUES

A number of important (and difficult) issues must be addressed prior to detailed consideration of organisational arrangements.

Commercialisation-Related Issues

Three issues have already been discussed in some detail when considering the place of commercialisation in defence maintenance work.[1] These are:

a. What maintenance tasks most directly affect operations?

b. How much maintenance should be performed on deployment?

c. How much maintenance should be retained in-house? This consideration depends on the preceding two issues (and several others).

Peacetime/Wartime Organisation

To what extent should peacetime systems be based on wartime requirements? The ideal organisational arrangements may differ between peacetime and contingency situations. This raises the question of how much reorganisation is appropriate when transitioning from one state to the other, bearing in mind that reorganisation is itself a source of inefficiency for some duration. If there are limits on the extent of reorganisation that should be attempted,

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1 Commercialisation is discussed in more detail in Chapter 19.

then some compromise must be struck between arrangements that are optimum for peacetime and those that are optimum for wartime.[2]

The size (in manpower terms) of operational units can be expected to swell during transition to contingency. In addition, over the duration of a long contingency, additional manpower would be rotated into deployed units to allow some (or all) of the original personnel to be returned home.[3] There would be some benefit in having all of these personnel under the control of the operational commander during peacetime, to simplify the augmentation of operational units and management of the rotation pool.[4]

However, this would mean that the operational commander would control a somewhat broader set of functions during peacetime than in wartime, since the augmentation and rotation personnel will be employed in non-operationally focused functions during peacetime. It is likely that control of these non-operational functions would constitute a management burden for operational commanders during a contingency; moreover, responsibility for those functions previously performed by augmentation personnel would need to be transferred to other commanders. This means that non-operational commanders must pick up functions for which they were not previously responsible—and for which the experienced manpower has been transferred to other duties. This would cause significant problems in the performance of these functions.

Therefore, continuity of *functions* across the peacetime/contingency transition is likely to be much less disruptive than continuity of *personnel*. Each organisation should be responsible for the same set of functions during peacetime and wartime, with personnel moving between them as required (and with additional staff being employed, or work contracted out, as required). This need to coordinate the movement of personnel between different organisations requires good central management of the manpower resource, and cooperation on the part of the various commanders.

ORGANISATIONAL CRITERIA

Logistics agencies must be responsive to the operational commander's requirements. However, this does not necessarily mean that all logistics agencies must be within the operational commander's chain of command; in fact, there are disadvantages in such an

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2 The issue of peacetime/wartime optimisation is not limited to organisational considerations alone. Many processes and systems have different requirements in the different scenarios; the issues of extent of reorganisation during transition and of optimising for one scenario and adapting for the other will be relevant in all such cases.

3 See p. 352.

4 AHQ/2101/25/1/EQ Pt 2 (6), *Technical Logistics Support to TFG*, ACAUST, 7 April 1994, paragraph 35; AHQ 3020/13/TECH Pt 1 (20), *Report of the Working Party to Consider TFG CMR and Associated Maintenance Issues*, DENGPP-AF, 16 May 1993, paragraph 21.

organisation. Direct command and control should be considered to be one possible means to an end (the end being responsive logistics performance).

This section considers criteria which help to determine how direct the operational commander's command and control of maintenance elements needs to be.

Directness of Benefit to Operations

On-aircraft maintenance, and maintenance of components in critically short supply, will directly affect availability, and should therefore be more closely guided by operational requirements.[5] Maintenance of other components should be buffered from direct operational impact by the existence of spare components. Accordingly, maintenance of these components does not need to be linked as closely to operational requirements.

USAF practice is for combat units to perform 'near real time' functions (eg. priority repair) in wartime—even if they do not perform these functions in peacetime.[6]

Flexibility Afforded

Short duration tasks can be rescheduled quickly to align with changing operational requirements. However, longer servicings cannot be easily interrupted and so cannot be as responsive to the rapidly-changing operational requirements. Since less close communication is required between operational and maintenance elements in this case, greater organisational separation is admissible (but not required).

Management Distraction

Commercial firms have found that direct ownership of large complex production activities imposes a large management burden, and there is thus a strong tendency to subcontract such work.[7] This allows the firm to determine and specify the required output without needing to become unduly involved in implementation details. By analogy, operational commanders should be permitted to concentrate solely on planning and executing operational missions, and should not need to consider detailed logistics issues.[8]

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5 SGTE/4060/13/MANAGEXT Pt 1 (7), *Technical Logistics Support to the TFG*, CO GTE LMSQN, 14 April 1994, Enclosures 1 and 2; and CLSA 058/1994, *TFG Logistics Support*, CLSA, 15 April 1994. An example of component maintenance impacting on availability is described in CO TFLMSQN 110/94, *Review of AHQ Paper on Technical Logistics Support to TFG*, CO TFLMSQN, 15 April 1994.

6 I.K. Cohen and R.A. Pyles, 'Empowering the Commands to Provide Logistics Support', 1992.

7 loc cit.

8 A/DGLOGOPS 85/94, *Technical Logistics Support to the TFG*, A/DGLOGOPS, 15 April 1994. ADFP4, Operations Series, *Mobilisation Planning*, First Edition, draft, 1994, paragraphs 405, 416, and 418 indicate that Service Chiefs of Staff, as opposed to Joint Force Commanders, have responsibility for, *inter alia*, logistics minutiae. While operational commanders should be shielded from logistics *detail*, they must nevertheless consider broader logistics issues.

The most obvious way to shield operational commanders from logistics distractions is to place logistics under an alternative command chain. Another, albeit somewhat less effective, option is the use of appropriate delegations of responsibility *within* the operational organisation.[9]

A practical guide to the amount of maintenance directly controlled by operational commanders should be the amount with which they are *comfortable*. However, the integration of logistics planning into operational planning argues for the inclusion of some logistics planning staff in the operational organisation, even when the latter directly controls very little maintenance.

Ease of Deployment Control

Deployment control is simplified if all deployed elements are under a single command chain (which will be headed up by an operational commander). Since the extent of deployed maintenance should vary with the nature of the contingency, all elements that *might* be deployed should always come under operational control, to avoid the need to reorganise prior to (or during) a contingency. A side-effect of this strategy would be that deployed commanders would directly control non-deployed maintenance elements in many cases.

Logistics Integration

Consolidating all maintenance with other logistics functions under a single command encourages better integration of logistics functions,[10] which may lead to greater efficiency.[11] The single command could be a dedicated logistics organisation (eg. HQLC), or a part of some other organisation (eg. AHQ).

Conflict of Interest

Separating logistics functions from direct control by operational staff facilitates attainment of higher standards, at the possible expense of operational responsiveness. Technical airworthiness is a primary example where this may be a concern.[12] Although there is current debate on the transfer of maintenance elements to operational control, it seems that logistics management functions (including engineering and maintenance planning) are to remain separate from the operational organisation,[13] at least for the time being.

The existence of independent regulatory bodies can serve to check the possible decline of standards due to operational pressures. Such regulatory bodies exist for engineering functions, and, to a lesser extent, other logistics management functions. However, there is no surveillance organisation which monitors RAAF *maintenance* standards—ironically, the

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9 SGTE/4060/13/MANAGEXT Pt 1 (7), loc cit.

10 SGTE/4060/13/MANAGEXT Pt 1 (7), Enclosure 1.

11 A/DGLOGOPS 85/94, loc cit.

12 DQPE/3/3/1/Air Pt 1 (11), *Technical Logistics Support to TFG*, DQPE-LC, 15 April 1994, Annex A.

13 DQPE/3/3/1/Air Pt 1 (11), loc cit.

only logistics function currently being performed under the direct control of operational staff (in part).

It should be borne in mind that attainment of high standards at the expense of operational responsiveness is definitely a peacetime emphasis. During a contingency, safety considerations (including maintenance standards) can be de-emphasised.[14]

Facility Sharing

Some groups of tasks share the same facilities (particularly GSE/ATE).[15] Some such tasks, when considered on their own, may appear to be most suitable for direct control by operational staff (eg. because of immediate effect on operations, and/or deployability); other tasks using the same facilities may *not* be preferred for direct operator control. Splitting such tasks between two separate command chains would entail some loss of efficiency, particularly if duplication of facilities is required. It could be that facilities will be a (minor) determinant of organisational boundaries, at least serving to preclude organisational splits that may otherwise have been desirable.[16] However, major USAF studies have indicated that the grouping of trades across OM/DM boundaries tends to reduce the capacity for intensive sortie production and rapid deployment, as a result of less clearly focused management structures.[17] Options such as different, but collocated, sections sharing common facilities should be considered. While this would complicate peacetime coordination of the use of facilities and equipment, it would avoid diluting the operational focus of front line maintenance units.

OWNERSHIP OF MAINTENANCE ELEMENTS

Organisations

There are three major types of organisations that may own maintenance elements that support military operations:

a. defence operational organisations (eg. AHQ units);

b. defence non-operational organisations (eg. HQLC units); and

c. civilian contractors.

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14 DI(AF) LOG 13-7, *Contingency Maintenance and Battle Damage Repair*, draft, 28 February 1994, paragraph 1; DI(AF) OPS 5-9, *Paramount Procedures*, 1 April 1982, paragraph 1; and LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993.

15 DQPE/3/3/1/Air Pt 1 (11), loc cit.

16 loc cit.

17 Major Gene E. Townsend, USAF, 'Air Force Maintenance: Issues and Challenges for the Eighties', *Air Force Magazine*, January 1980, pp. 56–61.

Operator Maintenance. Operator maintenance is that performed within (ie. controlled directly by) the operational organisation. It may or may not need to be deployable, and is not necessarily synonymous with Operational Maintenance (OM).

Defence Non-Operator Maintenance. Maintenance tasks may be performed by defence personnel (uniformed or civilian) who are not under the direct control of operational staff. This need not be limited to major aircraft servicings and component work, but could also include tasks in direct support of operations (such as flight servicings). It is conceivable that *all* defence maintenance elements could be under direct operator control, in which case there would be no defence non-operator maintenance; the reverse is also possible.

Contractor Maintenance. Many maintenance tasks do not need to be performed by defence personnel; where it is cost-effective to do so, such tasks may be contracted out.[18]

Combinations

The three organisational entities may be used together in various combinations. Each different combination has strengths and weaknesses when evaluated against the organisational criteria outlined earlier; the 'best' combination depends on the relative emphasis given to each of the criteria.

There will always be a role for contractor maintenance. Under some scenarios, the extent of contractor support may diminish during a contingency, for example if all aircraft DM were deferred for the duration of the contingency. However, component maintenance will always continue (except in very rare circumstances), and this will always involve contractors for at least some items. Accordingly, all of the options considered below include a contractor contribution.

Except where *all* maintenance is performed by the operational organisation, there must be some amount of *trust* between the users and their support agencies.[19]

Operator, Non-Operator, and Contractor Maintenance. This is the current RAAF practice, involving three separate kinds of organisations (AHQ/HQTC, HQLC, and contractors). This arrangement provides the flexibility to allocate individual maintenance elements to the most appropriate organisation. Those tasks providing greatest benefit when controlled by operational staff may be so controlled; 'swamping' operational staff with logistics considerations is avoided by hosting all other maintenance tasks in a separate organisation.[20] However, the operator/non-operator split can result in inefficiency through duplication and lack of integration; communications problems can arise; and demarcation disputes may occur.

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18 See Chapter 19.

19 The need for trust is emphasised in A/DGLOGOPS 85/94, loc cit.

20 Short interval, short duration on-aircraft tasks are the prime example of maintenance tasks that need to be most responsive to operational requirements. See Chapter 19.

Operator and Contractor Maintenance Only. In this scenario, the operational organisation performs *all* in-house maintenance work, effectively subsuming the non-operator component from the previous scenario. This arrangement guarantees the best possible operational responsiveness due to the minimisation of communications channels and alternative agendas.[21] Logistics efficiency should result from the more integrated system, although unchecked operational pressure could lower standards. The major disadvantage of this system is that operational commanders could become bogged down in matters that do not directly affect operations.

Non-operator and Contractor Maintenance Only. This scenario transfers all in-house maintenance—even flight servicings—to a non-operator organisation (such as HQLC). In many respects, this solution is opposite to the preceding. Its main benefit is that operational commanders are totally freed from logistics responsibilities (except for the need to communicate requirements). Since all in-house logistics processes are within a single organisation, greater efficiency should be possible, and independence from operational pressures should facilitate attainment of standards. However, the same independence may give rise to reduced responsiveness to operational requirements. Furthermore, deployment control would be more complicated since maintenance elements on deployment would not work directly for the deployment commander.[22]

Contractor Maintenance Only. When no in-house maintenance is required,[23] entrusting all maintenance to civilian contractors is an option. This situation shares many of the advantages of the preceding option (in addition to the benefits of increased civilian industry participation). However, operational responsiveness becomes more problematic (to the extent that fleets maintained in this manner may be considered to be 'operational'). Deployment support is not presently an option under a purely contractor maintenance arrangement (see Chapter 19).

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21 The practice of non-operational commands pursuing their own agendas (priorities) is identified in I.K. Cohen and R.A. Pyles, 'Empowering the Commands to Provide Logistics Support', 1992. Whether or not this arrangement does indeed guarantee the most responsive logistics delivery is subject to current debate; eg. AHQ/2101/25/1/EQ Pt 2 (6), op cit., (agrees); DQPE/3/3/1/Air Pt 1 (11), loc cit. (disagrees).

22 The possibility of deploying maintenance elements under HQLC control is suggested in A/DGLOGOPS 85/94, loc cit. This practice appears to be opposed to USAF practice: during *Desert Storm*, the organisation of at least some maintenance elements was revised to place them under direct operational control (Minutes of the Operation *Desert Storm* Lessons Learned ABDR Conference, Wright-Patterson AFB OH, 24 to 28 June 1991).

23 See Chapter 19. This arrangement is already in place for some 'non-operational' RAAF fleets, including VIP and trainer aircraft. Non-operational fleets are not subject to preparedness requirements, and will not be mentioned in the CPD. Contractor maintenance only is not an option for fleets which are subject to preparedness requirements, and so will not be discussed in detail.

OPERATIONAL INFLUENCE OF MAINTENANCE ELEMENTS—TRADITIONAL OPTIONS

Regardless of which organisation owns maintenance elements, the operational organisation has primary responsibility for executing combat missions. Therefore, *all* maintenance elements must be responsive to operational requirements to some degree. Mechanisms must be in place to ensure that operational requirements influence maintenance responsiveness. There are three basic alternatives:

a. direct control of maintenance elements by operational staff,

b. an independent self-determining peer logistics organisation, and

c. contractual relationships between operators and supplier organisations.

Direct Control by Operational Staff

Operational units may determine their own maintenance requirements, set their own priorities, and then have the tasks performed by their own maintenance elements. Such direct operator control of maintenance elements ensures the maximum responsiveness, for the reasons discussed above. Operators should directly control those logistics processes most affecting performance.[24]

This approach facilitates the incorporation of logistics planning into operational planning, which offers improved agility and endurance.[25] Its main disadvantage is the potential for management distraction.

Direct operator control must coincide with operational *ownership* of those elements, and is therefore not possible for maintenance tasks that are either contracted out or performed by another defence organisation.

Independent Logistics Organisation

Where a separate in-house logistics organisation exists (eg. RAAF HQLC, USAF AFMC), it is usually considered to be a peer organisation to the operational elements, being organisationally autonomous. Such a peer organisation determines its own priorities based on a combination of operator input, its own monitoring of perceived operational requirements, and its own agenda. This includes both 'strategic' issues such as organisational goals, and lower level issues such as forecasting operators' logistics (including maintenance) needs.

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24 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support', states that during wartime, the USAF tends to transfer certain logistics functions that have an immediate effect on operations from Materiel Command (analogous to RAAF HQLC) to combat units. The functions cited are priority repair and distribution (presumably scheduled maintenance responsibilities do not change). Similarly, control of Combat Logistics Support Squadrons (which provide BDR capability) was transferred to operational control during *Desert Storm* (Minutes of the Operation *Desert Storm* Lessons Learned ABDR Conference, loc cit.).

25 Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, p. 98.

The main advantage of an autonomous logistics organisation is that operational staff do not need to determine or perform their own logistics requirements; to a large extent, the logistics organisation remotely determines operational needs on behalf of the operators, and then arranges for the provision of the support deemed necessary (either by in-house work or by contracting). The close relationship within the logistics organisation between the logistics management and maintenance elements helps to ensure that production meets targets.[26]

The success of this arrangement crucially depends on the ability of the logistics organisation to remotely sense the operator's needs. Forecasting of logistics needs takes into account historical data, plus trends observed in demand rates. There will be some delay between the onset of a trend and its detection (and the initiation of corrective action); this delay can be reduced if input from operational staff is readily forthcoming and easily assimilated into the system. Moreover, without direct operational input, the logistics management system cannot *anticipate* changing operational requirements. Peacetime logistics data has been found to be an unreliable guide to determining contingency requirements; therefore, requirements should be driven more by operational expectations than by historical data or trends whenever possible.[27] However, an autonomous logistics organisation will be tempted to emphasise the data most easily available to it (ie. historical data).

The provision of communication from operational staff is made more difficult in wartime as logistics management is performed remotely from the deployed site. Unfortunately, such communication would become much more important during a contingency since the increased uncertainty of wartime requirements would, to some extent, invalidate peacetime processes which rely on steady or slowly changing requirements.[28]

The remote determination of logistics requirements equates to a 'push' system, which created many problems for the USAF during the Vietnam War.[29] In addition, logistics planning cannot be easily incorporated into operational planning. By contrast, a 'pull' system, where the operators determine their own requirements, was used in the Gulf War and was found to be superior.[30]

The autonomy of the logistics organisation effectively means that the responsibility to achieve operational goals is divided between the operational and logistics elements, since neither organisation controls all of the resources needed to get the job done.[31]

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26 This argument is advanced in CO TFLMSQN 110/94, loc cit., as a reason for transferring additional elements from operational to logistics control.

27 J.A. Stockfisch, 'Linking Logistics and Operations: A Case Study of World War II Air Power', RAND N-3200-AF, p. 53; *ADF Reserve Stockholding Policy Implementation Guidance*, draft, HQADF Logistics Division, December 1993, paragraph 100.

28 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'.

29 Major General Edward R. Bracken, USAF, 'Vietnam Logistics: Its Meaning for Tomorrow's Air Force', *Air Force Journal of Logistics*, Fall, 1986, pp. 18–21.

30 Waters, *Gulf Lesson One*, p. 298.

31 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'.

Contractual Relationship

A contractual relationship exists between defence and civilian companies performing defence work. In current RAAF practice, contractual requirements are determined, and the contract is managed, by an independent logistics organisation on behalf of the operators. In addition to potential financial benefits, a contractual arrangement allows the RAAF to specify its requirements without needing to get overly involved in the details of their achievement (hence avoiding management distraction).[32]

OPERATIONAL INFLUENCE OF MAINTENANCE ELEMENTS—A CONTEMPORARY ALTERNATIVE

Intra-Defence Contractual Relationships

The essence of a contractual relationship could be applied *within defence*, between the operators and other in-house logistics organisations (including maintenance elements). The benefits of this arrangement were identified by a USAF study that aimed to assess the potential value of adapting modern business practices to the USAF logistics environment.[33]

To a certain extent, a contractual relationship between operators and suppliers represents middle ground between the two extremes discussed above (*direct operator control* and *independent logistics organisation*). The logistics (including maintenance) elements are established as a separate organisational entity to the operators; however, *they are not self-determining*. Logistics requirements are determined by operational staff and effectively form the basis of a contractual relationship between the operators (users) and the logistics elements.[34] The logistics organisation is not considered to be a peer to the operators, but rather a supplier.[35]

Uncertainty

A user-driven system better suits the uncertainty of war: operational units will become aware of their needs as their plans and circumstances change; a user-driven logistics system will be more responsive than a system that involves 'hoping that formal data systems located in some rear echelon can track the fast-breaking situation or account for the subtleties of an unannounced, and changing, operational concept when trying to determine what the combat forces really need'.[36] Users would determine supply, repair and maintenance priorities, the need for lateral distribution or repair, etc. This approach implements a 'pull' logistics system

32 However, contract management introduces another form of management overhead.

33 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'.

34 DQPE/3/3/1/Air Pt 1 (11), loc cit., notes that 'some deeper maintenance may be more effectively organised by AHQ or HQTC'.

35 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'.

36 loc cit. A similar (albeit less emotively expressed) observation is made in CLSA 058/1994, loc cit.

rather than a 'push' system, and facilitates the incorporation of logistics planning within operational planning.

A USAF study (CLOUT[37]) endeavoured to determine the effects of more direct user control of the logistics system via simulation. Two scenarios were analysed: one where the deployment site was not under attack, and a second where attacks on the deployment damaged repair and spares holding facilities. Within each scenario, the number of Not-Fully-Mission-Capable (NFMC) aircraft was calculated for each of three logistics arrangements:

a. the 'normal' non-operator determined system;

b. a system where operators determine and direct lateral resupply and repair (but do not control depot production); and

c. as above, but with operators directly determining depot support requirements as well.[38]

The study revealed a clear improvement in aircraft availability as more logistics requirements were determined by the users, rather than externally (Figure 21-1). Presumably, this situation arises due to elimination of the time lag between operational requirements changing, and the determination and response to this by a separate logistics organisation. *Desert Storm* is cited as providing 'real world support' for the CLOUT findings.[39]

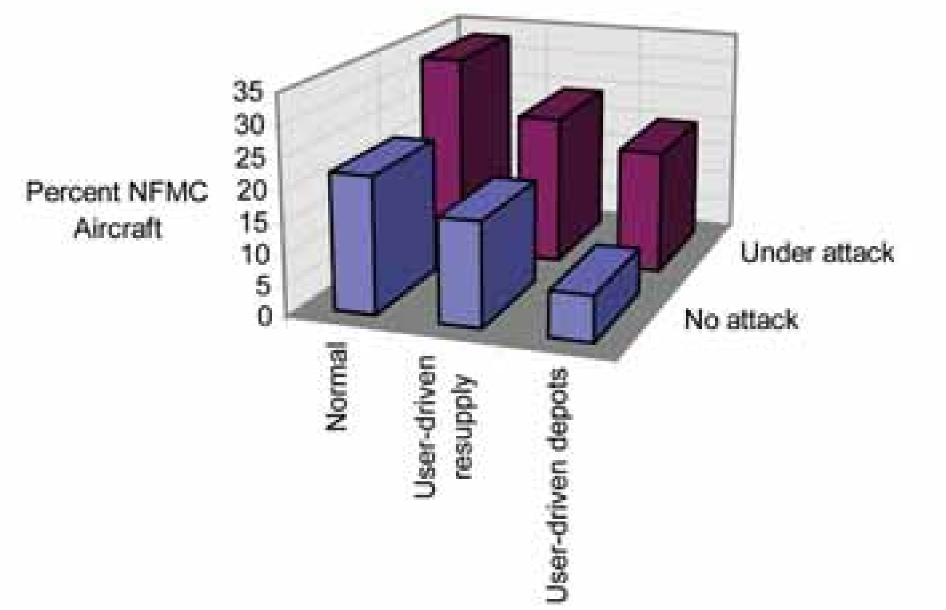

Figure 21-1: Benefit of User-Determined Logistics

37 'Coupling Logistics to Operations to meet Uncertainty and the Threat', Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'.

38 This does not mean operators micromanage depot production, but rather that they determine output priorities and timing in the same way HQLC does presently.

39 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'.

Responsibility

If a separate logistics agency is autonomous (such as HQLC), responsibility to meet operational goals is divided between the operational and logistics organisations: no *one* agency can be responsible for overall performance. Operators do not control the resources they need to discharge their duties; conversely, the logistics units have only internally-generated incentive to perform and improve (at least during peacetime).[40] A contractual user-supplier relationship empowers the users, enabling them to accept full responsibility; the supplier is motivated to become the user's supplier of choice.

Unsatisfactory Performance

Management provisions (similar to contractual or Memorandum of Understanding clauses) would need to be in place to cover cases of unsatisfactory performance on the part of the supplying organisation. A combined user/supplier 'board of directors' could consider actions such as:

a. reallocation of personnel within the supplier organisation;

b. reassignment of workload to different elements within the supplier organisation;

c. engaging different (civilian) contractors to those preferred by the supplier organisation;

d. transferring workload from the supplier organisation to a civilian contractor; and

e. transferring workload from the supplier to the user (ie. operator) organisation.[41]

The operators must have sufficient authority to ensure that they get what they need. They must therefore have the ultimate authority to remove work from the supplier and either perform it within their own organisation, or contract it out to a civilian organisation.[42]

Information Systems

An implication of operator-driven logistics requirements is that logistics information systems must be more robust, both physically to handle the deployed environment, and functionally to handle the rapidity of change and possible paucity of detailed information. A simple system that requires a minimum of data is consistent with use on deployment and could provide the flexibility to handle rapid change and unusual requirements.[43] Peacetime logistics systems are able to make use of more data and more complex algorithms due to the

40 loc cit.

41 loc cit.

42 This decision may be constrained by core/non-core and Manpower Required in Uniform (MRU) considerations. In some cases, contracting will not be acceptable, and the operator's only option will be to perform the work himself if a satisfactory solution cannot be reached by negotiation.

43 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'.

benign environment, basically steady-state system and luxury of time. Perhaps a deployable subset of a peacetime logistics system is required for contingency use, or a separate system may be required which interfaces with the peacetime system.[44]

Contrast with Current RAAF Organisation

The major difference between this arrangement and current RAAF practice is that HQLC has the responsibility to determine logistics requirements, based on operational needs specified by Air Command.[45] In some situations, the current RAAF arrangements are an inversion of the operator-managed approach. Logistics requirements determined by Logistics Management Squadrons (LMSQNs)—which are not under operational control—are sometimes performed by maintenance elements which are under operational control (eg. within 481 Wing).[46] This creates the curious situation whereby the LMSQN assesses the operator's requirements, and then informs the operator of what needs to be done.[47]

Application in the RAAF

Applying a user-supplier contractual relationship to the current RAAF organisation would involve changes which are, in some respects, the reverse of those currently being considered. LMSQNs, as currently formed, perform an admixture of logistics requirements *determination* and logistics *delivery*. These components would need to be cleaved apart; most elements with a responsibility to forecast logistics requirements should be transferred to Force Element Group (FEG) control.[48] This would clear the way for the formal incorporation of logistics planning into operational planning. The remnants of the LMSQNs would retain true logistics delivery functions, such as detailed planning against requirements set by the FEG, management of civilian contracts (effectively, subcontracts), engineering support, etc.

Alternatively, LMSQNs could be transferred to operational control as they are. This would retain the efficiency present within the LMSQNs, but would probably transfer more duties to the operators than they need or want. The possibility of operational pressure affecting the quality of logistics (especially engineering) also becomes more of a concern, although this could be managed by appointing an independent standards and auditing body.[49]

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44 Other conclusions concerning information systems are discussed in Chapter 23.

45 The Air Command Operational Preparedness Directives (ACOPDs—see p. 31) are the clearest statement of contingency operational requirements. Arguably, the indicators of aircraft (and systems) availability could be considered to be high-level logistics goals (treating the aircraft as merely the uppermost item in the item importance hierarchy—see Annex F.

46 CO TFLMSQN 110/94, loc cit.

47 In this role, the LMSQN becomes somewhat equivalent to a consulting organisation that determines the operator's needs on their behalf. However, the LMSQN is autonomous, whereas a consultancy would be controlled by the tasking organisation, which could over-ride its recommendations.

48 CLSA 058/1994, loc cit., mentions the possibility of FEGs owning LMSQNs (in toto). According to DQPE/3/3/1/Air Pt 1 (11), loc cit., neither AHQ nor HQLC currently favours such a transfer.

49 The Directorate of Technical Airworthiness (DTA-LC) already performs many aspects of this.

Financial responsibility should logically follow this shift in organisational structure. FEGs should have primary responsibility for their share of the logistics vote, and would need to consider financial constraints when determining logistics priorities. Funds would be transferred from the FEG to the LMSQN as ‘payment’ for their services.[50]

SUMMARY

Before attempting to determine an optimum organisational structure, a decision should be made concerning the emphasis to be given to peacetime and wartime requirements. Also, the extent of commercialisation should be considered.

The desirable extent of operational control or influence over maintenance elements is affected by the following:

a. directness of operational benefit afforded by direct control,

b. the flexibility which could be achieved,

c. extent of management distraction,

d. deployment control issues,

e. the desire for logistics integration,

f. possible conflicts of interest, and

g. issues concerning facility sharing between organisations.

Maintenance elements may be directly controlled by operational commanders, under separate command chains, or contractors. Generally, some combination of these options is used. Employing both operator and non-operator controlled elements allows a balancing of the directness of operational benefit against management distraction by assigning the various maintenance elements to the appropriate organisation; however, it suffers from a possible lack of integration, and communication and demarcation problems. If all in-service maintenance elements are operator controlled, responsiveness and integration are maximised, but there is greater management distraction and increased risk of conflicts of interest. Conversely, if all in-service maintenance is non-operator controlled, management distraction of operational commanders is minimised, but maintenance responsiveness may suffer.

Operational requirements may influence logistics elements most directly if those elements are under direct operator control. If a separate logistics organisation exists, it may determine

50 Transferring funds between organisations in this manner would be an additional administrative burden. A streamlined way of doing this should preferably be sought.

its own priorities. Often, this will be significantly influenced by historical data, whereas contingency requirements demand a more operationally responsive approach. Moreover, the incorporation of logistics planning into operational planning is discouraged by this organisational separation, and no one organisation can be levied with full responsibility to meet operational requirements, since no one organisation controls all of the resources required.

A compromise solution is for operational elements to determine logistics requirements, and 'contract out' logistics performance to a separate logistics delivery organisation. In this way, responsiveness is improved as the logistics organisation is not a peer, but a supplier organisation. This facilitates a 'pull' logistics system, and simplifies the incorporation of logistics planning into operational planning. To apply this arrangement to the RAAF would involve the transfer of at least some elements of LMSQNs to FEG control, and downgrading the status of logistics command. Financial delegations could also be brought into line with these arrangements.

Chapter 22
Personnel

INTRODUCTION

The majority of this study has focused on technical and management strategies required to ensure that the maintenance function can meet preparedness objectives. However, history shows that the most important asset is people. Defective policies and a lack of planning need not result in failure—given the right people. This chapter outlines the personnel qualities required, and some means of getting the best out of the available personnel.

LESSONS FROM HISTORY

Wartime

When one F-15 unit's aircraft first arrived at their deployment base in Saudi Arabia as the initial response to Operation *Desert Shield*, only a single maintenance person was available to receive and prepare the aircraft. '...the Chief did the only thing he could do under the circumstances—he enlisted cooks, cops, and engineers and had every aircraft ready to go inside an hour.'[1] More often, GSE and orderly room staffs were used for flight line and armament duties when required.[2]

Innovative maintenance practices contributed to the success of the maintenance function in supporting the demanding flying rates in the Gulf.[3] For example, improvisation, and making best use of the available skills, minimised the impact of the lack of an F-15 engine test cell in the Gulf. Some 11 engines were retained in theatre which would otherwise have had to have been sent to Germany for testing.[4]

The plethora of modifications developed for wartime use also provides many examples of ingenuity and resourcefulness.[5] So too do many of the maintenance tasks introduced to

1 Air Force White Paper, *Air Force Performance in Desert Storm*, Department of the Air Force, Washington DC, April 1991, p. 15, quoted in *Air Force Manual 1-1*, Volume II, Basic Aerospace Doctrine of the United States Air Force, March 1992, Essay T.

2 Discussion with CAPT Scott Loch, USMC, 24 February 1994.

3 Wing Commander Gary Waters, 'The Gulf War and Logistics Doctrine', *RAAF Supply*, March 1992, pp. 37-44; Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, pp. 138, 246.

4 Murray Hammick, 'Report from the Front: AMUs Underrated in USAF's Success', *International Defence Review*, 5/1991, pp. 451–2.

5 Some examples of contingency modifications are described in Chapter 17.

combat environmental degradation.[6] In addition, components that were not readily available through the supply system were often repaired in-theatre.[7]

Manpower productivity was unexpectedly high during the Gulf War, not just because of the working routine, but because the manpower was effectively a ‘captive audience’. With fewer distractions, both service and private, personnel put additional emphasis on the only activity available to them: work.[8]

Morale amongst coalition manpower was generally high during the Gulf War. The main impediment to morale was the uncertainty of the duration of individuals’ stays in the region. Plans to rotate personnel home (if any were indeed made) were not communicated to the units; understandably, estimates on the anticipated duration of the war were also not made known. As a result, personnel could not know how long they may be required to remain away from home. It seems that the *uncertainty* was the demotivational factor; had manpower plans been communicated, personnel would have had a better idea of their immediate future.[9] Even if distant or unwelcome, some knowledge of coming events provides a feeling of security.

Exercises

Several series of operational tests have shown that ingenious adaptation allows support units to perform far in excess of expectations.[10] Among these is the USAF’s 1987 Exercise *Coronet Warrior* , which was intended to validate the computer model used to determine the contents of fly-away kits.[11] The model predicted that after 30 days of intensive flying and no external resupply, only four of the original 24 aircraft would be fully mission-capable. However, in practice, 17 of the aircraft were fully mission-capable at the end of the exercise.

This huge difference was attributed to personnel innovation and productivity, and unexpectedly high levels of aircraft reliability. Crucial was the ability to repair components ‘on deployment’.[12] This allowed nominally unserviceable components to be returned to service when normally they would be out of commission for the rest of the exercise. To achieve such effective repair results, tradesmen were told that there were no rules (except for safety), which allowed for full use of ingenuity. Levels of repair beyond the normal charter of the deployed units were successfully attempted, and parts were fixed to a higher

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6 Environmental maintenance is discussed in Annex E.

7 Captain Scott Loch, USMC, *Innovative Maintenance Actions*.

8 Discussion with Captain Scott Loch, USMC, 24 February 1994.

9 loc cit.

10 *Air Force Manual 1-1*, loc cit.

11 See p. 88.

12 USAF forces aim to deploy a considerably greater depth of maintenance capabilities than the RAAF—see p. 173.

standard than anticipated. Cannibalisation was used creatively, and grounded aircraft were even used as test beds in some cases.[13]

ATTRIBUTES

Ingenuity

The ability to meet requirements in the absence of documented solutions, and without prior experience of the problem, requires personal ingenuity and resourcefulness. Contingency operations generate a plethora of unforeseen problems for maintenance personnel, so these attributes assume greater importance during wartime.

Battle Damage Repair (BDR) benefits significantly from the resourcefulness of personnel,[14] since much BDR is not covered by the standard procedures found in maintenance manuals. The repair of items in short supply, but which are not normally repaired on deployment or within the service, also demands personnel ingenuity.[15] Likewise, the management of cannibalisation benefits from a modicum of ingenuity.

Ingenuity can be encouraged during peacetime by adopting Total Quality Management (TQM) practices.

Adaptability

The uncertainty of war places a premium on adaptability.[16] This applies not only to maintenance staff, but to any personnel who may be seconded to perform maintenance-related duties. Aircrew can play a most significant role in this regard.[17]

The adaptability of RAAF tradesmen should be enhanced as a result of the Technical Trades Restructure (TTR). The TTR provides for multiskilling and accounts for the integration of technologies in modern weapon systems.

Communication

Communication is crucial in coordinating the activities of a large organisation. It becomes even more important during wartime, when unusual circumstances may require deviations from standard procedures. Good communication is also required if an organisation is to

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13 Jeffrey P. Rhodes, 'Eagles 17, Bean Counters 4', *Air Force Magazine*, April 1988, pp. 74–80.

14 Michael Self and Edward Kozlowski, *Air Force Logistics Command Operations in Desert Storm*, Headquarters USAF Logistics Command, HQ AFLC/XPOX, July 1991, p. 10.

15 LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993, paragraph 17.

16 *Air Force Manual 1-1*, loc cit.

17 DI(G) LOG XX-X, *Principles for the Maintenance of Technical Equipment*, draft, 1994, paragraph 10.

adopt centralised planning with decentralised execution, which appears to be the most effective organisational compromise.[18]

At a lower level, communication between aircrew and maintenance crews can significantly improve the efficiency of operational maintenance. Helpful and knowledgeable descriptions of unserviceabilities can greatly expedite their identification and rectification.

Manpower plans, even draft plans, should be communicated to deployed personnel. This would provide a sense of security, and would avoid the uncertainty that can act to undermine morale.

Productivity

National pride, and threats to national security, motivate personnel to greater efforts.[19] This particularly applies to the defence of Australia; the effect may not be as noticeable for other ADF roles such as peacetime operational tasks or multinational security operations. In fact, there may even be opposition to some such tasks.[20] Any attempt to factor in a productivity increase based on such sources of motivation must consider the nature of the task; ie. what is at stake. Nevertheless, USAF ground crews in the Gulf exhibited increased motivation,[21] presumably due to national pride, at least in part.

Productivity suffers when personnel have to work in NBC protective clothing.[22] The extent of this will increase in hotter climes, such as the Gulf (hence the USAF's NBC suit cooling system—see p. 328), or Australia's more probable area of operations.

Productivity is increased by the use of extended shifts. Twelve-hour shifts were adopted by F-15 maintenance units during the Gulf War.[23] ACOPDs specify working routines for maintenance personnel during contingencies. Adopting these arrangements would approximately double the annual productivity of RAAF members, before additional motivational factors (and impediments to productivity) are factored in.

Reduced supervision requirements can also improve productivity. The unit Senior Engineering Officer may authorise the relaxation of supervision requirements in an emergency.[24] The Self-Supervising Technicians introduced by the Technical Trades Restructure can help in

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18 Lieutenant General William G. Pagonis, *Moving Mountains – Lessons in Leadership and Logistics from the Gulf War*, Harvard Business School Press, Boston, Massachusetts, 1992, p. 224.

19 Captain Joseph F. Udemi, USAF, 'Modified to Meet the Need', *Airpower Journal*, Spring, 1989, pp. 51–64.

20 See p. 214 for examples.

21 Hammick, 'Report from the Front'.

22 Colonel Clifford R. Kreiger, 'Fighting the Air War: A Wing Commander's Perspective', *Airpower Journal*, Summer, 1987, pp. 21–31.

23 Hammick, 'Report from the Front'.

24 DI(AF) LOG 6-4, *Supervision and Inspection of Aircraft Maintenance Operations*, 11 March 1993, paragraph 10.

this regard, although manpower savings exacted as a result of TTR generally means that there are less people available (and required) to do the tasks necessary, not that tasks can be completed quicker or more tasks undertaken.

Effective contingency maintenance, and particularly Battle Damage Repair, requires responsiveness in a number of engineering processes. This is discussed in Chapter 15.

The entertainment of personnel on deployment may seem like a trivial consideration, but with no forethought, the effectiveness of the maintenance function may suffer. After a demanding 12-hour shift in dehydrating conditions, and with no home to go to, there is significant temptation for personnel to consume significant quantities of alcohol. Thirst can be reduced by the provision of sufficient liquids throughout the working day, even including soup for meals. Organised sports offer an alternative to the bar, and can allay the boredom that may otherwise set in after hours.[25]

Training

Training is perhaps the most important investment in personnel.[26] Thorough, detailed training permits members to apply their knowledge to solve unforseen problems; broad training increases the potential scope of employment of personnel. Training is therefore most important in developing personnel flexibility and ingenuity: if personnel are trained merely to do their job, and no more, flexibility and ingenuity will be much reduced. If training in common maintenance skills (such as rivetting, welding and soldering) is provided to all tradesmen of relevant and *allied* trades, significant improvements in personnel adaptability will result, with consequent increases in the flexibility and efficiency of the maintenance function. Some studies have indicated that there is a tendency to provide relatively narrow training within the RAAF logistics environment (particularly, logistics management).[27] Increased multi-skilling is a major emphasis of the Technical Trades Review.

Training should be appropriate to contingency requirements whenever possible.[28] Where contingency procedures are expected to differ from peacetime procedures (eg. BDR), it will be necessary to teach both. Obviously, it is preferable to minimise the differences between peacetime and contingency procedures to the maximum extent possible.

The need to rotate personnel into and out of the Area of Operations during a contingency will generate a considerably increased training burden over peacetime requirements. Training will be required as a result of the initial movement of Contingency Augmentation personnel, and the regular rotation of personnel throughout the duration of the contingency will create ongoing training demands. Most of this training would be performed by base Field

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25 My thanks to Group Captain (Ret'd) Kevin Griffin for these insights, based on Vietnam experience.

26 *Air Force Manual 1-1*, loc cit.

27 Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994, pp. 4-2, 5-5, 10-10, 11-2.

28 Self and Kozlowski, *Air Force Logistics Command Operations in Desert Storm*, p. 2.

Training Flights.[29] Contingency manpower plans (eg. Manpower Required in Uniform—see Annex H) must take this additional training burden into account, both in terms of instructors and students.

Experience

Deeper maintenance experience is crucial to the success of a BDR program. Only such experience can provide the detailed knowledge of weapons systems necessary to repair the kind of damage that occurs in practice.[30] Maintenance manuals will never be able to provide standard repairs for every kind of damage that may arise.

Responsibility

A balance needs to be struck between requiring personnel to take personal responsibility, and offering them organisational indemnity for errors of judgement. During a contingency, personnel should be encouraged to exercise maximum initiative; almost by definition, this involves operating in the absence of, or contrary to, existing guidelines. Invariably, some initiatives will prove incorrect. If members are severely penalised in such cases, initiative will be discouraged, and a more conservative risk avoidance approach is likely to result. Tradesmen may be unwilling or unprepared to do anything other than 'by the book'; maintenance requirements determination analysts may be loathe to adopt maintenance policies without sanction from the original equipment manufacturer.

Those personnel attributes sought during wartime should be encouraged and nurtured during peacetime. This means that peacetime policies that discourage initiative, such as undue personal responsibility, must be avoided. This may mean that the ADF needs to adopt a more avant-guard approach to its technical functions than civilian operators, who have no equivalent to contingency requirements. Some inefficiency, even risk, may result—but the benefits during a contingency are clear.

With increasing emphasis in the ADF on personal accountability and responsibility for decisions, some clarification on the extent of organisational indemnity offered may help to encourage personnel to develop their ingenuity.

Authority generally shifts away from command headquarters and logistics squadrons to operational units during a contingency. To enable this transfer of responsibility to function effectively, unit personnel must be able to exercise some significant measure of responsibility during peacetime, if only during exercises. For example, if units are to be responsible for approving at least some BDR designs during a contingency, they must be involved in the design process in some capacity during peacetime.

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29 HQTFG TFG/1201/9/P3, *TFG Contingency Manning Requirements*, CDR TFG, 24 February 1994, paragraphs 16, 23. Contingency Augmentation, and the management of personnel during a contingency, is discussed in Annex H.

30 Captain Jack Cooley, USAF, *USAF Combat Logistics Support Squadron Briefing*, Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, Section 4, Enclosure 7.

Likewise, procedures should be in place during peacetime to ensure that those organisations that would receive additional authority during a contingency have the infrastructure in place to properly discharge their contingency responsibilities. This issue caused problems for the Army Logistics Management Squadron when attempting to support the Operation *Gemini* deployment of Blackhawk helicopters in Cambodia.[31]

SUMMARY

History shows that good people are a most important asset in wartime. Personnel attributes and skills of benefit during a contingency include ingenuity, adaptability, communication, productivity, training, and experience.

Adaptability and communication skills of non-maintenance personnel can benefit maintenance performance in some cases. During a contingency, any spare members may be seconded to assist in maintenance duties, and aircrew co-operation with maintainers can significantly expedite aircraft turnaround.

Productivity is increased primarily by adopting changed working routines, but greater motivation during a contingency also accounts for a significant increase in productivity. Some attention to the provision of recreational activities can also assist productivity.

Broad training and experience of maintenance personnel are definite advantages during a contingency. Training requirements will increase significantly during a contingency due to the increased movements of personnel.

Personnel ingenuity can be encouraged during peacetime by the adoption and TQM, and by carefully balancing individual responsibility with organisational indemnity. An over-emphasis on personal accountability discourages experimentation beyond currently documented procedures, which is the essence of ingenuity.

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31 Captain Rob Crowe, 'ARMY LM SQN's Provision of Logistics Support for Operation *Gemini*', *The Logbook*, September 1994, pp. 19–23. Another complicating factor here was that Operation *Gemini* was a peacekeeping mission, and it is unclear whether peacetime or contingency procedures and delegations should apply in such situations. A clear statement on this issue should be made at the commencement of all such operations. Additionally, at the time, even the peacetime engineering authority procedures and delegations were somewhat tentative—contingency procedures and delegations much more so.

Chapter 23
Contingency Maintenance Management

INTRODUCTION

This chapter discusses the applicability of various maintenance management methods and expedients to contingency situations, including cannibalisation, servicing and production management, and the use of information systems.

CANNIBALISATION

One maintenance management expedient which is highly appropriate to wartime use is cannibalisation.[1] Cannibalisation can bolster availability levels in the face of shortages of spare components. Even though the inefficiency of cannibalisation does not reduce during a contingency, the requirement for maximum availability justifies its use. As a result, the rate of cannibalisation can be expected to increase significantly during a contingency.[2] It may be appropriate to factor this additional workload into estimations of deployment manpower requirements.

To maximise the efficient use of cannibalisation during a contingency, it must be practised during peacetime.[3] Thus, the peacetime attitude to cannibalisation should not be to *minimise* its use, but to limit it to the minimum level necessary to provide adequate experience in its use. This level needs to be established, and the experience must be shared around as many relevant maintenance managers as possible (bearing in mind that delegation levels may be pushed lower during a contingency). Plans for the use of cannibalisation during a contingency should be prepared during peacetime.[4]

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1 DI(G) LOG XX-X, *Principles for the Maintenance of Technical Equipment*, draft, 1994, paragraph 22b; and ADFP4, Operations Series, *Mobilisation Planning*, First Edition, draft, 1994, paragraph 434. Cannibalisation was introduced on p. 87.

2 Colonel Clifford R. Kreiger, 'Fighting the Air War: A Wing Commander's Perspective', *Airpower Journal*, Summer, 1987, pp. 21–31. Cannibalisation was indeed used extensively during the Gulf War (STLO NAVAIR 79/2/Air Pt 2 (61), *F/A-18 Persian Gulf Operations – Canadian Forces Engineering/Logistics Lessons Learned*, STLO NAVAIR, 10 July 1991).

3 loc cit.

4 DI(G) LOG XX-X, loc cit.

Factors Influencing Cannibalisation

The effectiveness of cannibalisation depends on the availability of spare components; the fewer spares available, the more important cannibalisation becomes. Figure 23-1 shows the results that may be achieved.

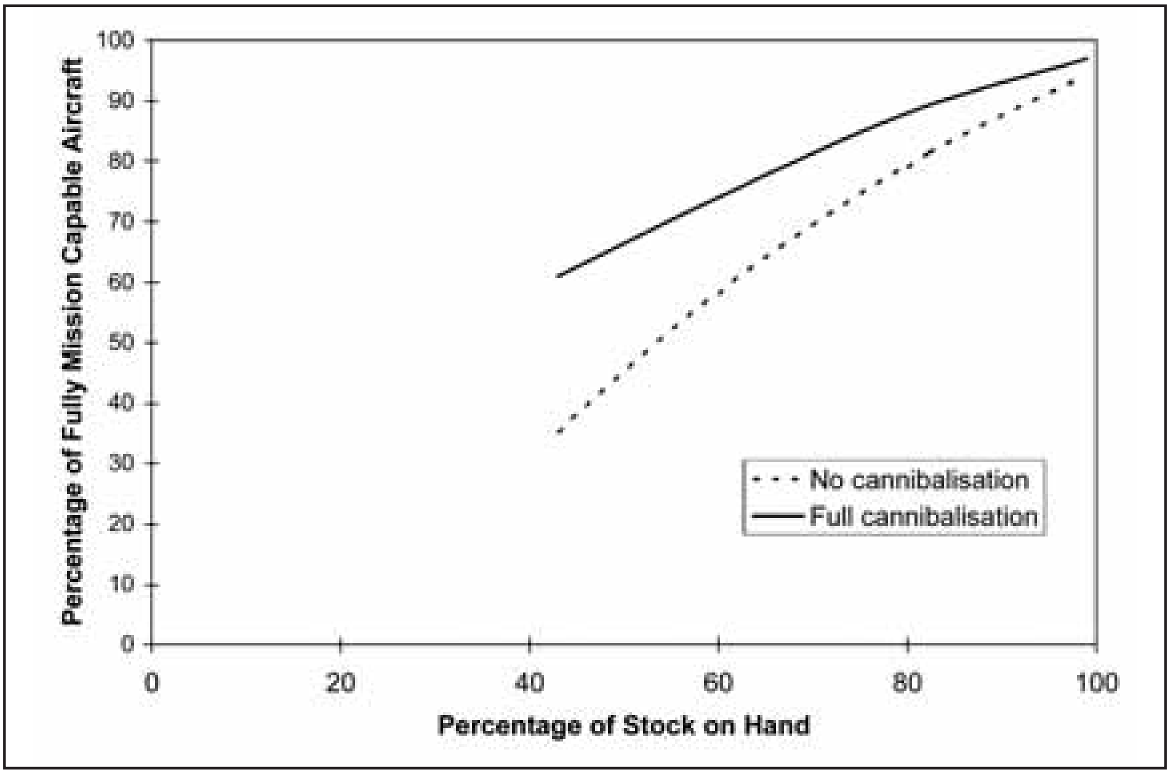

Figure 23-1: Effectiveness of Cannibalisation[5]

Cannibalisation of non-deploying aircraft may be required to complete Fly-Away Kits (FAKs). This practice may be necessary prior to deployments where resupply lines may be slow to establish or unresponsive, eg. where great distances are involved. The impact of this practice would be greater where small fleet sizes are involved, since non-deployed aircraft (if any) would generally be required for training and other contingency-related roles. The only 'spare' aircraft may be those undergoing maintenance.[6]

Control of cannibalisation (ie. minimising the adverse effects of cannibalisation) is assisted by close communication between those who cannibalise (typically deployed maintenance personnel) and those who provide the parts required (typically deeper maintenance venues).

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5 Based on John B. Abell and Thomas F. Lippiatt, 'Effective Logistics Support in the Face of Peacetime Resource Constraints', RAND, June 1990, Figure 9. This graph represents the results of a computer simulation of the availability of a fleet of 72 F-16C/D aircraft.

6 The USAF took this action prior to deploying for the Gulf War. As a result, many of the non-deploying aircraft were grounded; many others flew with missing components ('holes') (United States General Accounting Office, *Operation Desert Storm – The Services' Efforts to Provide Logistics Support for Selected Weapon Systems*, September 1991, pp. 25–26).

Collocation of these organisations is a significant advantage, but will not normally occur during a contingency.[7]

There is some evidence that increasing complexity (ie. higher technology) aircraft may benefit from greater levels of cannibalisation, possibly as a result of the larger number of *types* of spare components that must be stocked, and the lower numbers of each type actually held.[8] In addition, more recently introduced aircraft types will also frequently require more cannibalisation, until more experience is gained with the logistics support of the aircraft.[9]

Cannibalisation can be used more extensively when personnel have broader training and experience, particularly in Deeper Maintenance (DM). This allows a greater range of components to be cannibalised, since DM skills are required for the removal and refitting of many items.

Beyond Cannibalisation

Even when cannibalisation (and other expedients such as BDR) cannot return an aircraft to a standard where it is capable of performing *all* of its assigned mission types, the aircraft may still be usefully returned to service if it is capable of performing *at least one* of its mission types. Such partially mission-capable aircraft reduce flexibility in assigning aircraft to sorties, but can improve the overall level of availability.[10]

An aircraft which cannot be made even partially mission-capable may serve as a source of spare components which may be cannibalised to return other aircraft to serviceability (ie. used as a 'Christmas tree').[11] This practice must be managed carefully, since the option of repairing the aircraft and returning it to service relatively quickly is denied if it is extensively cannibalised. The short-term benefit of extensive cannibalisation must be balanced against the longer term possibility of returning an additional airframe to service.

Aircraft that are grounded for some period, eg. because they are a source of cannibalisation, can be put to use as test beds for fault finding and testing the serviceability of repaired components.[12]

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7 During the Gulf War, many intermediate level maintenance units deployed to the Gulf; this greatly assisted the efficient management of cannibalisation (discussion with Captain Scott Loch, USMC, 3 Squadron FLAMO, 24 February 1994).

8 These effects of technology are discussed in Chapter 18.

9 United States General Accounting Office, *B-1B Parts Problems Continue to Impede Operations*, July 1988, p. 47.

10 When this approach is used, availability should be measured in terms of the number of *fully* mission-capable aircraft and the number of *partially* mission-capable aircraft.

11 This approach was used in the Gulf War (James P. Coyne, *Airpower in the Gulf*, Air Force Association, Virginia, 1992, p. 133).

12 Jeffrey P. Rhodes, 'Eagles 17, Bean Counters 4', *Air Force Magazine*, April 1988, pp. 74–80.

MAINTENANCE SCHEDULING

Maintenance Interval Extensions[13]

The need for increased availability, and the de-emphasis of airworthiness and other peacetime goals, argues for greater flexibility in the use of maintenance interval extensions during a contingency. Authority to approve extensions should be delegated to deployed personnel to the maximum extent possible, to ensure responsiveness. This will require that data used in the maintenance requirements determination process be accessible on deployment.

Carried Forward Unserviceabilities[14]

Carried Forward Unserviceabilities (CFUs) should also be used more liberally during wartime, again reflecting the emphasis of availability over airworthiness. Maximum availability of engineering data on deployment would assist the making of informed decisions.

There are strong parallels between the considerations required for approving CFUs and for assessing BDR; therefore, the deployed BDR infrastructure could be a useful source of advice (or authority) concerning CFU deliberations. More significant damage may require disposition by non-deployed agencies, and even non-ADF agencies (such as the OEM). Streamlined processes and channels of communication are required in such cases.

Transitioning To and From Contingency Maintenance

The timing of the transition from peacetime maintenance schedules to contingency maintenance schedules must be well judged. A premature transition will unnecessarily degrade airworthiness and asset preservation (and even future availability); a tardy transition can mean that operational requirements cannot initially be met due to insufficient availability. There will be considerable pressure to move to contingency maintenance at an early stage due to the desire for maximum flying training during work-up, but the adverse implications for the remainder of the contingency of too early a transition must always be considered.[15]

The process of transitioning from one set of maintenance schedules to another is not a trivial exercise, unless the schedules are very similar. Some task durations will be extended; others will be reduced. Determining when to conduct the first contingency maintenance servicing without either undermaintaining items with reducing maintenance intervals, or overmaintaining items with extending intervals, is a difficult art.[16] Procedures for this need

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13 Maintenance interval extensions were introduced on p. 86.

14 CFUs were introduced on p. 87.

15 The Canadian Forces admit to moving to contingency maintenance schedules prematurely, prior to the Gulf War (STLO NAVAIR 79/2/Air Pt 2 (61), loc cit.).

16 A means of transitioning from one set of maintenance schedules to another is determined by HQLC at the completion of every Maintenance Engineering Analysis review (see p. 63). The process is scantily documented, and is largely retained by corporate knowledge. However, with the dissolution of the relevant section of HQLC, there is a significant risk that this corporate knowledge may be lost.

to be documented, and all contingency maintenance schedules should include a transition plan which can be quickly and easily implemented.

At the conclusion of a contingency during which contingency maintenance provisions have been exercised, it will be necessary to return aircraft to peacetime levels of airworthiness (and other sacrificed peacetime maintenance goals). Usually, additional maintenance will be necessary, and options and considerations for this are well documented.[17] Unlike the transition from peacetime to contingency, time will not be at a premium, so there is little need to plan for aircraft recovery in advance. Such planning is best left until the conclusion of the contingency in any case, when the state of the fleet can be properly assessed.

Deeper Maintenance Production Management

During peacetime, predictable usage patterns allow DM component production requirements to be reasonably accurately forecast; this allows DM production to be largely decoupled from immediate operational requirements. Variations from the expected usage patterns can usually be absorbed by spares holdings present in maintenance pipelines. This allows long-range predictions to be made regarding DM production requirements, which in turn allows cost-effective techniques such as batching production runs, just-in-time acquisition of subcomponents, etc. However, contingency logistics requirements are far less predictable.[18] The unpredictable nature of contingency operations requires that production management techniques used in ADF and contractor venues be closely linked to the continually changing requirements of the operational force.[19]

US research has indicated the magnitude of possible benefits that may be obtained from the use of an operationally-responsive DM production scheduling system. Predictably, the size of the benefit increases when production capacity is more limited: production scheduling decisions must be more accurate. Under tightly constrained capacity, a responsive priority repair system could achieve 80 per cent availability of the fleet studied after one year; a ‘first come, first served’ scheduling strategy could achieve only 50 per cent.[20]

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17 DI(AF) LOG 13-7, *Contingency Maintenance and Battle Damage Repair of Technical Equipment*, draft, 28 February 1994, paragraph 16; and DI(AF) AAP 7038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, paragraphs 746–747. Curiously, there is almost no documentation on processes for transitioning to contingency maintenance, for which time is of the essence, and the stakes are considerably higher.

18 I.K. Cohen and R.A. Pyles, ‘Empowering the Commands to Provide Logistics Support’, 1992.

19 During the Gulf War, the USAF Logistics Command made daily adjustments to maintenance production schedules (Michael Self and Edward Kozlowski, *Air Force Logistics Command Operations in Desert Storm*, Headquarters USAF Logistics Command, HQ AFLC/XPOX, July 1991, p. 15).

20 Abell and Lippiatt, ‘Effective Logistics Support in the Face of Peacetime Resource Constraints’. The whole study is quite complex and involves many other parameters and assumptions. The example quoted is only intended to show the *importance* of reactive scheduling, not the exact magnitude of the effect. Even a ‘first come, first served’ strategy is more responsive than simply working to long-range forecasts of requirements, which is how much RAAF and contractor component deeper maintenance is managed.

Experience bears out the significance of the difference between peacetime and contingency DM production scheduling requirements. At least one USAF Air Logistics Center had to modify its scheduling concepts to adapt to the requirements of the Gulf War, as the peacetime approach of large batch forecasting and scheduling proved ineffective.[21] Peacetime logistics data are of very limited use when attempting to predict wartime requirements.[22]

Many RAAF deeper maintenance venues are currently turning to commercial approaches to production management. Many defence contractors will also use similar methods. One popular method is *Manufacturing Resource Planning* (MRP), and its derivatives.[23] MRP is at its best when working with requirements which may be accurately forecast several months in advance. Changing requirements on a weekly basis will cause the MRP algorithm to attempt to update production schedules, but organisational inertia results in relatively slow changes to production priorities. As a result, the MRP algorithm can become somewhat unstable, issuing fluctuating requirements containing significant discrepancies. The responsiveness of MRP can be improved by a number of means (the use of *Just In Time* (JIT) is one of these), but still weekly variations to production requirements will cause problems. While MRP can still be used in such circumstances for longer-range planning and determining purchasing requirements, other means must be adopted for effective shop floor job control.[24]

A full JIT system offers many advantages over MRP (or MRP II) alone. However, it still requires a basically level (ie. unchanging) production schedule as a prerequisite. JIT emphasises, *inter alia*, the elimination of waste—this includes queues in production runs and spare stocks of inventory.[25] Any sudden variations in production requirements cannot be easily absorbed because of the absence of such buffers. JIT is therefore potentially very efficient and economical in a steady environment, but could not deal effectively with the unpredictability and variation of contingency requirements.

An Australian government study into ADF stockholding policy noted that ‘while the ideal just-in-time environment does not equate to the fluctuating demand patterns and “just-in-case” segments of the ADF inventory, variations of the just-in-time principle are being used

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21 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, paragraph 405a; and Warner Robins Air Logistics Center, ‘Making a Business of Acquisition and Logistics’, presentation delivered to *AOCLC* in 1991.

22 J.A. Stockfisch, ‘Linking Logistics and Operations: A Case Study of World War II Air Power’, RAND Corporation, p. 53.

23 In some sources, MRP stands for *Material Requirements Planning*.

24 J.E. Ashton, M.D. Johnson, and F.X. Cook, ‘Shop Floor Control in a System Job Shop: Definitely Not MRP’, *Production and Inventory Management Journal*, Second Quarter, 1990, pp. 27–31. The alternative to MRP advocated in this article for shop floor job control has some similarities with the *Theory of Constraints*. James T. Clark, ‘MRP to MRP II to JIT to CIM... The Journey’, in *1989 Conference Proceedings of the American Production and Inventory Control Society*, pp. 267–273, states that the most common failing in MRP II implementations is the lack of control on schedule changes. These must be restricted to the maximum extent possible—which is not consistent with contingency requirements.

25 Clark, ‘MRP to MRP II to JIT to CIM... The Journey’.

within the single-Services'. Even though JIT was first introduced in Japanese industry, the Japanese Self-Defence Force does *not* apply JIT to its stockholdings.[26]

Whereas most production control systems aim to balance capacity and demand, the Theory Of Constraints (TOC) advocates *excess* capacity, and *flow* is balanced against demand.[27] This surplus capacity allows variations in the level of demand to be more easily accommodated—which better suits the unpredictable nature of wartime logistics, and thus potentially offers improved responsiveness. There is some evidence that TOC approach is not as dependent on steady requirements, and offers a more responsive approach to scheduling.[28] At least one USAF depot is turning to TOC as a production scheduling tool, after finding that its peacetime practices were unsuitable for wartime requirements.[29] The US Navy is also interested in TOC.[30]

One study notes that contingency logistics systems must work with considerably less data than peacetime systems, and doubts that any formal information systems for the *prediction* (as opposed to scheduling) of DM requirements during a contingency are realistic.[31] Rather, the emphasis must be on *responsiveness*.

As a consequence of these uncertainties, it would be prudent to either exercise DM production scheduling tools to verify their performance under contingency conditions, or to simulate or model the performance of the algorithms used. In view of the time and expense required to conduct actual exercises, especially where contractors are involved, the latter option would be the more feasible (although the results would not be as conclusive).

DATA AND INFORMATION SYSTEMS

Technical Data

On deployment, personnel may need to attempt deeper levels of maintenance than they are normally responsible for.[32] Success in this would be greatly facilitated if all relevant

26 The Parliament of the Commonwealth of Australia, Joint Committee on Foreign Affairs, Defence and Trade, *Stockholding and Sustainability in the Australian Defence Force*, Australian Government Publishing Service, Canberra, 1992, pp. 30–31.

27 E.M. Goldratt and J. Cox, *The Goal*, North River Press, New York, 1986, p. 255. TOC was introduced on p . 91.

28 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'. TQM is also cited as being compatible with production in a rapidly changing environment.

29 Warner Robins Air Logistics Center, 'Making a Business of Acquisition and Logistics'.

30 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, paragraph 505.

31 Cohen and Pyles, 'Empowering the Commands to Provide Logistics Support'. MRP, MRP II and JIT are notoriously data-hungry, consistent with their aim of *predicting* requirements.

32 Warner Robins Air Logistics Center, 'Making a Business of Acquisition and Logistics'.

technical data were available on deployment.[33] Presently, this means deploying with many large maintenance manuals, but in the near future on-line manuals should be available, which would substantially reduce the bulk of such information. Alternatively, data not held at the deployment site could be accessed via computer communications with remote data repositories.

The same strategies would facilitate the design of repairs (eg. BDR) on deployment. Moreover, regardless of where repair design is conducted, the ADF must obtain and manage sufficient technical data to support repair design and maintenance requirements determination decisions.[34]

Information Systems

Most current RAAF information systems involved in predicting logistics requirements are largely driven by historical (peacetime) data. However, as stated above and in Chapter 21, peacetime data is not a reliable indication of contingency requirements. Logistics information systems must therefore be capable of responding to the rapidly changing contingency environment, deriving logistics requirements from day-to-day operational needs rather than from peacetime history.[35]

Chapter 21 suggested that logistics responsiveness is enhanced if logistics requirements are determined within the operational organisation (ie. AHQ and AHQ units). A responsive system must obtain significant input from operational staff on deployment.[36] This is consistent with the desirability of a 'pull' logistics system, and the associated need for deployable logistics information systems was verified by Gulf War experience.[37]

Although information systems may be required to perform differently under contingency conditions, it is important that they are recognisably similar in both scenarios, at least as far as the user is aware. This applies equally to paperwork and computer-based systems.[38]

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33 DI(AF) LOG 13-7, paragraph 18c states that technical data should be available on deployment to assist in BDR design.

34 LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993, paragraph 41d notes the requirement to maintain sufficient technical data within the ADF, if only to avoid the deterioration of the data which may result if it needs to be transferred between contractors.

35 The need for information systems to be responsive to operational needs is stated in DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, paragraph 10.28.

36 DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraph 46a, identifies the need for information systems to be able to perform critical functions at deployed locations.

37 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, paragraph 1004a. US plans for deployable information systems cover such areas as logistics planning, aircraft maintenance, and contracting. US forces aim to be more self-sufficient on deployment than Australia needs to be, and so its deployment information systems requirements will be more demanding.

38 DI(AF) LOG 2-1, loc cit., specifies the requirement for information systems to be able to perform critical functions in the *same manner* at deployed locations during a contingency.

Canadian experience during the Gulf War suggests that changing systems upon entering a contingency can lead to confusion.[39]

Greater integration of logistics information systems is also necessary to support some of the processes described in this study (in particular, Annexes C and G). Maintenance requirements determination and maintenance policy data, component maintenance histories, maintenance task durations and costs, and servicing management (eg. PERT) data are among the information that should be brought together.[40]

A specific requirement for information systems peculiar to wartime is the need to track the location of BDR applied to aircraft, and also the identity of components which have been subject to BDR, dubious parts substitutions, and other contingency-specific expedients. Such components should be tracked separately so that they are not used in preference to fully serviceable components during the contingency, and are not fitted to aircraft after the conclusion of hostilities.

Communications

Communications between the deployment site and non-deployed agencies will be critical to ensure responsiveness.[41] In addition to computer communications, this also applies to voice (telephone) and facsimile. The importance of such links is increased where engineering authority is not delegated to deployed personnel.[42]

While the Australian communications infrastructure is of a very high standard, the same is not true of all regional countries.[43] This could pose problems when supporting regional allies, or for contributions to multinational operations. Plans to manage such situations should be formulated in advance; useful strategies include increased deployment of technical data and information systems (complete with information), and increased delegation of authority.

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39 STLO NAVAIR 79/2/Air Pt 2 (61), op cit. In fact, this principle extends well beyond information systems: organisational structures, maintenance concept, unit responsibilities, and so on should not change dramatically when transitioning to wartime, lest confusion result. The greater the changes necessary, the more thorough the training and exercising for wartime should be.

40 DI(AF) AAP 1000, loc cit., states the need for logistics information systems to be sufficiently integrated.

41 DI(AF) LOG 13-7, paragraph 18b, notes the importance of communications in providing responsiveness, specifically of the engineering approval process.

42 Discussion with Captain Scott Loch, loc cit. USMC depended on engineering authority from US-based agencies during the Gulf War.

43 For example, the unreliability of facsimile communications between Thailand and Australia has disadvantaged deployments to the former country (discussion with Squadron Leader S.S. Hayes, TFLOGAIR, TFLMSQN, 23 February 1994).

PERSONNEL MANAGEMENT

The utilisation of maintenance personnel can significantly influence the effectiveness of the maintenance function. The adoption of longer working hours (ie. less time off) and the use of longer shifts can improve maintenance capacity and efficiency, and permit around-the-clock support to operations. In addition, reduced supervision requirements can be adopted when it is essential to obtain a further increase in maintenance capacity. These methods all support the increase in availability sought for contingency operations, at the possible expense of the de-emphasised goals (such as airworthiness, cost-effectiveness, etc). Personnel management aspects are discussed more fully in Chapter 22.

SUMMARY

The use of cannibalisation should increase during a contingency, and its effectiveness increases as spares availability falls. Cannibalisation may also be needed to fill Fly-Away Kits. The additional workload required for cannibalisation should be factored into manpower plans, and cannibalisation should be exercised during peacetime, rather than simply minimised. Good communication between operational maintenance personnel and component maintenance venues can improve the management of cannibalisation, and cannibalisation can be used more extensively if maintenance personnel have broader skills and experience (especially in deeper maintenance).

The practice of extensively cannibalising one aircraft to support many others (ie. 'Christmas trees') can be most effective, but must be carefully managed. Aircraft grounded due to cannibalisation (or other causes) can be used as test beds.

Maintenance intervals should be treated more flexibly during a contingency. Authority to extend maintenance intervals should be pushed down, and relevant technical data to assist with such decisions should be available on deployment. Carried Forward Unserviceabilities (CFUs) should be used and managed similarly, with deployed BDR personnel possibly serving as a source of advice. Streamlined support for more significant interval extensions and CFUs must also be available.

The transition from peacetime to contingency maintenance schedules must be properly timed, balancing the desire for maximum availability at the outset with the need to preserve airworthiness and availability for the duration of the contingency (and beyond). Procedures for devising the transition from one set of maintenance schedules to another need to be documented, and contingency maintenance schedules should include a transition plan.

Peacetime component production management techniques generally rely on the constancy and predictability of demands. However, contingency operations tend to generate unpredictable and rapidly changing requirements, necessitating a more responsive approach to scheduling. There is some evidence that such techniques as MRP, MRP II and JIT are not suited to a dynamic environment; TOC appears to be better suited to contingency circumstances (while still offering peacetime efficiency). In view of these concerns, depot production management techniques used in the ADF should be evaluated (eg. by simulation) to verify their satisfactory performance under contingency conditions; where necessary, contractors may need to be encouraged to have sufficiently responsive systems in place also.

Technical data of various kinds must be accessible on deployment, to permit maximum delegation of authority. Such data includes design data (to support BDR), maintenance requirements determination data (to support contingency maintenance and interval extension decisions), and maintenance manuals (to support deeper maintenance and repair on deployment, when necessary).

Logistics planning and scheduling information systems must be capable of being driven by day-to-day operational needs, in addition to (or instead of) historical data. Information systems must fully support deployed operations, and there is some benefit to logistics plans being determined from deployment sites. Information systems (including paperwork) should not change dramatically between contingency and wartime, so that user familiarity is retained. Greater integration of information systems is necessary to fully support contingency maintenance planning; information that should be brought together includes maintenance requirements determination and maintenance policy data, component maintenance histories, maintenance task durations and costs, and servicing management (eg. PERT) data. Logistics information systems must be able to track aircraft and components that have been subject to contingency expedients such as BDR, dubious parts substitutions, life extensions, and so on.

Communications to and from deployment bases are crucial to maintenance responsiveness, especially where engineering authority is not extensively delegated. Plans for operations in areas with poor communications infrastructure need to be made; this could have greatest application in supporting regional allies and multinational operations.

Chapter 24
Conclusions and Recommendations

'Nothing succeeds in war except in consequence of a well-prepared plan.'

Attributed to Napoleon I, 1769–1821

INTRODUCTION

The bulk of this chapter discusses the major conclusions and recommendations flowing from the analysis in the preceding chapters (primarily those in Part 3). Only the broader, 'higher level' conclusions and recommendations are contained in this chapter; for additional detail, refer to the summary at the end of the relevant chapter or Annex.

Before listing specific issues, some broader and more general observations are offered.

GENERAL OBSERVATIONS

Many defence forces advocate a policy of 'train in peace as you expect to fight in war' (or similar wording). While this philosophy is generally agreed within the RAAF, it is not specifically stated, and is not fundamental to the peacetime activities of the RAAF (at least in non-operational areas). This leads to a lack of focus on contingency-related issues, and paves the way for practices which are best (or only) suited to peacetime operations. The lack of clear guidance on this issue pervades many of the topics covered in this study.[1]

Preparedness concepts are not fundamentally limited to short warning conflict and peacetime operational tasks, but could also be applied to the other ADF roles (ie. providing an expansion base for major conflict, and contributing to multinational operations such as peacekeeping). The CPD provides goals for the former roles, but there are no quantified goals for the latter roles. Not surprisingly, the lack of goals leads to a lack of planning to meet the (non-existent) goals. Although expansion and multinational operations are lower priority tasks, some planning is still appropriate, and so indicative goals should be established. It is ironic

1 Examples include the lack of proper contingency maintenance schedules, organisational issues, information systems issues, lack of contingency modifications, and disincentive to use expedients such as cannibalisation.

that the ADF's most frequent operational role is multinational operations—one of the roles denied a planning base due to unspecified goals.[2]

Defence doctrine and policy is generally well documented for most of the topics addressed in this study. However, there is a lack of implementation (or planning for implementation) in many areas. This may be attributable to the relatively recent issue of many defence instructions, necessitated by such changes as the MATLOG review, LMSQN formation, and the rearranging of many series of defence instructions. However, it may also point to a resource imbalance between policy makers and policy implementers. If the current lag in implementation persists over the next few years, some transfer of resources should be considered. This may be feasible, given that a stable policy framework should be developed within this timescale. The state of implementation of higher level defence instructions should be monitored; an unimplemented policy achieves nothing.

In many regards, the maintenance function appears to lag behind other related functions, including engineering and Repairable Item (RI) management. This lag is evident in the lack of contingency planning, or even contingency planning studies, being conducted in the maintenance world. (A notable exception is Battle Damage Repair.) Given the significant and direct impact that maintenance work can have on aircraft availability, and hence preparedness, this is somewhat surprising. A possible reason could be a lack of advocacy at higher ranks: engineering and supply are Officers' professions, and tend to generate greater interest amongst the Officer corps; however, maintenance is largely the domain of trades people, and is not championed at high level to the same degree.

Although the integration of logistics functions is proceeding well within the ADF (largely due to the formation of LMSQNs), there are still many opportunities for greater integration and coordination. At the highest level, operational and logistics planning should be brought together. Also, the maintenance requirements determination process is not as well integrated into the logistics system as it might be: interfaces are needed with supply processes (RI management and spares assessing), unit-level maintenance management and control systems, maintenance history databases, and more powerful statistical tools (such as Weibull analysis). Contractor data should be as accessible as data gathered from RAAF units (the importance of this increases with the greater level of contractor support advocated by CSP). All of these integration requirements have significant implications for existing and proposed information systems.

2 Examples where the lack of planning becomes a problem are in support to deployments distant from Australia, and uncertainty as to whether multinational operations warrant contingency expedients (such as increased delegations of authority, use of BDR, contingency maintenance, and so on). Current planning focuses on declared contingencies within Australia's borders, so these issues are not considered.

SPECIFIC CONCLUSIONS AND RECOMMENDATIONS

Maintenance Goals

The main goals of the maintenance function are to provide required levels of airworthiness, missionworthiness, availability and cost-effectiveness. Mission generation and asset preservation criteria add a time dimension to these goals. The maintenance function also influences the levels of operational performance and flexibility that may be exercised. To a large extent, these goals are in conflict with one another, and tradeoffs must be struck between them.[3]

Priorities for maintenance (ie. the relative importance of the goals) differ between peacetime and contingency. Availability and operational performance and flexibility become much more important during a contingency; airworthiness and missionworthiness are still highly desirable but may be downgraded if necessary; and asset preservation and cost-effectiveness assume significantly lower priority during a contingency.[4]

To facilitate the attainment of maintenance goals during a contingency, various expedients may be necessary, including a relaxation of serviceability criteria, reduction in the amount of maintenance undertaken, the use of Battle Damage Repair, and greater flexibility in procedures and delegations. Conversely, additional maintenance may need to be undertaken to permit greater operational performance and flexibility, and for operations in adverse environmental conditions. Given the time required to develop and refine these expedients, *preparation must be undertaken during peacetime* to permit prompt and effective use of the expedients during a contingency.[5]

Contingency Maintenance Requirements Determination

The ideal amount of scheduled maintenance to undertake varies with the goals of the maintenance function. Likewise, the most appropriate servicing concept also depends on the goals. Since operational and maintenance priorities vary between peacetime and contingency, appropriate levels of scheduled maintenance required will generally differ between these scenarios, and even the servicing concept may need to be changed. Maintenance plans appropriate to contingency scenarios need to be developed in peacetime, since the work-up time immediately prior to a contingency will almost certainly be too short to do so.[6]

When adapting a peacetime scheduled maintenance program for contingency use, it is necessary to consider the adaptation of tasks already in the program, the addition of new tasks, and repackaging. Existing tasks may be abbreviated and/or performed less frequently

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3 See Chapter 6.

4 See Chapter 12.

5 See Chapter 12.

6 See Chapters 11 and 12.

(or not at all), and a set of criteria can be established to provide a framework to assist with such decisions. One such criterion is the likelihood that maintenance on the item will affect availability; an item importance hierarchy can be constructed to show which classes of items are most likely to do so. Maintenance on the aircraft itself generally has the most direct impact on availability.[7]

The adoption of more analytical methods for maintenance requirements determination may help to avoid the over-maintenance that usually results from subjective assessments. This would be particularly beneficial to contingency operations, when availability becomes paramount.[8] For example, the fact that the sustainability period is of limited duration may be exploited to provide additional gains in availability, by deferring scheduled maintenance that will not result in significant adverse effects for the duration of the contingency. Existing Maintenance Requirements Determination (MRD) processes are essentially steady-state, and are not suited to the identification of such opportunities. Accordingly, the MRD process needs to be augmented to provide this capability. This is a complex task, and may be best managed by a contractor or foreign service.[9]

Deferring maintenance tasks with longer intervals (such as DM tasks) can enhance availability for longer than the deferral of short interval tasks; this effect means that the relationship between peacetime and contingency levels of availability (ie. sustainability) can vary significantly between aircraft types.[10]

The optimum servicing concept to use in a contingency may be different to that chosen for peacetime, with a composite flexible-periodic concept appearing to offer many advantages. It is probably undesirable to change servicing concepts between peacetime and wartime, so a decision about which concept to adopt should consider the needs of both situations. Repackaging of servicings is likely to be required to re-optimise a maintenance program adapted for contingency use.[11]

There may be a need to consider contingency maintenance for components maintained off-aircraft. Due to the existence of delays in the maintenance pipeline, extending maintenance intervals will be more effective than reducing the scope or duration of maintenance tasks.[12]

The adverse environmental conditions in Australia's likely area of operations will make the adoption of additional maintenance tasks highly desirable. These tasks should be identified and documented in the same way as peacetime maintenance tasks. Changes to Standard

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7 See Chapter 13 and Annex F.

8 See Chapters 7, 11 and 13; and Annexes C and D.

9 See Chapter 13 and Annex G. The USN currently sponsors the Reliability Centered Maintenance (RCM) process, which is closest in nature to this aspect of MRD.

10 See Annex G.

11 See Chapter 13.

12 See Chapter 13.

Operating Procedures should also be contemplated, and the effects of environmentally-caused unreliability must be considered when determining stockholding levels required for contingency operations.[13]

Contingency maintenance programs should be developed for all aircraft types listed in the CPD. The Logistics Support Analysis (LSA) process is to provide the new environment for the performance of Maintenance Requirements Determination (MRD) in the RAAF. LSA has a multiple scenario capability, which could be used to conduct parallel analysis of peacetime and contingency requirements (and even analyses of multiple contingency scenarios). Currently, there are no plans to do this.[14]

Greater integration of aircraft servicing management and MRD would facilitate the optimisation of both processes, by allowing calculation of the relationship between component reliability and servicing duration. The performance of MRD within LMSQNs should assist the process by making available additional data, such as maintenance task durations and costs.[15]

Once developed, contingency maintenance schedules should be trialled in practice. However, there are significant problems with doing so in the most realistic manner, so limited duration trialling should be considered.[16]

Battle Damage Repair

Battle Damage Repair (BDR) techniques should be used to adapt unscheduled maintenance practices to suit contingency maintenance goals. Very significant increases in availability (or extensions to sustainability) can be achieved through the use of BDR. BDR requires a significant training investment, with ongoing continuation training and validation. Deeper maintenance experience very significantly increases the effectiveness of BDR; the decline of DM in the RAAF will therefore impact on the RAAF's BDR capability. DM requirements for BDR should be quantified and managed using the Manpower Required in Uniform (MRU) system as a high priority.[17]

DM venues have a responsibility to perform more significant aircraft repairs, if needed. Therefore, the BDR capability of contractors performing DM on RAAF aircraft should be assessed. If inadequate, additional contractual agreements may be required to rectify the situation, or alternative arrangements made for the provision of deeper BDR for affected weapon systems.[18]

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13 See Annex E.

14 See Chapters 7 and 14.

15 See Annex C.

16 See Chapter 14.

17 See Chapter 15.

18 See Chapter 15.

To maximise the potential benefits of BDR, the engineering approval process must be streamlined. Deployment personnel should be empowered to design and approve BDR to the maximum extent feasible.[19]

Apart from the concerns stated above, the RAAF's BDR policy and implementation planning is progressing well.

Modification and Configuration Management

The complexity of current processes for staffing modifications, and limitations in information systems, serve as disincentives to the identification and implementation of modifications to improve availability (and cost-effectiveness). Information systems and management processes should be improved to encourage greater use of modifications to meet these goals. Broadening logistics managers' accountability by adopting or emphasising performance measures other than financial expenditure (a peacetime priority) would also help.[20]

A surge of modification activity accompanies the onset of a contingency. There are significant disadvantages in such a last-minute rush. This situation can best be managed by anticipating contingency modification requirements to the maximum extent possible; in some cases, it may be feasible to design and approve (but not incorporate) contingency modifications in peacetime. In other cases, strategies to streamline the modification design and approval process can be employed; these should be devised and documented in peacetime. The need for haste emphasises the importance of a strong indigenous modification capability. Industry's role is particularly crucial where no in-house deeper maintenance capability is retained, and this responsibility should be clearly established during peacetime.[21]

The development of modifications is simplified if all aircraft are managed to a common configuration baseline to the maximum extent possible. 'Fitted for but not with' can also be used for the rapid incorporation of some capabilities, but has significant operational and maintenance disadvantages and should therefore be used carefully and sparingly. Complete modification of a subset of the fleet can go a long way to minimising the problems associated with the 'fitted for but not with' strategy. Configuration management must also consider the need for interoperability with allies, neighbours and other ADF services.[22]

Maintenance Locations and Responsibilities

A set of criteria should be used to determine which maintenance tasks should be conducted on deployment. Issues to be considered include the impact of the maintenance task on operations, the intensity of operations, the location and nature of the area of operations (AO), required level of mobility, allowable size of deployment, expected duration of contingency,

19 See Chapter 15.

20 See Chapters 9 and 17.

21 See Chapter 17.

22 See Chapters 9 and 17.

deployability of maintenance resources, and cost. These criteria can also be used to assess the effect of rotating aircraft and components from the AO to perform maintenance, and the need to establish cascading or progressive levels of deployed maintenance.[23]

Decisions must frequently be made concerning whether maintenance sections should work directly for operational commanders or whether they should be placed within a separate organisation. Such decisions should not be made without considering whether the resulting organisation should be structured for contingency or peacetime operation. There are advantages and disadvantages to each of the organisational options; in general, a tradeoff between responsiveness and management distraction must be made (although there are many other factors to be considered).[24]

There are significant disadvantages with the existence of an independent logistics organisation of the same status as the operational organisation, including the dilution of responsibility for operational goals, the difficulty of integrating logistics planning into operational planning, and the risk of an emphasis on historical data in place of responsiveness. Many of these problems could be minimised by downgrading the logistics organisation to the status of a supplier, rather than an equal to the operational organisation. The latter would be responsible for logistics requirements *determination*; the former for logistics *delivery*.[25]

Contingency contracting procedures need to be developed, and training in the use of these should be included in contract management courses. If civilians are to be used in the AO, plans must be made and exercised to provide sufficient safety and protection for them, to meet the legal requirements of Protocol 1 Additional to the Geneva Convention.[26]

A consequence of the Commercial Support Program (CSP) is increased dependence on civilian industry. This is likely to reduce the ADF's ability to support distant deployments, which may limit the options available for ADF contributions to multinational operations—currently the ADF's growth area.[27]

Increased use of Reserve forces should also be associated with CSP; however, it remains to be seen whether Reserve recruiting and retention can be retained at the required levels. Further reductions in the manpower levels of permanent forces should preferably be deferred until the targets for Reserve forces can be demonstrated to be achievable. Some indication of which CPD serials should be met using permanent forces alone, and which may be met with augmentation from Reserve forces, would assist manpower planning.[28]

23 See Chapter 16.

24 See Chapter 21.

25 See Chapter 21.

26 See Chapter 19.

27 See Chapter 19.

28 See Chapter 19.

The terms *operational maintenance* and *deeper maintenance* are intended to distinguish core and non-core maintenance capabilities; however, existing definitions are somewhat unclear. Alternative definitions may be derived which closely follow the core/non-core definitions, and take into account the criticality of the weapon system, whether the task is on-aircraft or off-aircraft, the state of spare parts pipelines, and whether the task is contingency maintenance or deferrable. A system should be established to cause the re-evaluation of core/non-core determinations whenever significant changes are made to the CPD.[29]

Commercialising peacetime servicings is complicated by the fact that these servicings contain some contingency maintenance tasks and some deferrable tasks. Moreover, the disposition of latent responsibilities such as aircraft recovery, modification and repair must be considered when commercialising a DM capability.[30]

Once contingency maintenance requirements are determined, relevant contracts should include contingency clauses to document the RAAF's expectations. Industry's ability to meet these as-yet-unspecified targets is not actively assessed, and means of improving industry's surge capability are not methodically exploited. There is a paucity of planning for industrial expansion to meet the ADF's requirements in higher levels of conflict.[31]

The Manpower Required in Uniform (MRU) system can ensure that sufficient uniformed manpower is retained so that the ADF can provide core capabilities during a contingency. For the MRU system to work properly, necessary data must be gathered during peacetime; *inter alia*, this includes identifying those positions that must have DM experience. Only in this manner can MRU ensure that sufficient DM capacity is retained in-house.[32]

The calculation of MRU data could be assisted by the use of an automated modelling capability. There would be significant benefits in integrating this with Logistic Capability Assessment (LOGCAS), although this level of integration is beyond current plans.[33]

The general reduction in overseas defence industry capacity may require increased self-reliance if Australia is to retain a constant level of logistics support. The Defence organisation needs to provide greater guidance on the priorities for the development and retention of local industry. Criteria that can be used to establish such priorities include the criticality of the weapon system, and the health of component supply pipelines.[34]

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29 See Chapter 19.

30 See Chapter 19.

31 See Chapter 19.

32 See Annex H.

33 See Annex H.

34 See Chapter 20.

Knowledge of international logistics agreements should be broadly communicated to ADF logistics managers. Similarly, guidelines for the use of host nation support by the ADF should be drafted and communicated.[35]

Maintenance Management

Information systems currently being introduced to model logistics performance all have their limitations. OPUS 9 cannot model dynamic scenarios such as the transition to a contingency, and LOGCAS is entirely dependent upon the provision of a flying program. These systems, as well as MRD, all require that maintenance and reliability data be provided as an input, but the information systems required to generate this information are not well integrated, and the process of extracting the data is laborious.[36]

Existing maintenance performance measurement systems are generally very weak at assessing performance against maintenance goals. Considerable work remains to be done in this area.[37]

Cannibalisation, and the use of 'Christmas trees', are important management practices during contingencies. Cannibalisation can also be used prior to contingencies to fill Fly-Away Kits. The expected amount (and inefficiency) of cannibalisation should be taken into account when preparing contingency manpower plans. For maximum effectiveness, cannibalisation should be *practised* in a controlled manner during peacetime, rather than discouraged outright. Good communication and breadth of experience also enhance the effectiveness and scope of cannibalisation. The use of 'Christmas trees' is a logical extension of cannibalisation; however, in general, no one aircraft should be used as a 'Christmas tree' for an extended period.[38]

Maintenance interval extensions and Carried Forward Unserviceabilities (CFUs) are also important expedients, and should be used more liberally and with greater delegations of authority during a contingency. Relevant technical data to support these (and other) decisions should be available on deployment, but systems to handle more difficult decisions must also exist.[39]

The timing of the move from peacetime to contingency maintenance standards is important, and either a premature or tardy transition can adversely impact on contingency maintenance performance. The process of determining exactly how to transition from one set of maintenance schedules to another needs to be documented, and a transition plan should accompany every contingency maintenance schedule.[40]

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35 See Chapter 20.

36 See Chapter 14.

37 See Chapter 14.

38 See Chapters 10 and 23.

39 See Chapter 23.

40 See Chapter 23.

Many popular component production management techniques (such as MRP II and JIT) do not appear to be well suited to the uncertainty and variability of contingency requirements; TOC seems to be a better system under such circumstances. Given these concerns, ADF (and contractor) production management systems should be carefully evaluated for effectiveness in contingency conditions. Simulation is probably the only feasible means of achieving this.[41]

Quality personnel are a most important asset during wartime. Even non-maintenance personnel, and especially aircrew, can aid the efficiency of the maintenance function. Personnel motivation and ingenuity provide for considerably improved performance during a contingency, but the magnitude of this effect is difficult to anticipate during peacetime. Broad training and experience is most important to realise the full potential of personnel, and wartime demands will significantly increase the requirement for training. Ingenuity can be encouraged during peacetime by such measures as TQM and by striking a careful balance between personal accountability and organisational indemnity.[42]

Data and Information Systems

ADF maintenance management information systems should provide better means for collecting data that would assist in MRD. Such data should be easily accessible to allow rapid tailoring of the maintenance program prior to and during a contingency. Greater integration of information systems is necessary to fully support contingency maintenance planning, which requires MRD and maintenance policy data, component maintenance histories (including identification of failure modes and the condition of items when due for scheduled maintenance), maintenance task durations and costs, and servicing management (eg. PERT) data. It must be possible to obtain these data from contractors (where appropriate), as well as from ADF sources.[43]

Information systems should provide capabilities for tracking BDR-repaired components, whether on-aircraft or off-aircraft.[44]

Technical data should be available (or accessible) on deployment to support the option of performing increased levels of maintenance and repair on deployment, as well as BDR design, and contingency maintenance and interval extension decisions. Communications to and from deployment sites are also important for these practices, especially where engineering authority is not extensively delegated. Communications infrastructure could be a problem when supporting regional allies and multinational operations; alternative management provisions should be available in such situations.[45]

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41 See Chapter 23.

42 See Chapter 22.

43 See Chapters 7, 14 and 23; and Annex C.

44 See Chapter 15.

45 See Chapter 23.

Contingency scheduled maintenance requirements, and the associated reliability estimates, are fundamental to the determination of contingency stockholding (and other logistics) requirements.[46] Logistics planning and scheduling information systems must not over-emphasise the use of historical data for planning and scheduling, but must be responsive to rapidly changing operational requirements, and must function similarly in peacetime and wartime. Deployment support is most important, possibly to the extent of allowing logistics plans to be *determined* by deployed staff.[47]

Technology

While technology can confer significant advantages, it has several adverse implications for maintenance. High technology systems are more complex, and not necessarily more reliable. Procurement and support costs are usually higher, logistics arrangements are more complex, maintenance manpower and skill levels are increased, self-reliance is reduced, the need for industry support is greater, and surge capacity is reduced. Improved maintainability (eg. modular design) and built-in test equipment can negate some of these disadvantages. The implications for maintenance of the use of technologically advanced equipment must be taken into account when considering the procurement of such equipment; technology should only be acquired when the operational need justifies the advantages over the disadvantages.[48]

As a result of the increased support demands of high technology equipment, some reduction in the 'tooth-to-tail' ratio is to be expected if the 'teeth' and 'tail' are measured simply in terms of manpower levels. However, when the additional *capability* of high technology equipment is taken into account, the ratio should be more favourable. Attempting to under-support advanced technology equipment would have adverse operational implications.[49]

46 See Annex E.

47 See Chapter 23.

48 See Chapter 18.

49 See Chapter 18.

Annexes

Annex A
Measures of Reliability Trends

INTRODUCTION

Reliability is the *probability* that an item will perform its *intended function* (ie. not fail) for a *specified period* when used under *specified conditions*. Since this definition is expressed in terms of probability, statistical methods are needed to work with reliability data. This annex outlines various ways of representing reliability information, and introduces two commonly used mathematical failure distributions. Armed with this knowledge, the significance of Mean Time Between Failures (MTBF) is re-evaluated.

MEASURES OF RELIABILITY

Probability Density Function

The most fundamental representation of probability is the *probability density function* (PDF). This is normally a graph of probability (or relative frequency of occurrence) on the vertical axis, and the relevant characteristic on the horizontal axis. For example, the distribution of the weight of a certain kind of commodity may look like the PDF in Figure A-1.

To produce a PDF to show how an item's reliability changes over time, the horizontal axis must represent the age of the item.[1] An example is at Figure A-2.

A reliability PDF is surprisingly easy to misinterpret. Figure A-2 does not necessarily indicate that beyond 400 hours the reliability of components increases; or, that a component is less likely to fail beyond the 400 hour point than it was previously. It is best to consider the performance of a set *number* of components: the graph predicts that many of these components will fail at about the 400 hour mark, and that successively fewer will fail thereafter. Few components can fail later in life because few components survive that long. Even if the PDF depicts a case where reliability improves with age (such as a wear-in failure pattern), the PDF will still taper off to the right, as the number of surviving items in the population reduces.

1 Recall that the age of the item should be expressed in the units that best suit its failure mode(s). See p. 50.

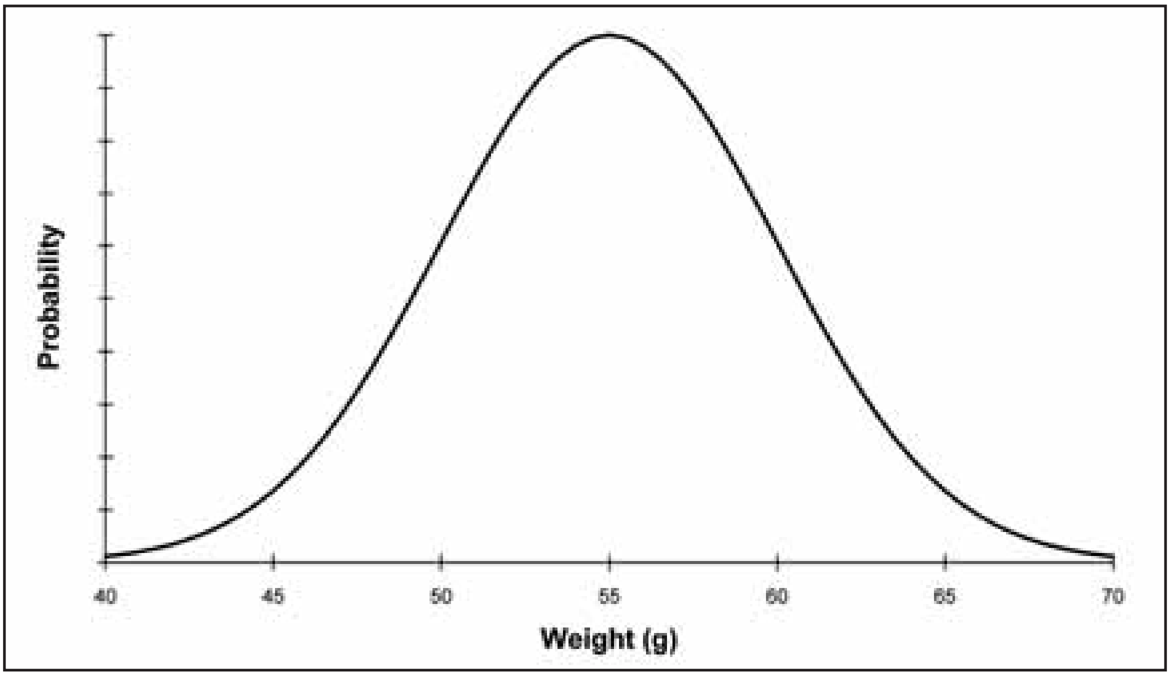

Figure A-1: Commodity PDF

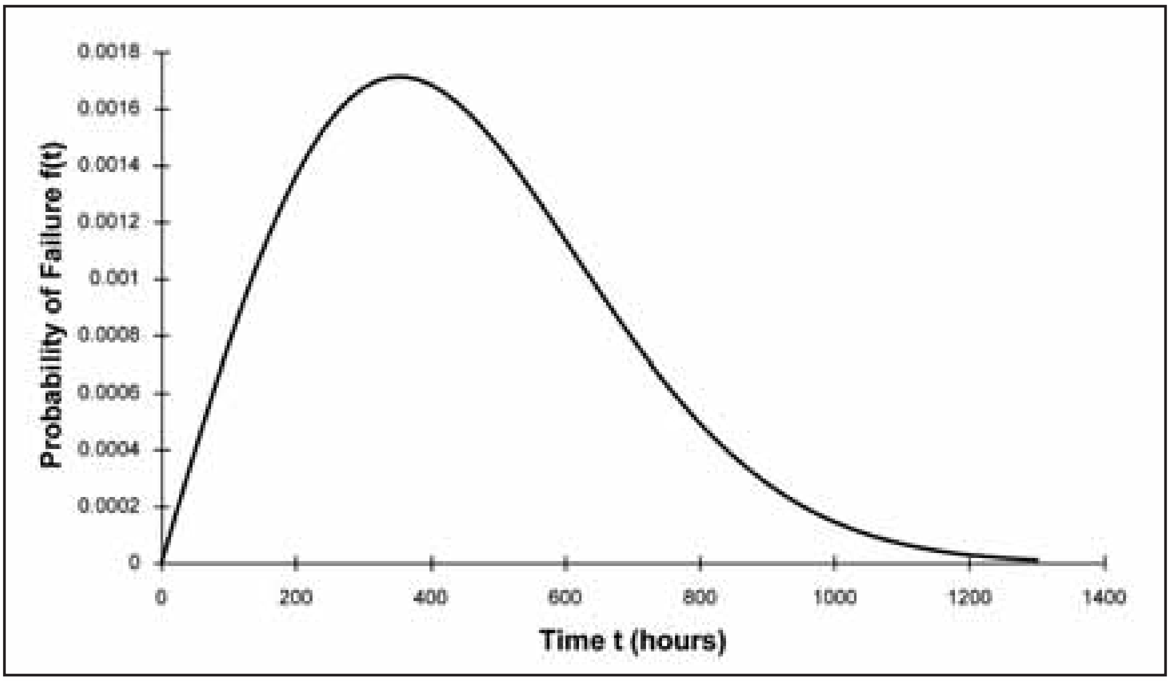

Figure A-2: Reliability PDF

Mathematical equations can be used to describe the shape of the PDF. The symbol *f(t)* is usually used to designate mathematical PDF equations. Two examples of such functions will be described later in this annex.

The units of probability on the vertical axis seem rather small. This is because the area under the whole of the curve, which represents the probability that *all* items in the population will eventually fail, must be one. The vertical axis indicates the probability that an item will fail *within a unit time interval*. For example, the probability that an item will fail between 199.5 and 200.5 hours, a unit time interval, can be read directly off the graph, and is about 0.00135.

It is more useful to be able to find the probability that an item will fail between two arbitrary points in time, such as between 100 and 200 hours. This can be found from the PDF by measuring the area under the curve between the two time values; however, it is easier to use the *cumulative probability function* for such calculations.

Cumulative Probability of Failure

The cumulative probability of failure graph plots the area under the PDF curve from zero to time *t* on the vertical axis, against time *t* on the horizontal axis. The meaning of this area is the probability that an item will fail between time 0 and *t*; ie, before time *t*.[2] Figure A-3 is the cumulative probability of failure graph for the PDF at Figure A-2.

This Figure indicates that the probability that an item will have failed before it reaches 200 hours life is 0.15. In other words, 15 per cent of the original population of items will have failed before they reach 200 hours. The probability that an item will fail within a particular time interval, eg. between 200 and 400 hours, can be found by subtracting the corresponding cumulative PDF values; in this case, 0.47 – 0.15 = 0.32.

Mathematically, the symbol *F(t)* is used to represent the cumulative probability of failure function.[3] It can be derived from *f(t)* by integration.

Reliability Function

A more optimistic measure of reliability is the reliability function. This is simply the inverse of the cumulative probability of failure, and therefore plots the probability that an item will *not* have failed before time *t*. Figure A-4 is the reliability graph for the same data as previously.

This graph shows that the probability that an item will survive to at least the 200 hour point is 0.85; or, 85 per cent of the population will still be in service after 200 hours. This agrees with the figure read from the cumulative probability of failure graph.

---

2 It does not make any difference whether failure is considered to occur 'before time *t*' or '*at or* before time *t*'. Mathematically, time intervals are infinitely thin; the probability of a component failing at time *t*=400.000 *exactly* is infinitely low. It really only make sense to talk about failures occurring in a set time *interval* rather than at a particular *point* in time. When we say that ten items failed at the 400 hour mark, we probably mean that they failed between 399.5 and 400.5 hours; ie. within a unit time interval.

3 In older references, *Q(t)* is used.

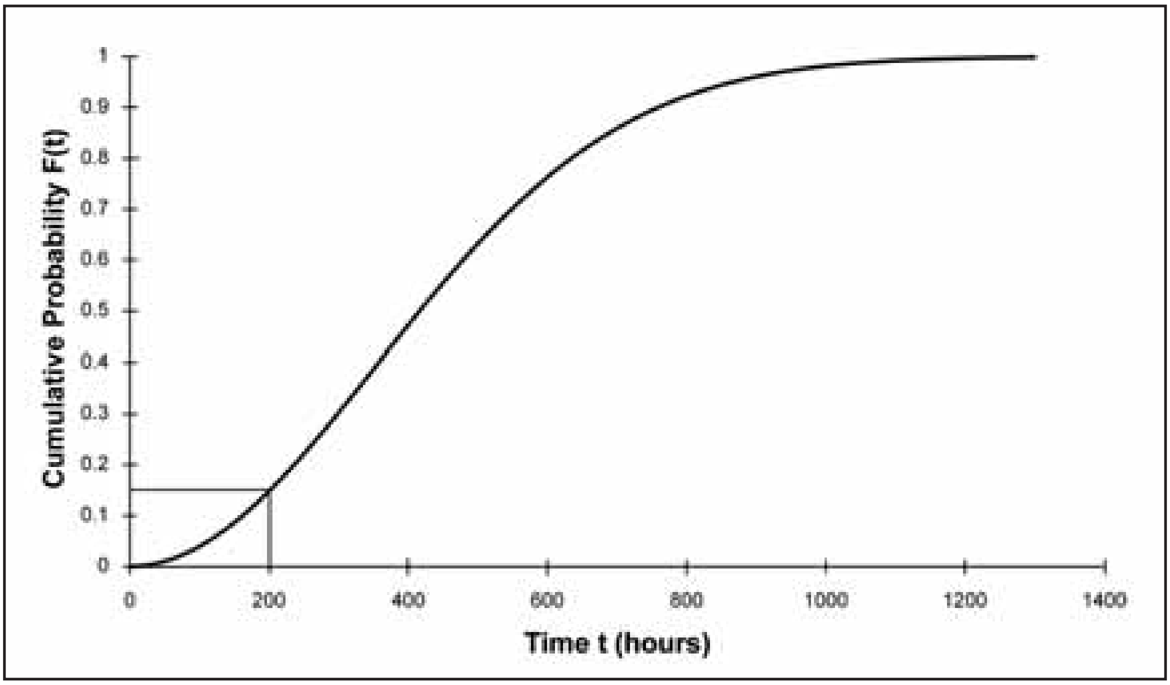

Figure A-3: Cumulative PDF

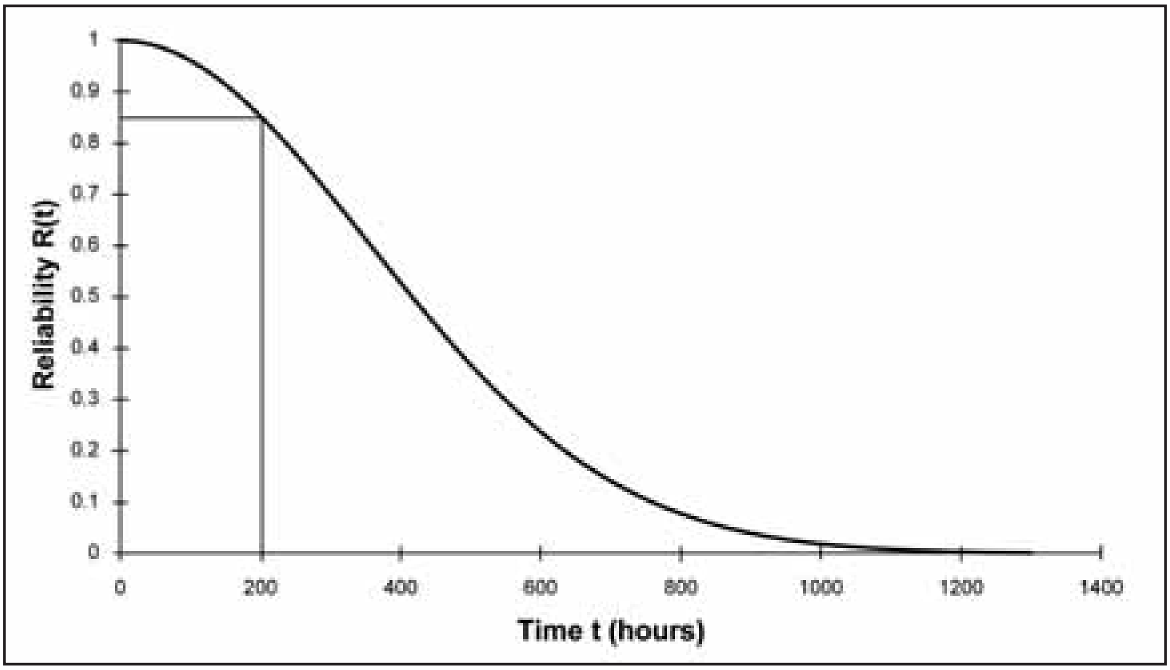

Figure A-4:Reliability Function

R(t) is used to denote the reliability function; it may be calculated from *F(t)* using:

$$R(t) = 1 - F(t)$$

None of the functions plotted so far enables us to determine whether an item's reliability is decreasing, increasing, or remaining constant as the age of items increases. This is a vital piece of information for maintenance requirements determination, as it is rarely appropriate to perform scheduled maintenance on a component that does not wear out. Moreover, if a wear-in failure pattern can be discerned for an item, we can attempt to improve in-service reliability by the adoption of an environmental test screening program.[4]

To use the information available so far could lead to inappropriate maintenance policies being set. For example, if the required reliability for the item under consideration is 85 per cent, the reliability function graph (Figure A-4) would indicate that a maintenance interval of 200 hours is required. However, unless the component was wearing out, and the maintenance action was able to restore its condition, the component's reliability will not improve. In fact, if the component is subject to wear-in, maintaining or replacing the item will *reduce* the reliability achieved.

Hazard Function

What is needed is a graph that shows how likely it is that an item will fail at time *t given that it has already survived up to that time*.[5] The PDF shows the probability of an item failing at time *t*, but does not take into account the probability of items surviving long enough to even reach *t*. The reliability function shows the probability of items surviving to time *t*. Combining the two concepts gives the hazard function. Figure A-5 shows the hazard function corresponding to the preceding graphs.[6]

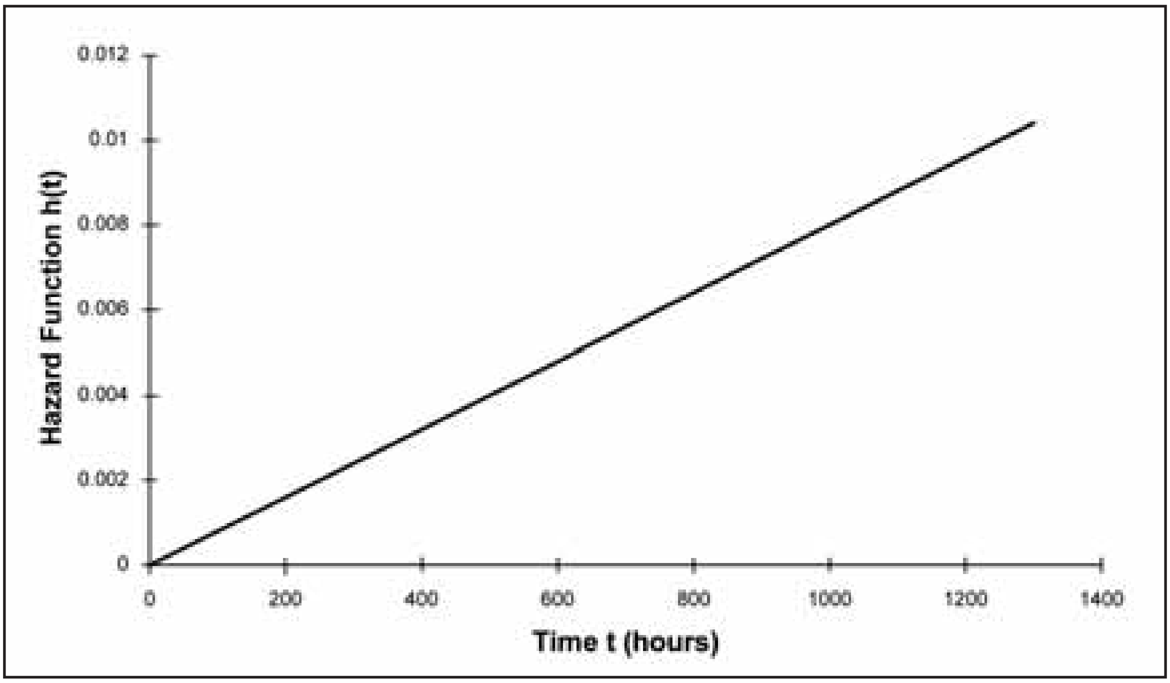

Figure A-5: Hazard Function

4 See p. 47.

5 Actually, the failure may occur *within a unit time interval* at *t*.

6 The reason that the hazard function graph does not look similar to any of the preceeding graphs, or any simple combination of them, is that it is found by *dividing* one function (PDF) by another (*R(t)*).

As with the PDF, the units of the hazard function are not particularly useful; however, the shape of the graph is most significant. The graph above shows that the probability of the item failing increases as the item ages; ie. the item exhibits a wear-out failure pattern. This item may be a candidate for some form of preventive maintenance.[7]

Other examples of hazard functions are at Figures 6-1 to 6-4.

Mathematically, the hazard function is denoted by *h(t)*, and may be calculated as follows:

$$h(t) = \frac{f(t)}{R(t)}$$

The hazard function is also known as the *instantaneous failure rate*, or simply *failure rate*.[8]

TWO USEFUL FAILURE DISTRIBUTIONS

The Exponential Distribution

The reliability of an item that is subject only to random failures will not change over time. This applies to many electrical and electronic components, where there are no significant time-dependent or usage-dependent failure modes, such as fatigue or wear.[9]

The hazard function of such items is a constant; this constant is called the *failure rate* and is indicated by λ.[10] The corresponding failure probability density function is an exponential decay;[11] specifically:

$$f(t) = \lambda e^{-\lambda t}$$

The Mean Time Between Failures (MTBF) of components with constant failure rate will also be constant. If the time taken to effect repair is neglected, the MTBF (θ)[12] is simply $1/\lambda$.

---

7 Other considerations must still be taken into account, eg. is there a maintenance task that can improve the reliability of the item? Is it more cost-effective to let it fail, and then replace it? See also Chapter 7.

8 This term is somewhat ambiguous, as *failure rate* is the name of the parameter in the exponential failure distribution (discussed shortly), where it is a constant and may be related directly to MTBF. However, the exponential distribution is a special case; in other cases, *h(t)* is not constant, and cannot be so easily related to MTBF.

9 As always, there are exceptions. Periodic usage of electrical equipment results in temperature cycling, which can induce failures in soldered joints or connections. These are common failure modes in circuit cards, and can exhibit wear-out.

10 λ is the Greek letter 'lambda'.

11 For a derivation, see I. Bazovsky, *Reliability Theory and Practice*, Prentice-Hall, New Jersey, 1961, Chapter 4.

12 θ is the Greek letter 'theta'.

λ is the only parameter that is necessary to specify the form of the exponential distribution for an item, and it can be easily estimated from failure data as λ=1/θ (ie. 1/MTBF).

The reliability of components exhibiting random failure is therefore given by:

$$R(t) = e^{-\lambda t} = e^{-\frac{t}{\theta}}$$

The exponential distribution is useful for the relatively simple mathematics associated with it. Assuming a constant failure rate for items is frequently done during early stages of a design, to enable first approximations of reliability and supportability requirements to be made. However, over-use of the exponential distribution should be avoided. Where accurate and complete in-service failure records are available, it is possible to determine whether an item's failure rate is constant or not. When it is not, a more appropriate failure distribution should be used.

The Weibull Distribution[13]

Unlike the exponential distribution, the Weibull distribution is not derived from a theoretical analysis of failure patterns; ie. it does not exactly model any particular theory or assumption of failure distribution.[14] The usefulness of the Weibull distribution is that it can approximate many different failure patterns: wear-in, random, or wear-out. The 'severity' or suddenness of wear-in or wear-out can also be approximated. Figure A-6 shows some of the forms that the Weibull distribution can take.

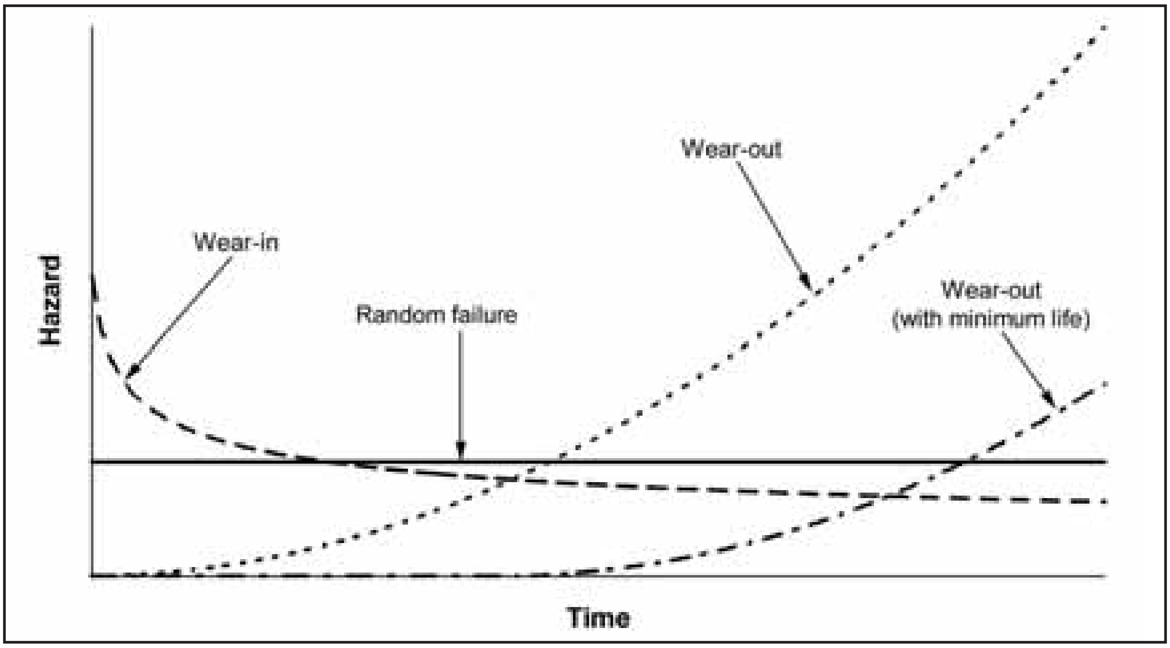

Figure A-6: Forms of the Weibull Distribution

13 This distribution is named after its originator: W. Weibull, *A Statistical Distribution Function of Wide Application*, ASME Paper 51-A-6, November 1951.

14 The exception is that the Weibull distribution *can* exactly model random failures, as the exponential distribution is a 'degenerate case' of the Weibull distribution.

The formula for the Weibull distribution, and the related reliability and hazard functions, are significantly more complex than those for the exponential distribution. Two or three parameters (η, β and sometimes γ)[15] are used to define a Weibull distribution, where only one parameter was necessary for the exponential distribution. None of the three parameters bears a convenient relationship with MTBF. Calculation of the best Weibull parameters to approximate an item's failure pattern is best performed by using a computer program.

When using Weibull analysis, it is important to bear in mind that it can only model *one* failure pattern at a time; ie. wear-in *or* random *or* wear-out.[16] If the component shows two or more of these patterns, the Weibull curve fitted will represent some sort of average of the patterns, but will not represent any of them accurately. If undue trust is placed on the fitted Weibull curve parameters, invalid conclusions can be made. For example, an item exhibiting both wear-in and wear-out may be approximated by a Weibull curve with a very gradual wear-out pattern over the entire life of the component (see Figure A-7).

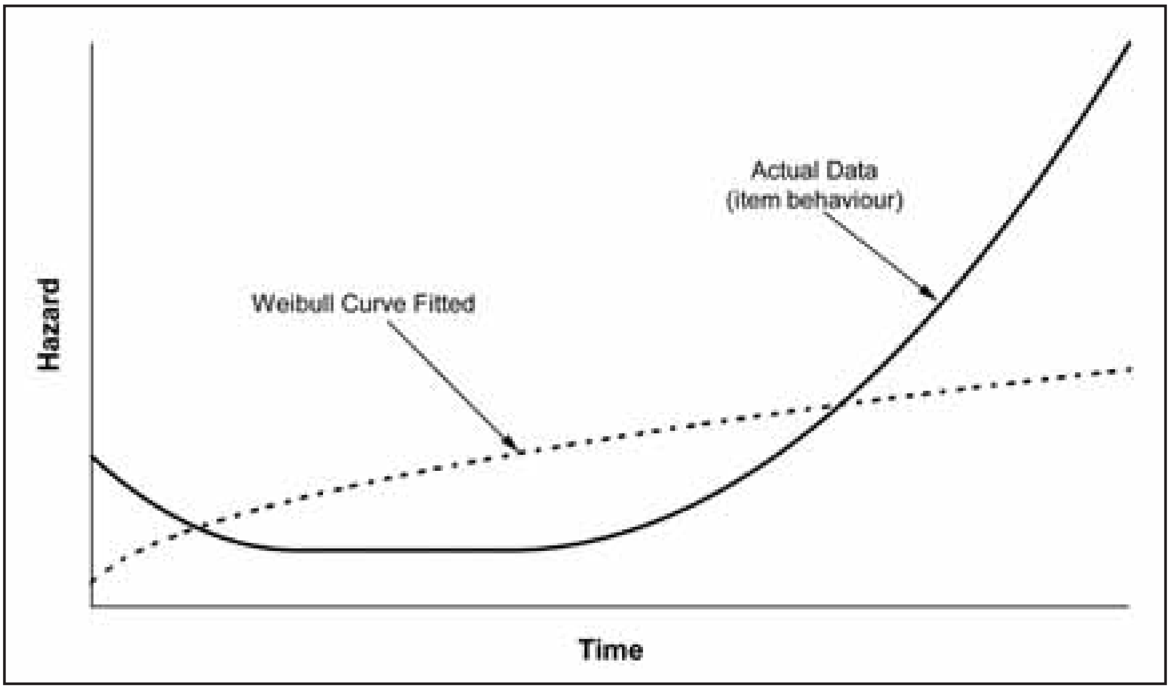

Figure A-7: Weibull and Multi-Modal Failures

Given the apparent subtlety of the wear-out pattern of the Weibull curve, it would be reasonable to perform no scheduled maintenance; if scheduled maintenance *were* to be performed, determining the appropriate interval would be very difficult. However, analysis of the *actual* data shows that scheduled maintenance (or scheduled throw-away) should be

15 'Eta', 'beta' and 'gamma' respectively.

16 This also applies to different severities of wear-in or wear-out. For example, Weibull analysis cannot accurately fit data representing two different wear-out failure modes, if one is significantly more sudden than the other or if they start at different times.

performed at the onset of the wear-out phase. Such a policy would improve airworthiness and missionworthiness as it would avoid virtually all of the avoidable (ie. wear-out) failures.

Detecting multi-modal failures using Weibull analysis alone is difficult. Measures of the 'goodness of fit' of the Weibull curve to the actual data will provide some clue, but a poor correlation between the curve and the data does not necessarily indicate a multi-modal failure pattern. Plotting a hazard function for the *actual* data (rather than a curve *fitted* to the data) can reveal such patterns,[17] but frequently the data are very 'noisy', and trends are hard to discern (this is why curves are often fitted!).

A third approach is to use a more flexible curve than the Weibull distribution. The *Hastings* distribution is an example; it comprises two Weibull curves, one offset from the other along the time axis, added together. The Hastings distribution can approximate *two* different failure patterns at the same time; eg. wear-in and then random. This is particularly useful when an item exhibits two relatively significant failure modes (eg. failure of two different subcomponents, or failure of one component in two different ways).

MEAN TIME BETWEEN FAILURE

Given this understanding of probability distributions and reliability measures, it is possible to re-evaluate the meaning and significance of Mean Time Between Failure (MTBF).[18]

Regardless of the failure pattern, or the existence of scheduled maintenance, a MTBF figure can always be calculated by dividing the total operating time accrued by the number of failures that occurred. This figure will be of use when attempting to estimate the number of failures that will occur in service, and hence provides an indication of airworthiness/ missionworthiness, and the need for appropriate spares or repair parts.

Beyond such general uses as these, MTBF can become very misleading. It is generally considered that MTBF is a measure of an item's inherent reliability (ie. the fundamental reliability achievable by an item by virtue of the way it is designed). As such, MTBF is not considered to be affected by maintenance policy; however, this is not the case. The existence of preventive maintenance effectively truncates the right-hand side of the hazard function graph, removing the possibility of failures beyond the maintenance interval.

This can be demonstrated by a simple (albeit seemingly contrived) example. Consider an item that has a 50 per cent probability of failing at a life since new (or overhaul) of exactly 200 hours. Those items that do not fail at 200 hours invariably fail at 400 hours. One group of such items is not subject to any preventive maintenance, so nature takes its course and

17 A method for doing this is in DI(AF) AAP 7001.038-2, *Procedures for Determining Aircraft Scheduled Maintenance Requirements*.

18 See also p. 44.

half the items fail at 200 hours, the rest at 400 hours. The MTBF for this group is the average of 200 and 400, ie. 300 hours.

A second group of the same items is subject to scheduled maintenance if and when they reach a life of 300 hours (see Figure A-8). Half of the items (eg. item A) will still fail at 200 hours; they are repaired and returned to service until their maintenance is due at the 300 hour point. The other half of this group (eg. item B) will be withdrawn from service for scheduled maintenance *before* they get to fail (which they would have done at the 400 hour mark). This 300-hour cycle will then repeat identically. Considering both items A and B, one failure occurred in a combined total of 600 hours of operation. The MTBF of this group is therefore 600 hours.

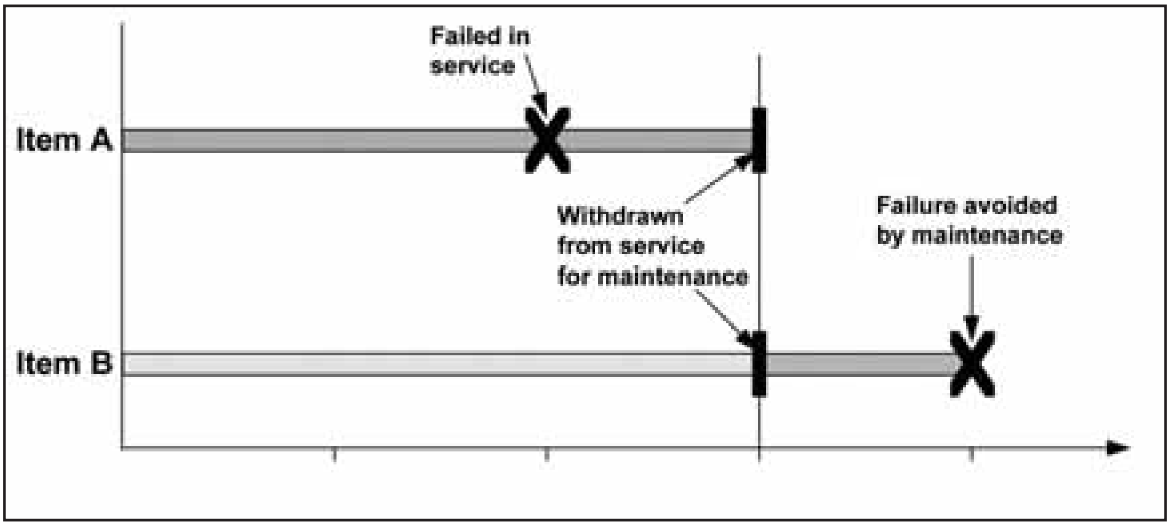

Figure A-8: Effect of Scheduled Maintenance

The introduction of scheduled maintenance has therefore doubled the MTBF—although the items are identical in each group. Certainly, the number of failures that occur in service is reduced when scheduled maintenance is introduced, but the inherent reliability of the items has not changed. MTBF can therefore be seen to be a measure of some combination of the item's inherent reliability and the effectiveness of the maintenance policy. In general, increasing the frequency of scheduled maintenance will increase the item's measured MTBF.[19]

When determining scheduled maintenance intervals, it is better to work from some figure or figures that truly indicate the inherent reliability properties of the item, without the complication of the effect of pre-existing scheduled maintenance. The parameters that specify the shape of an appropriate probability density function provide such non-biased measures. Fitting such a curve will give some measure of the inherent reliability of the item. It will also allow some extrapolation beyond the current maintenance interval to permit

19 An equation for calculating the *measured* MTBF based on the component's inherent reliability function *R(t)* is given in Bazovsky, *Reliability Theory and Practice*, p. 207. The equation does not encourage application in practice, but further reinforces the desirability of using measures other than MTBF!

consideration of the reliability of the item thereafter (ie. to allow assessment of the probable results of extending the current maintenance interval).

SUMMARY

Reliability information may be expressed as a probability density function, cumulative probability of failure, reliability function, or hazard function. The latter is particularly useful as it indicates whether the component is subject to wear-out, wear-in, and/or random failure patterns.

Mathematical functions can be used to approximate actual failure data. The exponential function models random failure, and is relatively simple to derive and use. However, it must be applied with some caution, as it cannot accurately fit wear-in or wear-out failure patterns.

The Weibull function can model wear-in, wear-out or random failure patterns. However, the flexibility of this function comes at the cost of ease of use. It can be extended to cover limited forms of multi-modal failure.

MTBF is a measure of some combination of the item's inherent reliability and the effectiveness of its current maintenance policy. MTBF cannot indicate an item's failure patterns, and should be used with great care (if at all) when assessing scheduled maintenance requirements.

Annex B
Aircraft Structural Integrity

INTRODUCTION

Aircraft Structural Integrity (ASI) management is critical to airworthiness. Moreover, ASI may give rise to relatively rigid and time-consuming maintenance tasks. This annex outlines the need for ASI, the main philosophies used to manage it, and the implications of ASI for aircraft maintenance.

SCOPE

The objective of ASI management is 'to enable air operations to be conducted within an acceptable level of risk of structural failure of aircraft to their planned withdrawal date'.[1] Although structural failure can occur as a result of many different failure modes, the major emphasis of ASI is the failure mode of *fatigue*.[2]

Although engines may be subject to fatigue damage, the RAAF does not apply structural integrity considerations to aircraft engines. Rather, engine manufacturers (OEMs) are relied upon to determine the implications of fatigue on their equipment.

FATIGUE

Fatigue is a phenomenon whereby the strength of some types of material reduces over a period of time if the applied load varies with time (see Figure B-1). Therefore, a structural component designed to withstand a certain load may fail when subjected to that load at some later time, if the material of which it is made has been weakened by fatigue. Many metals used in aircraft structures, including many steel and aluminium alloys, are prone to fatigue if the applied loads are sufficiently high.

Aircraft components are generally subject to various forms of cyclical loading, including wind gusts, manoeuvre loads, vibration from engines/gearboxes, takeoff/landing cycles, etc. As Figure B-1 shows, the effect of fatigue can generally be reduced by applying a gentler load spectrum to the component (or aircraft). The component may require the strength

1 DI(AF) ENG 5-2, *Aircraft Structural Integrity Management*, 20 December 1993, paragraph 7.

2 This emphasis arises in part from the complexity of the analytical tools used to manage fatigue. This annex follows the emphasis on fatigue.

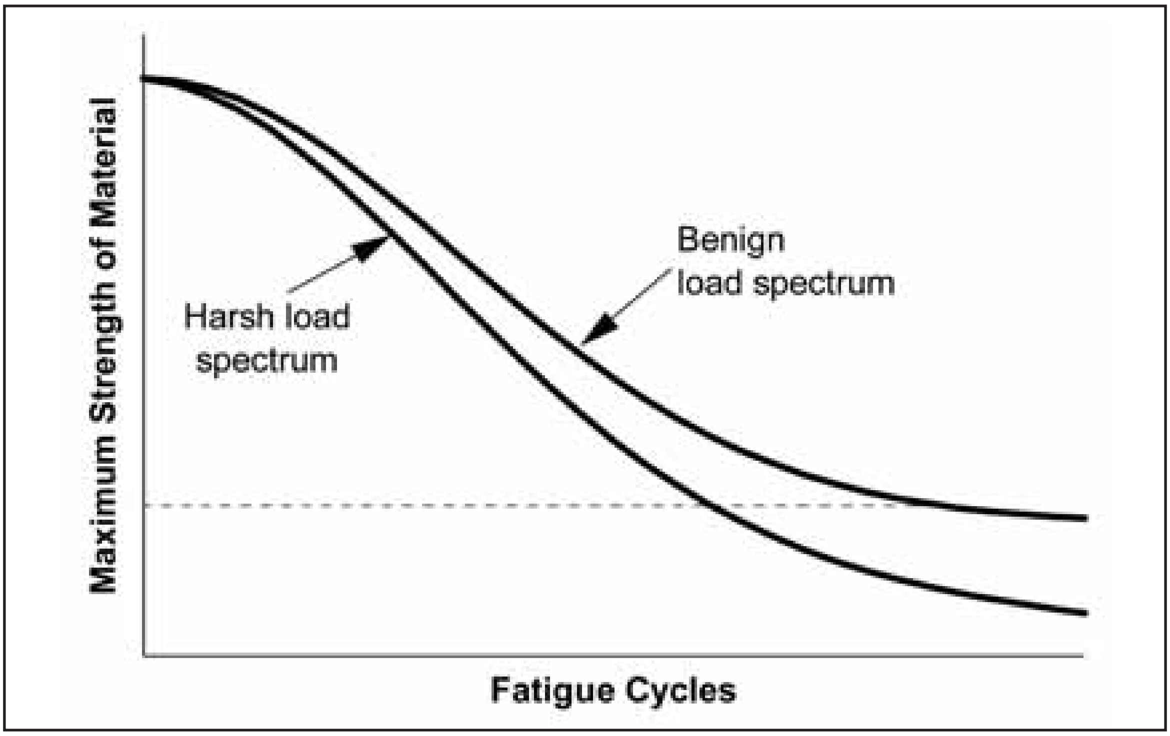

Figure B-1: Fatigue[3]

indicated by the dashed line in Figure B-1; if the usage is harsh, the component will be reduced to the minimum acceptable level of strength much quicker than if a gentler load spectrum were applied. In practice, the load spectrum can be made less severe by limiting g-loads permissible in manoeuvres, limiting the frequency of high-g manoeuvres, reducing airspeed (particularly at low altitudes), flying longer missions, etc.

PHILOSOPHIES

There are two philosophies for the assurance and management of Aircraft Structural Integrity (ASI):[4]

a. safety by inspection, and

b. safety by retirement.

Safety by inspection relies on the detection of damage before that damage grows to proportions which significantly degrade the component's strength or stiffness. This is only

3 This diagram is adapted from E.F. Bruhn, *Analysis and Design of Flight Vehicle Structures*, S.R. Jacobs and Associates, Indiana, 1973, Figure C13.17. It is somewhat of an oversimplification, as it does not represent load history or crack growth rate.

4 The methods described in this annex are entirely based on fatigue considerations (although similar considerations could be applied to other failure modes, such as corrosion).

feasible where the failure progression rate (crack growth rate) is relatively slow, and where cracking can be reliably and conveniently detected through some form of inspection.[5] The safety by inspection philosophy places no basic limit on the life of the equipment.

The safety by retirement philosophy involves removing components from service at some predetermined life. The most common approach to this is called 'safe-life', which requires that the probability of failure occurring before a certain life (the safe-life) is acceptably low. When this life is reached, the integrity of the component is no longer assured, and the component should be withdrawn from service. However, major structural components often cannot be feasibly removed from the aircraft, so either the whole aircraft must be retired from service, the safe-life extended (by additional testing or analytical considerations), or the component managed by a safety by inspection philosophy (if feasible).

Whole aircraft are generally considered to be managed by one of these approaches. However, in practice, some components in an aircraft are managed by one approach, and other components are managed by the other. For example, in a nominally safe-life aircraft (such as the Hornet), any components that prove not to be able to reliably survive to a useful safe-life must still be managed under safety by inspection. Conversely, in a nominally safety-by-inspection aircraft (such as the C-130), many components are not subject to specific inspection; these are in effect managed as fail-safe or safe-life.

As aircraft age, more of their structure is likely to be managed using a safety by inspection approach. The current trend of keeping military aircraft in service for long periods means that there will frequently be some element of safety by inspection during the life of the equipment—even for aircraft designed to a safe-life philosophy.

The only maintenance workload generated by components subject to safe-life management is the removal of life-expired components and their replacement by new components. By contrast, a greater maintenance effort may be necessary to effect the inspections required by a safety by inspection philosophy; this will impact on availability and maintenance costs to a greater extent (although the benefit is potentially longer life). Safety by inspection requirements may comprise a significant part of a maintenance program, so the emphasis of the remainder of this annex will be on such requirements.

MAINTENANCE IMPLICATIONS

Estimating Lives and Intervals

There are two means of estimating the appropriate inspection interval (for safety by inspection components) or safe-life:

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5 The 'fail-safe' philosophy is effectively a subset of safety by inspection. A fail-safe structure incorporates sufficient redundancy such that the failure of one part of it would not result in catastrophic failure of the whole. However, for ongoing assurance, it is necessary to detect the partial failure before a second, and possibly catastrophic, failure could occur.

a. empirically, or

b. analytically.

The empirical approach relies on fatigue tests as the source of the necessary data, which may include crack growth rates, critical crack length,[6] or simply the time taken for failure to occur (ie. the safe-life). Since components are never identical, some variation between components must be allowed for. In addition, only a small number of items (or aircraft) are actually subject to fatigue testing. For these reasons, statistical methods must be used to determine suitable lives based on the test results; the test results cannot simply be adopted verbatim. Fatigue tests, often on whole aircraft, are the normal means of establishing safe lives.

A common analytical approach is a Durability and Damage Tolerance Analysis (DADTA), which is a method of calculating inspection requirements for safety by inspection management. DADTA is often used to determine safety by inspection requirements for whole aircraft; if inspection requirements need to be determined for individual components, either a DADTA or fatigue test can be used.[7]

Durability and Damage Tolerance Analysis

The first step required in performing a DADTA is to identify those parts of the structure that will be subject to further analysis. Considerations include the criticality of the structure and the likelihood of fatigue being a significant failure mode. Locations nominated for further analysis are often referred to as Control Points.

For each control point, the material properties, structure geometry and load pattern are analysed to determine the following:

a. the size of the initial defect that may be present in the material, as a result of manufacturing imperfections or damage accrued in service;

b. the critical crack length; and

c. the rate of growth of a crack, as it grows from the initial defect size to critical length.

This information can be represented graphically, as in Figure B-2. The horizontal scale is related to some measure of the life of the component.

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6 Critical crack length is the length a crack will grow to relatively slowly; beyond the critical crack length, rapid crack growth occurs, causing sudden failure of the whole component.

7 The amount of data that needs to be determined for safety by inspection requirements is greater than that for safe-life. Minimum detectable crack size, crack growth rate, and critical crack size must all be determined in the former case; in the latter, only the time until failure needs to be determined (statistical considerations aside).

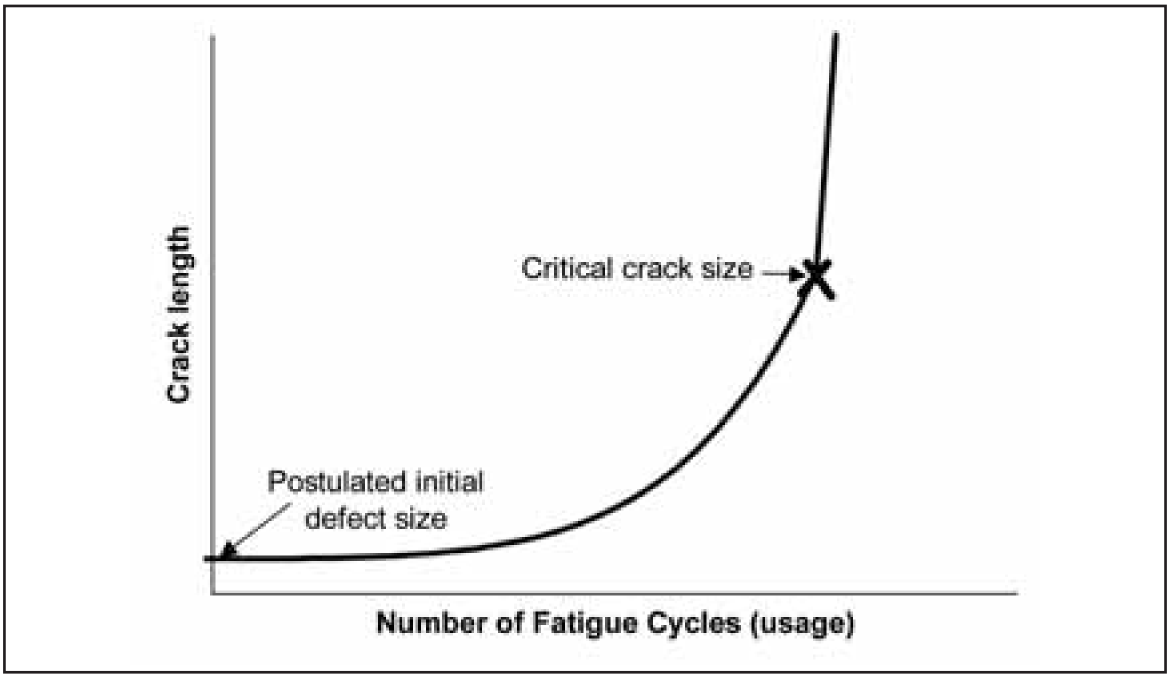

Figure B-2: Fatigue Crack Growth

Often, the initial defect size is very small, and a crack could grow for a significant period of time before it became long enough to be reliably detected. The minimum size of crack that can be detected with reasonable confidence must therefore be taken into account (see Figure B-3).

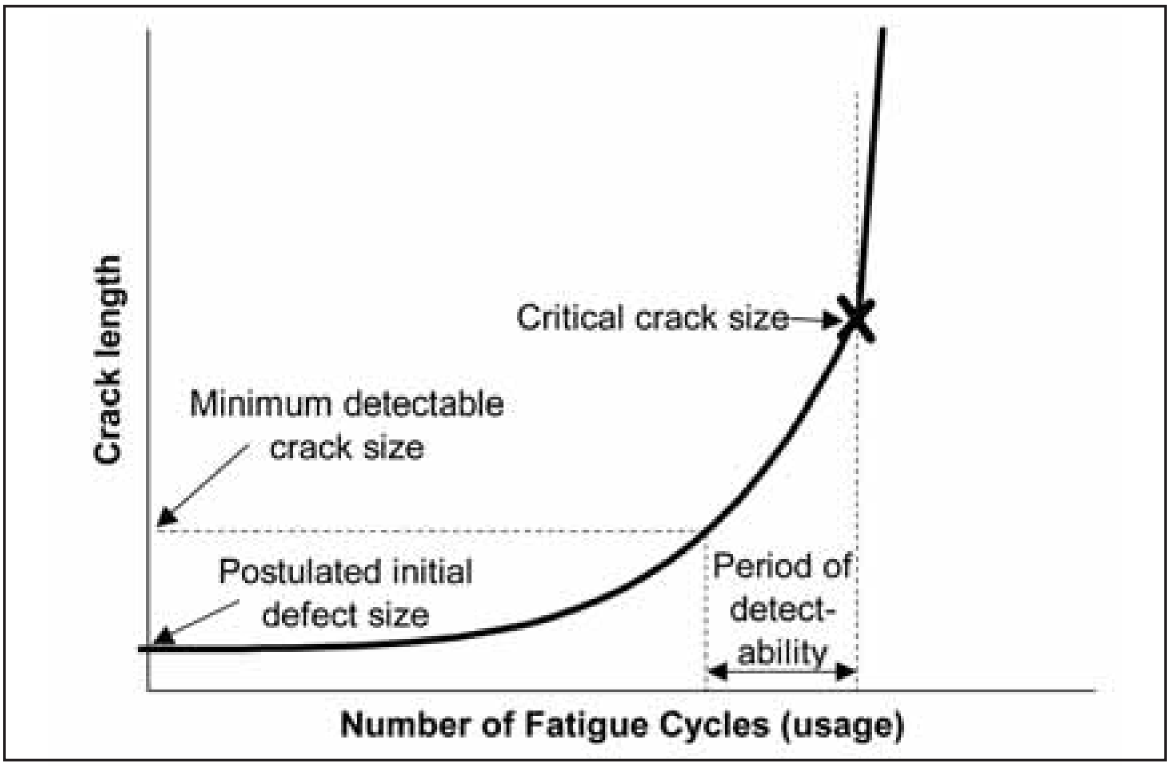

Figure B-3: Fatigue Crack Detection

The crack can only be detected reliably when it is larger than the minimum detectable size; and it must be detected before it reaches critical size. A period of detectability lies between these two points; the inspection interval must be no longer than this period to ensure at least one reasonable chance of detecting a crack before it causes component failure. Often, the inspection interval is set to *half* of this interval, to permit two chances of detecting a crack. This guards against the possibility that an inspection might miss a crack the first time around, and also provides some insurance against differences between aircraft.

The minimum detectable defect size has a significant bearing on the inspection interval that must be adopted. The earlier a crack can be detected, the longer its period of detectability will be, and inspections can therefore be performed less frequently. This generally results in increased availability and reduced maintenance effort.

As with fatigue testing, statistical considerations permeate the analysis. Statistics take into account the probability of various sizes of defects being present in the material, variability between components, the reliability of the inspection process, and so on.

Inspection Processes

There are a variety of inspection processes that can be used. At one extreme, the human eye (possibly aided with a magnifying glass) can be used. Beyond this, there are a number of methods of Non-Destructive Inspection (NDI) available, that can offer detection of smaller crack sizes,[8] subsurface defects, inspection of non-metallic components, inspection of inaccessible components, etc. All methods have their limitations and disadvantages also. Generally, specialist personnel and equipment are necessary to perform NDI.

Cold Proof-Load Test

Another means of 'inspection' is the Cold Proof-Load Test (CPLT), which is regularly conducted on the F-111. The basic process involves cooling the aircraft to change the material properties of the structure such that the critical crack size is much reduced. Loads are then applied to the structure. If nothing fails, no cracks greater than the (reduced) critical crack size can have been present; any cracks present must be smaller than the critical size. Knowing this, and applying DADTA-type considerations, it is possible to assure that any small cracks present will not grow to their (normal) critical size under normal circumstances within a certain period of time.

Because of the risk of damage to the aircraft, the loss of availability and the expense, CPLT is the inspection method of last resort. It is used to gain assurance of the integrity of structure that cannot be economically inspected by other means, and also serves to identify previously unknown critical areas.

8 The Magnetic Rubber inspection process, used extensively on the F-111, is capable of reliably detecting cracks down to about 0.4 mm (0.015 inches) in length. Other NDI methods include fluorescent dye penetrant, magnetic particle, eddy current, ultrasonic, and radiographic techniques.

ASI and Maintenance Schedules

Often, the intervals for ASI tasks are more rigid than many other task intervals, since ASI task intervals are either measured or carefully calculated. This precision is consistent with the airworthiness implications of ASI.[9] By contrast, the intervals for many other maintenance tasks cannot be precisely calculated, but represent a tradeoff between various considerations; often, subjective judgement is the only way to balance competing priorities.

As a result, when grouping maintenance tasks into servicings, ASI intervals may form a framework for the servicing intervals, since the ASI tasks cannot be extended beyond the set intervals.[10] Non-ASI tasks can often be extended or anticipated to align with an ASI task at about the same interval.

Some ASI requirements will be brought forward when packaging them into servicings (eg. a task that could be done every 600 hours may be incorporated into a servicing performed every 500 hours). The original (unpackaged) ASI task intervals are documented in Aircraft Structural Integrity Management Plans (ASIMPs). Knowledge of these intervals is useful, as interval extensions may be readily approved so long as the original interval is not exceeded, with no detriment to structural integrity.

In addition, the maintenance requirements for older aircraft managed using safety by inspection may contain a large proportion of ASI tasks. Some such tasks can be time consuming, requiring access be gained to relatively inaccessible parts of the aircraft's structure.

SUMMARY

ASI aims to ensure that aircraft do not succumb to structural failure. The main emphasis is on the failure mode of fatigue.

Two main philosophies are used to manage ASI: safe-life, and safety by inspection. In either case, maintenance requirements may be determined empirically (by testing aircraft structures) or analytically. DADTA is a means of analytically determining safety by inspection requirements.

9 Although ASI intervals are indeed precisely calculated or measured, arbitrary assumptions are used in determining the final interval. Because of the natural scatter of such natural phenomena as material properties, no component can be guaranteed to be 100 per cent safe if maintained in accordance with ASI intervals; conversely, failure is not guaranteed (or even likely) to occur as soon as an ASI interval is over-run. However, the component's structural integrity is *deemed* to be assured if it is managed in accordance with the ASI tasks and intervals; otherwise, there is no such assurance. It is in this sense that ASI intervals can be considered precise or inflexible.

10 This effect is certainly true of the F-111, where most servicing intervals coincide with major DADTA control point inspection intervals.

The maintenance requirements associated with safe-life management are less demanding than those for safety by inspection management. The rigidity of ASI task intervals means that these can form the basis of the aircraft's scheduled maintenance program.

Annex C
Maintenance Interval Determination

INTRODUCTION

This annex describes a means of balancing the various maintenance goals using mathematical means, resulting in the determination of an optimum peacetime scheduled maintenance interval for an item. This involves applying the measures of reliability and mathematical failure distributions introduced in Annex A.

The approach described is appropriate to components for which scheduled maintenance is justified due to wear-out failure modes. This annex also assumes that scheduled maintenance tasks are entirely effective in resetting the component's reliability to as-new, and that the life units used to measure the component's reliability are appropriate to the component's failure mode(s). Some item history data is assumed to be available, either from previous ADF service or from other operators' experience.

FITTING A FAILURE DISTRIBUTION

The first step is to fit a statistical distribution to model the failure data for the item.[1] The Weibull distribution is an appropriate choice, since it can model a wear-out failure mode (which the item must have to justify fixed interval preventive maintenance).

Fitting a mathematical distribution requires gathering considerable data on the lives of components at the time they failed, or were withdrawn from service for scheduled maintenance. From this data, statistical methods can be used to determine the form of the Weibull distribution that best approximates the actual failure pattern of the item.[2]

Properly, each failure *mode* should be analysed separately. This is because failure modes may have different failure patterns, and different maintenance activities may be appropriate for each. For example, a component may have two main failure modes: one may be random, the other wear-out. For the former, nothing should generally be done; for the latter, fixed-

1 While this is not strictly essential, having a mathematical relationship allows explicit solutions to be directly calculated, whereas working from raw data requires smoothing of the data and the use of iterative or graphical methods.

2 Where historical data is not available, eg. for newly introduced components, a failure distribution could be approximated from the expected MTBF and the performance of similar types of components. However, the inaccuracy of this approach probably renders it not worthwhile, especially given the time-consuming nature of an analysis of this kind. It is generally preferable to accept the manufacturer's recommendations for maintenance until some in-service experience is gained.

interval preventive maintenance may be appropriate. If the failure data are not separated, these issues could not be so easily determined—at least, the maintenance interval chosen on the basis of the aggregated data would almost certainly not be optimal.

However, in practice, failure data is seldom separated into failure mode sets for separate analysis. Current RAAF information systems make it virtually impossible to determine the failure modes corresponding to each failure; manual records enable this to be done in some cases, but the effort required is immense. Moreover, the number of failures of each failure mode will often be few, but the statistical methods used to fit failure distributions require at least some minimum number of failures. For these reasons, it is common to fit a single failure distribution using all of the failure data, regardless of mode. The results obtained from this distribution will not be as accurate if the item has failure modes which exhibit different failure patterns; however, if interpreted with caution, the results will still be better than guesswork.

AIRWORTHINESS AND MISSIONWORTHINESS

Having fitted a mathematical curve to the failure data, an equation for the cumulative probability of failure can be derived. This equation can be graphed; an example is at Figure C-1.

The cumulative probability of failure graph (or formula) can be used to balance the scheduled maintenance interval with the likelihood of in-service failures. The latter statistic directly relates to the maintenance goals of airworthiness and missionworthiness. If the item is safety-critical, in-service failures represent airworthiness risk; if mission-critical, missionworthiness risk.

Using the example graphed at Figure C-1, a scheduled maintenance interval of 200 hours will give a 15 per cent probability that an item will fail in service before it reaches its servicing.[3] This is because preventive maintenance is assumed to return the item to 'as new' condition, so that the part of the graph to the right of the 200 hour point is never reached. Components start at a life of 0, and if they reach 200 hours without failing (as 85 per cent should), they undergo preventive maintenance which effectively sets their life back to 0. Thus, the life of components cycles from 0 to 200 hours repeatedly.

If the figure of 15 per cent of items not making it to scheduled maintenance without failing is too high, more frequent preventive maintenance will be necessary. For example, if the

3 This statement can be misleading. It is tempting to attempt to calculate a figure for MTBF directly; eg. by assuming that if 100 components are each operated for 200 hours, 15 failures will occur, giving an (incorrect) MTBF of 200×100÷15, or 1333 hours. However, if a component *does* fail before 200 hours, it will be replaced by another component, which may *also* fail before the 200 hours are up, and so on. Thus, more than 15 failures would probably occur, and the MTBF would be somewhat below 1333 hours. The actual MTBF can be calculated from the failure distribution equation.

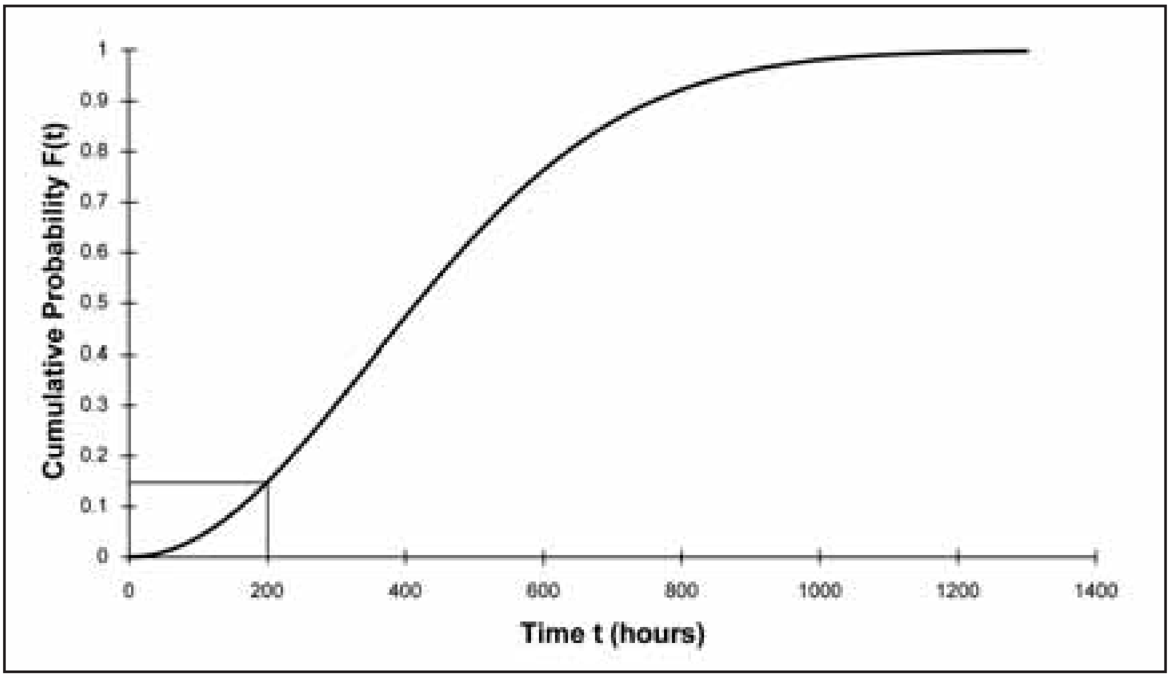

Figure C-1: Cumulative Probability of Failure

maximum acceptable risk of in-service failure is only ten per cent, scheduled maintenance must be performed about every 125 hours.

When establishing a reliability target for a component, the issues considered when performing a Failure Modes, Effects and Criticality Analysis (FMECA) should be taken into account.[4] For example, just because a safety-critical item has a probability of failure of ten per cent does not mean that the probability of aircraft loss is ten per cent: failure of an item does not invariably result in aircraft loss. The provision of redundancy significantly reduces the probability of aircraft loss; eg. if an aircraft has two parallel systems, each with a probability of failure between servicings of ten per cent, the probability of losing *both* systems between servicings is one per cent. The probability of losing both systems *during the one flight* is significantly lower again.[5]

Preferably, component reliability requirements should be determined 'top down'; ie. the required reliability target for the aircraft as a whole should first be established. From this, the required reliability of each of its major components and subsystems can be set, effectively apportioning the reliability requirement between the various components and systems. This process is then repeated for each of the major systems and components in turn: the reliability goal for the system as a whole is converted into reliability goals for each of its subsystems. This process repeats until reliability targets are established for individual components. If any individual target is unachievable, the reliability of the whole system may still be attainable

4 See p. 50.

5 The means of combining individual component reliability figures to determine system (and even aircraft) reliability are discussed on p. 44.

by requiring other subsystems to be more reliable than previously (ie. reapportioning the reliability).

AVAILABILITY

The component availability corresponding to a particular maintenance policy can also be assessed from Figure C-1. The scheduled maintenance interval is known, and the interval between unscheduled arisings (ie. failures, or MTBF) can be calculated. These figures can be combined with the downtime required for scheduled and unscheduled maintenance to yield a value for the availability of the component.

In the same way that an aircraft's reliability can be apportioned between its various systems and components, the availability of the aircraft as a whole results from the 'availability' of the components within it. This is an even more complex issue than apportioning reliability, and involves considering how the various maintenance tasks may be grouped (or 'packaged') into servicings, and how the tasks within each servicing will be scheduled.[6]

Thus, it is possible to trade off airworthiness risk against component availability.

COST-EFFECTIVENESS

Cost-effectiveness may be traded off against availability in a similar manner to that described above. However, instead of deducing airworthiness and missionworthiness risks from the failure distribution, the cost of maintenance must be estimated.

Unscheduled maintenance arisings (ie. repairs) generally cost more than scheduled maintenance arisings (ie. servicings). The condition of the component is usually worse, so more time and parts are required to repair it. Also, the timing of unscheduled arisings is not necessarily convenient; this can also amount to added cost.[7]

The frequency of unscheduled arisings must be calculated for the proposed maintenance interval, using the failure distribution in the same way as when calculating airworthiness risk. The cost of unscheduled maintenance over a given time period may be calculated by multiplying the frequency of unscheduled arisings by the cost per arising. The cost of *scheduled* maintenance over the same time period is calculated similarly, using the proposed scheduled maintenance interval and the cost per servicing. The total cost of maintenance is the sum of the scheduled and unscheduled contributions.

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6 Servicing packaging is introduced on p. 69; servicing scheduling is discussed on p. 84; the relationship between component and aircraft availability is further discussed on pp. 98 and 130.

7 A more complete list of cost factors is on p. 100.

This process can be repeated for a number of different scheduled maintenance intervals, so that the total maintenance cost associated with each possible policy is calculated. For components with wear-out failure patterns, and for which unscheduled maintenance costs more than scheduled maintenance, there will one particular policy that is cheapest. More frequent scheduled maintenance will not significantly reduce failures, and is therefore not cost-effective; less frequent scheduled maintenance would see a rise in the frequency of repairs required, the cost of which would outweigh the saving in scheduled maintenance cost (see Figure C-2).

For any given scheduled maintenance interval, it is thus possible to estimate airworthiness or missionworthiness risk, maintenance cost, and availability (at least for the component in isolation). These measures may be traded off against one another, guided by the prevailing emphases on the various maintenance goals, to determine the optimum scheduled maintenance interval. For the type of components for which this form of analysis is appropriate, it is usual to find that maximum airworthiness or missionworthiness requires the greatest amount of scheduled maintenance (ie. smallest interval), maximum cost-effectiveness requires somewhat less scheduled maintenance, and maximum availability requires the least amount of scheduled maintenance.

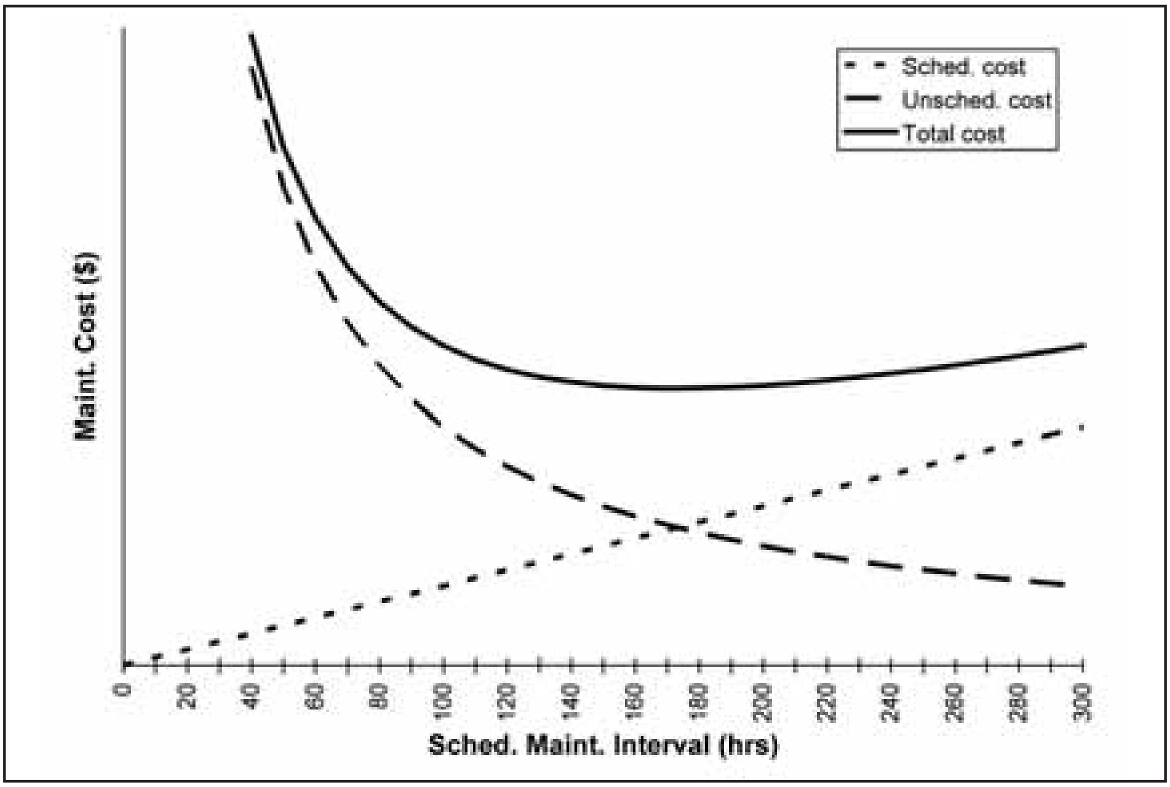

Figure C-2: Maintenance Cost

SUMMARY

To mathematically determine a scheduled maintenance interval for a component, a failure distribution should be fitted to describe its expected or observed wear-out characteristics. Ideally, data for each failure mode should be analysed separately, but the limitations of existing information systems make this very difficult.

The failure distribution allows the probability of in-service failure corresponding to any given scheduled maintenance interval to be estimated directly. The reliability of the aircraft overall can be estimated by combining the reliability figures for each of its components. This provides a measure of airworthiness or missionworthiness (depending on the criticality of the component).

Component 'availability' can be easily estimated for any given scheduled maintenance interval from the failure distribution pattern, by combining the frequencies of scheduled and unscheduled arisings with the average duration required for each. However, converting individual component availability figures to an availability figure for the aircraft overall would be very difficult, particularly for scheduled maintenance due to servicing packaging and servicing management complexities.

Assessing component maintenance cost is similar to the means of assessing component availability. The frequencies of scheduled and unscheduled arisings are combined with the average cost of each kind of arising. There is often a maintenance policy that yields a minimum maintenance cost, and this can be found by calculating the maintenance cost for a range of possible scheduled maintenance intervals.

Armed with means of calculating component (and aircraft) reliability, availability and maintenance cost for any given maintenance policy, a scheduled maintenance interval can be determined that provides the best compromise between the maintenance goals.

Annex D discusses how to determine scheduled maintenance intervals for another class of components: those with hidden function.

Annex D
Hidden Function Item Maintenance Interval Determination

INTRODUCTION

Annex C described a mathematical approach that can be used to help determine scheduled maintenance intervals for items which are subject to wear-out failure patterns. Generally, scheduled maintenance serves no purpose for items that do *not* exhibit wear out; however, there is a class of such items for which scheduled maintenance *may* be appropriate: items with hidden function.

This annex explains why scheduled maintenance may be appropriate for such items, and develops a simple mathematical method to assist in determining the best maintenance interval. A random (as opposed to wear-out) failure pattern will be assumed, which simplifies the mathematics.[1]

APPLICABILITY

Hidden Function

Items with hidden function are those items which may fail unnoticed. There are two conditions that can give an item hidden function:

a. the item is seldom used, so its serviceability is not regularly checked by use in operation (eg. defensive systems or mission-specific equipment); or

b. the failure of the item would normally go undetected (eg. an oil filter with a bypass valve, with no cockpit indication that the filter has become clogged and the valve has come into operation).

Much operational equipment will have hidden function. Defensive measures such as chaff and ECM will (hopefully) not be required on most sorties, so the failure of such systems could go unnoticed until it was necessary to use them. However, when such systems *have* to be used, it is highly desirable that they be serviceable!

1 Not all items with hidden function exhibit a random failure pattern. For those which do not, the more general approach outlined in the previous annex must be used, in conjunction with the rationale described in this annex.

Weapons delivery systems are another possible example of hidden function. A weapons delivery system may not be frequently used, but failure of such a system when actually required for a mission would probably result in mission failure.

Many modern systems, especially software-controlled systems, are subject to automatic self-test. This allows the systems to be checked when required and convenient, for example before every flight, or before every flight when the system may need to be used. This facility avoids the need for other forms of scheduled surveillance maintenance.

Random Failure Pattern

Much hidden-function equipment is electrical or electronic in nature, and could be expected to exhibit a random failure pattern. Normally, such components do not warrant scheduled maintenance: their reliability cannot be improved by performing scheduled maintenance. However, it is desirable to at least *check* the performance of hidden function systems to detect systems that have failed *before* the failure is discovered in flight—when the absence of the system could be a major problem. In this regard, the maintenance function is taking on a role that is normally implicit in operations: the detection of non-functioning equipment. Such detection is a form of surveillance maintenance; ie. assessing the serviceability of the equipment. If it is serviceable, no further maintenance work is necessary; if not, some form of corrective maintenance is required.[2]

SCHEDULED MAINTENANCE INTERVAL

From the criticality of the item or system, a limit for the acceptable probability of non-operation of the item can be established. This is the same as the average proportion of items in the population that will be unserviceable at any point in time. The surveillance maintenance (ie. inspection) interval required to achieve the desired level of reliability can be determined from the reliability function. Random failures give an exponential distribution, ie.:

2 It could be that the most appropriate form of corrective maintenance is an *overhaul* or *bay service*. These servicings are normally used for preventive maintenance; ie. to defer the onset of failure or degradation. However, once failure has been detected, these servicings may be used in a corrective manner. This can be overkill: overhauls generally aim to recondition all components in an assembly, whereas this may not be necessary just to rectify the specific problem that caused a failure. To perform a complete overhaul would remove the item from service longer than may be necessary; in a contingency environment, unnecessary lost availability is most undesirable. However, if the item was nearly due for a scheduled overhaul, or its general condition warranted it, a complete overhaul may be appropriate.

$$R = e^{-\frac{t}{\theta}}$$

where t is the time between inspections, R is the desired level of reliability, and θ is the MTBF.[3] Rearranging:

$$t = -\theta \times ln(R)$$

This equation allows the appropriate maintenance interval to be determined directly from the required level of reliability *(R)* and the item's fundamental reliability (MTBF, θ). This equation can be further simplified if the level of reliability sought is high; ie. R is nearly 1. In this case,

$$ln(R) \approx R-1,$$ [4]

which may be combined with the preceding equation to give:

$$t \approx \theta\,(1 - R)$$

It is important to use appropriate units for MTBF, as the maintenance interval will be in the same units. For example, if an ECM pod is found to be unserviceable on average once every 50 times it is used, but it is only used once every five flights, its MTBF would be 250 flights per failure. If it was acceptable for the pod to function with 96 per cent reliability, the required maintenance interval would be 250 × (1-0.96), or ten flights.[5]

Thus, the level of reliability of hidden function items with random failure patterns can be linked directly to the scheduled maintenance interval. The other implications of this maintenance policy, ie. availability and cost, may be estimated using the approach outlined in the previous annex.

SUMMARY

Items with hidden function may justify scheduled maintenance even though they may not exhibit a wear-out failure pattern. Typically, a surveillance maintenance task (such as a functional test) is appropriate.

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3 The exponential distribution was introduced on p. 298. Interestingly, a maintenance policy of $t=\theta$ (ie. maintenance interval being the same as the component MTBF) will give a reliability of 37 per cent; ie. 63 per cent of the population would fail *before* reaching MTBF. Why not 50 per cent? Although most items fail before reaching MTBF, some items remain serviceable well beyond MTBF; a few beyond twice MTBF. MTBF represents a weighted average of failure lives. This shows the danger of naïvely linking the maintenance policy to MTBF.

4 '≈' means *is approximately equal to*.

5 Of course, testing the equipment by turning it on will increase the usage of the pod; this may further reduce its reliability in service. The calculation can be adjusted to cover this situation.

Assuming a random failure pattern greatly simplifies the mathematics, and allows a straightforward relationship between reliability and maintenance interval to be established. The availability and cost-effectiveness of a given maintenance policy for items with hidden function can be estimated using the methods described in the previous annex.

Annex E
Environmental Effects

INTRODUCTION

The environment in which an aircraft operates can have a significant effect on the reliability and performance of its systems and subassemblies. In many cases, adverse effects can be minimised by appropriate alterations to the scheduled maintenance program, or by the incorporation of modifications.

This annex surveys the kinds of environment-related degradation that the RAAF may experience in its more likely areas of operations (the North and North-West of Australia). Because of the similarities between the environment in this region and that of the Persian Gulf area, many lessons can be learnt from the experience gained during Operations *Desert Shield* and *Desert Storm*.[1] Accordingly, much of the content of this annex is drawn from that experience.

The RAAF does not have any detailed policy or procedures concerning the introduction of environmentally necessitated maintenance tasks or modifications to suit contingency requirements. The content of this annex is therefore exhaustive (within the scope of the literature reviewed) to provide maximum guidance and data for the development of appropriate procedures.

EFFECTS AND REMEDIES

Effects of Sand, Dust and Foreign Object Damage

Sand erosion was expected to be a significant problem prior to the Gulf deployment. Not only was the ground covered in various kinds of sand, but a fine layer of sand dust was suspended in the air up to a height of several hundred feet[2] (around 100 metres). Sand and dust abrades moving parts, degrades and destroys bearings, and can jam controls and switches.

Many of the aircraft aprons used during the Gulf War were not initially sealed; for helicopter operations, this often remained the case. An increased amount of Foreign Object Damage (FOD), primarily from stones, resulted. General surveillance of the condition of aircraft

1 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, paragraph 413.

2 Murray Hammick, 'Sea Kings in Sand', *International Defence Review*, 5/1991, pp. 453–455.

surfaces was stepped up:[3] weekly inspections were adopted for the Canadian CF-18s;[4] USAF Combat Logistics Support Squadrons[5] inspected aircraft after every sortie.[6] Engine inspections (using borescopes) were also increased, to monitor FOD and sand erosion degradation.[7]

The presence of sand on moving components such as undercarriage hydraulic struts caused rapidly increased deterioration.[8] Different lubricants were used to reduce such problems in some instances.[9]

The sand contained large quantities of salt,[10] which accelerates the rate of corrosion damage, particularly in many aluminium alloys. The short duration of the Gulf War, coupled with the relatively dry environment, would have limited the extent of corrosion problems that developed during the deployment. However, some subsequent corrosion problems are to be expected, especially if all the sand cannot be removed from aircraft before they return to climates more conducive to corrosion propagation.

Sand erosion of engine turbine blades was predicted to be a particular problem. Fixed-wing aircraft (F-15[11] and F-111[12]) were not as severely affected as anticipated, although some problems were experienced.[13] The resistance of the F-111 engine to sand erosion is attributed

3 United States General Accounting Office, *Operation Desert Storm – The Services' Efforts to Provide Logistics Support for Selected Weapon Systems*, September 1991, p. 44.

4 *Operation Scimitar/Friction – CF-18 Maintenance*, Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, Section 4, Enclosure 2.

5 These units have primary responsibility for Battle Damage Repair and expediting supplies in combat.

6 Captain Jack Cooley, USAF, *USAF Combat Logistics Support Squadron Briefing*, Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, Section 4, Enclosure 7. These inspections were largely intended to search for battle damage, but would also serve to find FOD and other problems.

7 *Operation Scimitar/Friction – CF-18 Maintenance*, op cit.

8 United States General Accounting Office, *Operation Desert Storm*, p. 45.

9 James P. Coyne, *Airpower in the Gulf*, Air Force Association, Virginia, 1992, p. 131.

10 loc cit.

11 Murray Hammick, 'Report from the Front: AMUs Underrated in USAF's Success', *International Defence Review*, 5/1991, pp. 451–452.

12 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, p. 4-3.

13 ibid., p. 4-5; United States General Accounting Office, *Operation Desert Storm*, p. 42.

to the success of a modification incorporated previously for just such a contingency.[14] Sand ingestion into Auxiliary Power Units also caused some problems.[15]

Helicopter fleets were much more significantly affected than fixed-wing fleets, presumably as many helicopter operations must be conducted at low altitude, continually flying within the area of suspended dust.[16] Sand ingestion was a problem up to about 30 feet altitude. For the Royal Navy Sea Kings, this necessitated the continual operation of dust scavenge equipment, which was only intended for the spasmodic use expected in the European environment, with consequent degradation in the MTBF of the system.

Primarily as a result of wear on engine inlet guide vanes and compressor blades, the Sea King engine servicing interval had to be reduced from 200 to 100 hours.[17] US experience recorded helicopter engine lives dropping from 1200 to about 300 hours—sometimes as low as 100 hours.[18]

Helicopter rotors, and especially tail rotors, were particularly susceptible to sand and stone damage.[19] Main rotor leading edge pitting was reduced by the application of a protective tape.[20] This tape was not easy to apply successfully;[21] prior experience, or documented procedures for the application of the tape, would have hastened its effectiveness.

Sea King main rotor bearings also suffered from sand damage. The condition of the bearings was monitored using a form of vibration analysis.[22]

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14 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, p. 4-3. Current trends in combat engine design could have a significant effect on maintainability and supportability in a sand or FOD-laden environment. Fan, inlet guide vane, and compressor stages are increasingly being manufactured as single-piece integrally-bladed disks ('blisks'). Individual blades cannot be removed if damaged, requiring the whole disk to be replaced. Although many engines avoid this kind of construction for the more damage-prone fan or early compressor stages, this is not always the case; Sergio Coniglio, 'Combat Aircraft Engines Revisited', *Military Technology*, April 1994. Although neither blade or disk replacement would normally be attempted on deployment, substantial spares of replacement disks would need to be held in the system to allow rapid engine repair at a deeper maintenance venue. Blisks will be considerably more expensive and bulkier to store than individual blades. A significant trap is that the usage of 'blisks' would be negligible during peacetime, but could be substantial during a contingency.

15 United States General Accounting Office, *Operation Desert Storm*.

16 Hammick, 'Sea Kings in Sand'.

17 loc cit.

18 United States General Accounting Office, *Operation Desert Storm*, p. 44; and Department of Defense (US), *Conduct of the Persian Gulf War*, April 1992, Appendix F, p. F-63.

19 United States General Accounting Office, *Operation Desert Storm*, p. 42.

20 ibid., p. 44.

21 Hammick, 'Sea Kings in Sand'.

22 loc cit. Vibration Analysis is a form of Early Failure Detection (EFD)—see p. 52.

The effects of the sand erosion on helicopters could be reduced by operational measures, such as by flying above 500 feet (150 metres) and landing on hard surfaces wherever possible.[23] Existing Standard Operating Procedures (SOPs) did not fully address the problems of operations in the dusty environment.[24]

The fine dust in the Gulf environment got past standard covers and plugs used to seal the aircraft when not in use.[25] Many orifices are not normally covered at all,[26] and additional intake and orifice plugs were fitted to some fleets.[27] Plastic aircraft canopies were badly degraded by the blowing sand,[28] but the problem was actually exacerbated by use of the standard soft canopy covers, which rubbed the sand against the canopy. Rigid fibreglass covers were provided for F-15s to alleviate this problem.[29]

Other transparencies were also subject to sand erosion. F-15 mission effectiveness at night was seriously reduced by scratching and pitting of the forward-looking infrared window glass of the Low Altitude Navigation Targeting InfraRed for Night (LANTIRN) system. Attempts to polish out the damage proved unsatisfactory; modified carbon-coated windows were found to be more resistant to sand damage, and some aircraft were fitted with these during *Desert Storm*.[30]

The ingress of sand into avionics components significantly degraded their reliability. For example, the Canadian CF-18s suffered reduced reliability of radar transmitters, radio assemblies (and power supplies), and flight control computers by a factor of two to three.[31] Electronic warfare equipment was also significantly affected.[32]

Such large variations in reliability will cause significant and unavoidable increases in demand rates above predictions based on peacetime usage—even after the increased rate of effort is factored in. This serves as a warning that peacetime logistics data is an unreliable basis for forecasting contingency needs. If contingency demand rates are three times greater than predicted, spares shortages are highly likely in a contingency of any significant duration.

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23 United States General Accounting Office, *Operation Desert Storm.*

24 Hammick, ‘Sea Kings in Sand’.

25 United States General Accounting Office, *Operation Desert Storm*, p. 42.

26 Hammick, ‘Sea Kings in Sand’.

27 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, p. 4-5.

28 United States General Accounting Office, *Operation Desert Storm.*

29 Michael Self and Edward Kozlowski, *Air Force Logistics Command Operations in Desert Storm*, Headquarters USAF Logistics Command, July 1991, p. 13.

30 United States General Accounting Office, *Operation Desert Storm*, p. 45.

31 STLO NAVAIR 79/2/Air Pt 2 (61), *F/A-18 Persian Gulf Operations – Canadian Forces Engineering/ Logistics Lessons Learned*, 10 July 1991.

32 *Operation Scimitar/Friction – CF-18 Maintenance*, op cit.

A thorough vacuum cleaning of aircraft parts that could not be covered was necessary; towards the end of *Desert Storm*, Royal Navy Sea Kings were typically subject to three hours of cleaning every day.[33] Cockpits demanded special attention, requiring vacuuming and dusting down of instrumentation to keep sand and dust out of electronics.[34]

Washing of aircraft exteriors was conducted frequently,[35] to attempt to remove sand from rubbing surfaces. Undercarriage struts were wiped after every flight to reduce the incidence of sand damage to hydraulic components; engines were regularly flushed with water (or water and kerosene[36]) to prevent corrosion.[27]

Additional precautions were also necessary for removable components such as fuel tanks. The combination of the sandy environment and the very frequent fitment and removal of the tanks required that additional precautions had to be taken to avoid damage to fixtures, O-rings and plumbing.[38] During the Vietnam War, a shortage of benches, bags, and so on resulted in damage to components when removed items were simply placed on the ground. There is a need to achieve a minimum level of cleanliness to avoid such damage, and the provision of such simple supplies as plastic bags can have a considerable benefit.[39]

In some environments, the local wildlife can constitute an unusual form of foreign object damage. Animal excretion can be highly corrosive, and insects can infiltrate and damage pitot static, electrical and electronic systems.[40] Adequate covers over all orifices can minimise this problem, and suitable inspections may be required.

Effects of Temperature

The sealing of aircraft cockpits and cabins on the ground is desirable, as it limits sand and dust infiltration. However, in a hot climate, this practice can result in excessive temperatures in the cockpit: temperatures up to 170°F (77°C) were recorded in Hornet cockpits during *Desert Storm*.[41] This can cause failures of electronic components[42] and can degrade glues used within the cockpit (let alone necessitate the need for cooling prior to aircrew operation).[43] The fibreglass cover developed to protect the F-15 canopy also served to reduce the cockpit

33 Hammick, 'Sea Kings in Sand'.

34 *Operation Scimitar/Friction – CF-18 Maintenance*, op cit.; and Gary Waters, *Gulf Lesson One – The Value of Air Power*, Air Power Studies Centre, Canberra, 1992, p. 244.

35 United States General Accounting Office, *Operation Desert Storm*, p. 44.

36 Hammick, 'Sea Kings in Sand'.

37 Waters, *Gulf Lesson One*, p. 244.

38 Captain Scott Loch, USMC, *Innovative Maintenance Actions*.

39 Discussion with Mr K. Griffin, HQADF, 24 October 1994.

40 The original computer 'bug' was an insect acting in the capacity of a short circuit.

41 Discussion with Captain Scott Loch (USMC), FLAMO, 3 Squadron, 24 February 1994.

42 United States General Accounting Office, *Operation Desert Storm*; and Waters, *Gulf Lesson One*, p. 43.

43 Discussion with Captain Scott Loch (USMC), loc cit.

temperature;[44] a solution used on the Tornado fleet was to provide an external cooling system.[45]

Canopies themselves were prone to temperature-related degradation. RAF Tornado canopies were modified to reduce thermal distortion.[46]

Tyre and brake wear was also increased[47] (degraded brake performance may be caused by hot weather reducing heat dissipation and/or by sand on the contacting surfaces). The RAF changed to high temperature tyres to solve problems with Tornado tyres bursting;[48] the Canadian Forces also endeavoured to upgrade the tyres on the deployed CF-18s.[49]

Desert temperatures also take their toll on maintenance personnel. This problem is exacerbated if NBC protective clothing must be worn. The USAF developed a cooling suit for maintenance personnel, which allowed up to ten people to connect to a modified aircraft ground air conditioning unit.[50]

Effects of Humidity and Moisture

Although the environment in the Persian Gulf was generally not humid, moisture problems arose as a result of the temperature range: the cold desert nights caused condensation to form within electronic equipment. This necessitated careful mopping up of the pools of moisture before the equipment was operated.[51]

RAAF experience with operations in more humid climates indicates that humidity degrades the reliability of avionics systems.[52] Radars have proved particularly susceptible; DSTO is examining methods to reduce this problem. During the Gulf War, the USMC devised changed sampling procedures to avoid hydroscopic contamination of the radar coolant system caused by atmospheric humidity.[53] Missile system reliability is also affected by humidity.[54]

Aircraft canopies generally do not form a water-tight seal on the ground; this allows rain ingress, with consequent risk to electronic components.[55]

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44 Self and Kozlowski, *Air Force Logistics Command Operations in Desert Storm*.

45 Waters, *Gulf Lesson One*, loc cit.

46 ibid., p. 25.

47 *Operation Scimitar/Friction – CF-18 Maintenance*, op cit.

48 Waters, *Gulf Lesson One*, p. 243.

49 *Operation Scimitar/Friction – CF-18 Maintenance*, op cit.

50 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, p. 4-5.

51 Hammick, 'Sea Kings in Sand'.

52 Discussion with Captain Scott Loch (USMC), FLAMO, 3 Squadron, 24 February 1994.

53 Loch, *Innovative Maintenance Actions*.

54 Discussion with Squadron Leader S.S. Hayes, TFLOGAIR, TFLMSQN, 23 February 1994.

55 loc cit.

MANAGEMENT OF ENVIRONMENT-RELATED ISSUES

Environmental Maintenance Tasks

Table E-1 provides a summary of the effects and remedies described above.

Current RAAF policy is to use maintenance manuals and Unit Maintenance Orders (UMOs) to document most environmentally related maintenance requirements.[56] However, UMOs are not regularly consulted by maintenance crews when performing their tasks. It is preferable for the normally used manuals to document special requirements so that contingency maintenance procedures will be simplified, resulting in less confusion and consequently more effective maintenance. Unfamiliarity with contingency maintenance plans was cited as a major source of confusion in the Gulf War;[57] maximum consistency between peacetime and contingency procedures will serve to reduce this confusion.

Another reason to incorporate environmental requirements into standard maintenance publications is to encourage the integration of such considerations into other maintenance requirements determination procedures. UMOs are the responsibility of maintenance units, whereas the determination of peacetime maintenance requirements is the responsibility of the procurement project team and logistics management squadron. These latter agencies should be able to apply the same logic to the determination of environmental maintenance requirements as is used for peacetime maintenance requirements. This would lead to a more thorough, logical, simpler and more consistent set of contingency maintenance plans.[58]

Other Implications

In addition to maintenance (servicing and modification) activities, aircraft operating procedures can also reduce the undesirable effects of operations in adverse environmental conditions. Compromises must be made between operational need and convenience on one hand, and additional unreliability, lost availability and extra maintenance effort required on the other hand. Appropriate Standard Operating Procedures should be documented in anticipation of likely environments; these could be used on exercise to instil some measure of familiarity.

The additional maintenance efforts and changed operating procedures used in the Gulf were not sufficient to restore component reliability to peacetime levels in all cases. Significantly degraded reliability of avionics (including electronic warfare and missile systems), engines

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56 DI(AF) AAP 7038-1, *RAAF Aircraft Maintenance Philosophy and Policy*, Third Edition, 1983, paragraph 742.

57 STLO NAVAIR 79/2/Air Pt 2 (61), op cit.

58 This is not to say that operating and maintenance units should not be involved in the process of contingency maintenance requirements determination. These units will often become aware of problems in the first instance, and will be able to comment on the practicality of preventive measures. Units are (and should be) involved in all aspects of maintenance requirements determination.

of aircraft operated at low altitude, helicopter rotors and dust filtration systems must be expected. This will have an impact on appropriate spares holding levels, and will probably affect availability. Moreover, maintenance tasks that must be undertaken frequently are prime candidates for performance on deployment.[59]

Some of the systems which are expected to suffer reduced reliability have a *hidden function*,[60] including electronic warfare and missile systems. Such components may need to be subject to operational checks to verify their serviceability on a more frequent basis than in peacetime. Additionally, the importance of some such systems escalates significantly when involved in combat (eg. countermeasures), so peacetime maintenance practices will need to be carefully re-evaluated.

For some components, environment-related deterioration will result in demands for replacements and spares being disproportionate to the (increased) rate of effort. Stockholding levels for affected components should be based on expected failure rates rather than assuming that demands will increase in proportion to the rate of effort.

It is significant that the USAF thought it essential to provide protection from the Persian Gulf heat for its maintenance personnel. There are practical benefits in maintaining a comfortable, healthy workforce with good morale, including increased maintenance efficiency and effectiveness, and reduced support costs.

SUMMARY

The environment in which aircraft are based and operated can significantly affect reliability. Maintenance actions can be introduced to minimise the adverse impact of a harsh environment. Sand, dust, FOD, humidity, rain, and even wildlife can be a problem. Increased inspections, cleaning, use of covers, and modifications are appropriate remedial strategies.

Even with maintenance provisions in place, the reliability of some items can still be drastically reduced. Changes to Standard Operating Procedures can help in some cases, but it seems unavoidable that there will be significantly greater demands on the supply system for some components solely due to environmental causes.

As with all forms of contingency maintenance, potential tasks required to protect against environmental degradation should be identified and documented during peacetime. Preferably, such tasks should be determined and documented similarly to other maintenance tasks, to minimise the need to change or complicate maintenance management procedures during a contingency.

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59 See Chapter 16.

60 See p. 66.

Cause	Part of Aircraft	Effect	Maintenance Remedy
Stones	Exterior surfaces	FOD	Increased frequency of visual inspections of aircraft exterior; protective tape on rotor blades
Stones	Engine	FOD (esp. to fan, inlet guide vanes, early compressor stages)	Increased frequency of visual (borescope?) inspections
Sand, dust	Engine	Blade erosion	Increased frequency of visual (borescope?) inspections; more generous use of dust scavenge equipment in flight
Sand, dust	Exposed hydraulics, rubbing surfaces (undercarriage)	Degradation to seals, surfaces	Changed lubricant, regular wash and wipe down
Sand, dust	Engine	Corrosion	Regular flush with water (and kerosene?)
Sand, dust	Uncovered orifices	Corrosion	More and better covers and plugs; regularly clean (vacuum?)
Sand, dust	Dust filters, extraction systems	Clogging	Increased frequency of inspection/cleaning/ replacement
Sand, dust	Rotor blades	Erosion, pitting	Protective tape
Sand, dust	Exposed bearings	Degradation	EFD (vibration analysis?)
Sand, dust	Canopies	Scratching	Rigid covers
Sand, dust	Other transparencies	Scratching, pitting	Hardened surface
Sand, dust	Electronics, avionics	Sand and dust infiltration (accelerates corrosion, short circuits if dampened)	Regular (daily?) vacuum and dust
Heat	Cockpit electronics	Temp damage	Better canopy covers; external cockpit cooling
Heat	Cockpit glues	Degradation	Better canopy covers; external cockpit cooling
Heat	Canopies	Thermal distortion	Modification

Cause	Part of Aircraft	Effect	Maintenance Remedy
Heat	Tyres	Increased wear	Fit high-temperature tyres
Heat/sand	Brakes	Increased wear	Inspect/replace more frequently
Temp range	Electronics	Condensation	Mop up moisture
Rain	Cockpit electronics	Moisture ingress (short circuiting, corrosion)	Seal cockpits; mop up moisture
Animals/insects	Orifices, electronics	Corrosion, moisture, blockage	Use covers and seal orifices; inspections
Salt	Airframe, electronics	Corrosion	Protective surface treatments, washing, inspection

Annex F
Item Importance Hierarchy

INTRODUCTION

It is often important to be able to determine which groups of items (or maintenance tasks) are most critical from various points of view. The standard definition of criticality used for maintenance requirements determination cannot indicate 'availability criticality'. This annex adapts a common representation to indicate which groups of maintenance tasks are most likely to impact on availability.

BASIC HIERARCHY

One representation that attempts to describe the criticality of items from an availability viewpoint is the *Item Importance Hierarchy*. A typical hierarchy is at Figure F-1.

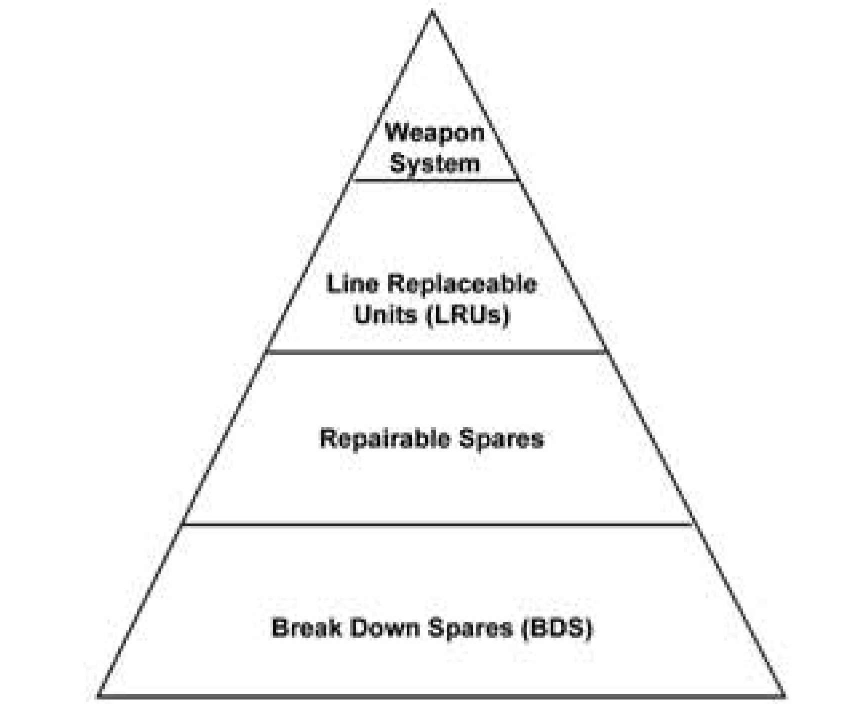

Figure F-1:Item Importance Heirarchy[1]

1 Michelle Maclean, *Preparedness and Repairable Item Management – Linking Logistics and Air Power*, Air Power Studies Centre, Canberra, 1994, Figure 2-4.

The form of the item importance hierarchy can be varied to suit the purpose for which it is intended. The version at Figure F-1 was originally intended to show the importance from a resupply point of view; a general conclusion drawn is that 'the most "important" components in terms of direct impact on aircraft availability are those spares which can be replaced directly on the aircraft'.[2]

A modified item importance hierarchy is shown at Figure F-2. This version better depicts the importance of item groups from a maintenance point of view.

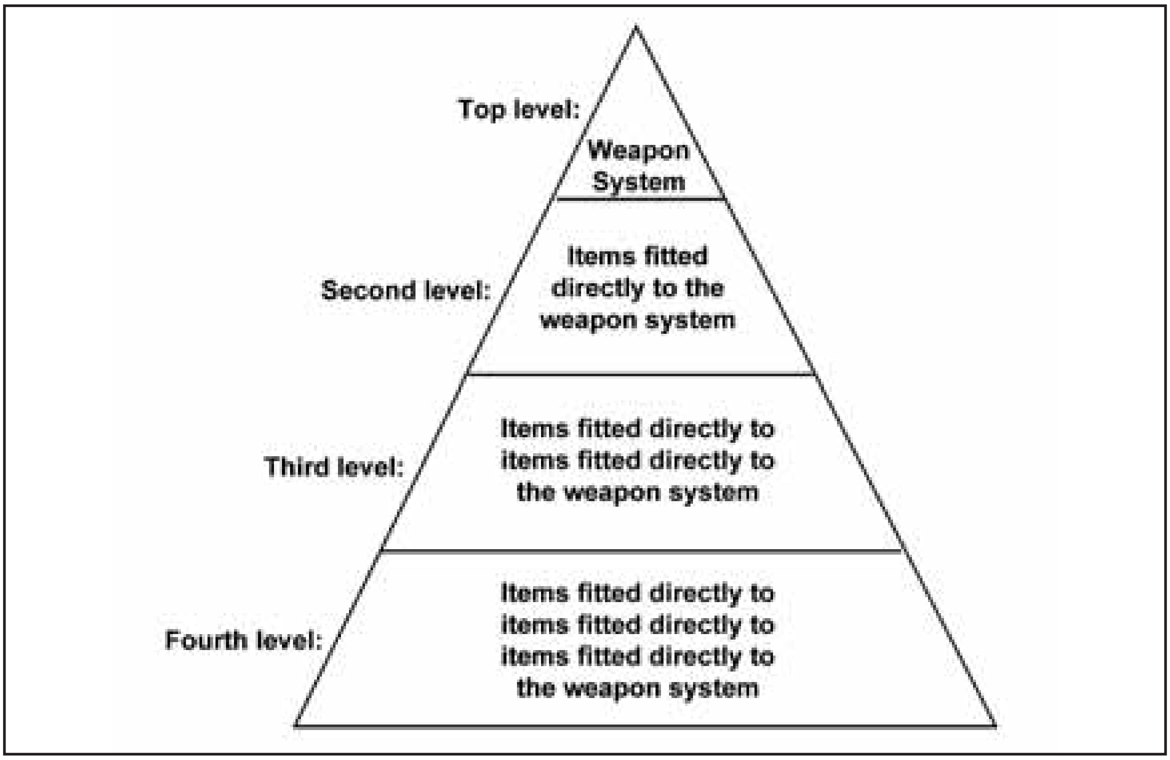

Figure F-2: Item Importance Heirarchy (Amended)

Overview

While the weapon system (eg. aircraft) itself may not be considered to be a 'spare', and therefore is not identified as the most critical item from a supply point of view, some maintenance tasks are performed directly on the aircraft, and so this level of the hierarchy is relevant.[3]

2 ibid., p. 2-9.

3 Figure F-1 makes several assumptions about the build structure of aircraft that are not universally true. It assumes that BDS are *only* fitted to repairable spares, which are *only* fitted to LRUs (which are the only components fitted directly to the aircraft). However, some BDS (eg. rivets) are fitted directly to the airframe: insufficient stockholdings of such BDS could immediately ground the aircraft. Repairability does *not* determine an item's potential impact on availability.

Levels in the hierarchy below the weapon system level will be loosely based on the build structure of the weapon system.[4] Items which may be directly removed from the weapon system will be at the second level; items which may be directly removed from these will be at the third level; and so on.

The reason for organising the hierarchy in this manner is the 'buffering' effect provided by the existence of serviceable spare items at each level. The criticality of the timeliness of maintenance on an item is reduced by managing the repair pipeline with surplus components, such that a 'run' on components should seldom reduce holdings of serviceable spares to zero. Thus, maintenance will only have a *direct* impact on component availability when the pipeline cannot supply a serviceable component when required.

Components further down the item importance hierarchy have an increasingly indirect effect on availability. The absence of a component well down in the hierarchy can only impact availability when the pipelines above it in the hierarchy have all 'failed', ie. have no spare components. For example, a fastener required to assemble a fuel control unit can only affect availability when there are no spare fasteners, no spare serviceable fuel control units, no spare serviceable engines (and no spare serviceable aircraft).

LEVELS WITHIN THE HIERARCHY

Top Level

At the highest (weapon system) level, there are no spares.[5] The absence of any aircraft undergoing maintenance immediately and directly affects aircraft availability. The aircraft itself can be considered to be the first level of build in the hierarchy.[6]

Second Level Items

The second level of the hierarchy comprises components which are replaced on the aircraft itself. An example is an aircraft engine.

Maintenance on a second level item will not impact availability (except by the time taken to remove and replace it), so long as there are spare items in the maintenance pipeline that

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4 The critical consideration in establishing the hierarchy is actually to distinguish between components that are separately provisioned (eg. components which have their own maintenance pipeline, or for which separate spares holdings are maintained). If one component is physically a subassembly of another, but it not separately provisioned (eg. because it is seldom detached), the two components should be considered to be a single entity: only one set of spares will be held.

5 ...assuming that all aircraft could be productively used during a contingency, if not on combat operations, then on operational training, etc.

6 Traditionally, 'first level of build' items are considered to be those that fit directly to the aircraft. However, these items appear at the *second* level of the item importance hierarchy; to simplify the terminology, level of build will here match the level within the hierarchy.

can be fitted while the removed item is undergoing maintenance. Only when there are no spare items in the pipeline can maintenance on second level items impact on availability.

Line Replaceable Units (LRUs) are a subset of second level items.[7] The term LRU implies that the replacement can be done on the flight line (ie. at operational maintenance level). However, components such as wings are equally 'exposed' in their potential impact on availability: if there are no spare wings when required, availability is affected. The only difference between LRUs and other second-level items is that LRUs must generally be removed and replaced more frequently, and this can be done more quickly and easily.

Third Level Items

Spare parts that may be removed or fitted directly to second level items constitute the third level of the hierarchy. An example is an engine fuel control unit, which may be removed from the engine and maintained separately; a pipeline for fuel control units may exist, which would normally contain some spare units. Maintenance on these items will not directly affect production of its parent item (the engine) unless there are no spare fuel control units. Even if this situation arises, aircraft availability will not be affected—as long as there are spare engines in the engine maintenance pipeline. Thus, third level items are effectively double-buffered from affecting aircraft availability; once because of spares holdings of the items themselves, and once because of spares holdings of the items to which they are fitted.

Lower Levels

Components at the fourth level of the item importance hierarchy are buffered from affecting availability by three sets of spares; and so forth.

VARIATIONS AND EXCEPTIONS

Components which do not require maintenance need not be represented in an importance hierarchy for maintenance purposes, so Break Down Spares (BDS) need not be shown. (However, the directness of their impact on availability will follow the structure of the hierarchy defined above.)

An aircraft may still be able to safely fly, and successfully execute at least some types of missions, without all components fitted. Some items are role-specific; their absence only means that the aircraft cannot execute one (or a subset) of its roles or mission types. The criticality of such items must also take into account the desirability of being able to perform the role for which the item is required. Role-specific minimum equipment lists for each weapon system should be developed to allow better management of such items.

7 LRU is a USAF term. The USN equivalent, used in Hornet-related areas, is Weapon-Replaceable Assembly (WRA).

The Air Command Operational Preparedness Directives' listings of systems required to be serviceable are an appropriate starting point.[8]

Although a given LRU (for example) may *not* be subject to maintenance, but a subassembly of it *is* subject to maintenance, the LRU must still appear at the second level of the hierarchy, with the subassembly below it. This is because spares holdings of the LRU will still serve to buffer delays or shortages of the subassembly.

A lack of spares for a component at a certain level does not automatically mean that any maintenance work on such components will affect the production or availability of items above it in the hierarchy. If such components can be removed, maintained and refitted within the maintenance time of their higher level assembly, no adverse impact will result. For example, components are often removed from an aircraft at the start of a major servicing, maintained as required, and then refitted before work on the aircraft itself is completed. The aircraft servicing is not delayed in this case, and no spares of the removed component are required. However, it is not always possible to guarantee the completion of component work within the maintenance time of its higher assembly, and so spare components are usually held.

Cannibalisation is another expedient that may be used to avoid impacting availability.[9] Because of the additional maintenance effort required, cannibalisation should be used as a last resort.

Some components may be removed from a higher level of assembly *in addition* to their immediate parent. For example, a rivet in a wing normally may be removed and replaced directly on the aircraft, without requiring the wing to be removed from the aircraft first. The rivet thus appears to be a second-level item; insufficient spares could directly affect availability. However, if this situation arose, it is possible to remove the wing and replace it with a serviceable spare wing. The rivet then appears to be a third-level item, buffered from impacting availability by the existence of a spare wing (although changing the wing will result in some lost availability). While this is an extreme example, it illustrates the point that many items cannot be rigidly assigned a place within a simple hierarchy.

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8 See p. 31.

9 See p. 87.

SUMMARY

The following generalisations can be drawn from the item importance hierarchy:

a. The aircraft itself is the most critical component from an availability point of view; any maintenance work performed on the aircraft must directly affect availability.[10]

b. The impact of component maintenance on availability can be buffered by the existence of spares holdings for the component.

c. The criticality of components reduces with increasing 'depth' within the physical build structure of the aircraft, due to the existence of spares holdings for items above it in the hierarchy.

10 It is quite possible that aircraft could not be used 24 hours a day even during a contingency. Restrictions such as numbers of aircrew, weather conditions, day/night operations, etc, may mean that there may be some opportunities to perform maintenance on the aircraft without affecting operations at all. The flexible maintenance concept can best exploit this possibility. Whether such an arrangement constitutes 100 per cent availability depends on the definition of availability.

Annex G
Exploiting the Sustainability Period

INTRODUCTION

Most maintenance requirements determination processes assume a *steady-state* scenario; ie. that the maintenance goals and consequent intervals do not change over time. However, when transitioning from peacetime to a contingency, and then supporting a contingency of limited duration, steady-state considerations alone cannot be used to determine optimum maintenance policies.

This annex shows how the finiteness of the sustainability period can be exploited to better meet contingency maintenance goals (eg. an emphasis on availability). The approach used builds upon that of Chapter 11.

THE RELIABILITY-TIME RELATIONSHIP

It is necessary to determine how quickly the level of availability would change after an alteration in the amount of scheduled maintenance. Figure G-1 is an extract of Figure 11-5 (p. 98), showing how the *total* amount of maintenance varies with the amount of *scheduled* maintenance (over a long period of time). Two points are marked: S_p, representing a peacetime level of scheduled maintenance, and S_c, representing a *contingency* level of scheduled maintenance. Corresponding *total* amounts of maintenance are T_p and T_c respectively. The total curve is the sum of the scheduled and unscheduled contributions, which are not shown on Figure G-1 (but see Figure 11-5).[1]

Graphing Against Time

Figure G-2 is an initial representation of the transition from the peacetime maintenance level to the chosen contingency maintenance level, plotted against time on the horizontal axis. The levels of scheduled, unscheduled and total maintenance are constant at peacetime levels (S_p, U_p and T_p), and then are assumed to suddenly change to the contingency levels (S_c, U_c and T_c) *as soon as* contingency maintenance schedules are adopted. Figure G-2 shows the total amount of maintenance increasing immediately from T_p to T_c, ie. there is no short-term benefit from the reduction in scheduled maintenance.

1 The astute reader may object that S_c is too low, since T_c exceeds T_p. However, these are *steady-state* values; this annex will endeavour to show that S_c may indeed be a reasonable policy—for a while.

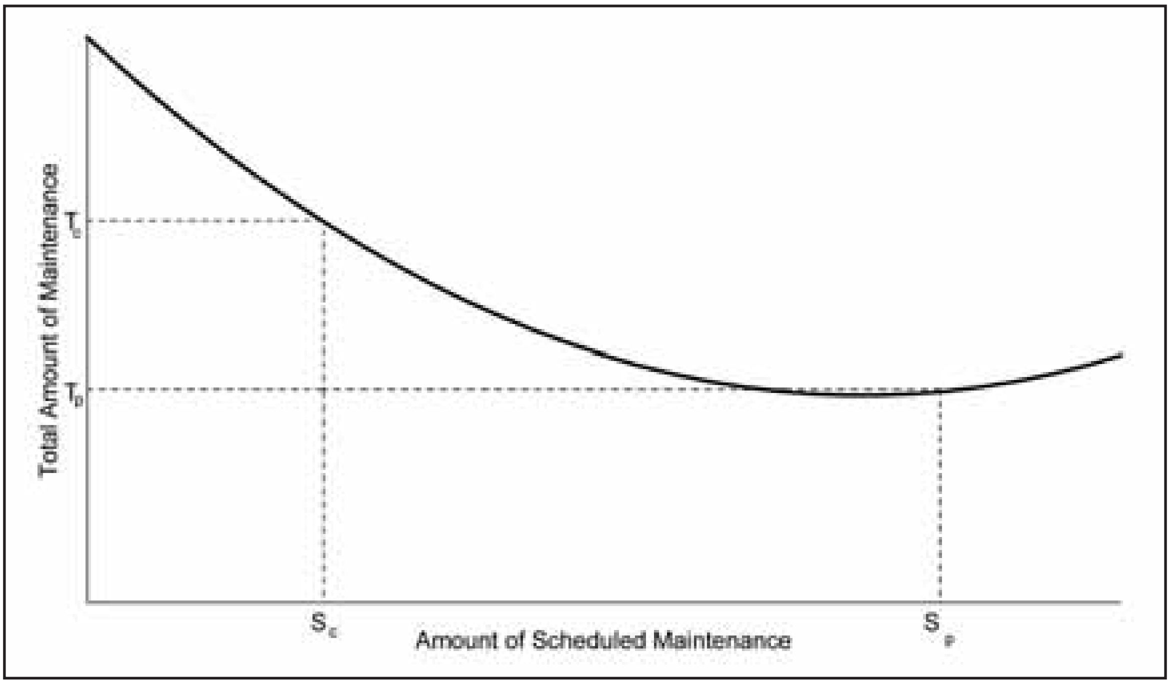

Figure G-1

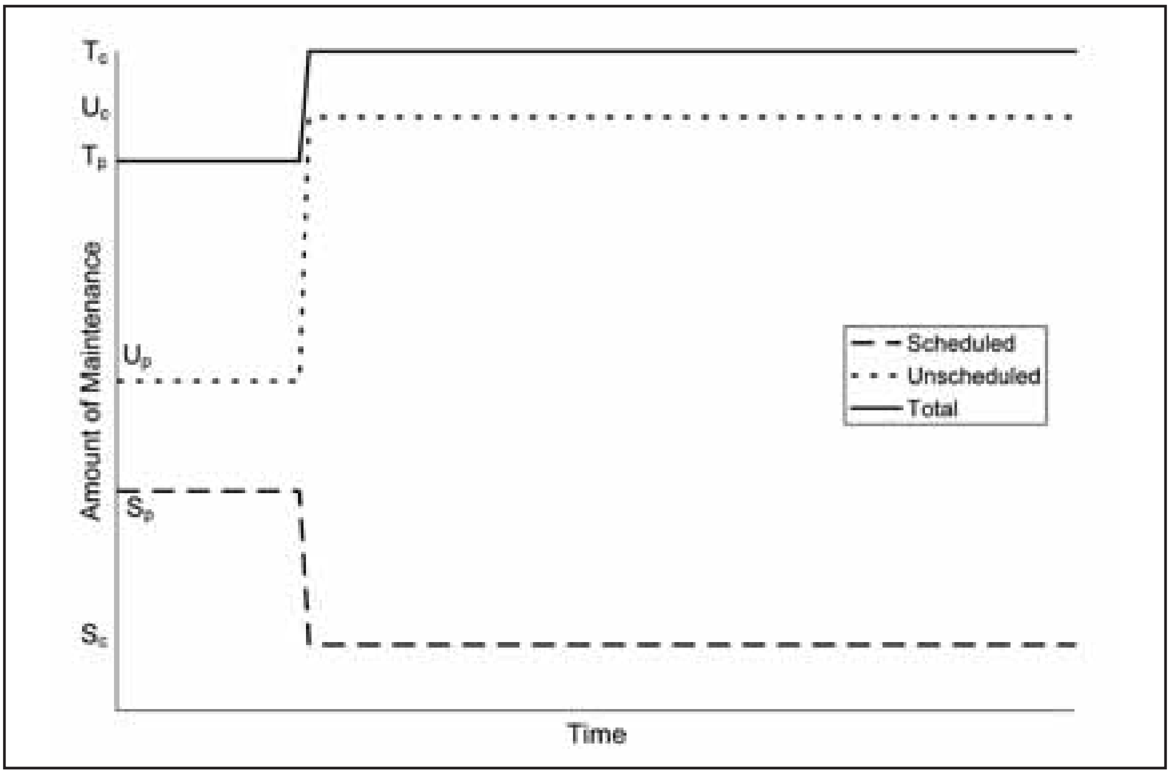

Figure G-2

'Period of Benefit'

In practice, the requirement for unscheduled maintenance will not rise as quickly as indicated on Figure G-2. The amount of unscheduled maintenance required will rise more slowly over time, and will only slowly approach the steady-state value. This is represented at Figure G-3.

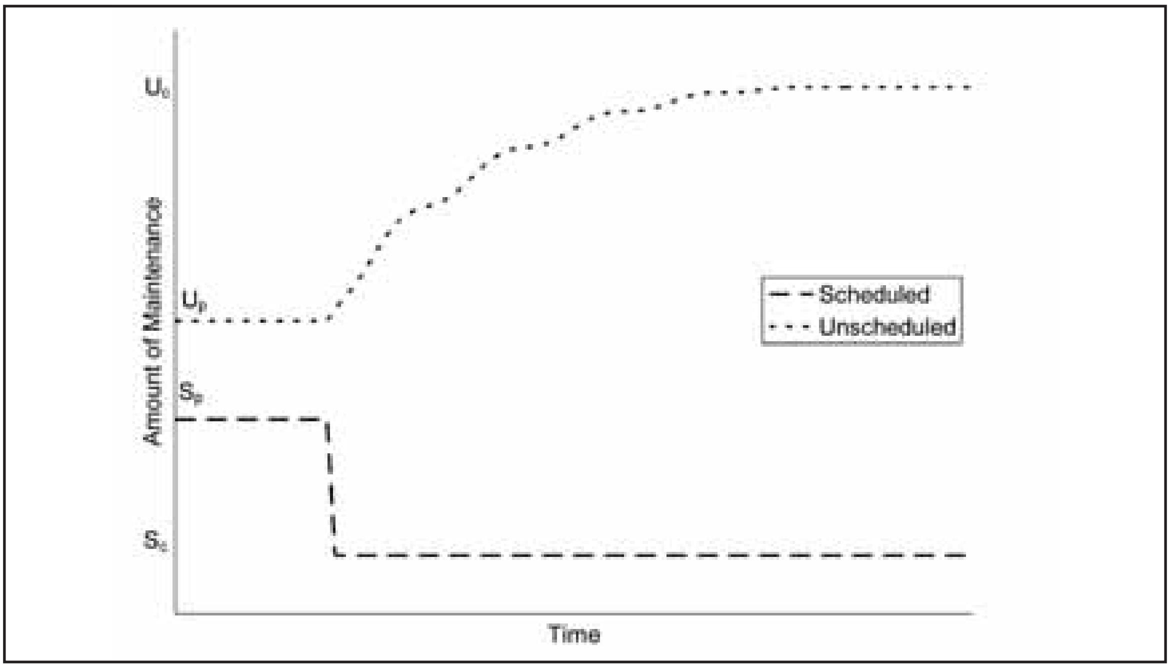

Figure G-3

The total amount of maintenance can be found by plotting a curve representing the sum of the scheduled and unscheduled components; see Figure G-4.

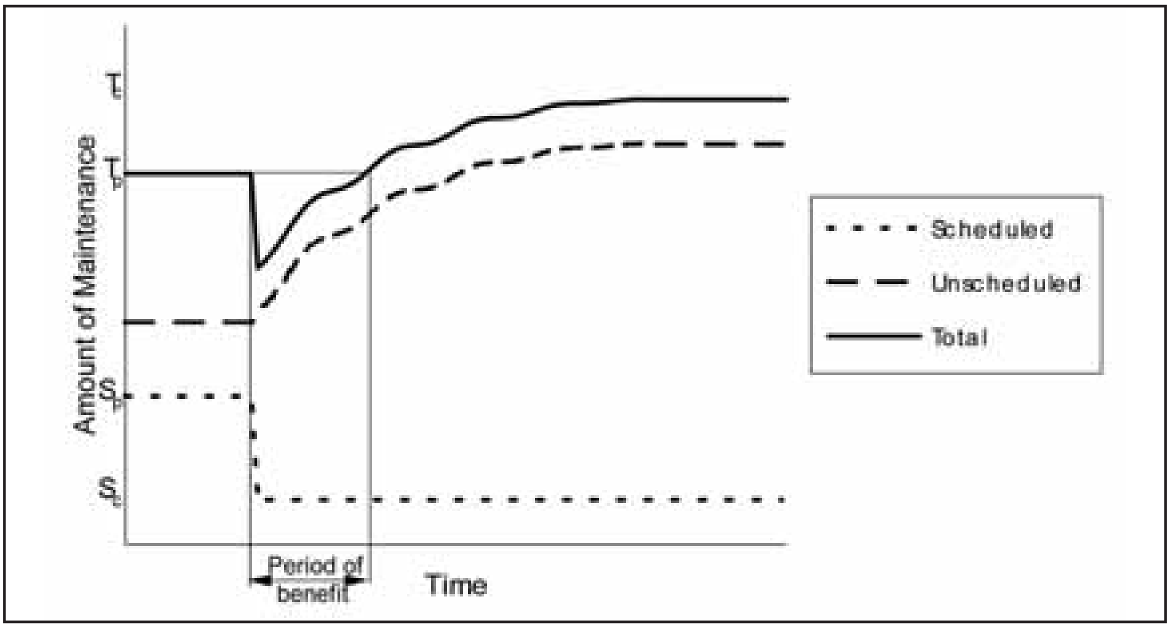

Figure G-4

The important difference between Figures G-2 and G-4 is that in the latter the *total amount of maintenance drops below its peacetime level for a period of time*, before climbing upwards past the peacetime level to reach the steady-state level T_c. This difference comes about because of the time lag between when scheduled maintenance is reduced and when unscheduled maintenance increases; or, more precisely, because of the slower rate at which unscheduled maintenance increases compared to the rate at which scheduled maintenance may be decreased.

While the total level of maintenance remains below the peacetime level (T_p), increased availability can be expected. The duration of this period of increased availability is marked on Figure G 4 as the 'period of benefit'. Effectively, a 'gap' has been opened up in the graph, where the amount of maintenance drops below the peacetime level for a limited period of time.[2]

Comparisons with Preparedness Objectives

The crucial question is: how long is the period of benefit? If it is particularly short, eg. a few days, the increased availability may allow a short-term surge of activity to achieve a specific military goal (but it would be necessary to consider the longer-term implications). If, however, the period of benefit is comparable to the sustainability period listed in the CPD for a particular serial, the phenomenon may be useful in helping to meet the CPD requirement.

To get a better idea of the duration of the period of benefit, it is necessary to assess the rate at which unscheduled maintenance increases.

APPLICATION

Which Tasks to Defer

In decreasing the amount of scheduled maintenance, decisions must be made about which maintenance tasks to defer or drop. Such decisions should take many factors into account; the peacetime maintenance interval is one factor which can be related to the period of benefit that may be expected.

Hypothetically, the scheduled maintenance workload could be divided into halves based on the maintenance interval of the servicings (or tasks). One half would contain all of the shorter interval tasks, the other half would contain all of the longer interval tasks. If the amount of scheduled maintenance is to be reduced to half, this could be done by dropping either the shorter interval tasks or the longer interval tasks.

2 The effect of the subsequently increased amount of maintenance, and what can be done about it, will be discussed later.

If the shorter interval tasks are dropped, the amount of unscheduled maintenance will rise fairly quickly. Short intervals would have been originally adopted because the mean time to failure of the items must be short: if not maintained often, they will probably fail.[3] Figure G-5 illustrates this effect, with a relatively steep rise in the amount of unscheduled (and therefore total) maintenance once the amount of scheduled maintenance is reduced.

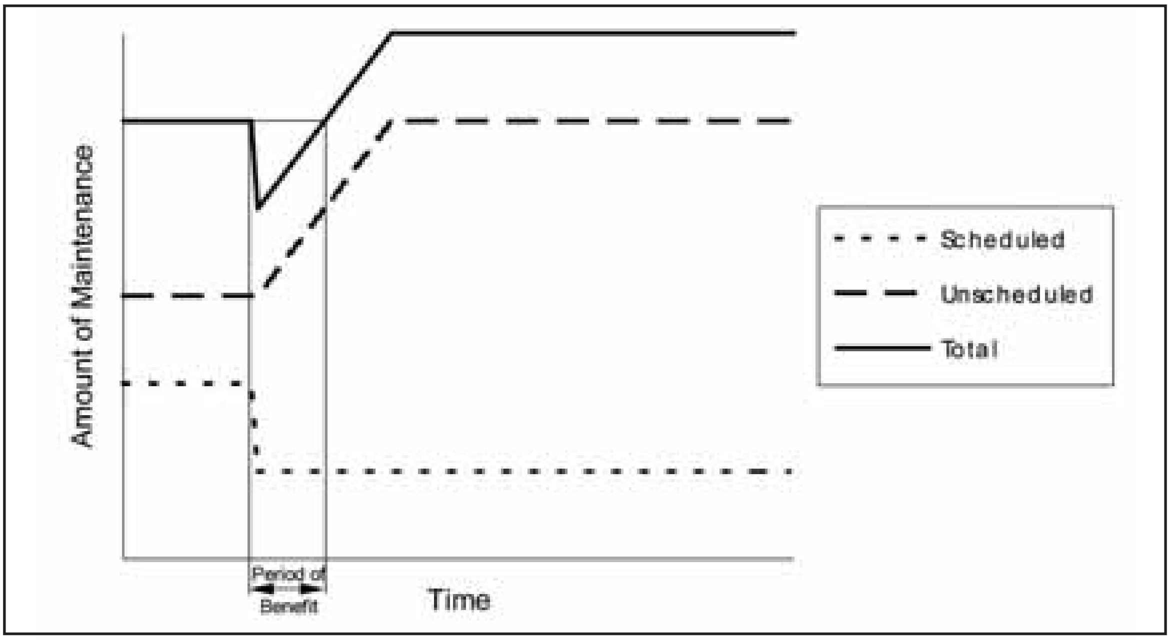

Figure G-5

If, however, the short-interval maintenance tasks are retained and the longer-interval maintenance tasks are deferred, a much more gradual increase in unscheduled maintenance will occur. Figure G-6 indicates this.

Predictably, the period of benefit is now significantly longer. The reduction in scheduled maintenance is the same (50 per cent), but different tasks have been shed to achieve the reduction compared to Figure G-5. The principle demonstrated between Figures G-5 and G-6 is that *deferring longer-interval maintenance tasks will be more beneficial to sustainability than deferring shorter-interval maintenance tasks*.

Deferring Deeper Maintenance

It is already documented that Deeper Maintenance (DM) may be deferred indefinitely during operations.[4] Although the term 'deeper maintenance' is not synonymous with longer-interval

3 This is an oversimplification: many other considerations influence the determination of maintenance intervals, including criticality of failure, convenience, etc.

4 DI(AF) AAP 1000, *The Air Power Manual*, Second Edition, Air Power Studies Centre, Canberra, 1994, p. 157. The main basis for this is that DM has a primary focus on maintenance aimed at asset preservation (DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, p. 5); and asset preservation assumes lower priority during contingencies (DI(AF) LOG 13-7, *Contingency Maintenance and Battle Damage Repair of Technical Equipment*, draft, 28 February 1994, paragraph 1).

maintenance, there is a strong correlation. The exact definition of DM is rather unclear (see Chapter 19), but indicators of DM include the extent of equipment and facilities required, and the amount of disassembly necessary. Good design practices assure that maintenance tasks requiring specialised equipment or significant disassembly need to be performed only infrequently, to maximise availability and reduce maintenance costs. There is therefore a general correlation between DM tasks and longer maintenance intervals.[5]

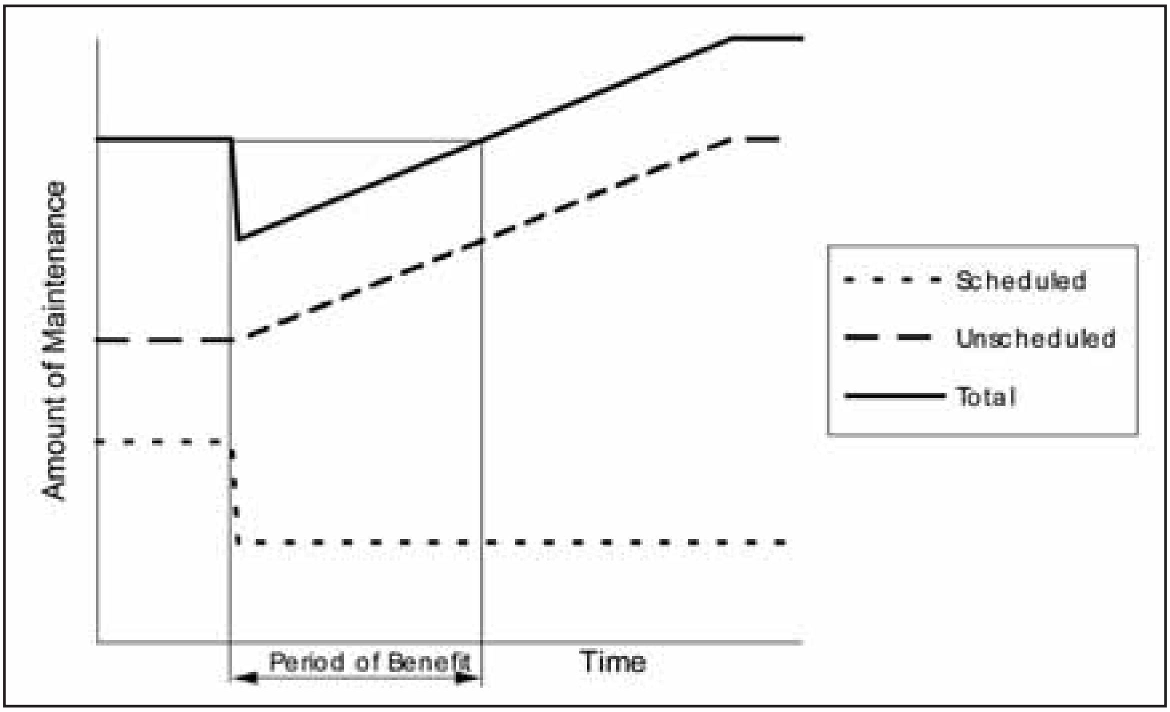

Figure G-6

It is fortuitous that DM generally contains a significant amount of asset preservation (which is of a lower priority during contingency), and that such tasks generally have a longer maintenance interval. The deferral of such tasks improves availability for longer than the deferral of shorter interval tasks, which enhances sustainability.

Proportion of Longer Interval Tasks

Even though two different types of aircraft may require the same amount of peacetime maintenance, they may differ in the sustainability benefits that can be obtained by deferring maintenance.

As an example, aircraft *A*'s peacetime maintenance requirement consists of one periodic servicing performed once every 12 months, with a duration of four weeks. Aircraft *B* also

5 For example, many asset preservation tasks, such as searching for and removing corrosion, need only be performed infrequently, due to the relatively slow rate of degradation caused by such failure mechanisms. Often, sophisticated equipment is used, and access to internal aircraft structure may be necessary. Therefore, preservation tasks are often deeper maintenance, and are often placed ('packaged') in longer interval servicings.

has a single periodic servicing; however, it must be performed once every three months, but only takes one week to perform.[6] Both aircraft are therefore subject to four weeks of scheduled maintenance per year, and have the same peacetime availability (based on the criterion of maintenance downtime alone).

If 50 per cent of each aircraft's maintenance could be deferred during a contingency, aircraft *A* would exhibit greater availability than aircraft *B* for a considerable period. For example, assume contingency maintenance was adopted immediately after a peacetime servicing. Six months later, aircraft *B*'s deferred maintenance tasks would be 'overdue' by three months; a significant amount of unreliability, and hence unscheduled maintenance, would be expected. Aircraft *A* is not even due for its maintenance work by the six month mark, and so its level of reliability, and unscheduled maintenance, should still be at peacetime levels (neglecting the effect of the contingency operations, BDR and environment). Aircraft *A* should therefore exhibit better availability at this stage. Figure G-7 shows the relative periods of reduced total amount of maintenance for aircraft *A* and *B*.

Even after 12 months of operating with deferred maintenance, aircraft *A* would exhibit better availability than aircraft *B*. The rate of increase of unscheduled maintenance required for aircraft *A* would be much more gradual than for aircraft *B*.

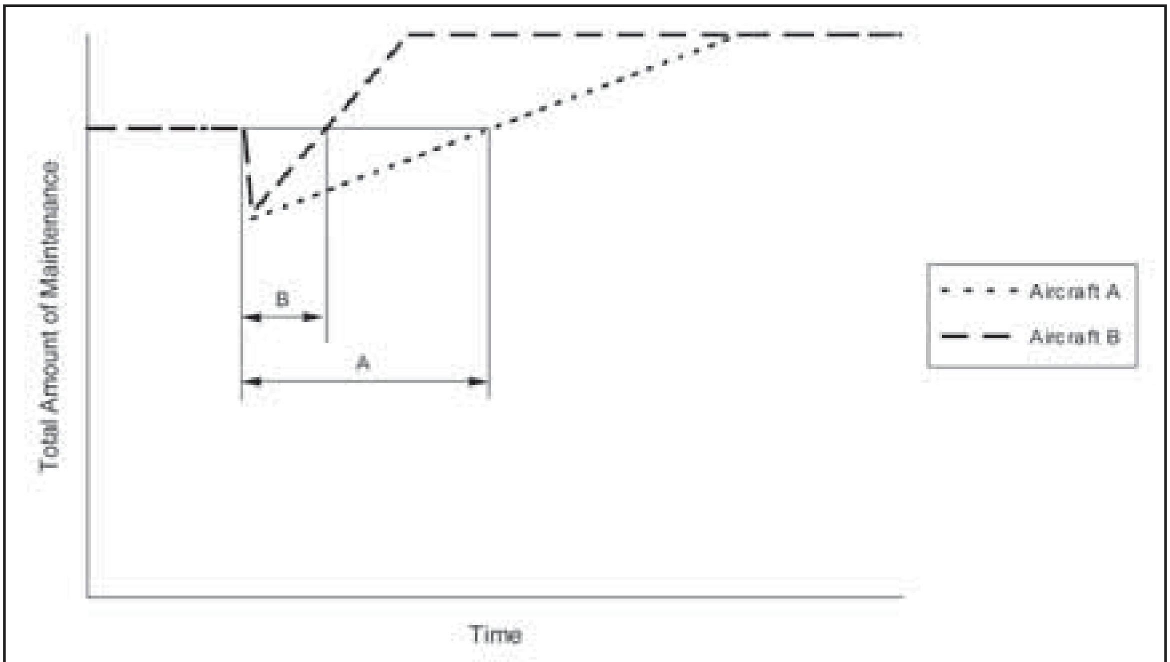

Figure G-7[7]

6 This latter example is *not* a case of phased maintenance, consisting of the same tasks and intervals as case A, but split between four smaller servicings. The intention here is that the *same* tasks need to be performed every three months, but this takes one-quarter of the time required to perform the annual tasks required for aircraft *A*.

7 Although not clear on the graph, after a long period of time (ie. on the right-hand side of the graph) the maintenance requirements for aircraft *A* and *B* may again be the same, as they were in peacetime, albeit at a higher level.

Even if aircraft *A*'s annual servicing comprised more than four weeks' work, and 50 per cent of each aircraft's maintenance were to be deferred, aircraft *A* could still exhibit higher availability for a period of time, due to the more gradual increase of the requirement for scheduled maintenance compared to aircraft *B*. In this situation, aircraft *A* would have *lower* availability than aircraft *B* during peacetime, but *higher* availability during a contingency, for a certain period of time. Figure G-8 illustrates this. If the period of time marked 'A' meets or exceeds the period of contingency, aircraft *A* is to be preferred to aircraft *B* (based on this criterion alone). Beyond the duration marked 'A', aircraft *B*'s peacetime availability is greater than aircraft *A*'s contingency availability, and so aircraft *B* becomes a better choice at some stage (all else being equal).

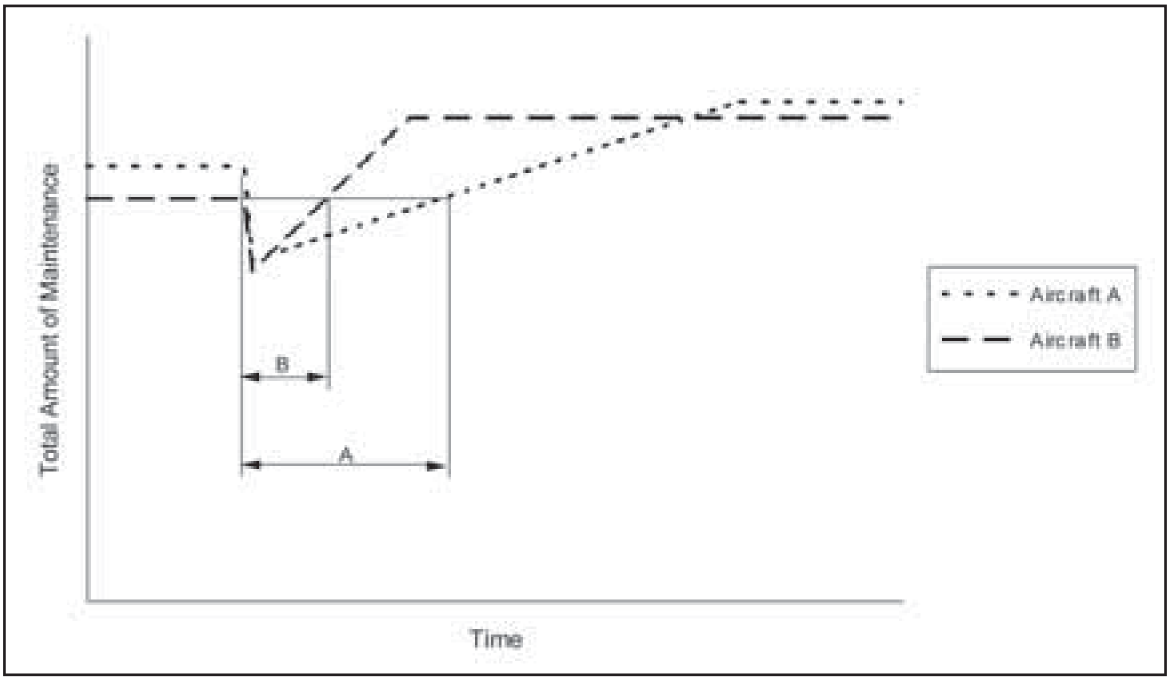

Figure G-8

The general principle is that the duration for which contingency availability levels can be sustained (an aspect of sustainability) cannot be directly inferred from peacetime availability levels; ie. contingency availability will not necessarily be directly related to peacetime availability. Even the size and period of contingency maintenance servicings will not provide a total picture of the expected sustainability characteristics of the aircraft's maintenance program. The extra information required is the duration and intervals of the deferred tasks: this will indicate the rate at which unscheduled maintenance can be expected to increase, and hence indicate the period of benefit that may be expected from task deferral.

Deferring Mixed Interval Tasks

So far, the effect of deferring scheduled maintenance tasks of *differing* peacetime intervals has not been considered. In reality, a thorough search of aircraft servicing schedules and maintenance plans would reveal many tasks that could be deferred; these tasks would not all have the same maintenance interval, but a mixture of intervals would be represented.

If the group of tasks to be deferred contained two distinct sets of tasks, with one set being all short interval tasks and the other set being all long interval tasks, then the resulting increase in unscheduled maintenance will be the summation of the increases for the two groups considered separately.[8] Figure G-9 illustrates this, assuming that the tasks *within each group* all have the same maintenance interval (and exhibit the same failure rate characteristics).

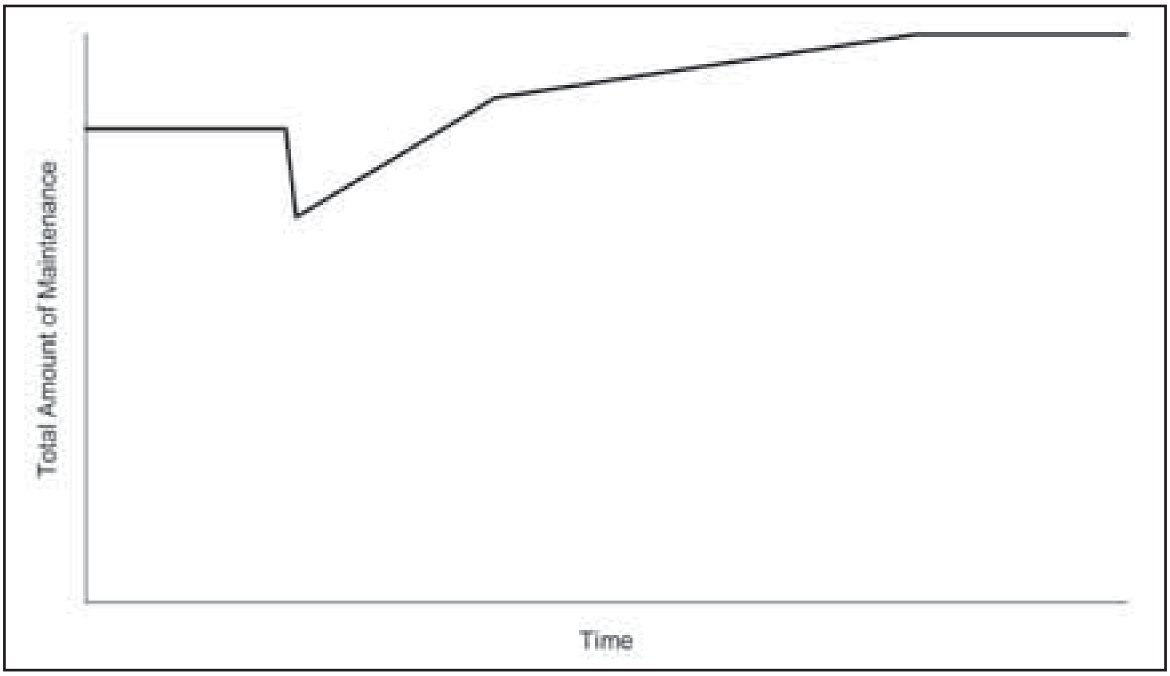

Figure G-9

Initially, the amount of maintenance required increases rapidly, as a result of the increasing unscheduled maintenance required as a consequence of deferring the shorter interval tasks. After a while, this constituent approaches a maximum value. Thereafter, the more gradual increase in the amount of unscheduled maintenance arising from deferring the *longer* interval tasks causes a further, but more gradual, increase in the total maintenance requirement, until this latter constituent also approaches its maximum value.

This analysis can be expanded to consider the effect of deferring a set of tasks with a *variety* of different task intervals, rather than just two. The kink in the graph at Figure G-9 becomes a smooth curve, as indicated in Figure G-10.

The steepness of the early part of this curve is determined by the proportion of shorter interval maintenance that has been deferred. The steeper the earlier part of the curve is, the shorter will be the period of benefit (reduced amount of maintenance).

8 In practice, there would be some 'saving' associated with the summation of the two sets of unscheduled maintenance work: it is quicker to fix two problems at the same time (or even sequentially), rather than independently.

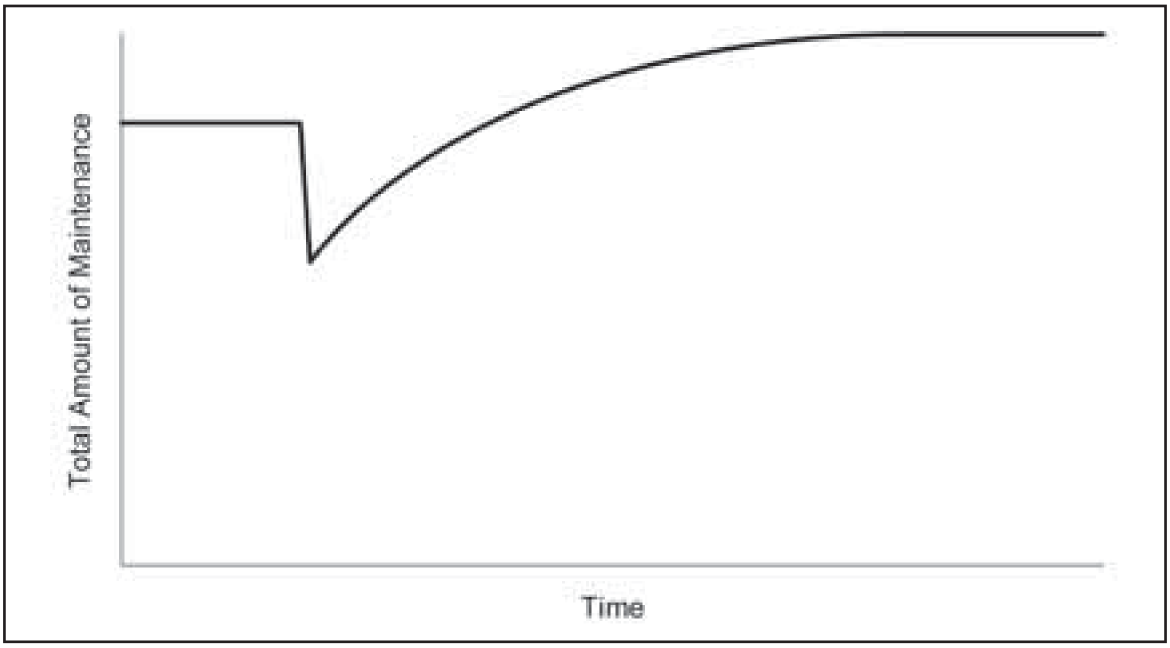

Figure G-10

The period of benefit for an item will be of the same order of magnitude as its maintenance interval. For example, if the maintenance interval is measured in days, the period of benefit may be a few days; if the interval is years, the period of benefit may be years. The usefulness of the period of benefit therefore depends on how maintenance intervals compare with sustainability (or surge) periods. If intervals are much shorter, the period of benefit is not likely to be useful; if intervals are similar or longer, the period of benefit may be worth exploiting.

It is necessary to be able to estimate *aircraft* availability based on *component* availability levels to properly assess the effect of exploiting component periods of benefit.[9]

Transfer Function

It is desirable to be able to quantify the amount of corrective maintenance required at any point in time after the reduction in preventive maintenance. This would allow the period of increased availability to be quantified, and hence allow calculation of the level of availability that could be expected. More generally, a mathematical function that calculates the shape of the *corrective* maintenance curve based on the shape of the *preventive* maintenance 'curve' is required. Such a function is called a *transfer function*.[10]

9 See p. 102.

10 *Transfer functions* are commonly used in engineering to relate one or more *input* functions to a resulting *output*, or result. An example in the field of aerodynamics is in the response of the aircraft to a given control movement: the control movement (eg. sudden pull back on the control column) is the input; the response of the aircraft (climbing, decelerating, possible oscillation) is the result. A transfer function can be used to estimate the response of the aircraft to the specified control movement.

A transfer function would also allow estimation of other information. During a contingency, it may be desirable to mount a short campaign requiring particularly high fleet availability (ie. a surge). A further reduction in preventive maintenance would permit this, but the resulting level of corrective maintenance could only be determined by considering both the effect of the initial reduction of preventive maintenance (ie. to contingency maintenance levels), and the further reduction immediately before and during the surge (ie. combat maintenance). It would also be possible to estimate how quickly corrective maintenance requirements would diminish after a return to higher levels of corrective maintenance; eg. after the conclusion of a contingency, or the conclusion of a surge within a contingency. The possible benefits of *increasing* preventive maintenance during work-up to reduce corrective maintenance during a contingency (at least initially) could also be assessed; and the same concept could be used immediately prior to a period of surge within a contingency. Figure G-11 illustrates some of these scenarios.

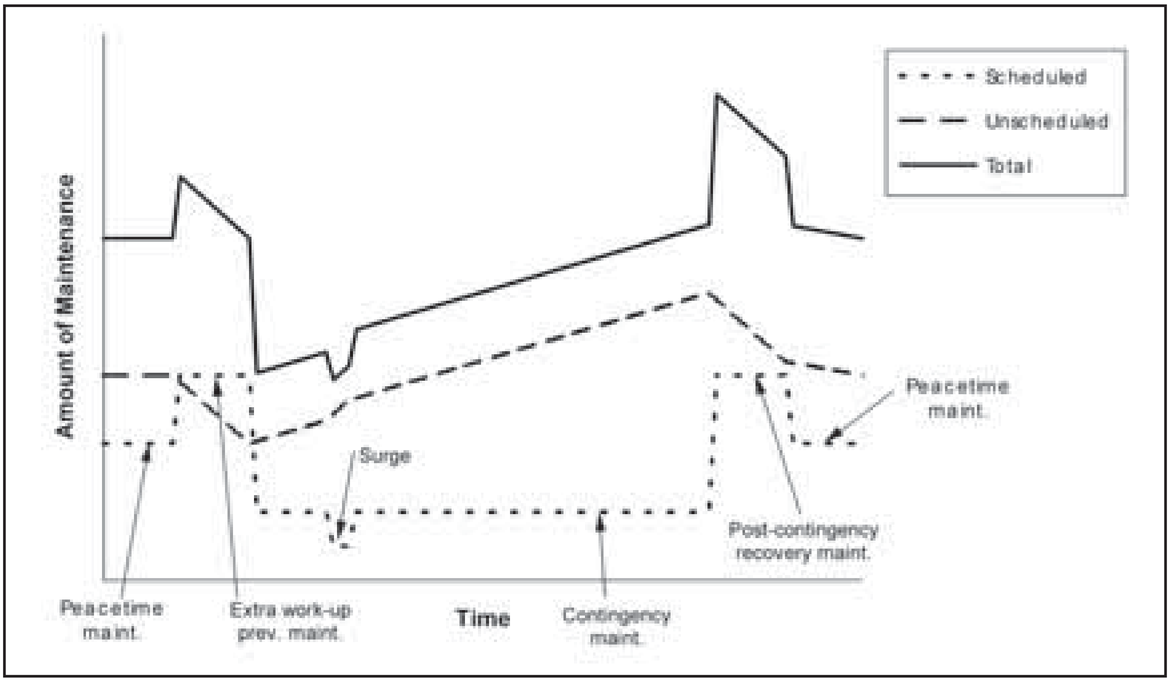

Figure G-11

This Figure reflects a great deal of complexity, and the time-consuming nature of the maintenance requirements determination process (and particularly the approach proposed in this annex) means that maintenance policies could not be recalculated in response to changing operational requirements during a contingency. However, it should be possible to develop maintenance plans in peacetime corresponding to likely operational requirements. Contingency maintenance plans can be established to optimise availability over a specified period of time, and additional expedients could be indicated that would be appropriate to combat or surge. The implications of these plans (eg. reduced reliability after the surge) could also be estimated, and operational commanders could take this into account when invoking such maintenance plans.

Future information systems could offer considerable support in helping to identify candidates for contingency, combat or surge maintenance changes. The ability to quickly identify components in terms of criticality and maintenance interval would be a start; the next step would be the additional inclusion of maintenance task duration information; and the automated calculation of the impact of task deferral on aircraft availability would be the ultimate goal.

SUMMARY

Reliability changes do not immediately follow changes to scheduled maintenance policies, but would lag somewhat behind. Therefore, a reduction in scheduled maintenance requirements will not be associated with a rise in unscheduled requirements (ie. repair) for a period of time; thus, the *overall* maintenance requirement may be reduced to a level below any steady-state level for some time. Increased availability is therefore achieved during this 'period of benefit'.

Deferring maintenance tasks with longer intervals gives a longer period of benefit. Deeper maintenance (DM) tasks generally have long maintenance intervals, so the deferral of DM tasks can create a relatively long period of benefit. Aircraft with a greater proportion of long-interval maintenance tasks compared to short-interval tasks may benefit more from task deferral, since the period of benefit will be longer. The duration of the period of benefit will be of the same order of magnitude as the maintenance interval, so the usefulness of the period of benefit depends on a comparison between maintenance intervals and sustainability periods (or combat or surge periods).

Exploiting the period of benefit concept would be facilitated by greater information system support. Improvements in integration between computer systems and data retrieval would provide some benefits, but more complex processing would be required to maximise automation of the process. Unless such automation is implemented, contingency maintenance plans to exploit the period of benefit must be prepared during peacetime. Such plans could cover multiple scenarios, such as different sustainability periods, and periods of combat and surge.

Annex H
Manpower Required in Uniform

INTRODUCTION

While core/non-core guidance determines which capabilities need to be performed by uniformed personnel and defence civilians during a conflict, it does not indicate how many more positions may be required to generate and sustain the required number of positions, taking into account the need to provide sufficiently broad training and to periodically rotate personnel out of the AO. The Report of the Interdepartmental Committee on the Wrigley Review acknowledged the possibility of shielding some intermediate level maintenance (ILM) positions from CSP where manpower rotation requirements could not be otherwise met (including by the use of reserves).[1] Out of this idea developed the concept of Manpower Required in Uniform (MRU).[2]

Not all core activities must be performed by uniformed personnel (some can be performed by defence civilians), and so not all positions performing core activities will be MRU—although most will be. Conversely, there will be a number of MRU positions performing non-core activities. This will mean that the corresponding activity cannot be subject to CSP without destroying the RAAF's ability to meet its contingency commitments.[3]

This annex outlines the assumptions behind MRU, the categorisation of personnel, and areas of further development.

ASSUMPTIONS

MRU is based on the level of capability specified in the CPD, and the Rates of Effort (ROE) derived from the CPD and published in Air Command Operational Preparedness Directives (ACOPDs). However, regardless of the length of sustainability periods, MRU considerations include the periodic rotation of personnel out of the AO. For planning purposes, the rotation cycle is 12 months deployed duty followed by 12 months in a support area.[4]

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1 Report of the Interdepartmental Committee (IDC) on the Wrigley Review, *The Defence Force and the Community*, AGPS, Canberra, 1991, p. 15.

2 The terms 'Members Required in Uniform' (MRU) and 'Personnel Required in Uniform' (PRU) are used in some circles.

3 CAS 264/1994, AF91/10169 Pt 4 (14), *First Cut MRU Submission – Air Force*, ACPERS, 5 April 1994, Annex A.

4 *Manpower Required in Uniform (MRU)*, AAP Chapter, draft, DMPC-AF, 1994, paragraph 14.

A daily working routine of 12 hours on duty followed by 12 hours off duty is assumed. While on duty, some personnel will spend four hours in Base Combatant Personnel (BCP) duties; whether this includes maintenance personnel involved in OM remains undecided. Personnel will work this routine nine out of ten days; however, no days off may be allowed during the combat period.[5]

One study has indicated that the level of maintenance manpower required is dictated largely by the need to provide 24-hour operations to cater for the peak activity levels that may occur during combat. The *average* activity level (rate of effort) is much less significant in determining the maintenance manpower levels required.[6]

CATEGORIES OF PERSONNEL

This section describes the various categories of personnel within MRU. Since MRU terminology and definitions are still evolving, the descriptions must be considered to be interim.

Initial Deployment Force (IDF)

The Initial Deployment Force (IDF) is 'the aggregate of the uniformed personnel required for initial deployment, based inside the area of operations'.[7] The IDF must be able to support operations to meet concurrent maximum CPD requirements. Some IDF positions will exist during peacetime; others will not (these will be Contingency Augmentation).

Contingency Support Manpower (CSM)

Posts which are required to be filled by *uniformed* personnel to directly support the contingency, but are based *outside* the AO are classified as Contingency Support Manpower (CSM).[8]

Rotation Pool (RP)

Every position in the IDF generates a requirement to find a corresponding uniformed position to cover the need to rotate IDF personnel out of the AO.[9] A Rotation Pool (RP) must therefore be retained, nominally of the same size as the IDF. It will be possible to provide some RP positions by training new recruits, but the balance of the RP must be found from

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5 ibid., paragraphs 18–20.

6 AHQ 3020/13/TECH Pt 1 (20), *Report of the Working Party to Consider TFG CMR and Associated Maintenance Issues*, DENGPP-AF, 16 May 93.

7 *Manpower Required in Uniform (MRU)*, paragraph 38.

8 ibid., paragraph 39.

9 Some positions may be required in the AO for periods of combat, as opposed to the full sustainability period. These positions will not generate a requirement for a RP position.

within existing positions.[10] Non-deploying positions, such as CSM, are prime candidates for identification as RP positions;[11] however, there will be some CSM positions which will not be in the RP, and vice versa.[12]

Recruited, Trained and Qualified (RTQ)

The IDF will be due for rotation out of the AO after 12 months.[13] Thus, trades which can be Recruited, Trained and Qualified (RTQ) to an operationally ready and deployable level within 12 months can be used as part of the Rotation Pool (RP). Subtracting times required to recruit new members and provide recruit training, some 200 days will be available in which training may be conducted. Any trade that can achieve its training requirements within 200 days can therefore use RTQ personnel as a part of its RP, reducing the need to find peacetime positions to cover all RP requirements.[14] Of course, there remains a need to ensure that some proportion of the RP consists of experienced personnel, to avoid manning deployments with only new recruits after the IDF returns.[15]

The feasibility of RTQ is adversely affected by the use of high technology equipment. For example, very few personnel required for Hornet maintenance can be trained to competency within a 12 month period.[16] Specialist skills are also likely to be more difficult to retain amongst reserves, unless specific peacetime roles are given to reserve forces that will require such skills to be regularly exercised.[17] The use of advanced technology therefore tends to require the retention of additional uniformed personnel within the RAAF.

Contingency Augmentation (CA)

The mapping of the contingency manpower requirements onto the peacetime structure of the RAAF requires that some sections must be marked for Contingency Augmentation (CA), to indicate that a position must be created and filled during a contingency which is absent during peacetime. This will arise where the size of the Initial Deployment Force (IDF) or Contingency Support Manpower (CSM) exceeds the peacetime establishment level.[18]

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10 Current estimates are that 25 to 30 per cent of RP positions can be filled by training new recruits.

11 *Manpower Required in Uniform (MRU)*, paragraph 47.

12 AF 91/33925 Pt 4 (46), *Development of Manpower Required in Uniform (MRU) – Situation Report*, DGPRM-AF, February 1993, Annex B, paragraph 6. An example of a CSM position which will not be in the RP is that of CAS, since there is no position with which CAS' position can rotate.

13 In reality, the rotation should be phased, to retain reasonably constant levels of experience in the AO.

14 *Manpower Required in Uniform (MRU)*, paragraphs 45–46.

15 In practice, the initial IDF personnel would not all be rotated out at the same time, to provide some continuity on deployment.

16 AHQ 3020/13/TECH Pt 1 (20), Annex C.

17 The designation of specific roles for reserve units was a part of Wrigley's conception.

18 *Manpower Required in Uniform (MRU)*, paragraph 32.

Conversely, a Contingency Augmentation Lost (CAL) annotation will be placed against positions established during peacetime which are identified to transfer to a CA position during a contingency.[19] Contractor and/or locally employed civilian support should be used to backfill CAL positions during a contingency where necessary.[20]

Contingency Manpower Requirement (CMR)

IDF, RP, CA and CSM are combined to give the Contingency Manpower Requirement (CMR). This is total uniformed manpower required to 'conduct operations, provide combat support for operations, man higher headquarters, and provide increased activity levels in non-AO logistics and training organisations.'[21]

Military Specialist (MS)

Some positions may be indicated as Military Specialist (MS) positions, where distinctively military skills or experience is necessary to ensure proper conduct of peacetime or contingency tasks.[22] MS positions may be justified to retain skills in such areas as maintenance, maintenance management, engineering, contract management and training,[23] all of which bear directly on the effectiveness of the maintenance function.

Where a MS position requires experience that can only be gained at a particular 'feeder' position, the latter position can be considered to be a Military Specialist Generator (MSG) position. If only general experience typical for the rank and mustering are required, the determination of the manpower 'structural overlay' will accommodate the requirement.[24] MS positions may exist within the IDF, CSM, or RP.

Some skills needed in the AO can only be obtained from experience in deeper maintenance,[25] and so there is a need to retain some uniformed DM capability to provide a training ground.[26] For this reason, the US Marine Corps retains military personnel in their depots to provide a pool of appropriately experienced personnel for deployment.[27] USAF and USN restrictions on commercialisation have already been mentioned. US services' requirements for such skills are arguably greater than those of Australia, as the US employs a policy of 'Global Reach', and therefore retains the potential to deploy more maintenance capability than Australia would generally require.

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19 ibid., paragraph 33.

20 ibid., paragraph 37.

21 CAS 264/1994, loc cit.

22 AF 91/33925 Pt 4 (46), Annex C.

23 *Manpower Required in Uniform (MRU)*, paragraph 50.

24 ibid., paragraph 53.

25 LD93-20656 Pt 1, *Maintenance Planning in Defence*, draft, LOGDIV SEO LS(C), October 1993, p. 11.

26 DI(AF) LOG 2-1, *Maintenance Policy for Technical Equipment*, 8 October 1992, paragraphs 20, 38.

27 Report on the Overseas Visit of Air Vice-Marshal W.M. Collins, AM, Air Officer Commanding Logistics Command, 20 September 1991–18 October 1991, p. 6-4.

Not only will there be a need for tradesmen with DM experience in the AO, but a cadre of engineers should also be available with a background which includes DM.[28] These engineers will be crucial for the assessment and design of significant battle damage repairs, and (to a lesser extent) the determination of contingency scheduled maintenance requirements and the development of contingency modifications.

In addition, it may be desirable for OM units to take over some DM tasks during a contingency.[29] This could be required to achieve greater responsiveness. The ability of OM units to do this would be complicated by a lack of DM-experienced tradesmen (and by contractual issues if the DM capability was provided by industry).[30]

Technical and engineering positions in DM which are needed to provide expertise for OM (and particularly on deployment) must be considered to be MRU. An alternative, or complementary, approach is to employ RAAF engineers within contractors' organisations to obtain the equivalent experience.[31]

Structural Overlay

On top of all of the above requirements, it is necessary to assure that a suitable number of positions exist for each rank and trade to ensure that the other MRU requirements can be met.[32] For example, if there is a need for some number of positions of a certain rank and mustering, that mustering must have sufficient positions of lower rank to ensure that the required number of more senior personnel can be 'generated'.

FURTHER DEVELOPMENT

MRU concepts are still undergoing development. The recent changes to the interpretation of the extent to which civilians can be used in the AO may have a bearing on the definitions of core and non-core; this, in turn, should have a follow-on effect on MRU.[33]

In addition, Wrigley's original concept involved significant reliance on the Militia (reserves) to bolster the permanent forces and assist in sustainability. The incorporation of reserve

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28 RAAF Engineering Planning Team, *Blueprint 2020 – Engineering the Future*, Departmental Publications, Canberra, 1993, pp. 8-11, 8-15.

29 DI(AF) LOG 2-1, op cit., paragraph 16.

30 However, many contracts include clauses to permit Defence to reallocate workload in times of emergency.

31 RAAF Engineering Planning Team, *Blueprint 2020*, p. 8-15. Although unusual, there are precedents for this latter option. US Marines obtained Hornet maintenance training and experience from USN and contractor resources (Captain Scott Loch (USMC), *Innovative Maintenance Actions*).

32 CAS 264/1994, op cit.

33 AF 91/33925 Pt 4 (46), paragraph 8.

forces into contingency manpower plans appears to need further refinement.[34] However, it would be particularly unwise to further reduce MRU figures until it can be demonstrated that the Militia's recruiting targets can be met, and experience levels retained.

Likewise, current MRU planning makes little provision for expansion for conflict beyond CPD scenarios. HQADF guidance requires that MRU include positions necessary to provide an expansion base.[35] Without clear guidance on the nature of major conflict, and consequent CPD-like descriptions of higher levels of capability, this must remain a fairly vague planning exercise.

MRU calculations are very laborious. Given the dynamic nature of the data, definitions and assumptions on which MRU calculations are based, it is likely that such calculations will need to be repeated periodically. A computer-based manpower modelling capability would simplify the process of repeating the MRU calculations.[36] Ideally, such a tool should be integrated into other resource modelling systems such as LOGCAS, since much of the underlying data and assumptions are common.[37] However, this level of integration is beyond the current (and planned) generations of RAAF information systems.

SUMMARY

MRU is an essential tool to ensure that the ADF can meet the manpower levels required to provide core capabilities during a contingency. MRU figures are based on CPD and ACOPD requirements, although the levels of manpower required may not be proportional to operational usage rates, but may be largely determined by the need to provide 24-hour maintenance capabilities.

MRU defines many categories of personnel, which relate to one another to ensure that all requirements can be met, while avoiding double-counting of any positions. MRU provides the capability to retain some in-house DM capability, *as long as the positions requiring this experience are identified*.

Future developments of MRU include better incorporation of the role of Reserves, planning for higher levels of conflict, and possible changes flowing from rulings on the employment of civilians in the AO. An automated manpower modelling capability could be developed to assist the process of recalculating MRU data.

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34 loc cit. Some consideration of the potential involvement of the RAAFAR in TFG contingency operations has been undertaken, but this effort appears exceptional (AHQ 3020/13/TECH Pt 1 (20), op cit.).

35 CAS 264/1994, loc cit.

36 TFG/1201/9/P3, TFG Contingency Manning Requirements, CDR TFG, 24 February 1994 suggested the development of a 'mathematical model ... to calculate both the CMR and the impact on operational capability'.

37 LOGCAS is discussed on p. 154.

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