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Human Factors Guidelines for Aircraft Maintenance Manual

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AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the monthly *Supplement to the Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
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PREFACE

Extract from an address by the President of the ICAO Council, Dr. Assad Kotaite, to the Plenary Meeting of the Aviation Study Group at Linacre College, Oxford University, United Kingdom, on 16 February 2001:

> "I suggest to you today that it is through the organizational perspective that we will break the current safety impasse in which we find ourselves. I strongly believe that the contribution of the aviation system's management towards enhancing safety is paramount. Regulators and airline management alike define the environment within which individuals conduct their tasks. They define the policies and procedures that individuals must follow and respect. They allocate the critical resources which individuals need in order to achieve the system's safety and production goals. Lastly, when the system fails, they must thoroughly investigate these failures and take all needed remedial action to avoid repetition. Simply put, managers play a fundamental role in defining and sustaining the safety culture of their organizations.
>
> "One crucial aspect of an organization's safety culture is the ability to deal with human error. From an organizational perspective, human error should become a warning flag for regulators and managers, a possible symptom that individual workers have been unable to achieve the system goals because of difficult working environments, flaws in policies and procedures, inadequate allocation of resources, or other deficiencies in the architecture of the system. We must face the fact that because of human error, unwanted, un-willful deviations from the norms will take place. However, deviations in and of themselves are not the problem. The danger lies not in experiencing operational deviations, but rather in not having an adequate process of managing these deviations.
>
> "Effective deviation management results from the free exchange of information about operational errors which lead to deviations. We must create, therefore, an operational environment where anyone can feel secure in coming forward and sharing information concerning deviations. In other words, humans must be part of the solution and not part of the problem. This is a non-punitive environment, which nevertheless retains individual and organizational accountability."

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FOREWORD

The safety of civil aviation is the major objective of the International Civil Aviation Organization (ICAO). Considerable progress has been made in increasing safety, but additional improvements are needed and can be achieved. It has long been known that the majority of aviation accidents and incidents result from less than optimum human performance, indicating that any advance in this field can be expected to have a significant impact on the improvement of aviation safety.

This was recognized by the ICAO Assembly, which in 1986 adopted Resolution A26-9 on Flight Safety and Human Factors. As a follow-up to the Assembly Resolution, the Air Navigation Commission formulated the following objective for the task:

> "To improve safety in aviation by making States more aware and responsive to the importance of Human Factors in civil aviation operations through the provision of practical Human Factors materials and measures, developed on the basis of experience in States, and by developing and recommending appropriate amendments to existing material in Annexes and other documents with regard to the role of Human Factors in the present and future operational environments. Special emphasis will be directed to the Human Factors issues that may influence the design, transition and in-service use of the future ICAO CNS/ATM systems."

One of the methods chosen to implement Assembly Resolution A26-9 is the publication of guidance materials, including manuals and a series of digests, that address various aspects of Human Factors and its impact on aviation safety. These documents are intended primarily for use by States to increase the awareness of their personnel of the influence of human performance on safety.

The target audience of Human Factors manuals and digests consists of managers of both civil aviation administrations and the airline industry (including airline safety, training, operational and maintenance managers), regulatory bodies, safety and investigation agencies and training establishments, as well as senior and middle non-operational airline and maintenance management.

This manual, a companion document to the *Human Factors Training Manual* (Doc 9683), is an introduction to the latest information available to the international civil aviation community on the control of human error and the development of countermeasures to error in operational environments. It provides practical guidance and supporting information in order to assist Contracting States in establishing standards which comply with the recent Human Factors-related amendments to the following two Annexes to the Convention on International Civil Aviation: Annex 1 — *Personnel Licensing* and Annex 6 — *Operation of Aircraft*.

This manual is intended as a living document and will be kept up to date by periodic amendments. Subsequent editions will be published as new research results in increased knowledge on Human Factors strategies and more operational experience is gained in regard to the control and management of human error in aircraft maintenance environments.

ACRONYMS AND ABBREVIATIONS

A&P	Airframe and Power Plant (mechanic)
AAIB	Air Accidents Investigation Branch (U.K.)
AAM	Office of Aviation Medicine (FAA)
AAR	Aircraft Accident Report
AC	Advisory Circular (FAA)
ACJ	Advisory Circular Joint (JAA)
AD	Airworthiness Directive
ADAMS	Aircraft Dispatch and Maintenance Safety (European Community)
ADREP	Accident/Incident Data Reporting (ICAO)
AME	Aircraft Maintenance Engineer *Note.— For the purposes of this manual, AME will be used to represent Aircraft Maintenance Technician/Engineer/Mechanic*
AMM	Aircraft Maintenance Manual
AMMS	Aurora Mishap Management System
AMO	Approved Maintenance Organization
AMP	Aircraft Maintenance Personnel *Note.— The term AMP has been used occasionally in this document in a generic sense to include all staff working in an aircraft maintenance organization, including mechanics, technicians, inspectors, supervisors, managers, planners and licensed aircraft maintenance technicians (AMTs). Where specific reference is made to AMTs, this is made clear in the text.*
AMT	Aircraft Maintenance Technician
AMTT	Aircraft Maintenance Team Training
ASAP	Aviation Safety Action Program (U.S.)
ASRP	Aviation Safety Reporting Program (U.S.)
ASRS	Aviation Safety Reporting System (U.S.)
ATA	Air Transport Association
ATC	Air Traffic Control
ATM	Air Traffic Management
BASIS	British Airways Safety Information System
CAA	Civil Aviation Authority
CAP	Civil Air Publication (U.K.)
CASA	Civil Air Safety Agency (Australia)
CBT	Computer-Based Training
Cd	Candela
CFR	Code of Federal Regulations (U.S.)
CFs	Contributory Factors
CHIRP	Confidential Human Factors Incident Reporting Programme (U.K.)
CITEXT	Centralized Interactive Text
CNS	Communications, Navigation and Surveillance
CRM	Crew Resource Management
dBA	Decibels — "A" weighted
DDA	Documentation Design Aid
EO	Engineering Order
ERNAP	ERgoNomic Audit Program
ETOPS	Extended Range Operations by Twin-engined Aeroplanes
FAA	Federal Aviation Administration (U.S.)
FAR	Federal Aviation Regulation (U.S.)
ft-c	foot-candles
GAIN	Global Aviation Information Network
HF	Human Factors
HVAC	Heating, Ventilation and Air Conditioning
IBT	Instructor-Based Training
ICAO	International Civil Aviation Organization
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements (JAA)
JIC	Job Instruction Card
Lm	Lumen
LOFT	Line-Oriented Flight Training
Lux	Lumens per square metre
MEDA	Maintenance Error Decision Aid (Boeing)
MEM	Maintenance Error Management
MEMS	Maintenance Error Management System(s)
MESH	Managing Engineering Safety Health
MOR	Mandatory Occurrence Report (U.K.)
MOU	Memorandum of Understanding
MRM	Maintenance Resource Management
N/A	Not Applicable
NASA	National Aeronautics and Space Administration (U.S.)
NDT	Non-Destructive Testing
NTSB	National Transportation Safety Board (U.S.)
OSH	Occupational Safety and Health
PA	Public Address
PC	Personal Computer
QA	Quality Assurance
ROI	Return on Investment
SARPs	Standards and Recommended Practices

SB	Service Bulletin
SHEL	Software/Hardware/Environment/Liveware
SL	Service Letter
SMM	Shift Maintenance Manager
STAMINA	Safety Training for the Aircraft Maintenance Industry
TC	Type Certificate (for an aircraft or product)
TEAM	Tools for Error Analysis in Maintenance
TOME	Tools/Operators/Machines/Environment
TQM	Total Quality Management
U.K.	United Kingdom
UKHFCAG	United Kingdom Human Factors Combined Action Group
U.S.	United States

GLOSSARY

Active failure: a type of human error whose effects are felt immediately in a system.

Assertiveness: verbalizing a series of "rights" that belong to every employee. Some of these rights include the right to say "no", the right to express feelings and ideas, and the right to ask for information.

Asynchronous communication: communication in which there exists a time delay between responses. Asynchronous communication is typified by a unique set of characteristics, such as the lack of non-verbal communication cues (body language, verbal inflection, etc.). Examples of asynchronous communication include an e-mail message sent from the day supervisor to the night supervisor or memoranda left between shifts or passed between the shop and the hangar.

Authoritarian leader: dictates action and the course of the team with little input from team members.

Communication: the process of exchanging information from one party to another.

Complacency: the degradation of vigilance in a situation.

Crew resource management: team-based Human Factors training for flight crews.

Human Factors: the scientific study of the interaction between people, machines and each other.

Human Factors principles: principles which apply to aeronautical design, certification, training, operations and maintenance and which seek safe interface between the human and other system components by proper consideration to human performance.

Human performance: human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations.

Instructional systems design: a generic term for the methodology of creating and implementing a training programme.

Inter-team: occurring between separate teams.

Intra-team: occurring within a team.

Latent failure: a type of human error whose effects may lie dormant until triggered later, usually by other mitigating factors.

Leadership: the ability to direct and coordinate the activities of group members and stimulate them to work together as a team.

Maintenance: the performance of tasks required to ensure the continuing airworthiness of an aircraft, including any one or combination of overhaul, inspection, replacement, defect rectification, and the embodiment of a modification or repair.

Maintenance resource management: a general process for improving communication, effectiveness and safety in airline maintenance operations.

Mental model: how a sub-system is depicted in a person's mind, i.e. how one thinks a system is put together and how it works.

Norms: expected, yet implicit rules of behaviour that dictate fundamental rules of dress, speech and basic interaction.

Participatory leader: encourages member participation and input to help lead the team's course of action.

Safety culture: a pervasive organization-wide orientation placing safety as the primary priority driving the way employees perform their work.

Situation awareness: maintaining a complete mental picture of surrounding objects and events as well as the ability to interpret those events for future use. Situation awareness encompasses such concepts as arousal, attention and vigilance.

Stressor: an event or object that causes stress in an individual.

Synchronous communication: real-time communication in which a minimal delay exists between the message being sent and the message being received. Examples include face-to-face conversation and communication via radio.

Team: a group of interdependent individuals working together to complete a specific task.

Team situation awareness: maintaining a collective awareness across the entire team of important job-related conditions.

INTRODUCTION

1. In 1988, United States Congressman James Oberstar was quoted as saying:

> "What can be done about the fact that rivet inspection is boring, tedious, mind-bending work, susceptible to human error? How do we ensure that the means established to communicate with each other are, in fact, effective and that the right information is finding its way to the right people at the right time? How do we know whether training of inspectors and mechanics is all it needs to be? And how do we ensure that it will be?"

The questions posed in this quotation are rhetorical, but also practical and important for everyone involved in the maintenance of aircraft. The quotation accurately identifies some, but not all, of the Human Factors issues addressed by recent amendments to Annex 1 — *Personnel Licensing* and Annex 6 — *Operation of Aircraft.*

2. Human Factors issues can be perceived as difficult to deal with because human beings are involved and human beings do not behave according to mathematical models. However, these issues must be addressed by regulators, the aviation industry and individuals with the same vigour that has been successful in addressing the technology problems of old and new aircraft. The purpose of this manual is to provide guidance on how to tackle these Human Factors issues successfully.

3. Errors made during the maintenance of aircraft have been costly not only in terms of monetary value, but in some cases injuries and deaths have resulted. Consequently, over the past several decades, industry (both aviation and non-aviation) and its trade bodies, academic institutions and individuals have developed, implemented and published a considerable amount of Human Factors material aimed at controlling such errors.

4. Maintenance errors are not inherent in a person, although this is what conventional safety knowledge would have the aviation community believe. Maintenance errors primarily reside in latency within task and/or situational factors in a specific context and emerge as consequences of mismanaging compromises between production and safety goals. The compromise between production and safety is a complex and delicate balance and humans are generally very effective in applying the right mechanisms to successfully achieve it, hence the extraordinary safety record of aviation. Humans do, however, occasionally mismanage task and/or situational factors and fail in balancing the compromise, thus contributing to safety breakdowns.

5. Successful compromises, however, far outnumber failed ones; therefore, in order to understand human performance in context, the industry needs to capture, through systematic analyses, the mechanisms underlying successful compromises when operating at the limits of the system, rather than those that failed. It is suggested that understanding the human contribution to successes and failures in aviation can be better achieved by monitoring normal operations, rather than accidents and incidents.

6. Contracting States with large commercial aviation activities have already initiated Human Factors programmes, which include the development and publication of guidance and training materials and the promotion of Human Factors awareness. This awareness promotion includes not only the aviation maintenance industry but also the personnel of the civil aviation authorities themselves.

7. In addition, recent amendments to Annex 1 and Annex 6 now require civil aviation authorities in all the Contracting States to observe standards to reduce the adverse effects of deficiencies in human performance on the maintenance of aircraft. It is intended that this manual will provide authorities with the tools to develop and implement such standards appropriate to their State's aviation activities. Table A presents the text of Human Factors Standards and Recommended Practices (SARPs) in the two Annexes that cover the maintenance of aircraft.

8. This manual is a guidance document based on the use of existing published material from numerous sources. The material is quoted, used as examples, referenced and/or discussed as appropriate.

Table A. Aircraft maintenance-related ICAO SARPs

Annex	*Chapter and Section*	*Paragraph and Text of the Standard or Recommended Practice*
Annex 1 — *Personnel Licensing*	Chapter 4. Licences and Ratings for Personnel Other than Flight Crew Members 4.2 Aircraft maintenance (technician/ engineer/mechanic)	4.2.1.2 Knowledge … Human performance e) human performance relevant to aircraft maintenance. …
Annex 6 — *Operation of Aircraft* Part I — International Commercial Air Transport — Aeroplanes	Chapter 8. Aeroplane Maintenance 8.3 Maintenance programme	8.3.1 The operator shall provide, for the use and guidance of maintenance and operational personnel concerned, a maintenance programme, approved by the State of Registry, containing the information required by 11.3. The design and application of the operator's maintenance programme shall observe Human Factors principles. …
	8.7 Approved maintenance organization	8.7.5.4 The maintenance organization shall ensure that all maintenance personnel receive initial and continuation training appropriate to their assigned tasks and responsibilities. The training programme established by the maintenance organization shall include training in knowledge and skills related to human performance, including co-ordination with other maintenance personnel and flight crew. …
Annex 6 — *Operation of Aircraft* Part III — International Operations — Helicopters Section II — International Commercial Air Transport	Chapter 6. Helicopter Maintenance 6.3 Maintenance programme	6.3.1 The operator shall provide, for the use and guidance of maintenance and operational personnel concerned, a maintenance programme, approved by the State of Registry, containing the information required by 9.3. The design and application of the operator's maintenance programme shall observe Human Factors principles. …

9. This manual is only designed to support the safety objectives and requirements of Annex 1 and Annex 6. Some Human Factors materials produced by other bodies include information intended to enhance worker safety, industry efficiency and/or career development for individuals. While these are very worthwhile objectives, they are not required by the Annexes and are not included in this manual except where they have an influence on aviation safety.

10. This document is designed as follows:

- Chapter 1. Why Human Factors in Aircraft Maintenance — Background Information and Justification: This chapter provides background information on the importance of Human Factors knowledge and the justification for its incorporation into the operation of maintenance organizations, including training programmes for their technical staff and aircraft maintenance engineers (AMEs)*.

- Chapter 2. Key Issues Related to Maintenance Errors: This chapter identifies some of the key issues which can lead to maintenance errors and contribute to in-flight incidents or accidents.

- Chapter 3. Countermeasures to Maintenance Errors: This chapter identifies some of the generic features of changes that need to be made to the maintenance organization (including the facility and the training) to reduce maintenance errors. Reference is made to various guidance material packages that are available.

- Chapter 4. Reporting, Analysis and Decision Making: This chapter examines the measurement and analysis of errors and the results of errors, including the determination of new or amended countermeasures intended to "close the loop".

- Chapter 5. Training: This chapter addresses the objectives and scope necessary to meet the requirements of Annex 1 and Annex 6. Examples are given of currently available training packages.

- Chapter 6. Regulatory Policy, Principles and Solutions: This chapter discusses the options available to a State's aviation regulatory body to develop its own standards in compliance with the SARPs of Annex 1 and Annex 6.

- Chapter 7. Additional Reference Material: This chapter contains sources of currently available material on the theories and subjects discussed in this manual.

* Annex 1 also offers the possibility of referring to these persons as aircraft maintenance technicians or aircraft maintenance mechanics. This manual will refer to them as aircraft maintenance engineers (AMEs), except in quoted material where another term is used.

Chapter 1

WHY HUMAN FACTORS IN AIRCRAFT MAINTENANCE — BACKGROUND INFORMATION AND JUSTIFICATION

1.1 EVOLUTION AND INTRODUCTION

1.1.1 Maintenance errors contribute to a significant proportion of worldwide commercial aircraft accidents and incidents and these occurrences are costly; yet until recently, little was known of the nature of maintenance errors and the factors that promote them.

1.1.2 The human element is the most flexible, adaptable and valuable part of the aviation system, but it is also the most vulnerable to influences which can adversely affect its performance. With the majority of aircraft accidents and incidents resulting from less than optimum human performance, there has been a tendency to merely attribute them to human error. However, the term "human error" is of little help in aircraft accident or incident prevention; although it may indicate WHERE in the system a breakdown occurred, it provides no guidance as to WHY it occurred.

1.1.3 Furthermore, the term "human error" allows concealment of the underlying factors that must be brought to the fore if accidents are to be prevented. For example, an error attributed to humans in the system may have been induced by inadequate design, inadequate training, badly designed procedures, and/or poor layout of job cards or manuals. In contemporary safety thinking, human error is the starting point rather than the stopping point in accident investigation and prevention. Ultimately, any safety audit must seek ways of minimizing or preventing human errors of any kind that might jeopardize safety.

1.1.4 Early efforts in Human Factors were directed towards the flight crew and demonstrated the dangers of ignoring the person as part of the socio-technical system. System-induced human errors, such as misreading altimeters or mis-selecting cockpit controls, have been reduced through better design to improve the interface between the pilot and the cockpit. Understanding the predictable aspects of human capabilities and limitations and applying this understanding in operational environments are therefore the primary concerns of Human Factors. Other early Human Factors concerns in aviation were related to the effects on people of noise, vibration, heat, cold and acceleration forces.

1.1.5 The understanding of Human Factors in aviation has progressively been refined and developed to include aircraft maintenance activities. It is now backed by a vast amount of knowledge which can be used to ensure that operators and maintenance organizations reduce errors during maintenance.

1.1.6 Many factors that can potentially compromise human performance can also jeopardize the safety and well-being of the aviation employee, particularly those performing aircraft maintenance tasks. Many of these factors which have implications beyond the prevention of aircraft accidents, e.g. industrial safety implications, are cited in this manual. However, notwithstanding the importance of such occupational safety and health (OSH) issues to the long-term effectiveness of the aviation system, the focus of this manual is on understanding how these Human Factors issues affect aircraft safety.

1.1.7 The safety and reliability of aircraft maintenance operations depend as much upon people as they do on the technical systems of aircraft, parts, tools and equipment. Nevertheless, accident and incident reports continue to show that aircraft maintenance engineers (AMEs) sometimes make errors, that aircraft maintenance organizations sometimes fail to organize and monitor their work effectively, and that these failures can have disastrous consequences. Furthermore, even when things do not go radically wrong, the evidence suggests that on a routine day-to-day basis, the systems which should ensure that work is accomplished to the highest possible standard are not functioning effectively. In response to new regulations which demand consideration of Human Factors issues of maintenance operations, many organizations are embarking on Human Factors programmes that involve training or incident investigation. Unfortunately, for a variety of reasons, these programmes are not always successful in achieving better ways of doing things.

1.2 MAINTENANCE ACCIDENTS AND INCIDENTS IN RELATION TO OTHER CAUSES

1.2.1 Air safety statistics have tended to understate the significance of maintenance as a contributing factor in accidents and incidents. For example, as shown in Figure 1-1, Accident data report figures for worldwide airline operations (collected under ICAO's Accident/Incident Data Reporting (ADREP) system from 1970 to 2000) show maintenance as a causal factor in only 10 per cent of accidents, compared with flight crew actions implicated as a causal factor in more than 60 per cent of accidents.

1.2.2 A recent study by The Boeing Company involving worldwide commercial jet aircraft now shows a significant increase in the rate of accidents where maintenance and inspection are primary factors. Figure 1-2 shows that in the ten years from 1990 to 1999, the annual average has increased by more than 100 per cent compared with the period from 1959 to 1989. During the same two periods, the number of accidents mainly caused by cockpit crew factors has dropped.

1.2.3 A paper by Ms. H. Courteney which was presented at the Royal Aeronautical Society conference "Safety is No Accident" held in London, United Kingdom, in May 2001 used data from the United Kingdom Civil Aviation Authority (CAA) Mandatory Occurrence Report (MOR) database to show the trend of maintenance error events per million flights over the period 1990 to 2000. The trend, displayed in Figure 1-3, shows a steady rise in these events, which approximately doubled over the ten-year period.

1.2.4 A reference list of some of the world's significant aircraft accidents and incidents where maintenance has been identified as a contributing factor can be found in Appendix A to this chapter.

1.3 THE COST OF MAINTENANCE ERRORS

1.3.1 Maintenance accidents and incidents are not only costly in terms of life and property, but they can also

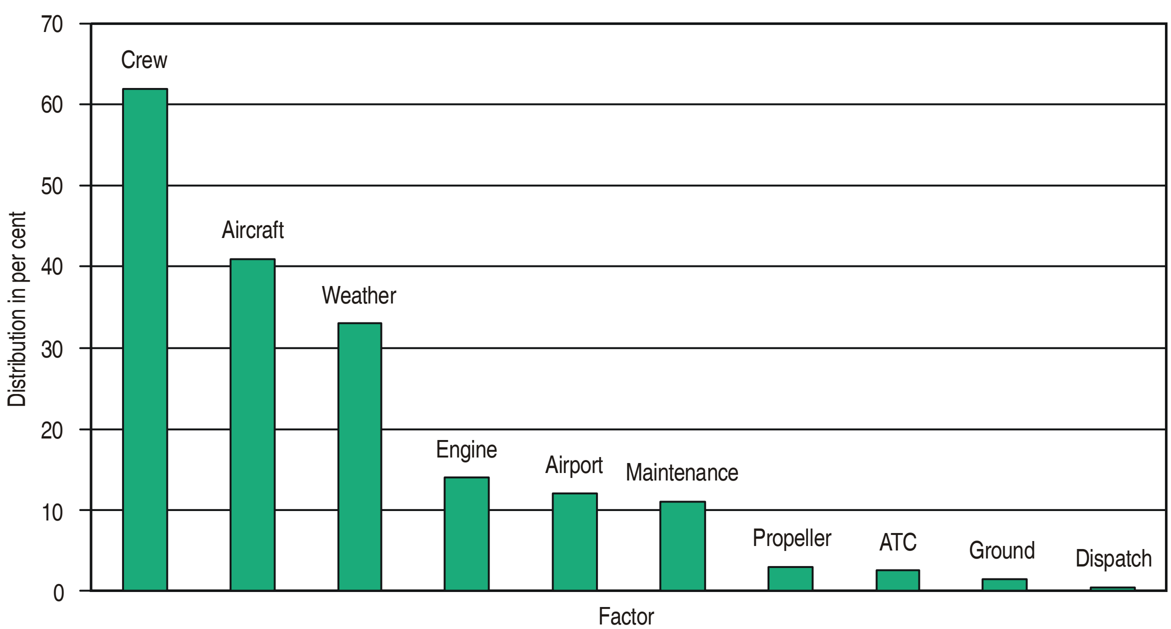
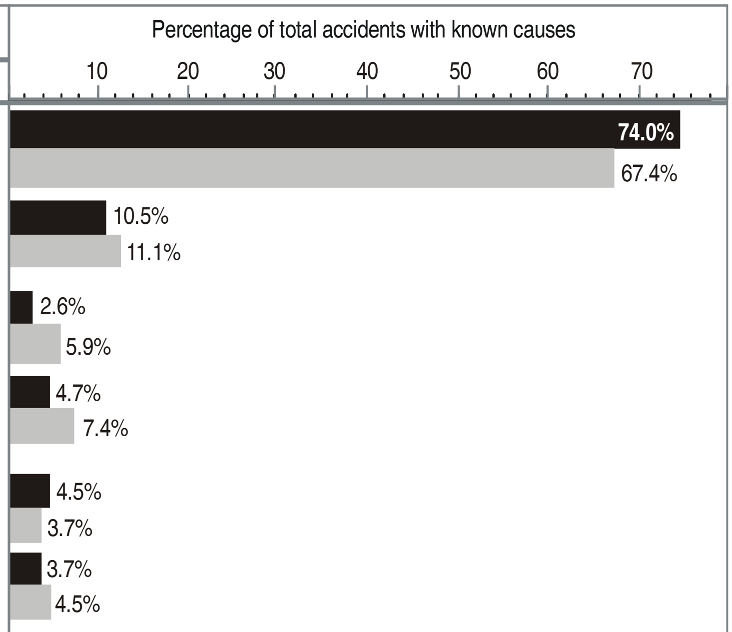


Figure 1-1. Accident data report factors distribution for worldwide airline operations (based on data reported to ICAO from 1970 to 2000)

Primary factor	Number of accidents 1959 – 1989	Number of accidents 1990 – 1999
Cockpit crew	281	91
Aeroplane	40	15
Maintenance and Inspection	10	8
Weather	18	10
Airport/ATC	17	5
Miscellaneous/other	14	6
Total with known causes	380	135
Unknown or awaiting reports	58	65
Total	438	200



Excludes
- Sabotage
- Military action

Legend
1959 through 1989
1990 through 1999

Figure 1-2. Maintenance error as a primary cause in hull loss accidents — worldwide commercial jet fleet (Boeing Chart)

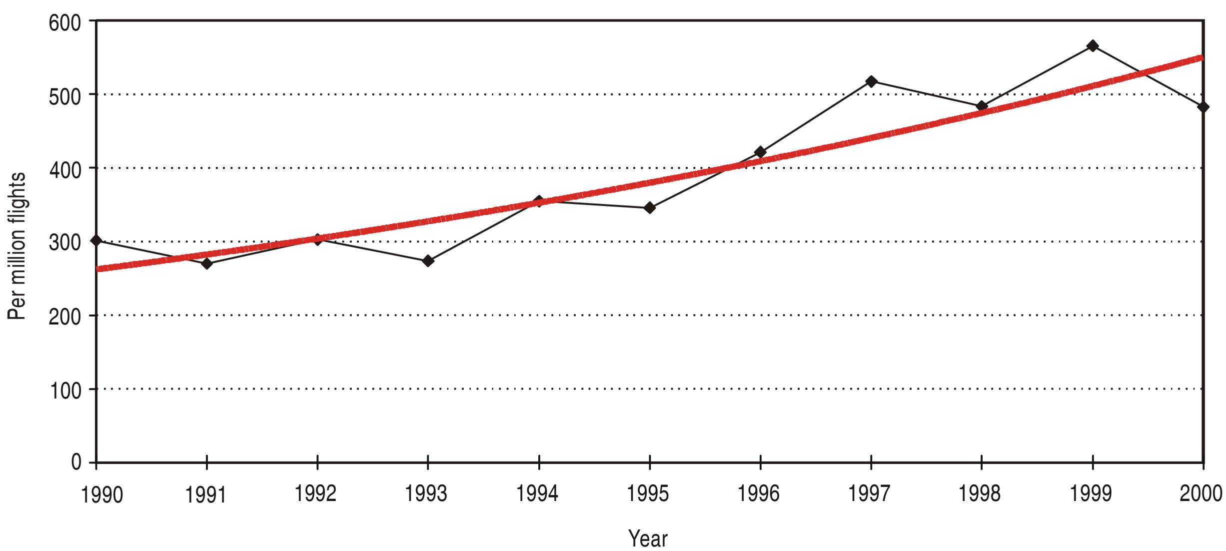


Figure 1-3. Maintenance error mandatory occurrence reports per million flights from 1990 to 2000

impose significant costs when flights are delayed or cancelled. In 1989, maintenance constituted 11.8 per cent of U.S. airline operating costs or more than U.S.$8 billion per year. The annual cost to the Australian airline industry is said to be in the order of several hundred million U.S. dollars per year. It has been estimated that each delayed aircraft costs an airline on average U.S.$10 000 per hour, while each flight cancellation can be expected to cost approximately U.S.$50 000. When these costs are considered, it is apparent that airlines stand to gain significant benefits by even a small reduction in the frequency of maintenance-induced delays, particularly those which occur closest to scheduled departure times, during line maintenance or when an aircraft is being prepared for departure.

1.3.2 There are few detailed maintenance error cost analyses in the public domain, but the cost of an accident causing a hull loss, even without the human costs, will obviously be many tens, perhaps hundreds, of millions of U.S. dollars. The results of one small-scale project called the "Installation Error Project" were reported at a conference in London, United Kingdom, in September 2000. The project involved two airlines, a manufacturer and a regulatory authority, and it studied ground damage during towing and hangar lift incidents in a typical year. The results were:

— 16 significant towing incidents per year at a total cost of U.S.$260 000; and

— 30 significant hangar lift incidents per year at a total cost of U.S.$120 000.

The following preventative measures were then introduced:

— Painting of centre and clear zone lines on the floors, standardizing hangar door lights, modifying work platforms and training personnel at a total cost of U.S.$52 000; and

— Refurbishing the controls and refreshing the awareness of operational checks on the equipment, which added no extra costs.

As a consequence, the following results were observed:

— A 75 per cent reduction in towing incidents. This saved U.S.$143 000 per annum; and

— An 87 per cent reduction in the number of lift damage events. This saved U.S.$88 000 per annum.

These savings on their own may not seem significant when compared to the total cost of the maintenance activities. However, if they are considered as a sample of what can be achieved by spending a relatively small sum of money on preventative measures, the results in terms of the return on investment (ROI) are very significant, perhaps even impressive, as can be seen as follows:

— Aircraft towing measures: payback period of 3.2 months – an ROI of 2.75; and

— Hangar lift measures: payback period of 1.8 months – an ROI of 5.5.

The conclusions of this study are summarized as follows:

— Organizations and their workers acted intuitively rather than counting the costs of errors; and

— Using ROI to identify Human Factors intervention priority is in its infancy.

Although ROI should not be used as the only criteria for Human Factors intervention, it is clearly a potentially useful tool, especially for justifying expenditures.

1.4 THE COST OF HUMAN FACTORS INTERVENTIONS

1.4.1 A strategy for dealing with the costs of making/not making Human Factors interventions has been documented by ICAO in the *Human Factors Guidelines for Air Traffic Management (ATM) Systems* (Doc 9758). Even though Doc 9758 is associated with air traffic management systems, its approach on Human Factors interventions is valid for the aircraft maintenance industry also. Doc 9758 identifies the following three strategies for dealing with Human Factors issues based on a Eurocontrol document entitled *Human Factors Module — A Business Case for Human Factors Investment:*

1. *"Do nothing" approach:* no initiatives are taken to counter Human Factors issues and only when problems arise will they be addressed;

2. *"Reactive" approach:* consideration of Human Factors issues is left to the last stages of the development process; and

3. *"Proactive" approach:* Human Factors issues are fixed before they become problems.

1.4.2 The Eurocontrol document provides the following additional information on the strategies:

"The cost scenarios of the three different strategies are illustrated in Figure [1-4]. The first ('do nothing') approach illustrates how cost related with human performance issues will increase rapidly over the life-cycle of the system. If some concern for human performance issues is dealt with in the final stages of the development process, the cost scenario will develop in a less aggressive yet increasing manner.

"However, if an early awareness to the Human Factors and human performance issues is introduced in a proactive manner, the cost will develop in a rather different manner. The figure illustrates how cost is higher compared to the other approaches due to the investments made early in the process, but also how the early anticipation of problems takes the air out of later and more expensive problems.

"The reluctance to provide the necessary resources to embark on a proactive approach is probably based on the notion that it is better to wait and see where the problems occur and then intervene. While this strategy may, apparently, save some money, especially when the system is being developed, experience shows that the bill will have to be paid later … with interest."

1.4.3 Referring to Annex 6, Part I, 8.3.1, the phase identified as "Design" in Figure 1-4 may be assumed to align with the "design of the operator's maintenance programme" while the phases identified as "Implementation" and "Operation" may be assumed to align with the "application of the operator's maintenance programme".

1.4.4 The *Human Factors Training Manual* (Doc 9683) includes the following advice under the heading "Why Management Should Take an Active Stance on Safety":

"When contemplating trade-offs between safety and production, management should evaluate the financial consequences of the decision. Since this trade-off involves risk, management must consider the cost involved in accepting such risk, i.e. *how much will it cost the organization to have an accident*. While there are insured costs (those covered by paying premiums to insurance companies) which can be recovered, there are also uninsured costs which cannot, and they may be generally double or triple the insured costs. Typical uninsured costs of an accident include:

- insurance deductibles
- lost time and overtime
- cost of the investigation

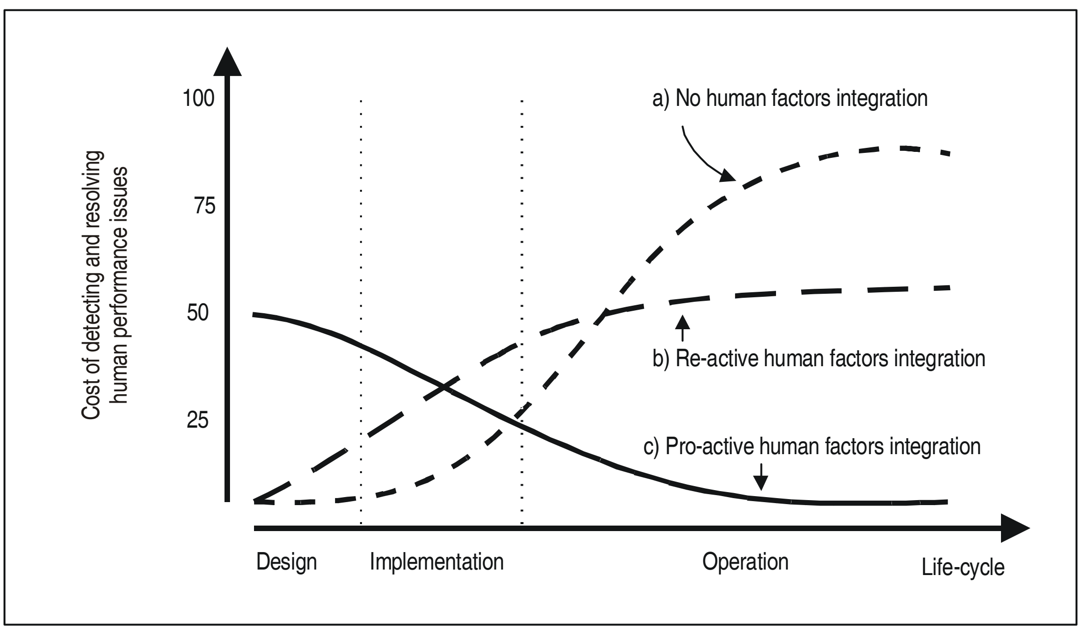


Figure 1-4. Cost scenarios of three different life-cycle strategies

- cost of hiring and training replacements
- loss of productivity of injured personnel
- cost of restoration of order
- loss of use of equipment
- cost of rental or lease of replacement equipment
- increased operating costs on remaining equipment
- loss of spares or specialized equipment
- fines and citations
- legal fees resulting from the accident
- increased insurance premiums
- liability claims in excess of insurance
- loss of business and damage to reputation
- cost of corrective action

"Those in the best position to effect accident prevention by eliminating unacceptable risks are those who can introduce changes in the organization, its structure, corporate culture, policies and procedures, etc. No one is in a better position to produce these changes than management. Therefore, the economics of aviation safety and the ability to produce systemic and effective change underlie the justification for management to act on safety."

1.4.5 The Air Transport Association (ATA) of America, Inc. also supports a proactive approach in a Human Factors programme as can be seen in the following paragraph of its ATA Specification 113 on "Maintenance Human Factors Program Guidelines":

"A forward-looking Aviation Maintenance Human Factors Program will provide an organization the framework to preclude or reduce the possibility of loss associated with workplace accidents, incidents, injuries and deaths. It will also provide management the feedback necessary to position the workforce for future growth and improved performance. By identifying the elements affecting human performance and the obstacles to improvement, management will be better armed for strategic planning. Also, when the workforce recognizes the organization's effort to remove hazards, educate and value safety, a natural increase in professionalism, performance and morale should occur. In addition, the general public will value the contribution to the industry and the recognition of safety initiatives."

1.5 THE MEANING OF HUMAN FACTORS — CONCEPTS AND DEFINITIONS

1.5.1 Human Factors as a term has to be clearly defined because when these words are used in the vernacular they are often applied to any factor related to humans. One definition of Human Factors which is accepted by ICAO was proposed by Professor Elwyn Edwards and declares that "Human Factors is concerned to optimize the relationship between people and their activities, by the systematic application of human sciences, integrated within the framework of systems engineering". Its objectives can be seen as effectiveness of the system, which includes safety and efficiency, and the well-being of the individual. Professor Edwards further elaborates on his proposed definition, indicating that the word "people" includes both sexes, and that "activities" indicates an interest in communication between individuals and in the behaviour of individuals and groups. Lately, this has been expanded upon to include the interactions among individuals and groups and the organizations to which they belong, and to the interactions among the organizations that constitute the aviation system. The human sciences study the structure and nature of human beings, their capabilities and limitations, and their behaviours both singly and in groups. The notion of integration within systems engineering refers to the Human Factors practitioner's attempts to understand the goals and methods as well as the difficulties and constraints under which people working in interrelated areas of engineering must make decisions. Human Factors uses this information based on its relevance to practical problems.

1.5.2 A simpler and more practical definition has been published by the United Kingdom Health and Safety Executive:

"Human Factors refer to environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety."

1.5.3 Human Factors is therefore about people in their living and working situations; about their relationships with machines, with procedures and with the environment around them; and also about their relationships with other people. In aviation, Human Factors involves a set of personal, medical and biological considerations for optimal aircraft, aircraft maintenance and air traffic control operations.

1.5.4 It can be helpful to use a conceptual model to aid in the understanding of Human Factors. One practical diagram to illustrate this conceptual model uses blocks to represent the different components of Human Factors. The model can then be built up one block at a time, with a pictorial impression being given of the need for matching the components.

1.5.5 The *Human Factors Training Manual* (Doc 9683) uses the SHEL model (the name being derived from the initial letters of its components: Software, Hardware, Environment, Liveware). This model is reproduced as Figure 1-5 and was first developed by Professor Edwards in 1972, with a modified diagram to illustrate the model developed by Captain Frank Hawkins in 1975. The following interpretations are suggested: liveware (human), hardware (machine), software (procedures, symbology, etc.), and environment (the situation in which the L-H-S system must function). This building block diagram does not cover the interfaces which are outside Human Factors (hardware-hardware; hardware-environment; and software-hardware) and is only intended as a basic aid to understanding Human Factors.

1.5.6 Liveware. In the centre of the model is a person, the most critical as well as the most flexible component in the system. Yet people are subject to considerable variations in performance and suffer many limitations, most of which are now predictable in general terms. The edges of this block are not simple and straight, and so the other components of the system must be carefully matched to them if stress in the system and eventual breakdown are to be avoided.

1.5.7 In order to achieve this matching, an understanding of the characteristics of this central component is essential. Some of the more important characteristics are the following:

a) Physical size and shape. In the design of any workplace and most equipment, a vital role is

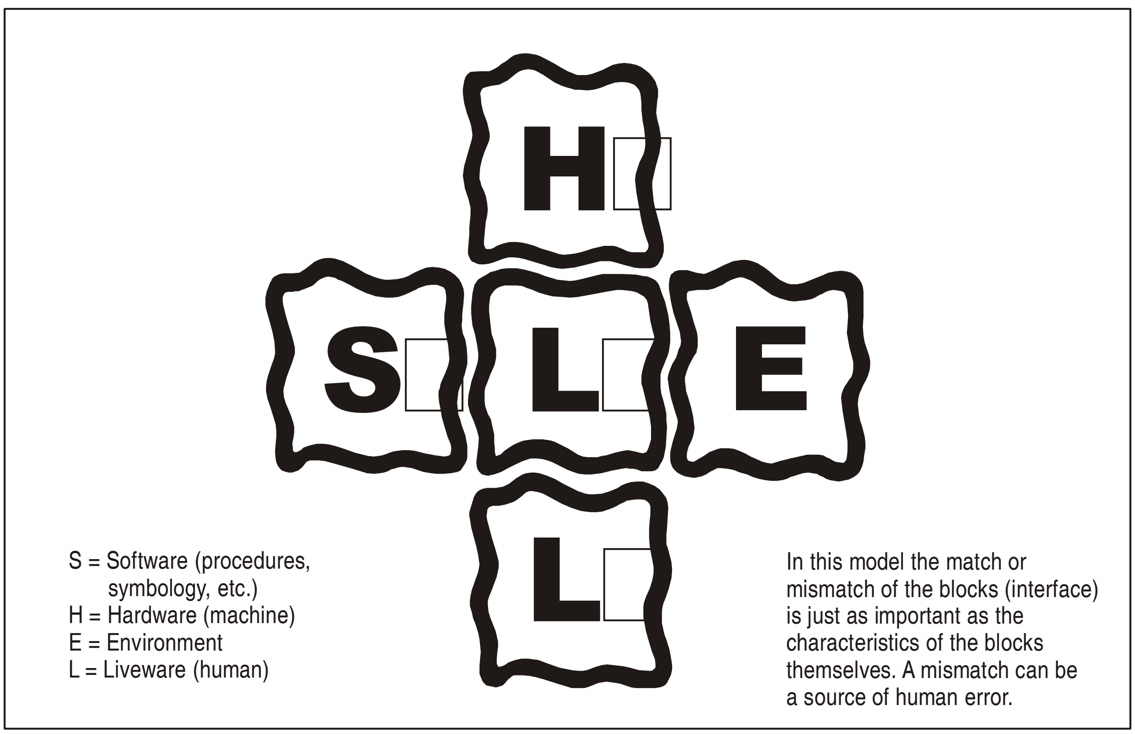


Figure 1-5. The SHEL model as modified by Hawkins

played by body measurements and movements, which will vary according to age and ethnic and gender groups. Decisions must be made at an early stage in the design process, and the data for these decisions are available from anthropometry and biomechanics.

b) Physical needs. People's requirements for food, water and oxygen are available from physiology and biology.

c) Input characteristics. Humans have been provided with a sensory system for collecting information from the world around them, enabling them to respond to external events and to carry out the required task. But all senses are subject to degradation for one reason or another, and the sources of knowledge here are physiology, psychology and biology.

d) Information processing. These human capabilities have severe limitations. Poor instrument and warning system design has frequently resulted from a failure to take into account the capabilities and limitations of the human information processing system. Short- and long-term memory are involved, as well as motivation and stress. Psychology is the source of background knowledge here.

e) Output characteristics. Once information is sensed and processed, messages are sent to the muscles to initiate the desired response, whether it be a physical control movement or the initiation of some form of communication. Acceptable control forces and direction of movement have to be known, and biomechanics, physiology and psychology provide such knowledge.

f) Environmental tolerances. Temperature, pressure, humidity, noise, time of day, light and darkness can all be reflected in performance and also in well-being. Heights, enclosed spaces and a boring or stressful working environment can also be expected to influence performance. Information is provided here by physiology, biology and psychology.

The Liveware is the hub of the SHEL model of Human Factors. The remaining components must be adapted and matched to this central component.

1.5.8 Liveware-Hardware. This interface is the one most commonly considered when speaking of human-machine systems: design of seats to fit the sitting characteristics of the human body, of displays to match the sensory and information processing characteristics of the user, of controls with proper movement, coding and location. The user may never be aware of an L-H deficiency, even where it finally leads to disaster, because the natural human characteristic of adapting to L-H mismatches will mask such a deficiency, but will not remove its existence. This constitutes a potential hazard to which designers should be alert. With the introduction of computers and advanced automated systems, this interface has repositioned itself at the forefront of Human Factors endeavours.

1.5.9 Liveware-Software. This encompasses humans and the non-physical aspects of the system such as procedures, manual and checklist layout, symbology and computer programmes. Liveware-software problems are conspicuous in accident reports, but they are often difficult to observe and are consequently more difficult to resolve (for example, misinterpretation of checklists or symbology, and non-compliance with procedures).

1.5.10 Liveware-Environment. The human-environment interface was one of the earliest recognized in flying. Initially, the measures taken all aimed at adapting the human to the environment (helmets, flying suits, oxygen masks, anti-G suits, etc.). Later, the trend was to reverse this process by adapting the environment to match human requirements (pressurization and air-conditioning systems, soundproofing, etc.). Today, new challenges have arisen, notably ozone concentrations and radiation hazards at high flight levels and the problems associated with disturbed biological rhythms and related sleep disturbance and deprivation as a consequence of the increased speed of transmeridian travel (or overtime and shift work in the case of aircraft maintenance). Since illusions and disorientation are at the root of many aviation accidents, the L-E interface must consider perceptual errors induced by environmental conditions, for example, illusions during approach and landing phases. The aviation system also operates within the context of broad political and economical constraints, and those aspects of the environment will interact in this interface. Although the possibility of modifying these influences is sometimes beyond Human Factors practitioners, their incidence is central and should be properly considered and addressed by those in management with the possibility to do so. This topic is developed in Chapters 2 and 3 of this manual.

1.5.11 Liveware-Liveware. This is the interface between people. Training and proficiency testing have traditionally been done on an individual basis. If each individual team member was proficient, then it was assumed that the team consisting of these individuals would also be proficient and effective. This is not always the case, however, and for many years attention has increasingly turned to the breakdown of teamwork. Flight crews, air traffic controllers, maintenance engineers and other operational personnel function as groups, and group influences play a role in determining behaviour and performance. In this interface, we are concerned with leadership, crew cooperation, teamwork and personality interactions. Staff/management relationships are also within the scope of this interface, as corporate culture, corporate climate and company operating pressures can significantly affect human performance. Chapter 5 of this manual describes some current industry approaches to Human Factors training programmes for operational maintenance personnel.

1.6 QUALITY SYSTEMS AND HUMAN FACTORS

1.6.1 In any organization a quality system can be established in order to improve the processes, products and services that the organization creates and delivers. Where aviation regulations call for a quality system, they usually require that the system be "independent". Hence the quality system would be independent of any Human Factors programmes and vice versa. A quality assurance system is an option in place of a "system of inspection" in order "to ensure that all maintenance is properly performed" in an approved maintenance organization (Annex 6, Part I, 8.7.3.2 refers).

1.6.2 A study undertaken as part of the European Community Aircraft Dispatch and Maintenance Safety (ADAMS) project reported that a typical quality system has two parts — quality system and quality assurance — which can be described as follows:

> "The Quality System ensures the fulfilment of all applicable airline and authority requirements. By meeting these requirements, minimising non-conformities and thus supporting precision in all work performed, airline operations will be safer, more efficient and profitable. … A Quality System has to be Quality Assured.
>
> "Quality Assurance is provided when an independent body is established, separate from the entity, for monitoring and reporting according to an established Quality Assurance Program. In practical terms, Quality Assurance results from a systematic check that all elements of the Quality System are applied as required to an entity."

1.6.3 In the context of Human Factors, an important function of a quality system could be to ensure the correct operation of a Human Factors programme already in place in an organization.

1.7 TRAINING OF TECHNICAL AND AME STAFF

1.7.1 Human performance is cited as a causal factor in the majority of aircraft accidents. If the accident rate is to be decreased, Human Factors issues in aviation must be better understood and Human Factors knowledge more broadly and proactively applied. By proaction it is meant that Human Factors knowledge should be applied and integrated during the systems design and certification stages, as well as during the operational personnel certification process, before the systems and the people become operational. The expansion of Human Factors awareness presents the international aviation community with the single most significant opportunity to make aviation both safer and more efficient.

1.7.2 The recognition that basic Human Factors education was needed throughout the industry led to various approaches to formal training in different countries. This recognition, tragically emphasized by the investigation of a number of accidents resulting almost entirely from deficiencies in the application of Human Factors, led ICAO to implement Human Factors training requirements into the training and licensing requirements included in Annex 1 (1989) and Annex 6 (1995).

1.7.3 Training in Human Factors has an important role to play in the management of error in aircraft maintenance.

1.8 GLOBAL OR LOCAL SITUATION?

In 1989, the U.S. Federal Aviation Administration (FAA) initiated the Human Factors in Aviation Maintenance Research Team project in order to focus on a variety of Human Factors aspects associated with the AME and other personnel supporting the maintenance system goals. Part of this research included a study to compare findings internationally. The U.S. FAA/Office of Aviation Medicine

Human Factors Guide for Aviation Maintenance (1998), Phase IV Progress Report, Chapter 9, summarizes these international findings under the title "Reliability in Aircraft Inspection: UK and USA Perspectives" as follows:

> "In response to recent concerns about the reliability of aircraft inspection and maintenance procedures, the [UK] CAA and the FAA have been investigating human factors issues. Two investigators who had separately studied human factors in civil aircraft inspection undertook to study each others' jurisdictions to compare techniques and problems in the USA and UK. Aircraft inspection sites were visited jointly and separately in both countries, with an analysis made of the overall inspection/maintenance system and of larger [hangar] floor operations.
>
> "The overall conclusion was that similarities were more common than differences due to the technical specification of the tasks, the regulatory similarities and the skill and motivation of inspectors. Differences between companies outweighed jurisdictional differences in many areas, suggesting that a common policy can be followed to improve such areas as visual inspection lighting, physical access to inspected areas, and the informational environment.
>
> "Larger differences were observed in the areas of work organisation and non-destructive testing (NDT), with sharing of experiences in both areas being possible for improved inspection reliability.
>
> "In the UK, the inspectors and maintenance technicians were closely integrated in the formal organisation, with inspectors often acting as supervisors for a maintenance team which performed the repair. In the USA, a more formal division existed between inspection and maintenance, with coordination usually through the supervisory levels. While both approaches are viable, both need better support for integration and communications. Training is needed in supervisory skills, as well as management structures and documentation which allow all concerned to obtain the information necessary to successful task completion.
>
> "In NDT operations there was a difference in emphasis between the two countries, with the USA more concerned with rule-based performance and the UK with knowledge-based. In addition, inspectors in the USA were less likely to be NDT specialists, performing both NDT and visual inspection, although changes are now occurring in this. Although both jurisdictions require both operating modes at different times, this fact is not well recognised. Hence, the training and documentary support for both levels is lacking, as is a clear indication of switching rules between the two.
>
> "With the increasing internationalisation of the aircraft maintenance industry, accelerated by well-publicised events with aging aircraft, differences may be expected to disappear over time. However, this should be a controlled process leading to utilisation of the best features of different jurisdictions if the full potential of inspectors within the system is to continue to be realised."

1.9 ACCOUNTABILITY AND RISK MANAGEMENT

1.9.1 Accountability within an organization is concisely described in the European Community ADAMS project report as follows:

> "All aircraft maintenance organisations operate in a framework of accountability under the law. This accountability of the organisation to external authority is reproduced by an internal system of accountability, some of which directly reflects external legal requirements (signing for work done), some of which derives from company regulations (including discipline, job descriptions, performance reviews and promotions procedures). Directly and indirectly this system of accountability is a major motivating factor on how people behave. Accountability provides the motivation amongst those whose responsibility it is to take action (at whatever level) to change whatever needs to be changed to lead to more effective performance. This motivation has to overcome resistance from the inertia born of established practice, and the pressure of immediate deadlines."

The report continues by asking, "How are management accountable for safety?" and the answer given is illustrated by various ways in which this accountability can go wrong. This manual discusses the role of management in Chapter 2, 2.3, and countermeasures in Chapter 3.

1.9.2 Risk Management. The *Operator's Flight Safety Handbook* developed by the Aviation Operator Safety Practices Working Group of the Global Aviation Information Network (GAIN) initiative defines risk management as:

> "The identification, analysis and economic elimination, and/or control to an acceptable level, [of] those risks

that can threaten the assets or earning capacity of an enterprise. In this case, a commercial airline. The risk management process seeks to identify, analyse, assess and control the risks incurred in airline operations so that the highest standard of safety can be achieved."

(See also Chapter 2, 2.3, and Chapter 3, 3.3, of this manual.)

1.10 THE NEED FOR STANDARDS

1.10.1 The Standards and Recommended Practices (SARPs) in Annex 1 and Annex 6 require appropriate regulatory action by the aviation regulatory bodies of States. The aim of this manual is to provide some practical information and guidance to those regulatory bodies so that they can develop and introduce Human Factors regulations and guidance material in conformance with the Annexes. Implementation by their operators and maintenance organizations should then enhance airworthiness by the reduction of human errors.

1.10.2 Human Factors initiatives have already been introduced in several countries as a result of incidents or accidents. The European Community ADAMS project report gives the following insight into the maintenance industry background at the time the study was undertaken:

> "Aircraft maintenance organisations are changing rapidly. Many are reorganising, or re-engineering their internal structures and processes. Some are downsizing, or taking over or being taken over by other companies. Many are becoming independent subsidiaries of their parent organisations and there is a growth in 'repair shop' organisations. Aircraft maintenance technologies are also being transformed through new aircraft systems, diagnostic tools and information technologies. Accompanying these changes are new concepts of training, changes in the apprenticeship system, shortages in key qualified staff, and a growth in contract labour. All of these changes have an impact on the way in which aircraft maintenance operations are organised, managed and performed. In order to manage these changes more effectively many organisations are turning to 'human-factors' programmes to help them manage the 'people side' of their organisations, in order to ensure that standards of safety, reliability and productivity are maintained and preferably enhanced."

1.10.3 The ADAMS project report then identified the following elements as important for successful introduction of a Human Factors programme into an organization:

- Provide total managerial support of the Human Factors programme: Avoid marginalizing the programme in one department that has little influence when decisions are taken;

- Consider more than one focus: For example, rather than just having a single focus on training, also ensure that the work environment changes to align with the training;

- Set clear objectives for the Human Factors programme;

- Ensure follow through from problems that are diagnosed to solutions;

- Manage people effectively; and

- Evaluate results to measure the effectiveness of the programme.

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Appendix A to Chapter 1

MAJOR ACCIDENTS AND INCIDENTS WITH MAINTENANCE HUMAN FACTORS CAUSAL FACTORS

Several of the major accidents and incidents where maintenance Human Factors have been identified as a significant causal factor are summarized from aircraft accident reports (AARs) and other documents of the United Kingdom Air Accidents Investigation Branch (AAIB) and the United States National Transportation Safety Board (NTSB) below:

McDonnell-Douglas DC-10-10, Chicago, U.S.A., 25 May 1979 (Ref. NTSB/AAR 79/17)

On 25 May 1979, a McDonnell-Douglas DC-10-10 aircraft crashed into an open field just short of a trailer park about 4 600 feet northwest of the departure end of runway 32R at Chicago-O'Hare International Airport, Illinois. During the take-off rotation, the left engine and pylon assembly and about 3 feet of the leading edge of the left wing separated from the aircraft and fell to the runway. The aircraft continued to climb to about 325 feet above the ground and then began to roll to the left. The aircraft continued to roll to the left until the wings were past the vertical position, and during the roll, the aircraft's nose pitched down below the horizon. The aircraft crashed into the open field and the wreckage scattered into an adjacent trailer park. The aircraft was destroyed in the crash and subsequent fire. All 271 persons on board were killed. In addition, two persons on the ground were killed and two others were injured. The NTSB determined that the probable cause resulted from maintenance-induced damage leading to the separation of the No. 1 engine and pylon assembly at a critical point during the take-off. The separation resulted from damage by improper maintenance procedures which led to the failure of the pylon structure. Contributory factors were identified as the design of the pylon attach points which were vulnerable to damage during maintenance; and the design of the leading edge slat system which was found vulnerable to damage and which resulted in an asymmetric condition and the undemanded aircraft roll. Also noted were oversight deficiencies which had failed to detect and prevent the use of improper maintenance procedures.

Lockheed L-1011, Miami, U.S.A., 5 May 1983 (Ref. NTSB/AAR 84/04)

During maintenance of a Lockheed L-1011 aircraft, AMEs failed to fit O-ring seals on the master chip detector assemblies. This led to loss of oil and engine failure during the aircraft's flight from Miami, U.S.A., to Nassau, Bahamas, on 5 May 1983. The captain decided to return to Miami and the aircraft landed safely with only one engine working. Investigation showed that the AMEs had been used to receiving the master chip detectors with O-ring seals already fitted and that informal procedures were in use regarding fitment of the chip detectors. This problem had occurred before, but no appropriate action had been carried out to prevent a reoccurrence.

Boeing 737-200, Hawaii, U.S.A., 28 April 1988 (Ref. NTSB/AAR 89/03)

This in-flight accident on 28 April 1988 involved 18 feet of the upper cabin structure of a Boeing 737-200 suddenly being ripped away due to structural failure. One flight attendant was swept overboard during the decompression while seven passengers and one flight attendant were seriously injured. The aircraft made an emergency landing at Kahului Airport on the Island of Maui. The Boeing 737-200 involved in this accident had been previously examined, as required, by two engineering inspectors. One inspector had 22 years of experience and the other, the chief inspector, had 33 years of experience. Neither found any cracks in the skin of this aircraft during their inspection. However, post-accident analysis determined that there were over 240 cracks in the skin at the time of the inspection. The ensuing investigation identified many human-related problems leading to the failed inspection.

BAC 1-11, Didcot, U.K., 10 June 1990 (Ref. U.K. AAIB/AAR 1/92)

In June 1990, a BAC 1-11 was climbing through 17 300 feet on departure from Birmingham International Airport, U.K., when the left windscreen, which had been replaced prior to the flight, was blown out under the effects of cabin pressure which overcame the retention of the securing bolts. Eighty-four of the bolts, out of a total of 90, were smaller than the specified diameter. The commander of the aircraft was sucked halfway out of the windscreen aperture and was restrained by cabin crew while the co-pilot flew the aircraft to a safe landing at Southampton Airport.

Investigation revealed that the Shift Maintenance Manager (SMM), short-handed on a night shift, had decided to carry out the windscreen replacement himself. He consulted the maintenance manual and concluded that it was a straightforward job. Upon removal of the windscreen, he decided to replace the old bolts and, taking one of the bolts, a 7D, (the windscreen should have been fitted using 8Ds) with him to the Stores room, he looked for replacements. The Stores supervisor advised him that the job required 8Ds, but the SMM decided that 7Ds would do since this was the size of the bolt that had been in place previously. As there were not enough 7Ds in stock in the Stores room, the SMM drove to where more stock could be found in carousels in an area underneath the International Pier. The lighting in this area was poor and the labels on the carousels were old and faded. The SMM used sight and touch to match the bolts. However, he erroneously selected 8Cs which were one size down in diameter. He also picked up six 9Ds thinking that the attachment of the outboard corner post fairing strip would need longer bolts. When the SMM fitted the windscreen, he used 84 of the 8C bolts collected from the International Pier carousel and failed to notice that the countersink was lower than it should be when the bolts were in position. When he came to the outboard corner post fairing strip, he realized that the 9D bolts were too long, so he retrieved and refitted six of the old 7D bolts that he had removed with the fairing (without noticing the difference in torque achieved between the new and old bolts). He completed the job himself and signed it off (the procedures not requiring a cabin pressure check or duplicate check).

There were several Human Factors issues contributing to this incident, including perceptual errors made by the SMM when identifying the replacement bolts, poor lighting in the storage area underneath the International Pier, failure on the SMM's part to wear spectacles, circadian effects, poor working practices, and possible organizational and design factors.

McDonnell Douglas DC-10-10, Sioux City, U.S.A., 19 July 1989 (Ref. NTSB/AAR 90/06)

In July 1989, a DC-10-10 experienced a catastrophic failure of the No. 2 tail-mounted engine during cruise flight. The separation, fragmentation and forceful discharge of stage 1 fan rotor assembly parts from the No. 2 engine led to the loss of the three hydraulic systems that powered the aeroplane's flight controls. The flight crew experienced severe difficulties controlling the aeroplane, which subsequently crashed during an attempted landing at Sioux Gateway Airport, Iowa. There were 285 passengers and 11 crew members on board. One flight attendant and 110 passengers were fatally injured.

The U.S. NTSB determined that the probable cause of this accident was the inadequate consideration given to Human Factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility. This resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines.

Embraer 120, Eagle Lake, U.S.A., 11 September 1991 (Ref. NTSB/AAR 92/04)

On 11 September 1991, an Embraer 120 aircraft suffered in-flight structural break up and crashed with no survivors in a cornfield near Eagle Lake, Texas. The accident occurred because the attaching screws on the top of the left side leading edge of the horizontal stabilizer had been removed the night before during scheduled maintenance, leaving the leading edge/de-ice boot assembly secured to the horizontal stabilizer by only the bottom attachment screws.

The report of this accident is of particular interest to the study of Human Factors. The wording of the accident report placed the blame upon the individual technician(s) who failed to refit the horizontal stabilizer de-ice boots correctly. A dissenting statement by U.S. NTSB Member John Lauber referred to corporate culture as being partially to blame, in addition to the many contributory factors leading to the incorrect refitment.

Airbus A320, Gatwick, U.K., 26 August 1993 (Ref. U.K. AAIB/Aircraft Incident Report 2/95)

This incident occurred on 26 August 1993 and involved an Airbus A320 during its first flight after a flap surface change. The aircraft exhibited an undemanded roll to the right on take-off, a condition which persisted until the aircraft landed safely back at London Gatwick Airport 37 minutes later. The investigation discovered that during maintenance to replace the right outboard flap, the right wing spoilers had been placed in maintenance mode (so as to move freely) and moved using an incomplete procedure; specifically the collars and flags were not fitted. The purpose of the collars and the way in which the spoilers functioned were not fully understood by the engineers. This misunderstanding was due, in part, to familiarity of the engineers with other aircraft (mainly 757s) and contributed to a lack of adequate briefing on the status of the spoilers during the shift handover. The aircraft was dispatched with the spoiler actuators still in maintenance mode. The free-floating spoilers were not detected during the standard pilot functional checks.

Boeing 747, Narita, Japan, 1 March 1994
(Ref. NTSB/SIR 94/02)

On 1 March 1994, a Boeing 747 landed at New Tokyo International Airport in Narita, Japan, with the front of the No. 1 engine touching the ground. A fire developed but was quickly extinguished by local firefighters and there were no casualties. During maintenance on the aircraft prior to the accident, the No. 1 pylon aft diagonal brace primary retainer had been removed but not reinstalled. The NTSB special investigation report found that:

- Maintenance and inspection personnel who worked on the aeroplane were not adequately trained and qualified to perform the required maintenance and inspection functions;

- The inspector who performed the non-destructive testing inspection of the No. 1 pylon diagonal brace fitting properly completed the inspection, but he improperly signed off on several subsequent steps of the centralized interactive text (CITEXT) system instruction card. This could have led other maintenance and inspection personnel to interpret that the maintenance actions on the fuse pin retainers on engine No. 1 had been completed when they had not;

- The "OK to Close" inspection of the pylon area was hampered by inadequate lighting and perceived dangers of the scaffolding;

- The CITEXT used by Northwest Airlines was inadequate because it lacked the pertinent information contained in the FAA-approved maintenance manual, it did not follow Northwest Airlines' GEMM policy, and it did not contain specific instructions for actions, components or systems that were specific to the Boeing 747 No. 1 engine pylon;

- AMEs and inspectors of Northwest Airlines did not adequately understand the application of the CITEXT and "red tag" systems for critical maintenance items;

- Maintenance supervisors and managers of Northwest Airlines failed to ensure that the work practices of the AMEs and inspectors were conducted in accordance with the approved maintenance manual;

- The work environment for the heavy maintenance of the aeroplane was inadequate and contributed to an error-producing situation for the workers;

- The lack of adequate and organized storage of removed parts contributed to the failure to reinstall the fuse pin retainers;

- FAA oversight of the maintenance facility at Northwest Airlines failed to detect deviations in "red tag" procedures; and

- FAA inspectors failed to apply FAA-developed Human Factors elements and allowed an inadequate work environment in the hangar to exist.

Douglas DC-9-32, Atlanta, U.S.A., 8 June 1995
(Ref. NTSB/AAR 96/03)

On 8 June 1995, as the scheduled ValuJet Airlines' domestic passenger flight began its take-off roll, a "loud bang" was heard by the aeroplane occupants and air traffic control personnel. The right engine fire warning light illuminated, the flight crew of a following aeroplane reported to the ValuJet Airlines' crew that the right engine was on fire, and the take-off was rejected. Shrapnel from the right engine penetrated the fuselage and the right engine main fuel line, and a cabin fire erupted. The aeroplane was stopped on the runway, and the captain ordered the evacuation of the aeroplane.

The NTSB determined that the probable cause of this accident was the failure of Turk Hava Yollari maintenance and inspection personnel to perform a proper inspection of a seventh stage high compressor disk. This allowed a detectable crack to grow to a length at which the disk ruptured, under normal operating conditions, propelling engine fragments into the fuselage.

Boeing 737-400, Daventry, U.K., 23 February 1995
(Ref. U.K. AAIB/Aircraft Incident Report 3/96)

On 23 February 1995, after taking off from East Midlands Airport in the U.K. en route for Lanzarote Airport in the Canary Islands, Spain, a Boeing 737-400 suffered a loss of oil pressure on both engines. The aircraft diverted and landed safely at Luton Airport. The investigation discovered that the aircraft had been subject to borescope inspections on both engines during the preceding night and the high-pressure (HP) rotor drive covers had not been refitted, resulting in the loss of almost all the oil from both engines during flight.

The line maintenance engineer was originally going to carry out the task and started to prepare one of the engines for inspection. However, for various reasons, he swapped jobs with the base maintenance controller and, consequently, gave him an oral briefing of what he had done so far. The paperwork for the job was not familiar to the base maintenance controller since it was line maintenance paperwork, however, he did not consider it necessary to draw any additional reference material. The base maintenance controller selected a fitter to assist him. While having many interruptions, they carried out the task, except they failed to refit the rotor drive covers. No ground idle engine runs (which would have revealed the oil leaks) were carried out. The job was signed off as complete.

Boeing 747, Gatwick, U.K., 2 November 1996
(Ref. U.K. AAIB Bulletin 5/97)

Immediately after take-off of a Boeing 747 on 2 November 1996, its 4L door handle moved to the "open" position during the climb. The captain elected to jettison fuel and return to Gatwick. The aircraft landed safely. An investigation revealed that the door torque tube had been incorrectly drilled/fitted. The maintenance manual required a drill jig to be used when fitting the new undrilled torque tube, but no jig was available. The Licensed Aircraft Maintenance Engineer and Fleet Technical Liaison Engineer elected to drill the tube in the workshop without a jig, due to time constraints and the operational requirement for the aircraft. The problem with the door resulted from incorrectly positioned drill holes for the fasteners in the door torque tube.

Airbus A320, Gatwick, U.K., 20 January 2000
(Ref. U.K. AAIB Bulletin 7/2000)

On 20 January 2000, as an Airbus A320 aircraft rotated on take-off from London Gatwick Airport, both fan cowl doors detached from the No. 1 engine and struck the aircraft. The doors were destroyed and localized damage resulted to the No. 1 engine and its pylon, the left wing, the left flaps and slats, the fuselage and the fin. It is likely that the doors had been closed following maintenance but not latched prior to the accident. When the doors are closed, there are no conspicuous cues to indicate an unlatched condition and no flight deck indication. Similar incidents have occurred on at least seven other occasions worldwide.

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Appendix B to Chapter 1

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Chapter 2

KEY ISSUES RELATED TO MAINTENANCE ERRORS

2.1 INTRODUCTION

2.1.1 The accident/incident record can provide a valuable insight into some of the common types of maintenance error which have been reported as causal factors during the past. For example, Table 2-1 shows a summary of maintenance-related accident/incident findings from three States (all with large commercial aviation activities) cross-referenced against the sections of this chapter. The variations in causal factors are wide and there is agreement on only 10 of the 21 categories. Cultural, organizational and regulatory differences between these States may account for this.

2.1.2 As there are wide variations in causal factors for the three States in Table 2-1, it is likely that other such wide variations exist between other States. This conclusion suggests that each State aviation regulatory body should tailor regulatory and guidance material to suit the situation in its own State in order to produce optimum air safety results.

2.1.3 Many texts on Human Factors assume that people (human beings), have not changed over the past few decades. While the basic physical characteristics of people may well have stayed the same, it is likely that many aspects of the hangar workforce and its management have changed considerably. Following research in this field, the FAA Office of Aviation Medicine (AAM) Human Factors in Aviation Maintenance Research Team produced its Phase I Progress Report, dated November 1991, which describes the evolution of the United States maintenance industry and its people from the 1960s to 1990. It seems reasonable to suppose that changes have continued to take place in the years following this particular report. The report is considered in more detail in Appendix A to this chapter.

2.1.4 This chapter uses extracts from material developed by various organizations to explain some of the factors which, like the examples in Table 2-1, are known to increase the probability of maintenance errors.

2.2 REGULATORY OVERSIGHT

2.2.1 The following quotation from Professor James Reason's book *Managing the Risks of Organizational Accidents* probably reflects the perception that many aviation regulatory bodies have of their role:

> "The regulators' lot — like the policeman's — is not a happy one. Not only are they rarely loved by those they regulate, they are now ever more likely to be blamed for organizational accidents. Over the past 30 years, the search for the causes of a major catastrophe has spread steadily outwards in scope and backwards in time to uncover increasingly more remote contributions. Prominently and frequently featured in this extended causal 'fallout', are the decisions and actions of the regulatory authority."

2.2.2 Is compliance with regulations the main goal? How does the aircraft maintenance industry perceive the role of the regulator and the regulations? The following quotation from the European Community ADAMS project report may provide a partial answer to these important questions:

> "When managers are asked: 'How do you know whether your organisation is safe?' one of the most common replies is: 'Because we are complying with the regulations'. This standard reply represents a withdrawal of responsibility for the company's safety performance. The framework of JAR 145 regulations is built around the philosophy of granting approval to maintenance organisations which have an adequate management system to ensure safe operations. Thus the regulator only indirectly regulates the safety of the operation — the responsibility is on operational and quality management to ensure safety.
>
> "If management then looks to compliance with the regulator's requirements as its standard of safety, the system becomes circular, with no independent standard of safety. Compliance with regulations is only the first step in formulating an effective safety policy."

Table 2-1. Comparison of maintenance-related accident/incident causes between three States cross-referenced against the sections of Chapter 2

Chapter 2 Section No.	*U.S. National Transportation Safety Board*	*U.K. Air Accidents Investigation Branch*	*Transport Canada*
2.2	Inadequate regulatory oversight	Inadequate regulatory oversight	
2.3	Inadequate maintenance programme		
2.3	Inadequate management oversight		
2.3	Incorrect parts or tools	Inadequate equipment or parts	Inadequate resources
2.3		Inadequate pre-planning of work	
2.3		Inadequate staff numbers	
2.3 and 2.5		Time pressure to complete task	Pressure
2.4	Procedural deviations	Failure to use AMO or MM procedures	Norms or habits
2.4	Inadequate knowledge/training		Inadequate knowledge
2.4	Available resources not used		
2.4 and 2.9	Human performance limitation	All errors occurred during night working	Fatigue, stress, lack of assertiveness
2.5	Failure to respond to cues/ warnings		Lack of awareness or complacency
2.5	Failure to anticipate effects		
2.5		Interruptions	Job distraction
2.5		Supervisors doing hands-on tasks themselves	
2.5		A "can-do" attitude	
2.5			Lack of teamwork
2.5 and 2.8	Communication failure	Shift or task handover	Poor communication
2.6	Inadequate maintenance environment		
2.7	Design deficiency		
2.8	Inadequate promulgated information	Confusing manuals	

2.2.3 Experience has shown that it is necessary for industry to go beyond mere compliance with the regulations in order to achieve enhanced levels of air safety. One possible second step is for an organization to establish its own internal standard for safety. The ADAMS project report suggests that the criteria should include the following:

- Compliance with technical standards and best practice;
- Effectiveness of management processes, i.e. an effective quality system based on elements such as the organization, standards, procedures, documentation, resource control, training and evaluation and feedback systems; and
- Measurement of safety outcomes, such as:
  - — rates of incidents and accidents, recommendations implemented and implementation evaluated;
  - — audits and recommendations implemented and evaluated; and
  - — quality discrepancy reports received, and actions taken and evaluated.

2.2.4 The State, along with its aviation regulatory body, of course, also has a responsibility under the Chicago Convention to regulate in compliance with ICAO Standards and Recommended Practices.

2.3 THE ROLE OF MANAGEMENT

2.3.1 Organizations in socio-technical systems have to allocate resources to two distinct objectives: production and safety. In the long term, these are clearly compatible goals; but given that resources are finite, there are likely to be many occasions when there will be short-term conflicts of interest. Resources allocated to the pursuit of production (see Figure 2-1) could diminish those available to safety and vice versa. When facing this dilemma, organizations with inadequate structures may emphasize production management over safety or risk management. Although a perfectly understandable reaction, it is ill-advised and contributes to additional safety deficiencies.

2.3.2 As a complex socio-technical system, aviation requires the precise coordination of a large number of human and mechanical elements for its functioning. It also possesses elaborate safety defences. Accidents in such a system are the product of the conjunction of a number of enabling factors, each one necessary but in itself not sufficient to breach system defences. With constant technological progress, major equipment failures or operational personnel errors are seldom the root cause of breakdowns in system safety defences. Instead, these breakdowns are the consequence of human decision-making failures which occur primarily within managerial sectors.

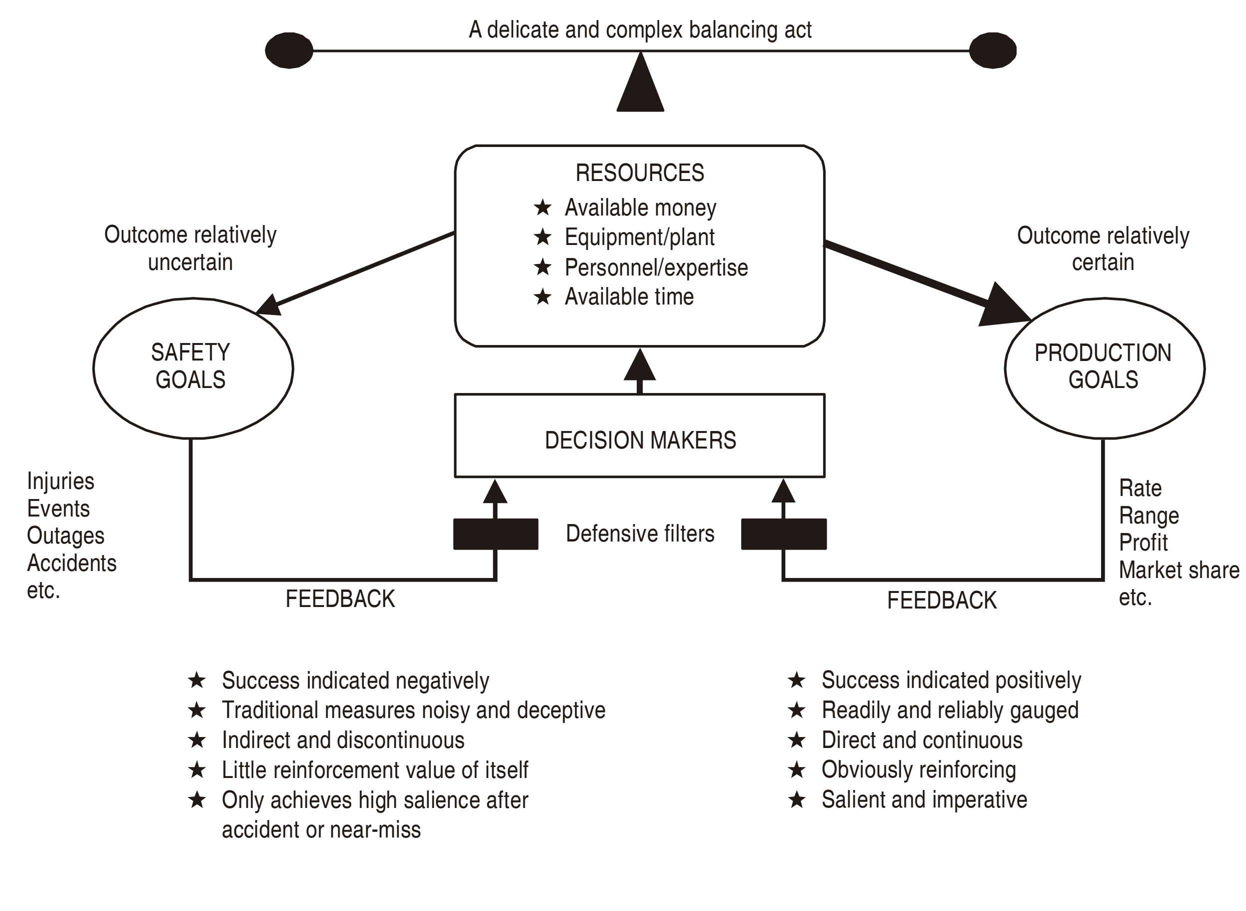
2.3.3 Analysis of major accidents in technological systems has clearly indicated that the preconditions to disasters can be traced back to identifiable organizational deficiencies. It is typical to find that a number of undesirable events, all of which may contribute to an accident, define an "incubation period" which is often measured in terms of years, until a trigger event, such as an abnormal operating condition, precipitates a disaster. Furthermore, accident prevention activities in socio-technical systems recognize that major safety problems do not belong exclusively to either the human or the technical components. Rather, they emerge from as yet little understood interactions between people and technology. The environment in which these interactions take place further influences their complexity.

2.3.4 A superficial management response to organizational-induced maintenance errors is to ask why the procedures are not being followed. The short answer, as provided by Taylor and Christensen in their book *Airline Maintenance Resource Management*, would be as follows:

> "If the process isn't being adhered to, first consider the process design itself to be faulty, not the individual. Understanding and compliance issues must be included in the design. Employees are not to blame when the system makes it hard for them to understand and comply with expectations. The process design needs to be improved."

2.3.5 People are the most important resource in any aircraft or equipment maintenance organization. The manner in which management deals with its people will significantly affect the organization's output both in terms of production and standards. The ADAMS project report summarizes this point as follows:

> "An organisation, which ignores, or feels threatened by, quality reports, or which cannot take effective action in response to serious incidents, which reacts punitively when people make well intentioned mistakes, or which makes unrealistic or inappropriate demands, will see



Source: James Reason. 1990. *Human Error*. Cambridge University Press.

Figure 2-1. A summary of some of the factors that contribute to fallible, high-level decision making

the skill and professionalism of its people go towards protecting themselves and not towards improving the organisation."

An "open" culture which encourages upward communication and responds to constructive criticism will, therefore, have a positive effect on the organization.

2.3.6 Experience both in Europe and the United States has shown that Human Factors initiatives are not always entirely successful. The European Community ADAMS project report lists the following as the most common reasons:

"• *Marginalised:* human factors programmes can become marginalised in a separate department or specific 'champion' who has little influence when decisions are taken. A lack of perceived effectiveness leads to the weakening and ultimate end of the programme.

"• *One sided:* many human factors programmes have a single focus, often on training for example. When people then return to their previous work environment after training, disillusion occurs if that environment has not changed and the old ways of working are still reinforced.

"• *Focus on diagnosis not change:* human factors expertise has well-developed methods for diagnosing what went wrong. Often, there is too little focus on changing the situation to prevent it happening again.

"• *Lack of clear objectives:* human factors programmes often have objectives that are not easily defined, for example, — what is to be achieved by increasing awareness? What does the prevention of error mean? Such programmes do not have a clear link between the focus of the intervention (usually people's attitudes or behaviour) and the outcomes that the organisation needs.

"• *No commitment to evaluation:* few human factors interventions are accompanied by systematic evaluation of their effectiveness. Developing an effective human factors programme involves a significant investment. It is appropriate to measure the effectiveness of this investment."

The above reasons for a possible lack of success can be countered by using the best principles of managing people effectively. The best principles, therefore, should be built into all aspects of the production and management system of an aircraft maintenance organization if human errors are to be reduced.

2.4 TRAINING

2.4.1 As regulators drive towards a reduction in aviation accident and incident rates, they must take into consideration the following factors: aircraft and their equipment are complex, the workload in maintenance organizations is heavy, and public safety has a high profile. These factors combine to justify a high standard of training for AMEs, their supervisors and managers. The same factors also justify a high standard of training for management and inspector staff in a State's aviation regulatory body.

2.4.2 The AME requires a high level of practical mechanical aptitude and, in most States, regulations require formal training for the granting of an aircraft maintenance (technician/engineer/mechanic) licence[1]. Annex 1 now requires that such training include the knowledge of "human performance".

2.4.3 In industry there is a tendency to think of training as a distinct activity that is completely separate from other management and work tasks. However, thoughtful consideration of the two domains — training and management — reveals many parallels in their requisite skills and abilities. Both good training and good management require the ability to assess employee needs, evaluate personality characteristics, develop performance requirements that are challenging while not beyond each person's capabilities, and assess performance. Training should be considered an integral part of good aviation maintenance management.

2.4.4 As a State aviation regulatory body's management and inspection staff need to develop and adopt regulations and guidance material and to monitor industry compliance with this material, their level of Human Factors training needs to be deeper and more extensive than for industry personnel. It may even be necessary for a State aviation regulatory body to hire Human Factors specialists (also known as Industrial Psychologists).

2.5 HUMAN INSPECTION RELIABILITY

2.5.1 It has been evident for most of recorded history that people are prone to commit errors. As the well-known saying goes, "To err is human." In his paper to the Royal Aeronautical Society Conference in 1998, Mr. David Finch described the experience of a well-qualified aeronautical engineer who had worked with many different inspectors in maintenance organizations over many years. He explained that inspectors are subject to human limitations and fallibility. Through lack of training, experience, resources, support and all the reasons currently being identified in Human Factors programmes, they may fail to survey an area or fail to observe or recognize a defect. Having seen and recognized a defect, they may yet be mistaken, or succumb to persuasion, in their judgement of its significance. Some of the main factors which are known to increase the probability of human error are identified in the remainder of this section.

2.5.2 The normal sequence of tasks performed during aircraft maintenance can be generically summarized as follows:

SET UP — ACCESS — REMOVE — TEST/REPAIR/ OVERHAUL (as required) — INSTALL — TEST/ ADJUST — CLOSE-UP.

The installation phase of a maintenance task has been identified in many studies as the most likely to result in an

1. Annex 1 considers the terms in brackets as acceptable additions to the title of the licence. Each ICAO Contracting State is expected to use in its own regulations the one it prefers.

error. The kinds of errors by AMEs which have been recorded in studies by Professor James Reason in *Managing the Risks of Organizational Accidents* have been combined with data presented by Mr. E. A. Ingham of the U.K. CAA in a conference paper in 1996 and are summarized below in order of frequency of occurrence (starting with the most frequent first):

- Omissions such as fastenings left undone or incomplete, items left locked/pinned (not reactivated), caps left loose or missing, items left loose or disconnected, items missing, loose objects/tools not removed, lack of lubrication, and panels, etc. not refitted;
- Incorrect installation of parts;
- Wrong parts fitted;
- Crossed connections and other electrical wiring discrepancies; and
- Improper fault isolation inspection and/or functional test.

2.5.3 Factors which are known to affect the individual working in an organization are shown on the "Dirty Dozen" series of posters issued by Transport Canada as follows:

- *Lack of communication:* nothing should ever be assumed;
- *Complacency:* constant repetition can cause errors in judgement;
- *Lack of knowledge:* when coupled with a "can-do" attitude, error is more probable;
- *Distraction or interruption:* after a distraction or an interruption, a person may resume a job thinking that the job has progressed further than it has;
- *Lack of teamwork:* when linked with poor communication, major errors may occur;
- *Fatigue:* until it becomes extreme, a person is often unaware of being fatigued;
- *Lack of resources:* difficult release/not-release decisions and a "can-do" attitude can cause errors;
- *Pressure:* operators' flight schedules can be used to exert pressure;
- *Lack of assertiveness:* coupled with pressure, increases error probability;
- *Stress:* a normal part of life unless excessive, then error is more probable;
- *Lack of awareness:* not using common sense or thinking of the consequences; and
- *Norms or habits:* peer group "standards" are not necessarily right.

2.5.4 A study conducted in a large airline, using brainstorming techniques with 150 AMEs, examined why AMEs make errors. The most important reasons are shown in the following list:

- Boredom;
- Failure to understand instructions;
- Lack of available instructions;
- Rushed;
- Pressures from management to defer work;
- Fatigue;
- Distractions at a critical time;
- Shift change;
- Poor communication;
- Use of incorrect parts;
- Poor lighting;
- Failure to secure fasteners; and
- Unauthorized maintenance.

The list shows that the AMEs themselves understand that communication, or its lack, is directly related to errors in their work. Also, it is notable that some items in this list are similar to those shown in 2.5.3 of this chapter.

2.5.5 Chapter 14 of the FAA *Human Factors Guide for Aviation Maintenance* contains a summary of psychological research material, based on the work of Professor James Reason, which explains that errors (i.e. failures of planned actions to achieve their desired goal) by AMEs may fall into one of three categories, namely:

1. *Slips:* The plan of action may be perfectly adequate, but the actions do not go as planned — there is unintended failure during execution of the task. Slips may be further defined as *rule-based slips* (followed correct, established rules, but not properly) or *skill-based slips* (established skill level not achieved);

2. *Mistakes:* The actions may go according to plan, but the plan is not adequate to achieve its intended outcome. Mistakes may be further subdivided as *rule-based mistakes* (followed rule that is incorrect or wrong for the task) or *knowledge-based mistakes* (failed to choose right path in carrying out a task for which no pre-packaged rules were available, e.g. trial and error learning); and

3. *Violations:* Whereas slips and mistakes are unintentional, in most cases violations are deliberate. People generally intend the non-compliant acts, but not the bad consequences that occasionally ensue. Violations may be further subdivided as *routine violations* (where corners are cut in order to take the path of least effort, or where aggressive instincts are indulged) or *necessary violations* (where the non-compliance is committed simply in order to get the job done, i.e. where tools, equipment or procedures are inadequate).

2.5.6 Chapter 14 of the FAA *Human Factors Guide for Aviation Maintenance* explains that failures are the consequences of human errors. Although most human errors do not have serious consequences, a small percentage can cause or contribute to safety lapses or, in severe cases, aircraft incidents/accidents. Failures can be divided into two categories depending on the length of time that passes before there is an adverse impact on aviation safety, namely:

1. *Active failures:* These failures are the result of unsafe acts (errors and violations) committed by those at the human to system interface whose actions can, and sometimes do, have immediate adverse consequences, i.e. the negative outcome is almost immediate; and

2. *Latent failures:* These failures are created as a result of decisions taken at the higher echelons of the organization. Their damaging consequences may lie dormant for a long time, only becoming evident when they combine with local triggering factors which breach the system's defences.

2.5.7 The FAA *Human Factors Guide for Aviation Maintenance* reports that in a study carried out within the engineering facilities of a major world airline, twelve local factors (associated with line maintenance activities) and eight organizational factors were identified as having an adverse effect on the working practices of people stationed on the hangar floor. The local factors varied from one workplace to another (e.g. from a hangar to a workshop); however, the upstream organizational factors remained the same throughout the system as a whole. More detailed information on the local and upstream organizational factors is provided in Appendix B to this chapter.

2.6 ENVIRONMENTAL FACTORS

2.6.1 Aircraft maintenance is generally performed in one of the following three environments: a) the workshop for components; b) the hangar for a complete aircraft; and c) the open air, on the ramp or apron for line maintenance. The FAA *Human Factors Guide for Aviation Maintenance* gives the following concise reasons why the design of the hangar maintenance facility is so important:

> "The most fundamental human factors concept related to facility design is that a facility should be viewed as a place where human workers perform tasks. This seems simplistic and, perhaps, too obvious even to be mentioned. However, it is important to realize that maintenance facilities are much more than just places to park airplanes. A careful study of the tasks that are going to be performed in a facility provides valuable insight into what areas a facility must have, where they must be located, and how each must relate to all others. A properly designed facility helps maintenance workers do their jobs. A poorly designed facility hinders workers."

2.6.2 The FAA *Human Factors Guide for Aviation Maintenance* also introduces the concept of "environmental stress" caused by elements in the worker's environment. Cramped physical spaces, poor lighting, noise, heat, cold, humidity and lack of airflow can all cause a decrease in performance. When several of the environmental effects are combined, stress levels will be higher than for the individual causes. It is important to note that environmental stress can result in both physical and mental impairments. For example, excessive heat causes the inability to concentrate as well as the more obvious symptoms of physical distress.

2.6.3 Aircraft maintenance engineers working on line maintenance are responsible for performing required scheduled checks and resolving defects from flight crew. Many are also involved with additional tasks such as refuelling, dispatch and push back. Most of the line maintenance work is performed on the ramp or apron, which is a much busier environment than the hangar and which is subject to all types of weather and lighting variations. The ramp is a busy place with fuelling, baggage and catering activities, etc. and, as a result, access is often difficult.

2.7 ERGONOMICS AND HUMAN FACTORS

2.7.1 The term *ergonomics* is used in many States to refer strictly to the study of human-machine system design issues. However, in many countries the terms *ergonomics* and *Human Factors* are used interchangeably. The *Human Factors Training Manual* (Doc 9683), Part 1, Chapter 4, defines the difference between the two as one of emphasis. Human Factors has acquired a wider meaning, including aspects of human performance and system interfaces which are not generally considered in the mainstream of ergonomics.

2.7.2 It is evident from a study of the accidents and incidents in Appendix A to Chapter 1 that in many cases the maintenance tasks, technology or working conditions were not well matched to the humans involved in the activities.

2.7.3 Chapter 3, 3.9, attempts to provide solutions to the problems of adapting technology and working conditions to human beings.

2.8 COMMUNICATION AND DOCUMENT DESIGN

2.8.1 In their book *Airline Maintenance Resource Management,* Taylor and Christensen report on a study, conducted in a large airline, which examined why AMEs make errors in documentation and paperwork. The study was conducted with 160 foremen, lead mechanics and AMEs who brainstormed a list of errors and their causes. In summary, poor communication, pressure and distractions were generally seen as the most important causes. The detailed list is as follows:

- Poor communication regarding technical information, including poor management responses to shop floor queries regarding company maintenance procedures;

- Poor maintenance system practices regarding information, including maintenance control system documentation often incorrect, lost or misplaced, and dissatisfaction with technical advice;

- Merger-related information issues, such as merger opportunities lost and superior documentation systems not adopted following a company merger;

- Insufficient time allowed for daytime transit checks and associated documentation;

- Logbook changes did not involve user mechanics and the new design was reported to cause sign-off and data errors;

- Engineering information (e.g. Engineering Orders (EOs) and Airworthiness Directives (ADs)) too complicated and/or redundant with no user involvement in its generation;

- Documentation too complicated and not enough time allowed for completion;

- Policy manuals not clearly written, hard to access and difficult to use resulting in errors;

- Training in company documentation insufficient; and

- Problems experienced with type and condition of maintenance information technology, including maintenance data access equipment unsatisfactory, microfilm images distorted and/or unclear, and computer system not user-friendly.

2.8.2 Document design is clearly a factor in several items listed above. The FAA *Human Factors Guide for Aviation Maintenance (Phase VII Progress Report)* classifies document design issues generically as follows:

- *Information readability:* This is a primary issue in document design and concerns the following two aspects: the typographic layout and the language structure. Both aspects have a significant effect on the reading speed and the accuracy of the material;

- *Information content:* This deals with the issues of both textual and graphic material. It is important that the material be appropriate, up to date, accurate, complete, easy to comprehend and unambiguous;

- *Information organization:* This refers to how information is organized in a document. In order that the information can be used by either expert or novice user, it should be classified into relevant categories and layered in terms of detail. The information also needs to be arranged in a logical sequence; and

- *Physical compatibility:* This relates to the handling and usage of a document. When designing a document, it is important to consider its physical compatibility with the task at hand. A work card, either of paper or a computer-based device, which has been degraded by weather or aircraft fluids or which is heavy, an unwieldy size, and/or incompatible with the local light levels, the tools used or with the task at hand, will not encourage use.

2.9 FATIGUE OF MAINTENANCE PERSONNEL

2.9.1 Fatigue is generally associated with tiredness after work or effort, either physical or mental. Other symptoms of fatigue include weakness, stress, depression, health problems and the tendency to make mistakes. Excessive hours of work, poor planning, insufficient staff, bad shift scheduling and a working environment with no proper control of temperature, humidity or noise are all known to contribute to fatigue in the aviation maintenance environment.

2.9.2 Fatigue is listed as one of the "Dirty Dozen" on the series of posters issued by Transport Canada. In several of the reports of accidents and incidents listed in Appendix A to Chapter 1, maintenance work performed at night by staff who may have been affected by fatigue or lack of sleep was identified as a causal factor. These "reportable" flight accidents and incidents are not the only examples of a fatigued workforce. For example, one operator with a fleet of twelve aircraft has had the following "non-reportable" incidents before flight:

- Extensive structural damage to an aircraft due to incorrect jacking procedures;

- Extensive structural damage to two aircraft due to a towing collision;

- A tool left behind in an aircraft; and

- Three maintenance staff seriously injured due to a road accident driving home from work after a long shift.

2.9.3 Sleep is associated with fatigue and can be affected both by lifestyles and habits outside work and by the shift system operated by the maintenance organization. There is a considerable amount of evidence in many industries to show that shift work can result in increased fatigue and reduced safety. Research has also shown that shift systems can be designed so that fatigue build-up and sleep disruption are minimized.

2.9.4 Humans have internal body rhythms, often known as biorhythms. The circadian, daily biorhythm is of particular relevance to shift work because there is evidence in transport and other industries to show that the risk of an accident is at its highest in the very early hours of the morning, i.e. 2 to 3 a.m. There is also evidence that shows that the period of least risk is in the late morning, i.e. 10 to 12 a.m.

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Appendix A to Chapter 2

EVOLUTION OF COMMERCIAL AIRCRAFT MAINTENANCE, 1970–1990

1. In November 1991, the FAA Office of Aviation Medicine Human Factors in Aviation Maintenance produced its Phase I Progress Report on a study dealing with the evolution of commercial aircraft maintenance from 1970 to 1990. The report's Summary paragraph states that it represents a combined picture of maintenance management and organizational behaviour in eight United States maintenance operations, including small and large air carriers and repair stations. Although this study reflects the experience of only one State, similar kinds of changes (perhaps with differing timescales) are likely to have been experienced by other States with large aviation operating industries. The following text is reproduced from the report:

"Evolution of commercial aircraft maintenance, 1970–1990

"During the course of the site visits for the present study a number of long-service heavy maintenance managers and supervisors described their views of the industry. What follows is the remarkably consistent picture which emerged, from these discussions, of the changes during the 1960s, the 1970s, and the 1980s in airline maintenance.

"In the late 1960s and early seventies modern jet airliners (Boeing 707, and Douglas DC-8 in particular) were well established in the U.S. commercial fleet. Douglas DC-9 and Boeing 727 were newly introduced as smaller load, shorter trip, but still high altitude high speed aircraft. At that time the organization of hangar maintenance was guided by the skill and experience of general foremen. To them reported shift foremen and specialist mechanics prepared mainly by their duty tours in military aviation. Already included before the 1960s began were schedulers (or time-keepers) to monitor job assignment documents, and instructors to improve and broaden the mechanics' performance and skills on the newer aircraft. The oil crisis of 1973 sent fuel and ticket prices up, causing a reduction in passengers, and caused many airlines to lay-off newer, less experienced mechanics.

"By the late 1970s and early 1980s the experienced mechanics and their supervisors had reached a high level of competence. Job cards for work assignment had been proven effective and the process of standardizing the work flow in hangar maintenance had created a need for a larger role for the 'work planner.' In 1979–1980 the further oil shortages, higher fuel prices, the air traffic controllers' work slowdown, and deregulation all converged to force many carriers to reduce costs further in face of increased competition. With aircraft maintenance technically under control with an ample and competent workforce, more AMP [aircraft maintenance personnel] cuts were made.

"Currently, in 1990, we find reduced numbers of experienced heavy maintenance mechanics and inspectors — the still-lingering result of AMP layoffs during the economic turbulence of 1979–83; coupled with the exodus of senior AMPs prompted by retirements, promotions, and interdepartment transfers to maintenance shops. Following the recession and deregulation, what we find are myriad signs of a cost-conscious industry — the most obvious signs of which are reduced parts inventories, and the lean AMP staffing levels. Finally, as we well know now, the fleet of new transport aircraft in 1970 has become 'aging aircraft.' Together these changes result in the typical 1990 hangar maintenance organization guided by shift foremen and/or planners. The latter are increasingly computer-literate and tasked with digitizing the job card and work planning/tracking system. With the hiring of new AMPs, and with the increasing complexity of new aircraft maintenance, training departments and their instructors have become once again an important aspect of maintenance effectiveness.

"The current hangar maintenance AMP staff typically has a bimodal experience distribution of 30-plus years, and 3 or fewer years. There are relatively few heavy maintenance AMPs with company tenure between those two peaks. With the increase of aging fuselages and Airworthiness Directives (ADs) to attend to them, the greatest demand for new mechanics has been in sheet metal repair. Thus most sheet metal mechanics are new, and most of these are young. Many sheet metal mechanics hold an A&P [Airframe and Powerplant] license, but are newcomers to the field, having done other work first. In many cases these new A&P do not have military experience, and if they do, they are not necessarily immediately qualified for A&P work with commercial transport category aircraft. For instance experience as a military aviation crew chief provides limited but deep experience in weight & balance; while repair in helicopters provides minimal understanding of repair on pressure cabins. There are also some AMPs who come into airline maintenance work after spending time in defense-related and/or commercial aircraft manufacturing. They usually know little about repair, although they are often very competent in sheet metal riveting. While some of them may know little about repair, many AMPs today are not hired as experts in aircraft repair, but to specialize in sheet metal work only.

"In summary: The prominent foreman role of the 1970s, reduced during the 1980s has re-emerged in the 1990s in order to manage the many new AMPs in the heavy maintenance work force. An added complexity is that computerized planning systems (including the planners, schedulers, coordinators who operate them) constitute a challenge to the foreman's traditional authority, and the 'authority of knowledge' held by the 'master craftsman' in this industry."

2. The report then presents the remaining results of the study, starting with the unfiltered results as obtained from the formal protocol developed for the site visits. This is followed by the opinions, attitudes and feelings (specifically those dealing with company and maintenance system culture, mission or values) expressed by the aircraft maintenance personnel during the visits. Next, technical system data are described which deal with the aircraft and elements comprising the "critical path" of the overhaul. Finally, social system data are presented from the analyses.

3. The Conclusions section of the report opens with the following paragraph:

"Among the accepted causes of work quality is the committed attitude, the high level of knowledge, and the positive state of mind of employees performing that work. Conversely, negative attitudes, lack of knowledge, and disquieted mind relate to poor quality and a reduction of safe conditions and outcomes. This study obtained measures of the amount of communication about the work and interpersonal support, the levels of trust, and the degree of frustration or facilitation of human needs. Important sources of employee attitude and state of mind in aviation maintenance were found. The conclusions to follow are directed at stressing these important aspects."

The Conclusions go on to cover the following topics:

- Major organizational components;
- Dedication;
- Enjoyment of work;
- Respect for co-workers and managers;
- Participatory management;
- Key variance control;
- Teamwork;
- Internal maintenance system boundaries;
- Mission definition and findings;
- Culture;
- Aircraft maintenance personnel experience; and
- Control of work assignment.

4. The recommendations of the report, which are set out as change proposals and management guidelines, are summarized as follows:

- Develop communication guidelines;
- Increase the workforce competence;
- Develop a clear mission with clear-cut goals and objectives;
- Develop a commitment to human values;
- Create and endorse teamwork;
- Reduce the emphasis on the individual in favour of greater teamwork among aircraft maintenance personnel; and
- Promote excellence in management performance.

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Appendix B to Chapter 2

EXAMPLES OF LOCAL AND ORGANIZATIONAL FACTORS

1. INTRODUCTION

1.1 The information in this appendix is based on the FAA *Human Factors Guide for Aviation Maintenance.*

1.2 In a study carried out within the engineering facilities of a major world airline, twelve local factors and eight organizational factors were identified as having an adverse effect upon the working practices of those on the hangar floor.

2. LOCAL FACTORS

The twelve local factors identified are:

1. *Knowledge, skills and experience:* Unfamiliarity with a defect or aircraft type, lack of specific training or skills, inappropriate experience for a job, changes in aircraft type clashing with past routines or expectations, etc.

2. *Morale:* Personality clashes, frustration, unhappiness with the work situation, inadequate incentives, insufficient consultation with the workforce, etc.

3. *Tools, equipment and parts:* Problems with availability, quality, location, delivery and/or collection, identification, handling heavy or awkward items, etc.

4. *Support:* Problems with support from other areas, people unavailable in other areas, undermanning of avionics or other specialist trades, third-party companies and their local representatives, etc.

5. *Fatigue:* Problems with tiredness, working at an unusually slow pace, noticeable increases in slips, lapses and fumbles, disturbed sleep patterns as sleep patterns need to be adjusted at the start of a shift pattern (e.g. from a series of day shifts to a series of night shifts), inadequate balance between work and rest, etc.

6. *Pressure:* Problems with heavy workload, the workforce being spread too thinly over the jobs, high number of interruptions, hassle from management or customers, too little time to do the job to the highest standards, etc.

7. *Time:* Problems with shift patterns, time of day or night, closeness to the deadline, etc.

8. *Environment:* Problems with weather (rain, snow, fog, etc.), temperature (either too hot or too cold), high noise levels, inadequate lighting, insufficient environmental protection, etc.

9. *Computers:* Unfamiliarity with the computer type or mode of operation, unfriendly interfaces and software, the introduction of a new system, insufficient terminals, some people being "computer shy", etc.

10. *Paperwork, manuals and procedures:* This includes unclear Technical Log entries, unavailability of relevant manuals or procedures, failures to complete paperwork correctly, inconvenience or difficulty in locating relevant material, etc.

11. *Inconvenience:* This relates to ease of access (or lack of it) to the job, pace of work going on around, congestion around the aircraft, airside traffic conditions, etc.

12. *Safety features:* Problems with hazard warnings, quality of safety equipment, safety training and awareness of hazards, personal protective equipment, etc.

3. ORGANIZATIONAL FACTORS

While local factors varied from one workplace to another (e.g. from a hangar to a workshop), the upstream organizational factors remained the same throughout the system as a whole. The following eight organizational factors were selected as being the most influential adverse latent influences:

1. *Organizational structure:* This includes worries about restructuring and downsizing, ill-defined duties and responsibilities, too many layers of management, necessary tasks not covered by the existing structure, etc.

2. *People management:* Lack of top-level awareness of problems at the sharp end, ill-defined career pathways, the wrong balance between incentives and disciplinary measures, workforce insufficiently consulted, etc.

3. *Provision and quality of tools and equipment:* Lack of proper equipment and resources in the workplace, existing equipment inadequate to cope with new aircraft types, cost cutting put before the needs of the job, out-of-date workplace facilities, etc.

4. *Training and selection:* Trade skills out of step with current needs, inadequate balance between avionics and mechanical trades, insufficient licensing incentives, recruitment and selection not netting the right kind of apprentices, etc.

5. *Commercial and operational pressures:* Conflicts between quality standards and commercial and operational pressures, conflicts between safety standards and commercial and operational pressures, etc.

6. *Planning and scheduling:* Poor quality of planning and scheduling, remoteness of planners from the reality of the job, conflicts between the long-term strategic plans and the immediate needs of the present jobs, unclear or unworkable plans and schedules, etc.

7. *Maintenance of buildings and equipment:* Inadequate maintenance of buildings and equipment, requests for necessary work or improvements either not acted upon or deferred on cost grounds, etc.

8. *Communication:* Workforce isolated from managerial decision makers, bottom-up communications ignored, communications that are unclear or ambiguous or that promote a “them and us” attitude, etc.

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Appendix C to Chapter 2

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Chapter 3

COUNTERMEASURES TO MAINTENANCE ERRORS

3.1 INTRODUCTION

3.1.1 In their book *Beyond Aviation Human Factors,* Maurino, Reason, Johnston and Lee put Human Factors solutions into the context of other existing safety countermeasures in aviation as follows:

> "Throughout its almost one hundred years of history, different periods in aviation favoured different approaches to the control and avoidance of human error. These included widely ranging strategies, varying from exhortations to professional behaviours in one extreme, to the attempt to displace humans from control through large-scale automation and technology at the other, with numerous combinations in between. Moreover, at each opportunity, the approach of preference was heralded by its proponents as the final solution to human error in aviation. Human Factors itself could not escape from such misleading simplification, having once been proclaimed — some twenty years ago — the last frontier in aviation safety. Obviously, it is not."

3.1.2 This chapter explains some of the possible countermeasures and interventions, which are intended to reduce the probability of aviation accidents and incidents due to human errors made during maintenance.

3.1.3 A model developed by Professor James Reason, of the University of Manchester (United Kingdom), provides an insight into error generation within organizations and what organizations can do to manage it (see Figure 3-1).

Note.— A detailed discussion of the Reason model is provided in the ICAO Human Factors Training Manual *(Doc 9683).*

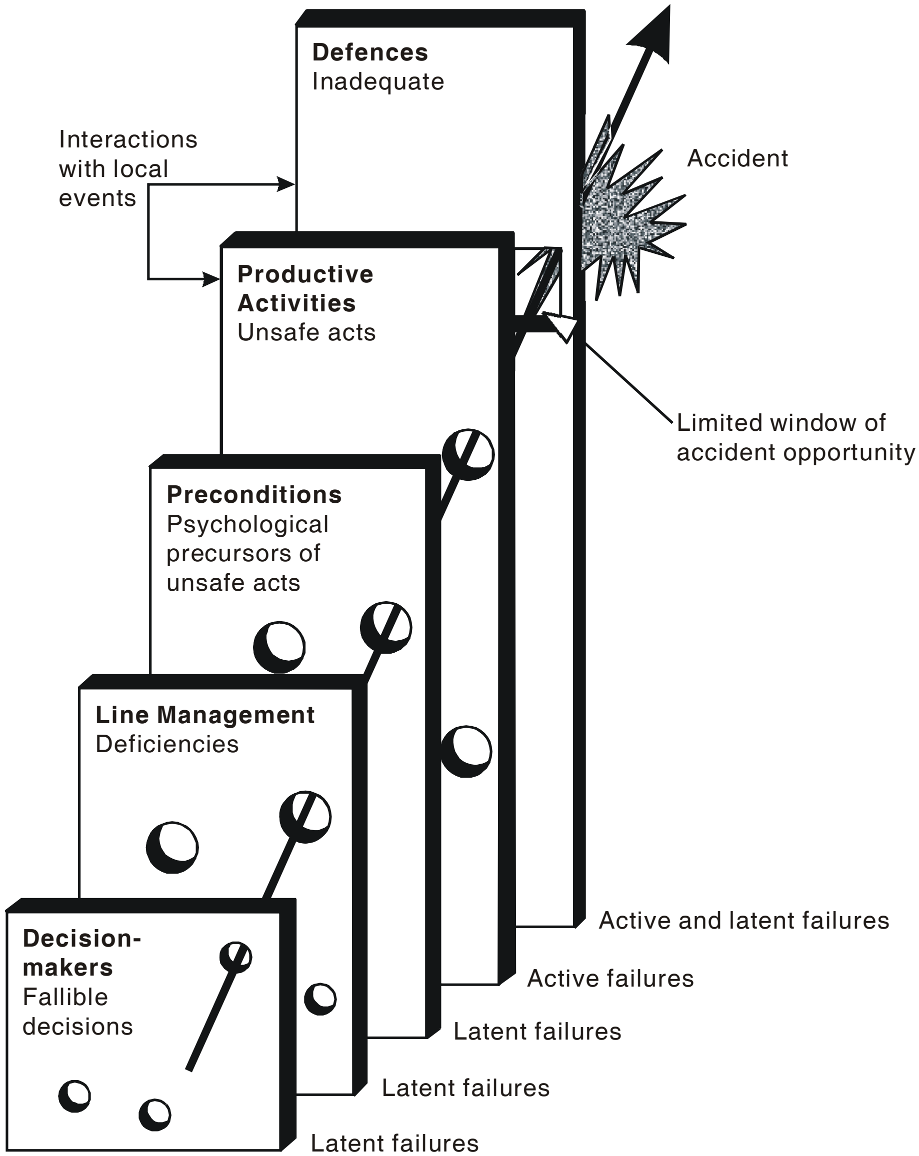
3.1.4 The Reason model proposes that accidents seldom originate exclusively from the errors of front-line operational personnel (e.g. AMEs) or as a result of major equipment failures. Instead, they result from interactions of a series of failures or flaws already present in the system. Many of these failures are not immediately visible, and they have delayed consequences.

3.1.5 As mentioned in Chapter 2, failures can be of two types depending on the immediacy of their consequences. An **active failure** is an error or a violation that has an immediate adverse effect. The front-line operator usually makes such errors. A **latent failure** is a result of a decision or an action made well before an accident, the consequences of which may lie dormant for a long time. Such failures usually originate at the level of the decision maker, regulator or line manager, that is, with people far removed in time and space from the resulting event. These failures can be produced at any level of the system by the human condition, for example, through poor motivation or fatigue.

3.1.6 Latent failures, which originate from the adverse effects of strategic decisions, may interact to create "a window of opportunity" for an AME, a pilot or an air traffic controller to commit an active failure that breaches all the defences of the system and results in an accident or incident. The front-line operators are thus the inheritors of a system's defects. They are the ones dealing with a situation in which technical problems, adverse conditions or their own actions will trigger the latent failures present in a system. In a well-guarded system, latent and active failures will interact, but they will seldom breach the defences.

3.1.7 Based on the work by Reason and others, aviation accident/incident investigators are coming to realize that "human error" is not the end of the investigation process but rather its starting point. The objectives of investigations thus become to find out why these errors were made, to determine how they could have breached defences and led to disaster in certain cases, and subsequently, to make recommendations for improving the safety of the overall system.

3.1.8 Many areas of aviation have shifted their focus from eliminating error to preventing and managing error.



Source: James Reason. 1990. *Human Error.* Cambridge University Press.

Figure 3-1. Modified version of James Reason's model of accident causation, showing the various human contributions to the breakdown of a complex system

Human error is recognized as an inevitable component of human performance. Therefore, complex socio-technological systems should take this into account by design. The concepts of error tolerance and error resistance in technology, design and operational procedures best exemplify this new focus. The aircraft maintenance area needs to follow this trend in order to meet the Human Factors requirements of Annex 6.

3.1.9 The concept of error tolerance can be illustrated by the comparison between a typewriter and a personal computer being used as a word processor. A typewriter is hardly error tolerant: if a wrong key is struck during the typing of a text, the entire text has to be retyped in order to produce a faultless paper. Later models of typewriters include correction facilities to help overcome this problem to a degree, but the corrections made are still noticeable to the trained eye of readers. A computer-based word processor, on the other hand, is highly error tolerant in this respect: if a wrong key is struck, the backspace key provides a simple but effective means to correct the problem. In fact, by separating the composition stage and the printing stage, an opportunity to correct a multitude of errors is created.

3.1.10 The concept of error resistance can also be illustrated using the example of a personal computer. Many potentially destructive commands that can be issued by the user will first trigger a "question" from the computer to confirm that the user really wants the programme to execute that command and often require a second input from the user before the programme goes ahead to perform the action. Examples are deleting files, formatting disks and terminating applications (programmes) before saving work done with those applications. Therefore, a personal computer by design can be seen to resist potential errors by users that would negate the purpose of using the personal computer in the first place.

3.2 ERROR MANAGEMENT PROGRAMMES — THE GENERIC FEATURES

3.2.1 The goal or purpose of an error management programme must be agreed upon and must be measurable and achievable. For example, a goal to "raise awareness" of Human Factors would be achievable, but it would not be measurable and, therefore, by itself would not meet the intent of the Human Factors requirements of Annex 6.

3.2.2 Error management has two components: *error reduction* and *error containment*. Error reduction comprises measures designed to limit the occurrence of errors. Since this will never be wholly successful, there is also a need for error containment — measures designed to limit the adverse consequences of those errors that still occur.

3.2.3 In aviation and elsewhere, human error is one of a long-established list of "causes" used by the press and accident investigators. However, human error is often a consequence rather than a cause as it can be shaped and provoked by upstream workplace and organizational factors. As mentioned before, identifying a human error is merely the beginning of the search for causes, not the end. The human error, just as much as the disaster that may follow it, is something that requires an explanation. Only by understanding the context that provoked the human error can there be hope to limit its recurrence.

3.2.4 It is essential to recognize the following basic facts about human nature and error as the foundations of an error management programme:

- Actions are almost always constrained by factors beyond a person's immediate control;
- People cannot easily avoid those actions that they did not intend to perform in the first place;
- Errors have multiple causes: personal, task-related, situational and organizational; and
- Situations are more amenable to improvement than people where the workforce is skilled, experienced and largely well intentioned.

3.2.5 Human behaviour is governed by the interplay between psychological and situational factors. This applies to errors as to all other human actions. Such claims raise a crucial question for all those in the business of minimizing potentially dangerous human errors: which is the easiest to remedy, the person or the situation?

3.2.6 General practice seems to point to the person. After all, people can be retrained, disciplined, advised or warned in ways that will make them behave more appropriately in the future — or so it is widely believed. This view is especially prevalent in professions that take pride in their willing acceptance of personal responsibility — among these are AMEs, pilots and air traffic controllers. Situations, in contrast, appear as givens: people seem to be stuck with them. As a consequence, errors in aviation are often suppressed. They go unreported and therefore appear not to exist. If errors do not exist, they need not and cannot be managed.

3.2.7 In many areas of aviation, however, a developing trend is clearly to favour the situational rather than the personal approach to error management. There are many reasons for this including the following:

- Human fallibility can be moderated up to a point, but it can never be eliminated entirely. It is a fixed part of the human condition, partly because errors, in many contexts, serve a useful function (for example, trial-and-error learning);
- Different error types have different psychological mechanisms, occur in different parts of the organization and require different methods of management;
- Safety-critical errors happen at all levels of the system, not just at the operational end;
- Measures that involve sanctions, threats, fear and appeals have only a very limited effectiveness. In many cases, these measures can do more harm than good (for example, to one's morale, self-respect and sense of justice);
- Errors are a product of a chain of causes in which the precipitating psychological factors — momentary inattention, misjudgement, forgetfulness and preoccupation — are often the last and least manageable links in the chain; and
- The evidence from a large number of accident and incident inquiries indicates that these bad events are more often the result of error-prone situations and error-prone activities than they are of error-prone people.

Error management, therefore, must be aimed at the performance of the system of the maintenance organization rather than at the performance of the individuals working within that system.

3.3 IMPLEMENTATION AND ORGANIZATION

3.3.1 The FAA *Human Factors Guide for Aviation Maintenance* explains the process of establishing a Human Factors programme as follows:

> "A number of different approaches can be used to introduce human factors methods and concepts into an organization. These approaches differ with regard to the degree of continuity and integration with other organizational procedures. For example, one way to introduce human factors is to address each problem area as a specific, isolated task. As each new problem area is identified, by whatever means, then it is analyzed and 'solved' by an ad hoc team put together for the occasion.
>
> "A slightly more integrated approach might be to create a human factors focus within each maintenance department. This person or group is then responsible for taking a consistent approach to human factors issues within the department. At the top end of the integration scale, human factors can be programatically embedded in the overall maintenance organization.
>
> "As human factors practitioners, we take the position that any approach to implementing human factors methods within an organization can be beneficial. However, some approaches are more efficient than others. Consider the common operational practice of making engineering changes. Obviously, each engineering change could be implemented on a case-by-case basis. This would probably result in re-inventing procedures for each change. However, organizations have found that a consistent engineering change process, implemented on a company-wide basis, is much more efficient and easy to control.
>
> "Human factors should be viewed in the same light as other initiatives that affect fundamental work practices, such as Total Quality Management (TQM). Human factors is much more successful when completely integrated into the work environment."

3.3.2 The implementation process will inevitably vary between the "off-the-shelf" Human Factors programmes that have been developed. There is, however, general agreement that steps similar to the following are necessary for the successful implementation of a Human Factors programme in a maintenance organization:

- Gather evidence to support the need for a Human Factors and/or error management programme. Evidence could include new State regulations issued in response to the ICAO Annex requirements for Human Factors, accidents or incidents either within the State or elsewhere, and a likely positive return on investment results;
- Use the evidence gathered to convince the top level of management to make a commitment to improve

Human Factors awareness and performance within the organization. Management needs to demonstrate to its entire staff that its commitment is a long-term one. It should be clear that the company intends to do business this way in the future;

- Conduct a review of the current facilities, culture, procedures, systems and work practices in order to establish what changes are needed. There are a wide variety of methods available for this review ranging from internally manned "consultations" in the workplace to computer-based audit tools such as the "ERgoNomic Audit Program" (ERNAP) (see 3.8 of this chapter) or the use of external consultants;

- Analyse the results of the review according to the review method chosen. It is good practice to communicate the results to all personnel. This feedback to staff will be recognition of their support during the gathering of evidence and should encourage them to support the change proposals;

- Use the analysis to determine and implement a change plan or programme which is likely to need the following elements: appointment of a coordination person (or group), resource allocation, Human Factors and/or MRM training, and communication; and

- Monitor and evaluate the change plan results both during implementation and continuously afterwards. Take action to eliminate undesirable trends as appropriate.

3.3.3 The placement of a Human Factors programme within the structure of an organization is clearly a high-level management decision. Responsibility for the programme, its implementation and operation must be firmly located and identified within the organization. A recent survey of maintenance organizations by a major United States aircraft manufacturer was published in ATA Specification 113. It shows the following results for where the Human Factors function was placed in maintenance organizations:

Human Factors Programme Placement	*Per cent of Organizations*
In Quality Assurance/ Quality Control	58%
In Maintenance Control	30%
In other Departments	12%

3.3.4 Maintenance Control and Quality Assurance/ Quality Control tend to be perceived as support functions in most aircraft maintenance organizations. The benefit of placing a Human Factors programme in such a support department is that it can serve in a consultatory role to other departments without being influenced by the organizational cultures of those departments.

3.4 COMMUNICATION AND MAINTENANCE RESOURCE MANAGEMENT

3.4.1 United States National Transportation Safety Board Member John Goglia, a former AME, gives the following view on individualism, teamwork and communication in his introduction to the book *Airline Maintenance Resource Management: Improving Communication* by J. C. Taylor and T. D. Christensen:

> "A desirable trait in the past, individualism can be a problem in the current safety environment. Those involved in aviation safety must learn to work as teams, and they must reform their linear communication style. This is an especially difficult barrier for maintenance employees. With their engineering focus, maintenance managers and technicians possess highly technical skills, but sometimes lack the communication skills necessary to ensure safety in today's complex operations.
>
> "What is needed is a better balance of technical skills and social skills. Workplace communication must be improved if the job is to be done right.
>
> "Supervisors, leads, and staff must continually strive for excellence in communication. Furthermore, new programs must be designed to accommodate worker needs and play to their strengths."

3.4.2 The FAA *Maintenance Resource Management Handbook* defines Maintenance Resource Management (MRM) as "a general process for improving communication, effectiveness and safety in aircraft maintenance operations". In the same way that Crew Resource Management (CRM) was developed to address safety and teamwork issues in the aircraft cockpit, FAA researchers, in conjunction with industry partners, developed MRM to address teamwork deficiencies within the aircraft maintenance environment. By doing so, they hoped that MRM would foster a culture of safety in all aircraft maintenance operations. One important difference between MRM and

CRM is that the MRM target audience is much wider and more diverse and typically would include not only AMEs but also inspectors, support personnel and managers.

3.4.3 The nature of aircraft maintenance operations is significantly different from flight crew operations. For example, maintenance crews are often separated from one another by time and space (hangars, workshops, shifts, etc.). The AME's working environment encompasses a great variety of tasks in different settings with a large number and variety of people. Hence, the focus of the training for maintenance personnel depends on where their actions fit in the context of the maintenance activity as a whole.

3.4.4 In summary, MRM represents the next logical step in the evolution of team-based safety behaviours. Just as technical skills alone were not enough for flight crews to manage complex systems, AMEs should be taught skills that enable them to work safely in a complex system. MRM teaches more than just team skills; it teaches and reinforces an organizational philosophy in which all members of the organization are oriented towards error-free performance. This orientation can be accomplished by teaching maintenance managers and AMEs how to do the following:

- To be aware that the effects of their actions ripple throughout their organizations;
- To utilize all their available resources safely and effectively; and
- To propagate a safety culture.

3.4.5 The overall goal of MRM is to integrate the technical skills of maintenance personnel with interpersonal skills and basic Human Factors knowledge in order to improve communication and effectiveness. The promulgation of a good safety culture is at the core of MRM's basic philosophy. The MRM training should encourage individuals to feel personally responsible for safety and should provide them with the tools to develop in that direction. If MRM is to be effective, AMO staff must be encouraged to use those tools and to be shown that the tools make a difference.

3.5 INSPECTION AND QUALITY SYSTEMS

3.5.1 Annex 6, Part I, 8.7.3.1, requires that an organization establish procedures which ensure "good maintenance practices". Paragraph 8.7.3.2 then offers the following two options for compliance with 8.7.3.1:

- By establishing an independent quality assurance system to monitor compliance with and adequacy of the procedures; or
- By providing a system of inspection to ensure that all maintenance is properly performed.

The associated aviation requirements in States are known to specify one or the other of these options.

3.5.2 Aviation history records the appointment and approval of company employees as inspectors in 1916 to cater for the intensive manufacture of military aircraft. In the early 1950s, military procurement was again the driver for quality to replace inspection systems. Quality systems were, and still are, based on the principle that "quality can only be **engineered** into a task, not **inspected** into it".

3.5.3 The quality system concept, therefore, appears to offer an organization the solution to all its problems, perhaps even including the control of human error. But can a maintenance organization rely totally on a quality system to ensure an error-free future? Professor Reason in his book *Managing the Risks of Organizational Accidents* asks this important question: "Are such quality assurance (QA) measures a sufficient guarantee of the airworthiness of an aircraft?" He answers that the incident record suggests "they are not".

3.5.4 The inevitable conclusion is that a maintenance organization must have either a quality assurance system, or a system of inspection as well as a programme for observing Human Factors principles as required by the operator. A quality assurance system could, however, have a valuable role in monitoring the operation and effectiveness of a Human Factors programme in an aviation maintenance organization.

3.5.5 From an implementation viewpoint, a quality system has some features in common with a Human Factors programme. For example, a quality system requires the same management commitment, the same kind of leadership, training for all employees, internal assessments and corrective action processes. Although 3.3.4 of this chapter suggests that both initiatives can work well together in one department, it must be remembered that they are fundamentally different — the quality system being primarily concerned with process and products, while Human Factors is concerned with people and their environment.

3.6 ERROR MANAGEMENT IN AIRCRAFT MAINTENANCE

3.6.1 Most attempts at error management in the field of aircraft maintenance have been piecemeal rather than planned, reactive rather than proactive, event-driven rather than principle-driven. They have also largely ignored the substantial developments that have occurred in the behavioural sciences over the last 20 to 30 years in the understanding of the nature, varieties and causes of human error. In summary, they have:

- Addressed the last error rather than having anticipated and prevented the next one;
- Focussed on active failures rather than latent conditions;
- Focussed on the personal rather than the situational contributions to error;
- Relied heavily on warnings and disciplinary sanctions against individuals;
- Employed blame-laden, meaningless terms such as “carelessness”, “bad attitude” and “irresponsibility”;
- Not distinguished adequately between random and systematic error-causing factors; and
- Generally not been well informed of current Human Factors knowledge regarding the causes of human error, accidents and incidents.

3.6.2 A maintenance error management programme in an aircraft maintenance organization (see also Chapter 4, 4.3.6) should therefore include measures to:

- Minimize the probability of error by the individual or team;
- Reduce the error vulnerability of particular tasks or task elements;
- Discover, assess and then eliminate error-producing (and violation[1]-producing) factors within the workplace;
- Diagnose organizational factors that create error-producing factors within the individual, the team, the task or the workplace;
- Identify and improve practices which enhance error detection;
- Increase the error tolerance of the workplace or system;
- Make latent conditions more visible to those who operate and manage the system; and
- Identify and improve the organization’s intrinsic resistance to human error.

3.6.3 The phrase “good maintenance practices” is used in Annex 6 as part of the requirement for the approval of a maintenance organization. The phrase is also reflected in the national approval legislation of some States. One State’s aviation regulatory body considers this to be interpreted as follows:

- Human Factors awareness training;
- Procedures for the control of tools to prevent them being left in aircraft;
- User-friendly and effective stage sheets and job cards;
- Authorizations for tasks, such as engine runs and taxiing;
- Recording of non-scheduled tasks, such as gear pins or engine runs;
- Proper implementation of lessons learned from accidents and incidents;
- Effective shift or team handover procedures; and
- Duplicate or “Required Item” inspections.

This list has been developed from many decades of analysis of accidents and incidents involving aircraft on that State’s register and should not be considered as comprehensive. Other States may well have different experiences.

3.6.4 Aircraft maintenance is very dependent on procedures and documentation of actions. Sometimes when it seems as though this documentation is slowing down completion of tasks, it is described as “paperwork” as it

1. In Professor Reason’s terms, “violations are deviations from safe operating procedures, standards or rules. Such deviations can be either deliberate or erroneous.”

may be perceived by managers or flight crew as a nuisance. It should be remembered, however, that this documentation is essential and has the following four fundamental functions:

- To describe the work to be performed;
- To record events, stages of completion and actions taken;
- To enable continuity from shift to shift and place to place; and
- To provide a legal and traceable record of actions.

3.6.5 Many Human Factors programmes are available "off the shelf" and are produced by various bodies. All have the aim of reducing aircraft maintenance errors. These programmes and the large volume of other literature that exist all agree, in general, that the basic elements needed for a good Human Factors programme are as follows:

- A goal or purpose of the programme;
- Implementation into the organization;
- Training of the workforce at all levels;
- Error management; and
- Ergonomic analysis of the working environment.

For success, all of these elements require data gathering, analysis, as well as management support and action for improvements. The programmes available at the time of writing this manual are listed in Table 3-A-1 in Appendix A to this chapter. Any material in these programmes which meets the intent of the above elements is identified in Table 3-A-1.

3.6.6 Turnover or handover from one shift to another is a critical phase in the maintenance process and has been identified as a contributory cause in several aircraft accidents and incidents. Within a shift turnover or handover there will usually be task handovers of individual tasks. Task handovers can also take place within shifts, perhaps from one individual to another as a result of shortages of parts or some other logistic reason. Some suggested "tools" to assist in enhancing the effectivity and formalizing both the shift and task handover processes are shown in Appendices B and C to this chapter. In summary, the main characteristics for a successful turnover or handover are as follows:

- Effective shift handover needs the following two characteristics: "ownership" and "formality". The individuals concerned must assume personal ownership and responsibility for the tasks they perform and must want to ensure that those tasks are completed properly. The formality relates to the level of recognition given to performing the shift handover process. The process must be defined and documented.
- Effective task turnover or handover is dependent upon the same two characteristics, i.e. ownership and formality. Ideally, the process will be performed face to face. Where this ideal is not possible, total reliance has to be placed on written communication. Where task cards are in use, they will not have been designed to cater for the control of task (or shift) handover. It will therefore be necessary for a supplementary card or sheet to be raised to communicate the true status of the work so that the person taking up responsibility can use the combined documentation to know what is required to properly complete the task.

3.6.7 Occasionally AMEs or their supervisors will need to perform a task which has not been scheduled or planned. On these occasions, it will be necessary to raise a local work card or stage sheet. Appendix D to this chapter includes suggestions for this activity.

3.7 ERROR CAPTURE

3.7.1 Capturing or finding errors before they cause an aviation accident or incident plays an important role in the safety net of any programme for reducing the effects of human error in aircraft maintenance. There are many mechanisms for error capturing, including function checks, leak checks, inspection of tasks before signing for work done by others, independent duplicate inspections and pilot pre-flight checks. These mechanisms are well known and, in many cases, have been in State regulations in one form or another for many decades. They are briefly described in the following paragraphs.

3.7.2 Many accident and incident investigations have revealed that the function checks or engine ground runs had not been carried out. Most aircraft maintenance manuals require these checks, as their benefit in error prevention or error capture is well known. If performed properly, function and leak checks will detect if something is not installed, secured properly or adjusted correctly or if it does not meet specified criteria in the manuals. This is (and has been for a very long time) an inherent part of the maintenance process. For example, in the majority of cases, it is impossible to carry out a duplicate inspection on a flying control system or component without a function check since the range of movement, control stop clearances, control system friction or loading checks cannot be determined in any other way.

3.7.3 Duplicate inspections are inspections where the task or process is performed and checked by the same appropriately qualified person, and then an independent check is carried out by a second suitably qualified person. Both the first and second checks should be thorough and, in the case of control systems, should ensure that they include function checks for freedom and full range of movement. While some States or aviation regulatory bodies have requirements for duplicate inspections or required inspection items, others do not.

3.7.4 There is no universally agreed list of tasks or points against which duplicate inspections should be carried out. This reflects the different perception of the value of duplicate inspections or simply a cultural belief, whether right or wrong, that the normal inspection process cannot fail. The following is a suggested list of considerations to help determine which tasks might warrant duplicate inspections:

- The criticality of the task and consequences of failure;
- The vulnerability of the task to human error (which might be determined by previous incidents, a risk assessment, etc.); and
- The presence or absence of other checks (e.g. function checks).

It should not be assumed that just because other checks are present in the procedures or aircraft systems that they will be effective. It is generally better to have several mechanisms for detecting error and not to rely on just one, or relax checks (e.g. duplicate inspections) on the assumption that a problem will be detected by one of the other error detection mechanisms (e.g. pre-flight checks by pilots). Excessive use of duplicate inspections should be avoided. Too much use, combined with inadequate manpower, can result in checks being skimped and may reduce the effectiveness of the duplicate inspection as an error-capturing mechanism. In summary, an independent inspection by another person is likely to be more effective than a second inspection carried out by the person doing the task. Duplicate inspections are therefore considered to be an effective mechanism for trapping errors, but should not be relied upon as the only mechanism since they are not always 100 per cent successful.

3.7.5 Pilot pre-flight checks are not specifically intended as a mechanism for capturing maintenance errors. Nevertheless, they are intended to act as another barrier to prevent such an error from resulting in an accident or incident.

3.7.6 Design for error resistance will form an important feature of future aircraft designs, and Annex 8 — *Airworthiness of Aircraft* was amended in 2001 to require this aspect to be considered. However, this manual will not go into detail concerning design for error resistance, since this manual is not intended for designers and manufacturers. Maintenance personnel should be aware of areas where design improvements might be made so that they have an opportunity to provide input to the appropriate people. Examples where design improvements could be made include:

- The removal of cross-connectability, e.g. by having parts which cannot physically fit;
- Cockpit warning lights for unlatched cowlings;
- Paint finishes and colours that aid in crack and flaw detection;
- Accessible inspection panels where they are needed;
- Indicators showing whether something is open or closed;
- Use and positioning of placards; and
- Guarding of moving parts or areas where foreign objects could be trapped or where snagging or chafing might occur.

3.8 ENVIRONMENTAL INTERVENTIONS

3.8.1 Annex 6, Part I, 8.7.4.1, requires that the working environment of the AMO be appropriate for the task to be performed. There are two aspects to this requirement: first, the environmental requirements of the task itself (for example, air quality) and, second, the effect of the environment on the human beings who perform the work.

3.8.2 The environment in a workshop is generally easier to control than in a hangar. Where the components are small, an "office style" environment will be suitable in most cases. However, in some cases, the nature of the components will require an environment that is controlled to specific parameters. For example, composite structure repairs are likely to require both temperature and humidity control while instruments will, in addition, require very clean air.

3.8.3 The FAA *Human Factors Guide for Aviation Maintenance* identifies the following environmental issues which are important for the AMO in the context of Human Factors:

- *Access to the work area itself:* This may be difficult because of clutter;
- *Storage and retrieval:* Quick access to tools, fixtures, test equipment, materials, parts, portable work platforms, procedures and technical documentation is necessary;
- *Sound and noise:* Many sounds are essential for the proper conduct of the work, such as voice communication or audio signals from equipment. Noise is unwanted sound and can be distracting and stressful;
- *Work platforms:* Many parts of large commercial aircraft are well beyond the reach of a human being on the floor. To reach these areas, various sizes and types of work platforms are required;
- *Lighting:* Humans are not very adept at performing precision work with low levels of illumination. The size of most hangars presents some challenging lighting problems; and
- *Temperature, humidity and airflow:* Conditions outside a fairly narrow range can quickly degrade human capabilities — both physical and mental.

Occupational health and safety regulations or codes in many countries address some or all of these issues. However, they are not primarily concerned with, nor do they generally affect, human performance within maintenance facilities. This manual does not address these aspects.

3.8.4 An audit of the AMO facility is one way to establish if the environment complies with a State's requirements. The FAA *Human Factors Guide for Aviation Maintenance* proposes that the intent of a facility audit is for AMO staff to look at the overall facility to determine whether it meets certain objective and subjective criteria. A facility audit does not examine any particular task; rather it is a process to gather specific types of information. The FAA Guide recommends that the AMO facility audit should comprise the following activities:

- *Direct measurements:* This may include measuring lighting, noise, temperature, relative humidity, airflow, access, etc.;
- *Questionnaires/"Opinionnaires":* The people working in the facility can record in questionnaires/ "opinionnaires" how they feel about the features of the facility and how they work and dress. Analysis of the responses can identify faulty assumptions and potential problem areas;
- *Structured interviews:* A flexible, interactive, person-to-person conversation may bring out ideas and information that might be lost in a questionnaire response; and
- *Checklist walkthrough:* This activity involves a physical review of the facility by a person using a structured checklist but does not "close out" the opportunity to examine other aspects of the facility. The FAA Guide assumes that AMO staff will conduct the walkthrough.

Appendix E to this chapter provides information on different environmental factors in the aircraft maintenance environment. It also provides a suggested outline for checklists and interviews dealing with environmental factors. Changes to the facility also need to be controlled in order to ensure that they are necessary and will not degrade existing functionality. These should be reviewed using a similar process as for the environmental factors.

3.8.5 Facility audits of large AMOs are time consuming. A State aviation regulatory body should be clear and ensure that "ownership" of these audits and the resolving of problem items is the responsibility of the AMO management. The checklist walkthrough in Section 8 of Appendix E to this chapter provides a suitable checklist for use by a maintenance inspector when the facility is declared satisfactory by the AMO management. It should be borne in mind that the results of such a walkthrough will vary with different conditions, for example, during the day, night, summer and winter.

3.9 ERGONOMIC INTERVENTIONS

3.9.1 The FAA *Human Factors Guide for Aviation Maintenance* provides the following quotation:

> "Principles of good human factors practice must be applied to individual jobs, if the full benefits of a human factors program are to be achieved."

Ergonomics — the science of fitting the job to the human — can be a good tool to apply Human Factors to many aircraft maintenance tasks.

3.9.2 The concept of ergonomics is applicable to a number of interfaces between AMEs and their working environment, such as their information requirements, environment, equipment and the physical activity in their workspace. The analysis of these interfaces can provide valuable and important information for management interventions for improvement. One way for the AMO to perform this analysis is by means of an ergonomic audit.

3.9.3 It has long been recognized that proper job design can have an important effect on productivity and error rates. The FAA *Human Factors Guide for Aviation Maintenance* offers two different systems for an AMO to conduct an audit and analyse the AME/task interface, namely:

- *The ERgoNomic Audit Program (ERNAP):* This is a programme specifically designed for the analysis of aircraft maintenance activities. It is based on a checklist concept to collect data before, during and after maintenance, either on paper or directly into a portable computer. See Appendix F to this chapter for more details; and

- *The Organizational Systems Design Process:* This programme starts by requiring some fundamental definitions of organizational goals and technical and social system inputs/outputs. It then addresses variances (e.g. un-repaired aircraft), allocates functions, designs the workplace and social system before finally proposing a system for continuous improvement.

The AMO must then analyse the results of the audit and make appropriate management decisions to change the workplace and its equipment so as to enhance the task interface with the AME.

3.9.4 The terms "workplace" and "equipment" are very general when used in the context of an ergonomic audit. It is therefore important to understand that the prime purpose of designing, or redesigning, the workplace and its equipment is as follows:

- To determine what the worker is required to do;

- To identify what information, tools, controls and procedures are needed; and

- To provide those elements in their proper size, form and format.

3.9.5 The workplace and equipment items that are frequently identified by ergonomic audits as needing change are as follows (not in order of importance):

- Workbenches and chairs;

- Fixtures, e.g. access staging;

- Tools and test equipment;

- Task lighting;

- Computer interfaces;

- Company work cards and procedures; and

- Aircraft or equipment instruction manuals and technical specifications.

3.10 DOCUMENTARY INTERVENTIONS

3.10.1 Considerable research shows that significant improvements in error rates can be achieved by the application of Human Factors principles to the design of documents used in the aircraft maintenance activity. The details of this research are presented in the FAA *Human Factors Guide for Aviation Maintenance (Phase IV Progress Report).*

3.10.2 In order to enable AMOs and operators to use this research, the "Documentation Design Aid" (DDA) was developed for use by engineers and technical writers who control the technical content of work instructions and who control the process of transforming the content into a work instruction document (work card, job card, task card, stage sheet, etc.). See Appendix G to this chapter for details on the DDA.

3.10.3 Annex 6 (Part I, 8.3.1 and Part III, Section II, 6.3.1) requires that the "design and application" of the operator's maintenance programme observe Human Factors principles. As a result, the operator is responsible for ensuring that:

- The design of the programme observes Human Factors principles; and
- The application of the programme by the AMO observes Human Factors principles.

3.10.4 An aircraft maintenance programme design that observes Human Factors principles (and also follows the recommendations for Type Certificate (TC) holders) should have the following features:

- Task or job sequences which are likely to reduce the probability or effect of error in its application (for example, performing engine maintenance with different work teams or between different flights);
- Work packages which suit an operator's specific operation (for example, overnight packages); and
- Task or job cards or sheets which meet a standard for good document design.

3.10.5 In order to apply an aircraft maintenance programme so as to observe Human Factors principles, the AMO should have the following features, as appropriate to its scope and size:

- Satisfactory environment and ergonomics;
- Procedure documentation which meets a standard for good document design;
- Management that has satisfactory processes to achieve improvements in communication, effectiveness and safety in its operations (for example, these processes could include MRM and a quality system);
- Error management systems for reporting, investigating, analysing, measuring and taking corrective action; and
- Aircraft maintenance manuals (or equivalent documentation) which have been assessed to a standard for good document design.

3.10.6 The long-standing and widely accepted industry standards for aircraft maintenance technical manuals are those published by the Air Transport Association of America. (Until 1999, these standards were in ATA Specification 100 and ATA Specification 2100. In 2000, these two documents were incorporated into ATA Specification 2200.) These standards are, perhaps, best known for the aircraft zone or system numerical identifiers that are instantly recognized by maintenance personnel. Except as outlined below, the ATA recommendations are generally consistent with Human Factors principles:

- The maximum number of levels of paragraph breakdown exceeds the maximum of three which is recommended as best Human Factors practice;
- Capital letters are recommended for "caution" or "warning" text rather than lower case letters which are proven to be easier to read;
- The policy recommendation to assume users are unfamiliar with the aircraft can result in too much detail being provided for experienced users; and
- The only policy recommendation for writing is: "It should be written in clear, logical, easy-to-read style. …" As a policy objective, this is ideal. The FAA "Documentation Design Aid" includes more detailed information as to how this can be achieved.

In cases where the aircraft maintenance manual has been developed in conformity with the ATA Specifications, operators will need to consider the above points when ensuring that the application of their maintenance programme by the AMO observes Human Factors principles. It should be noted that Annex 8 does not require that the continuing airworthiness publications observe Human Factors principles.

3.11 FATIGUE INTERVENTIONS

3.11.1 The United Kingdom CAA Airworthiness Notice No. 47 provides the following advice for the individual licensed AME concerning fatigue:

> "Tiredness and fatigue can adversely affect performance. Excessive hours of duty and shift working, particularly with multiple shift periods or additional overtime, can lead to problems. … Individuals should be fully aware of the dangers of impaired performance due to these factors and of their personal responsibilities for the standards of their work."

It is obvious that one cure for fatigue is sleep — this means long-term restful sleep that is not disturbed by the effects of alcohol or caffeine. Some "coping mechanisms" are suggested in Chapter 4 of the FAA *Human Factors Guide for Aviation Maintenance.* The measures suggested include help from local supervisors who need to recognize and deal with the effects of fatigue, and help from the individual workers themselves by their recognizing the symptoms and dealing with them as with any other stressful situation in life. Changing or rotating staff, supervision, and tasks or task sequencing are also known to reduce the risks of error due to fatigue. The following paragraphs suggest other measures that can help combat fatigue.

Shift work

3.11.2 The ADAMS project accepts that aviation is a 24-hour operation with significant pressure to meet deadlines. It suggests that shift-work systems should be designed with the following principles in mind in order to minimize the effects of mental and physical fatigue:

- Provide regular opportunities for sufficient night sleep to prevent the accumulation of "sleep debt";
- Provide a predictable shift system which allows workers to plan their schedule of rest and sleep to minimize sleep loss. Rotating shift patterns prevent this and should be avoided;
- Allow at least two successive nights' sleep in order to allow for recovery from accumulated fatigue and sleep debt;
- Take account of reduced physical and mental capacity at night by avoiding the scheduling of such work under strong time pressures;
- Be flexible so as to take account of an individual's ability to cope with the disruptions of shift work (e.g. age and domestic circumstances);
- Have the same support services available at night as during the day (e.g. administration, planning, quality, canteen/cafeteria and welfare);
- Allow opportunities for individuals to recover from conditions which give rise to fatigue and sleep loss; and
- Although overtime work is one option for completing tasks not completed during a shift, repeated overtime should be discouraged as it may possibly lead to reduced staff motivation and performance. The alternative is to pass the work to the next shift.

3.11.3 The FAA *Human Factors Guide for Aviation Maintenance,* Chapter 4, entitled "Shiftwork and Scheduling" identifies that mental and physical fatigue is directly associated with higher error rates. The FAA Guide goes on to state, first, that shift work can contribute to fatigue by disrupting the normal wake/sleep cycles and, second, that most aircraft maintenance work is performed at night. The FAA Guide recommends the following processes to develop possible countermeasures:

- Evaluate exiting schedules to identify if a particular schedule has caused, or is likely to cause, performance problems;
- Develop effective and appropriate shift turnover or handover procedures;
- Introduce countermeasures; and
- Train individual supervisors and workers to cope with their shift schedules.

The FAA Guide includes or references evaluation questionnaires and other material to help determine suitable countermeasures.

3.11.4 Shift work is defined in a report by Professor Simon Folkard entitled "Work Hours of Aircraft Maintenance Personnel" as "any arrangement of daily working hours that differs from the standard daytime hours, i.e. between about 07:00 and 19:00". The report reviews the relationships between shift work and health and safety. In addition, it provides some recommendations for good practice in shift-work patterns.

3.11.5 The basic aim of any set of guidelines for "good practice" in setting shift patterns must clearly be to minimize the risk of an error or mistake being made. The approach suggested in Professor Folkard's report is based on the objective trends in risk where these are available, and to supplement this with evidence from studies of fatigue or sleep duration where objective risk data is unavailable. Examples of successful approaches range from a relatively simple set of limitations on the work hours of a particular occupational group, such as the United Kingdom CAA's "Scheme for the Regulation of Air Traffic Controller's Hours", to more general schemes, such as Western Australia's scheme for "Fatigue Management" in commercial vehicle drivers. The report states that the aims of guidelines for "good practice" in setting shift patterns should be to:

- Minimize the build-up of fatigue over periods of work;
- Maximize the dissipation of fatigue over periods of rest; and
- Minimize sleep problems and circadian disruption.

A summary of some of the possible good practices for shift setting and management recommended in the report are shown in Appendix H to this chapter.

Breaks

3.11.6 Research has shown that short breaks in the task activity improve performance and reduce errors. A break of about 15 minutes every 2 to 3 hours is very beneficial to human performance.

3.11.7 Sleep and fatigue are related, and responsibility rests with the individual to apply sensible habits in sleep and during rests or breaks between duty periods. Management and local supervision, however, have a responsibility to control shifts, breaks, duty periods and overtime to minimize fatigue.

Drinks

3.11.8 Insufficient drinking of water is known to contribute to the symptoms of fatigue. Maintenance staff should have easy access to clean, potable water. Coffee is identified in the FAA *Human Factors Guide for Aviation Maintenance,* Chapter 4, as the only legal "over-the-counter" stimulant but warns that even this can have undesirable side effects.

Maintenance programme application

3.11.9 The application of a maintenance programme is required by Annex 6 to observe Human Factors principles. Planning the process, location, personnel and tasks can have a significant effect on the likelihood of human error. Some of the issues that should be taken into account during the planning process are summarized in Appendix I to this chapter.

3.12 SOME SIMPLE INTERVENTIONS

3.12.1 Many of the interventions suggested by the various Human Factors guides or handbooks mentioned in this manual involve the AMO or operator in extensive audits and possibly expensive programmes of change within their organizations. However, many maintenance organizations and individual AMEs have, over the years, developed or learned from military service some simple low-level interventions to help avoid errors. Introduction of Human Factors or error management programmes does not necessarily mean that these traditional or "custom-and-practice" measures could, or should, be abandoned. Each should be examined on its own merits. The kinds of measures which have been noted are listed in the following paragraphs. The list is not exhaustive.

Tools, test equipment and parts

3.12.2 Tools, test equipment, parts, etc. that are left on board an aircraft after maintenance have the potential to obstruct flight controls or affect other vital systems. Interventions and State regulatory practices currently differ widely in their attempts to eliminate this very significant hazard. The following are examples of long-standing arrangements, which alone, or in combination, can provide good control of these kinds of items:

- A shadow board or box for hand tools (wrenches, screwdrivers, etc.) that uses contrasting coloured outlines to provide a visual cue if a tool has not been replaced;
- Hand tools that are marked and are the personal property of the AME;
- Checklists for each AME's toolbox and checked prior to aircraft release;
- Specific loose object area inspections prior to final panel closures; and
- Tool control via a stores loan system with personal "tool checks" or electronic card controls to identify the individual who has possession of a tool.

Separation of tasks

3.12.3 Some State regulations require that vital points such as flight control systems be identified and require a second or independent check or inspection by a different person. The idea is that "fresh eyes" will see an error or discrepancy. A variation on this theme (usually for Extended Range Operations by Twin-engined Aeroplanes (ETOPS)) is for the engine work or the engine maintenance work crew to be separated on multi-engined aircraft. The intention is that the separation will avoid the same error being made on all engines by one person or one crew.

Interruptions

3.12.4 Interruptions are a proven cause of maintenance errors. Some companies use a variety of methods to keep the aircraft as "sterile" as possible while it is undergoing maintenance while at the same time enabling access to be controlled by local supervision for those persons who really need it (e.g. planners and regulatory authority inspectors). Some examples are as follows:

- Having signs or other methods to ensure that casual company visitors are excluded from the aircraft and the area immediately surrounding it except by specific permission of a particular person (e.g. foreman and supervisor); and

- Arranging that personnel not physically working on the aircraft take incoming telephone calls.

Access to outdoor areas for functional tests

3.12.5 Providing proper and timely access to, or provision of, areas for engine running, weather radar testing and any other functional test which must be performed outdoors can sometimes be a problem. For example, many airports have engine ground running curfews which can make this kind of testing impossible when maintenance has been performed overnight and the shift finish time is earlier than the end of the curfew. Effective solutions can be to:

- Reschedule the work that requires an engine run;

- Make permanent arrangements at the formal management level with the appropriate (air traffic control or airport) authority for such runs to be performed (e.g. at a particular time, in a particular location or dependent on wind direction);

- Build a noise containment area or ground-based fixed silencers; and

- Modify the aircraft or the work package in conjunction with the TC holder to eliminate the need for such a test.

Cross-connections

3.12.6 Systems which have been cross-connected have been reported on many occasions after maintenance activities. This has been noted on both electrical and fluid systems. However, wiring cross-connections appears to be most frequent. In most cases, functional testing would have detected the error, but maintenance manuals may not require this in every case. As a result of such cross-connection incidents, one State has issued the following advice as "good maintenance practices":

- Parts removed or disconnected should be tagged, labelled or colour-coded to aid correct reassembly;

- Company policy, procedure and training should emphasize the importance of functional testing when wiring or plumbing has been disturbed, whether this is specified in the manufacturer's recommendations or not; and

- Any such cross-connection events should be reported to the appropriate aviation regulatory body and the TC holder for the product.

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Appendix A to Chapter 3

HUMAN FACTORS PROGRAMMES

Table 3-A-1. Comparison of basic elements of "off-the-shelf" Human Factors programmes

Programme Title	*Training Course*	*Error Management*	*Ergonomics and Environment*	*Implementation*	*Goals*
European Community Aircraft Dispatch and Maintenance Safety (ADAMS) — *Human-Centred Management Guide for Aircraft Maintenance*	Objectives and method suggestions: Appendices 16 and 17. Summary of "STAMINA" programme offered by NLR in the Netherlands.	Advice and reference to JAR 145: Chapter 4.	Concise but comprehensive advice: Chapter 3, Appendices 7 and 8.	No specific section on this topic but included generally throughout.	Comprehensive and concise: Chapter 2.
GAIN — *Operator's Flight Safety Handbook*	No.	Description only of immunity-based reporting: paragraph 3.5.	No, only in the flight crew context.	In part: Section 3.	Yes, but only in the flight crew context: Section 2.
Boeing — *Maintenance Error Decision Aid* (MEDA)	No.	A very complete and comprehensive process for investigating errors.	No.	No.	No, only for MEDA itself: "Introduction".
ICAO — *Human Factors Training Manual* (Doc 9683)	Very brief: Part 1, Chapter 6, and Part 2.	Descriptions of problems and suggestions for some interventions: Part 1, Chapter 6.	Comprehensive ergonomic information: Part 1, Chapter 4.	In part: Part 1, Chapter 1.	No specific section on this topic but included generally throughout.
FAA — *Human Factors Guide for Aviation Maintenance*	Course development process only: Chapter 7.	Very complete and comprehensive: Chapters 13, 14, 15 and 16.	Very complete and comprehensive: Chapters 5 and 6.	Comprehensive process recommendations: Chapter 2.	Yes: Chapter 1.
FAA — *ERgoNomic Audit Program* (ERNAP)	No.	No.	A very complete and comprehensive process for auditing facility and procedures.	No.	No.
U.K. Human Factors Combined Action Group (UKHFCAG) — *People, Practices, Procedures*	MRM course outline: Appendices C and D.	Very concise but comprehensive: Appendices A to G.	Concise description: Steps 2 and 3.	Yes: Steps 1 to 5.	No specific section on this topic but included generally throughout.

Programme Title	*Training Course*	*Error Management*	*Ergonomics and Environment*	*Implementation*	*Goals*
ATA Specification 113 — *Maintenance Human Factors Program Guidelines*	Course development process only: Chapter 5.	Concise and comprehensive outline description: Chapters 4 and 6.	Overview: Chapter 7.	In part: Chapter 3.	In part: Chapter 3.
FAA/Galaxy Scientific Corporation — *Maintenance Resource Management Handbook*	MRM course development process and sample curriculum: Chapter 5 and Appendix C.	No specific section on this topic but included generally throughout.	Described in part: Chapter 2.	Training implementation only: Chapter 3.	Concise paragraph: “Objectives”.
U.K. CAA — *Human Factors and Aircraft Maintenance Handbook*	Principles only: Part 1. Also list of providers.	Comprehensive outline description: Part 3.	Comprehensive outline description: Part 3.	Comprehensive description: Part 1.	Briefly, yes: “Foreword”.
U.K. CAA — CAP 455, Airworthiness Notice No. 71, *Maintenance Error Management Systems*	No.	Comprehensive reporting and corrective action system for an AMO.	No.	Comprehensive: paragraph 2.	Concise and clear: paragraph 1.

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Appendix B to Chapter 3
SHIFT TURNOVER/HANDOVER

1. INTRODUCTION

1.1 It is universally recognized that at the point of changing shifts, the need for effective communication between the outgoing and incoming personnel in aircraft maintenance is extremely important. The absence of such effective communication has been evident in many accident reports from various industries, not just aircraft maintenance.

1.2 The goal of the shift turnover/handover is the accurate, reliable communication of task-relevant information across the shift changes, thereby ensuring continuity of safe and effective working.

1.3 The information in this appendix is summarized from the FAA *Human Factors in Aviation Maintenance and Inspection* CD-ROM.

2. CONCEPTS

2.1 Conceptually, shift turnover/handover can take place in three different situations. The first, and most common, occurs when operations are manned on multiple shifts and an outgoing shift must turn over job and task responsibilities to an incoming shift. The second applies when going from an unmanned situation to a manned one. For example, a maintenance facility may be unmanned for some period of time each day or week and then an incoming shift of workers must assume all responsibilities as the facility is made operational again. The final shift turnover/handover condition occurs when a worker's job responsibilities must be assumed by another person before the end of the first worker's shift. This happens when on-the-job illness, personal emergencies, etc. require a worker to leave the job before the scheduled quitting time.

2.2 An important concept related to shift turnover/handover is when it actually begins. The common perception is that shift turnover/handover occurs only at the transition between the shifts. Some shift turnover/handover standards make the point that shift turnover/handover should really begin as soon as the new shift starts. Throughout a shift, the workers/supervisors should be thinking about and recording what information should be included in their handover to the next people or shift.

2.3 This appendix will concentrate on the most common shift turnover/handover condition — an incoming shift must relieve an outgoing shift. Except for the shift turnover/handover meeting, however, all of the components of the shift turnover/handover process are applicable to other turnover/handover situations as well.

3. ELEMENTS

Effective shift turnover/handover depends on three basic elements:

a) The ability of the outgoing workers/supervisors to understand and communicate the important elements of the job or task being passed over to the incoming people;

b) The ability of the incoming workers/supervisors to understand and assimilate the information being provided by the outgoing people; and

c) A formalized process for exchanging information between outgoing and incoming people and a place for such exchanges to take place.

4. CHARACTERISTICS

4.1 Two characteristics must be present for effective shift turnover/handover to take place: ownership and formality. Individuals must assume personal ownership and responsibility for the tasks they perform. They must want to ensure that their tasks are completed correctly — even when those tasks extend across shifts and are completed by somebody else.

4.2 Formality is the level of recognition given to the shift turnover/handover procedures. The shift turnover/handover process should be defined in the maintenance organization procedure manual. Managers and supervisors should be committed to ensuring that cross-shift information is effectively documented and delivered. Demonstrable commitment is important as workers quickly perceive a lack of management commitment when they fail to provide ample shift overlap time, adequate job aids and dedicated facilities for the handovers to take place.

4.3 An effective shift turnover/handover process is composed of at least four components:

- Shift turnover/handover meetings;
- Turnover/handover walkthroughs;
- Turnover/handover checklists; and
- Work status markers.

Guidelines for each of these elements is provided below. All should be included in the turnover/handover process.

5. AIDS

Research has shown that the following processes, practices and skills can aid effective communication at shift turnover/handover:

a) People have to physically transmit information in written, spoken or gestured (non-verbal or body language) form. If only one medium is used, there is a risk of erroneous transmission. The introduction of redundancy, by using more than one way of communicating, i.e. written, verbal or non-verbal, greatly reduces this risk. For this reason, information should be repeated via more than one medium, for example, verbal and one other method such as written or diagrams, etc.;

b) The availability of feedback to allow testing of comprehension, etc. during communication increases the accuracy. The ability for two-way communication to take place is therefore important at shift turnover/handover;

c) A part of the shift turnover/handover process is to facilitate the formulation of a shared mental model of the maintenance system, aircraft configuration, work tasks, etc. Misunderstandings are most likely to occur when people do not have this same mental "picture" of the state of things. This is particularly true when deviations from normal working procedures have occurred, such as having the aircraft in the flight mode at a point in a maintenance check when this is not normally done. Other considerations are when people have returned following a lengthy absence (the state of things could have changed considerably during this time) and when turnovers/handovers are carried out between experienced and inexperienced personnel (experienced people may make assumptions about their knowledge that may not be true of inexperienced people). In all theses cases, turnovers/handovers can be expected to take longer and extra time should be allowed; and

d) Written communication is helped by the design of the documents, such as the turnover/handover log, which considers the information needs of those people who are expected to use it. By involving the people who conduct shift handovers and asking them what key information should be included and in what format helps accurate communication. Their "buy-in" contributes to the use and acceptance of the process.

6. BARRIERS

Research has also shown that certain practices, attitudes and human limitations can act as barriers to effective communication at shift turnover/handover. For example:

a) Key information can be lost if the message also contains irrelevant, unwanted information. People also only have a limited capability to absorb and process what is being communicated to them. In these circumstances, it requires time and effort to interpret what is being said and to extract the important information. It is important, therefore, that only key information be presented and that irrelevant information be excluded; and

b) The language we use in everyday life is inherently ambiguous. Effort therefore needs to be expended to reduce ambiguity by:

- carefully specifying the information to be communicated (e.g. by specifying the actual component, tooling or document);
- facilitating two-way communication which permits clarification of any ambiguity (e.g. by

asking questions such as: "Do you mean the inboard or outboard wing flap?");

- expending effort to identify, minimize and repair misunderstandings (which are a natural and inevitable feature of human communication) as they occur; and

- expending effort to address complacency. People and organizations may say that their communication is unproblematic, implying that successful communication is easy and requires little effort. This leads to overconfidence and complacency. Organizations can address this complacency by:

  — emphasizing the potential for miscommunication and its possible consequences; and

  — developing the communication skills of people who are involved in shift turnovers/ handovers.

7. GUIDELINES

7.1 The following guidelines apply for operations that are manned on multiple shifts to allow for continuous 24-hour maintenance. When shifts do not cover a full 24-hour period, for example, early and late shifts with no night shift, the handover has no face-to-face communication. In such cases, there is an inherent risk, and organizations should be aware that the potential for ineffective and inefficient communication is much higher.

Shift turnover/handover meetings

7.2 The primary objective of the shift turnover/ handover is to ensure accurate, reliable communication of task-relevant information across the shifts. However, this does not recognize the user's needs for other information which may also be required to enable a complete mental model to be formed which will allow safe and efficient continuation of the maintenance process. Examples of such information could be manning levels, authorization or licence coverage, staff sickness, people working extended hours (overtime), personnel issues, etc.

7.3 The shift turnover/handover process should comprise at least two meetings. It starts with a meeting between the incoming and outgoing shift managers/ supervisors. This meeting should be conducted in an environment that is free from time pressure and distractions.

7.4 Shift managers/supervisors need to discuss, and update themselves on, tactical and managerial matters affecting the continued and timely operation of the maintenance process. The purpose of this meeting is therefore to acquaint themselves with the general state of the facility and the overall status of the work for which they are responsible. Outgoing managers/supervisors should summarize any significant problems they have encountered during their shift, especially any problems for which solutions have not been developed or are still in progress. Table 3-B-1 lists the kinds of topics that should be covered in the managers'/supervisors' shift turnover/handover meeting.

Table 3-B-1. Topics for the managers'/supervisors' shift turnover/handover meeting

Status of the Facility
Workstands/docking/test equipment
Construction work
Work Status
Aircraft being worked
Scheduled aircraft incoming/outgoing
Deadlines
Aircraft status against planned status
Manning Levels and Status
Authorization/licence coverage
Certifying staff
Non-certifying staff
Identity of personnel working overtime
Identity of contract staff
Sickness
Injuries
Training
Other personnel issues
Problems
Outstanding/in work/status
Solved
Information
ACs, ADs, SLs, etc.
Company technical notices
Company policy or procedure notices

Walkthroughs

7.5 After the meeting between shift managers, and the assignment of tasks, there is a need for supervisors and certifying staff to meet and exchange detailed information related to individual jobs and tasks. The most effective way to communicate this information is for the affected incoming and outgoing personnel to go over the task issues while examining the actual jobs on the hangar floor or at the workplace. A mutual inspection and discussion of this nature is called a "walkthrough". Table 3-B-2 lists the kinds of topics that should be covered in the walkthrough meeting by supervisors/certifying staff.

Table 3-B-2. Topics for the supervisors'/certifying staff's walkthrough meeting

Jobs/tasks in progress
Work cards being used
Last step(s) completed
Problems encountered: Outstanding/in work/status or solved
Unusual occurrences or events, defects or faults
Resources required/available
Location of removed parts, tooling, etc.
Parts and tools ordered and when expected, or shortages
Proposed next steps
Communications with planners, technical services, workshops, managers, etc.

Checklists

7.6 The walkthrough information exchange should be structured with a checklist. Shift turnover/handover information can also be given verbally from outgoing to incoming workers. In this case, checklists are used to structure the turnover/handover conversation and ensure that the outgoing worker does not inadvertently fail to pass along important information. This mode of operation is the same as various cockpit procedures that are governed by checklists, such as take-off, landing, in-flight engine restart, etc.

7.7 The only objective research related to shift turnover/handover communication in the aviation maintenance domain involved written shift turnover/handover inspection logs. The researchers stressed the importance of writing down important information. Their rationale noted that verbal information, while more convenient, is also more prone to distortion and simple forgetting.

7.8 It appears that verbally exchanging turnover/handover information, according to a formal checklist, is more likely to conform to the way AMEs typically work. The more compatible the procedure, the more likely it is that AMEs will follow it.

7.9 Shift turnover/handover checklists that cover all of the topics in Table 3-B-2 are recommended. If particular types of information not found in Table 3-B-2 are required for particular job categories, then specialized checklists should be developed for these jobs. Checklists should be no more than one page in length and should conform to the formatting requirements for work cards.

Work status markers

7.10 A serious type of shift turnover/handover error can occur when an incoming worker assumes that the outgoing worker has completed a job when the job has not, in fact, been completed. A very simple way to address this potential error is to provide explicit work status markers that can be affixed to, or in the vicinity of, a worksite or component being repaired. This is the same idea as attaching "remove before flight" streamers to certain aircraft components.

7.11 Colour-, pattern-, and shape-coded "work complete" and "work in progress" cards can be attached to each work card. When AMEs complete all the steps in a work card procedure, they place the "work complete" card on the module or structure being worked. If a shift ends before the work is complete, then the "work in progress" card is placed on, or temporarily attached to, the worksite. This technique can prevent an incoming AME from assuming that work on a particular module is complete, when, in fact, it is still in progress. Of course, this information should be transmitted during the walkthrough discussion. However, the idea is to provide more than one barrier to prevent human error from propagating throughout the system.

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Appendix C to Chapter 3

TASK TURNOVER/HANDOVER

1. INTRODUCTION

1.1 The information in this appendix is summarized from the United Kingdom Civil Aviation Authority's guidance material entitled *Aviation Maintenance Human Factors* (CAP 716).

1.2 The handing over of tasks from one person to another does not always occur at the point of changing shifts. Often it is necessary to hand a task over during a shift. This appendix deals with two common situations, namely:

- Unfinished task handed over to someone who is present at the time; and
- Unfinished task left for an unidentified person to take over at a later stage.

2. HANDING OVER A TASK DIRECTLY TO ANOTHER PERSON

When a task is being directly handed over to someone who is present at the time, the process and concepts are the same as for a walkthrough (see Appendix B to Chapter 3). The process is done face to face using verbal and written communication. The written element is normally to ensure that the task cards or non-routine process sheets are accurately completed and clearly identify the stage at which the task has reached. Any deviations from normal working practices or procedures must be clearly highlighted during the walkthrough. For example, if when changing a valve, a clamp that was not required to be removed as per the maintenance manual was disturbed to aid removal and installation of the valve, this should be indicated. Many errors have occurred in these circumstances because the person taking over the task assumes that everything has been performed as per the maintenance manual, drawings, procedures, etc. From the point of view of effective communication, it is essential that the outgoing person record the deviation and that it be discussed in the walkthrough.

3. HANDING OVER A TASK FOR SOMEBODY TO COMPLETE AT A LATER STAGE

It is not uncommon that a job is left incomplete during a shift, for example, someone being called away from one task to attend to a more urgent task on another aircraft. In such a case, it is often not known who will eventually take over the job of completing the task and certifying the release to service. This type of situation presents a far greater risk and challenge to effectively communicate the stage of task accomplishment and what remains to complete the job. Face-to-face communication is not possible. Everything depends on the written communication. There is no way to check the understanding of the person expected to finish the task.

4. TASK CATEGORIES

4.1 Tasks performed by AMOs can be classified as:

- Scheduled (perhaps as part of a maintenance or modification programme which has been pre-planned); and
- Non-scheduled (resulting perhaps from the need to rectify a defect found in flight or on the ground).

Scheduled tasks

4.2 Normally, the manufacturer, maintenance organization or the operator of the aircraft issues task cards at the beginning of the maintenance input for scheduled tasks. In all cases, the card and associated task breakdown written on it assume that the same person will start and finish the job. The task card was not designed to be used as a turnover/handover document (although depending on the circumstances, it is possible that it could be used as the handover document or form part of one). Task cards break down jobs into discrete stages. Ideally, jobs should always be stopped at one of these stages so that the last sign-off on the card represents the exact stage at which the job has been reached. In this case, the card can be the turnover/handover document. However, a job may be stopped at a point which is between the stages identified on the card, or the stage sequencing has not been followed or deviates from normal work procedures (such as in the example of disturbing the additional clamp to aid removal and installation of a valve). When this occurs, additional written information must be used to clearly identify the point of exit from the task and what is required to complete the job and restore serviceability. Non-routine cards or sheets should then be used to record and transmit the necessary relevant information. An example of a task card is at Table 3-C-1.

4.3 In Table 3-C-1, the job has been accomplished fully up to stage d). Additionally, however, the hydraulics have been depressurized so part of stage e) has been accomplished. A supplementary card, worksheet or non-routine sheet (the terminology will vary from one company to another) must therefore be raised to communicate that the task card does not reflect the true state of the aircraft. In this case, the wording could be as indicated in Table 3-C-2.

4.4 The combination of both the task card and the non-routine worksheet should provide sufficient information for the person picking up the job to know the present status of the work and what is required to complete or continue it.

Non-scheduled tasks

4.5 All non-scheduled tasks intended to be performed on the aircraft or its components should be documented in such a way as to define the work to be accomplished. This is not only good maintenance practice but will facilitate the issue of a maintenance release on completion. Any task above the level of simple should be controlled by breaking down the work into discrete and documented stages with the provision for appropriately authorized staff to sign off or stamp when each step is completed. The document used in this control process is often called a “stage sheet”. The stage sheet is particularly useful in the case of complex tasks or when there is a handover to another person or shift. It also provides a record of who did what and when. Management and supervisors in maintenance organizations have a responsibility to ensure that there are formats, a procedure and adequate time for maintenance staff to record stages in this way.

Table 3-C-1. Example of a task card

GO FAST AIRWAYS A/C type: B737 MP ref.: MS/B737/668 Aircraft registration: G-OFST			
Flight controls			
Additional work card raised: Yes			
27-00-56	Flap synchronizing system	Mechanic	Inspector
	a) Check that the cable tensions are correct (mm 27-50-02).	***Mick Spencer***	⑨ stamp
	b) With the flaps selected up, disconnect the operating link from one transmitter gearbox only.	***Mick Spencer***	⑨ stamp
	c) Pressurize the hydraulic system and select flaps down.	***Mick Spencer***	⑨ stamp
	d) Make sure that the flaps start to move and then the system cuts out.	***Mick Spencer***	⑨ stamp
	e) Depressurize the hydraulic system and connect the transmitter operating link.		
	f) Pressurize the hydraulic system and make sure that the flaps operate correctly.		

Table 3-C-2. Supplementary non-routine worksheet

GO FAST AIRWAYS Non-routine worksheet			
Defect	Action Taken	Mechanic	Inspector
Reference card 27-00-56. Card completed fully up to stage d). Hydraulic system depressurized but the transmitter operating link is not reconnected. Operating link to be reconnected prior to performing stage f).			

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Appendix D to Chapter 3

PLANNING AND RECORDING NON-SCHEDULED MAINTENANCE TASKS

1. INTRODUCTION

1.1 Inaccurate, incomplete or non-existent maintenance documentation has been cited as a contributing factor in several maintenance error accidents and incidents.

1.2 Some of the information in this appendix is summarized from the U.K. CAA document entitled *Aviation Maintenance Human Factors* (CAP 716).

2. THE REGULATION

Non-scheduled maintenance tasks can arise from scheduled maintenance inspections or from defects recorded on operational aircraft. Both scheduled and non-scheduled maintenance tasks require a maintenance release to be issued when all maintenance relating to the task(s) has been completed. It therefore follows that the documents recording a non-scheduled maintenance task must contain sufficient detail to enable the Certifying AME to determine that the task has been carried out to the standard which will enable that AME to issue a maintenance release for return to service.

3. THE MEANS OF COMPLIANCE

3.1 Scheduled maintenance tasks on aircraft vary widely in complexity. Normally, the work is issued by the operator or AMO in the form of task cards (terminology varies from one company to another, e.g. job cards, worksheets and process sheets) raised for each scheduled task. To provide a record and to aid control of complex tasks by maintenance personnel at the shop floor level, the format design of the task card normally breaks down each task into a number of simple, discrete steps. The task card format should also have provision for appropriately authorized staff to sign off/stamp when each stage is completed.

3.2 In a similar way, non-scheduled maintenance tasks should be broken down into steps to provide a detailed record of maintenance which is to be carried out and certified on completion of each step or group of steps as they occur. Frequently this breakdown will, of necessity, be generated at the shop floor level. The AMO procedures should facilitate this by the provision of the necessary task cards (sometimes called stage sheets) and procedures for AMEs and supervisors to use. (See also Appendix C to Chapter 3 for guidance on the use of stage sheets for handover purposes.)

3.3 Task cards for scheduled maintenance are an everyday document for AMEs. They not only identify the job to be performed, but they normally break down the tasks into stages to allow for individuals to sign off or certify the various stages. The reasons for breaking down the job into discrete tasks is often wrongly seen as record keeping and to identify who did what part of a job so that if there is an incident, the employer or regulator can take action against the person. While it does confer accountability for the work, this could be achieved by other means. The primary purpose of a task card is to simplify and identify the task to be performed and to provide advice on the correct sequence how to do the task. It is a job aid to help the AME plan and complete the task efficiently and fully.

3.4 Task breakdown into stages is a good maintenance practice as it enables personnel to record work to be carried out and provides a record of the accomplishment of that work. Human Factors studies in maintenance repeatedly show that the use of properly prepared stage sheets when carrying out tasks considerably reduces the opportunity for maintenance errors occurring.

4. DEVELOPING NON-ROUTINE TASKS CARDS

4.1 The purpose of Table 3-D-1 is to guide the operator, AMO or AME on the need to develop new task cards. If a task contains any one of the attributes in the left-hand column, then an operator or maintenance organization should develop pre-printed task cards if the task stages are particularly numerous or lengthy. The right-hand column provides the reasons and goals that are to be achieved by the documentation.

4.2 If an AME is responsible for a task where there is no pre-prepared task card and the task contains attributes similar to those in the left-hand column of Table 3-D-1, the AME should initiate action to construct one. The AMO should have procedures and formats to enable the AME to do this, and the completed card or sheet must then form part of the records required for the work performed.

Table 3-D-1. Determining the need for stage breakdown on task cards

Task attributes	*Reasons and goals*
Task is complex	1. Structures the sequence for the various sub-tasks. 2. Identifies the significant stages in the process. 3. Provides cues and prompts. 4. Helps prevent errors of omission because: • The greater the amount of information in a procedural step, the more likely that items within the step will be omitted; and • Procedural steps that are not obviously cued by preceding actions or that do not follow in a direct linear sequence are more likely to be omitted.
Task involves multiple trade disciplines	1. Identifies which task requires specialist task disciplines. 2. Ensures that specialist tasks are performed in the correct sequence. 3. Provides evidence that the specialist task has been performed.
Task that could extend over shifts	1. Provides clear evidence of what tasks have been performed and what is outstanding. 2. Complements the task or shift handover process. 3. Helps prevent errors of omission because the larger the number of discrete steps in an action sequence, the greater the probability that one or more will be omitted.
Well-practised, routine tasks where the consequence of error is unacceptably high (safety or economic impact)	1. Well-practised or routine tasks are susceptible to “slips” and “lapses”. Errors of omission are most common in these circumstances. Examples are: • Distraction or interruption causing the person to “lose his place” upon resumption of the task; and • Premature exit. The last activity in a task is known to be the one most frequently omitted. Humans are particularly vulnerable to this kind of error when under time pressure. Examples are not torque tightening a pipe coupling, wire locking or calling up an engine run for leak checks. 2. Written sheets serve as “mind joggers” to avoid forgetting a step.
Task involves the recording of measurements or calculations	1. Measurements that are required to be recorded are more likely to be captured if pre-supplied paperwork is available with the facility to do so. 2. Provides a prompt that recording of data is required. 3. Recording the measurements and providing a place for doing the calculation augments the limited capacity of the working memory.
There is a need to identify or provide supplementary information	In order to do a task, it is frequently desirable and often necessary to have additional information. Examples are: • Company procedures affected by the job; • Company or customer standards; • Alternate processes; • Tooling required and acceptability of alternate tooling; and • Part numbers, SB or SL numbers.

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Appendix E to Chapter 3
ENVIRONMENTAL FACTORS

1. INTRODUCTION

1.1 A good deal of aviation maintenance is performed during night-time hours; however, humans are not particularly adept at performing precision work under low illumination levels. For the visual inspection tasks, which make up a large proportion of routine aircraft maintenance, it is vital that workers have an adequate level of the right type of lighting. Adequacy of illumination may well be the most important environmental issue affecting maintenance performance.

1.2 As maintenance can be carried out on maintenance benches, at test stands, on external surfaces of the aircraft, within the aircraft fuselage and beneath the aircraft/wings, the lighting conditions in each situation may vary dramatically. Direct measurements of lighting are necessary in most cases to determine exactly how much light there is and if it is adequate.

1.3 The FAA *Human Factors Guide for Aviation Maintenance*, Chapter 5, has a considerable amount of useful guidance information on facility design and for changes to that design. Some of this information is related to worker safety, but the remainder is concerned with the reduction of the probability of maintenance errors. This appendix is a summary of the guidance material in the FAA Guide that an AMO should normally follow.

2. LIGHTING

2.1 The potential problems associated with lighting in the maintenance workplace are discussed below.

Too little light where it is needed

2.2 In a number of night-time maintenance facilities examined in research carried out by C. G. Drury, an average of 51 foot-candles (ft-c) of light were available. However, it is recommended that a minimum of 75 ft-c be required for normal tasks. In addition, very difficult, critical inspection situations may require a minimum of 95 ft-c or special lighting (e.g. polarized or infrared).

2.3 Individual light requirements may double with age. Whereas 50 ft-c may be sufficient for a 25-year-old worker to perform a task, a 55-year-old may need 100 ft-c to perform the same task.

2.4 An FAA audit of major carriers found that for work conducted below the wings, inside the fuselage and in the cargo areas, illumination was poor. Lights were frequently placed too far from the work being performed and were too few in number. The result was that illumination levels in shielded regions ranged, on occasion, from only 1 to about 14 ft-c. As mentioned above, this is a lot lower than the minimum level of 75 ft-c that is recommended for repair tasks.

Glare

2.5 Glare is light that interferes with accomplishing a task. The glare may be direct (in the line of sight) or indirect (bouncing off the viewed object). The best way to deal with direct glare is to shield the light source from view or to move it out of the line of sight. Indirect glare may be reduced by shielding or filtering. It may also be possible to reduce glare by reducing the amount of light generated.

Colour

2.6 An FAA audit of major air carriers found a variety of lighting systems in use, including mercury vapour, metal halide, and high-pressure sodium lights. Although these lights differ in colour rendition, the principal problem was with the resulting level of illumination. For work performed on upper/lateral external surfaces of the aircraft, illumination levels were deemed adequate. These levels averaged 66 ft-c during the day and 51 ft-c for night maintenance work. However, poor illumination was found below the wings, etc.

3. HEATING, VENTILATION AND AIR CONDITIONING (HVAC)

3.1 Humans work best within a fairly narrow range of temperature, humidity and airflow. Conditions outside this range quickly degrade physical and mental capabilities and eventually become quite dangerous. This aspect of human performance has been studied extensively over the last few decades and, consequently, quite specific data exist regarding the amount and types of work that can be performed in various ambient environments. Especially in large open hangars, controlling temperature, humidity and airflow is very difficult. A combination of facility design, workspace design, clothing and procedures must keep workers within a safe range of ambient conditions.

Temperature

3.2 Many aviation maintenance tasks take place in large hangars, frequently with open doors. Since it is difficult to precisely control the temperature in such a facility, it is important to understand the safety and performance effects of various temperatures. The following table summarizes the general effects of ambient temperature on performance:

Temperature ^{o}C	^{o}F	*Performance Effect*
32.2	90	Upper limit for performance
26.7	80	Maximum acceptable upper limit
23.9	75	Optimum with minimal clothing
21.1	70	Optimum for typical clothing and tasks
18.3	65	Optimum for winter clothing
15.6	60	Hand and finger dexterity begins to deteriorate
12.8	55	Hand dexterity reduced by 50%

High temperatures

3.3 In order to reduce the amount of heat produced and transmitted to individuals, the following process modifications and barriers are suggested:

- Allow workers to lose heat through convection and evaporation;
- Do not force workers to wear unnecessary clothing or equipment and keep their physical exertion level low;
- Provide fans, air conditioning or personal cooling garments, as appropriate;
- Ensure that individuals are fit, suitable and acclimatized to the heat; and
- Supply emergency treatment and sufficient rest time in a cooler environment.

Low temperatures

3.4 Low temperatures can be as stressful and dangerous as high temperatures. The effects of cold can be more subtle and insidious than those of heat. Cold stress can usually be effectively handled by providing the following elements:

- windbreaks;
- local heat sources; and
- dry, windproof, layered clothing.

4. SOUND AND NOISE

4.1 Noise is unwanted sound. Noise is not only distracting and stressful, it can cause permanent hearing loss. In the design of aviation maintenance facilities, the goals are to make certain sounds easy to hear and to isolate and protect workers from noise.

4.2 In the aircraft maintenance environment, many sounds are desirable and, in fact, necessary for the proper conduct of work. These sounds include person-to-person voice communication, telephonic communication, public address (PA) messages and audio signals from test equipment or aircraft systems. This should be considered in the context of a normal working environment. Average noise levels within hangar areas, measured by an FAA audit team were found to range typically from 70 to 75 dBA. This is acceptable for an industrial environment and does not require hearing protection. The following is a summary of the general effects of noise on performance:

- noise is a fatiguing stimulus even at levels below 65 dBA;
- generally acceptable noise levels are 70 to 75 dBA; and
- occasional levels of 110 dBA are a concern.

When riveting or other pneumatic tools were being used, levels of about 90 dBA were recorded and levels in excess of 110 dBA can be produced. There is a direct correlation between the average noise level present at a job and the job's accident rate.

4.3 Excessive noise is a special concern at airlines where propeller-driven aircraft are the mainstay of the fleet. These aircraft operate at a high decibel level and can increase the possibility for hearing impairment when aircraft taxi and run-up operations are routinely conducted near the maintenance hangar.

5. AIR QUALITY

Air quality is traditionally more of an industrial hygiene issue than a Human Factors issue. However, air quality can directly affect certain human performance levels. It is possible for some airborne toxins to increase the risk of cumulative trauma disorders by impairing peripheral blood flow (to the hands, for instance). Increased carbon monoxide levels can reduce mental alertness, increasing the risk of an accident or error. It is necessary to keep oxygen levels around 20 per cent to ensure optimum performance. An efficient heating, ventilation and air conditioning system is critical for maintaining appropriate humidity, air content and air movement levels.

6. ACCESS

People need good footing to prevent them from slipping and falling, especially if they are carrying, pushing or pulling an object. There are serious implications for poor facilities and the danger they may impose. Too many visitors and/or telephone calls can be disruptive to workers and can lead to errors.

7. STRUCTURED INTERVIEW

Many of the environmental factors can be physically measured and recorded, for example, temperature and humidity. It is important to establish how the workers feel about the environment in which they work. One way to find out is to conduct interviews. Such interviews can be formal or informal, structured or unstructured. A suggested outline for a structured, formal interview is as follows:

- Introduction of the facilitator and participants;
- Establishment of the interview purpose and associated "ground rules";
- Description of the facility to be discussed; and
- Inclusion of the following agenda items:
  - — Temperature, humidity and airflow;
  - — Noise levels and the ability to communicate;
  - — Lighting;
  - — Stairs, ramps and ladders;
  - — Work platforms;
  - — Aisles, exits and general access;
  - — Incident record; and
  - — Summary.

8. CHECKLIST FOR A STRUCTURED WALKTHROUGH

A suggested outline for a structured walkthrough is presented below:

A. General observations

1. Is the area generally clean and free of trash, obstructions and debris?
2. Are aisles and walkways clearly marked and clear of obstructions?
3. Is the signage adequate to convey a sense of location?
4. Have workers modified any of the signs or made signs of their own?
5. Are storage areas being used as intended?
6. Is there an obvious, well-marked exit from the area?

7. Are there well-marked parking areas for forklifts and tugs, and is the equipment parked there?

B. Lighting

8. Does the lighting appear to be fairly even in the area, or are there bright and dark spots?

9. Is there any noticeable flicker from the lighting system?

10. Are all of the facility lights in working order?

11. Have workers modified the light fixtures?

12. Are there battery-powered emergency lights near exits, stairs and ramps?

13. Are AMEs bending over their work to obtain a closer view?

14. Is supplemental task lighting being used in the area? Why?

15. Is there any obvious glare from the facility lights? Where and what type?

16. Do colours appear to be natural, or do they look strange?

17. Are light controls clearly marked and easy to reach?

C. Ramps, stairs and ladders

18. Are there handrails on all ramps, stairs and fixed ladders?

19. Is the cross-section of all handrails circular? If not, what shape are they?

20. Are all stair and stair ladder treads covered with non-slip material?

21. Are all landings covered with non-slip material?

22. Do open stairs and ladders have safety screens behind them?

23. Do all portable ladders have non-skid feet?

D. Sound and noise

24. Can you understand what is being said on the PA system?

25. Have any PA speakers been modified by workers?

26. If hearing protection is required, are all people in the area wearing it?

27. Can you converse with someone four feet away without raising your voice?

28. Have any equipment enclosures been removed or left open?

29. Can you converse on the telephone and understand the person you are calling?

30. Can you converse on the radio and understand the person you are talking with?

31. Are workers using equipment that emits audio signals?

E. Heating, ventilation and air conditioning

32. Do you feel hot or cold?

33. Can you tell a difference in temperature between your head and your feet?

34. Is there any detectable air movement in the area? Is there too much?

35. Are supplemental fans or blowers being used in the area?

36. Are supplemental heaters being used in the area?

37. Is the area exposed directly to the outside?

38. Does it feel particularly humid in the area?

39. Can you detect any noxious smells or "chemical" odours in the area?

F. Miscellaneous

40. Have workers complained to you about a specific facility feature in the area?

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Appendix F to Chapter 3

THE ERGONOMIC AUDIT PROGRAM (ERNAP) FOR APPROVED MAINTENANCE ORGANIZATIONS

1. INTRODUCTION

An ergonomic audit programme should be an important element in the AMO's error reduction strategy. Chapter 2 of the FAA *Human Factors Guide for Aviation Maintenance* refers to ergonomic audits. In addition, the "ERgoNomic Audit Program" (ERNAP) is available on the FAA *Human Factors in Aviation Maintenance and Inspection* CD-ROM and the FAA Web site: www.hfskyway.com. The programme is designed for use on a personal computer but, alternatively, data collection may be done using paper-based checklists. A description of the checklists is reproduced in this appendix.

2. ERNAP DATA COLLECTION MODULE

2.1 Data collection is classified into three phases:

— Pre-maintenance;

— Maintenance; and

— Post-maintenance.

These three data collection phases are classified into four major Human Factors groups as shown in Table 3-F-1.

Table 3-F-1. ERNAP classification

Human Factors Groups	*Data Collection Phases*		
	Pre-Maintenance Phase	*Maintenance Phase*	*Post-Maintenance Phase*
Information Requirements	a) Documentation b) Communication	f) Documentation g) Communication	w) Buy-back
Environment	c) Visual characteristics	h) Task lighting i) Thermal characteristics j) Operator perception k) Auditory characteristics	
Equipment/Job Aids	d) Equipment design e) Access equipment	l) Equipment availability m) Access equipment	
Physical Activity/ Workspace		n) Hand tools o) Force exertion p) Manual material handling q) Vibration r) Repetitive motion s) Physical access t) Posture u) Safety v) Hazardous materials	

Checklists

2.2 There are 23 checklists that form part of ERNAP, one for each topic in Table 3-F-1. A brief description of each checklist is given below identified by a letter that corresponds to a topic in the table. By using separate modules and checklists, ERNAP allows the users to make partial, specific or complete and comprehensive audits.

Pre-maintenance phase

a) Documentation: Concerns itself with information readability and information content: text, graphics and information organization.

b) Communication: Examines between-shift communication and availability of lead mechanics/ supervisors for questions and concerns.

c) Visual characteristics: Looks at overall lighting characteristics of the hangar: overhead lighting, condition of overhead lighting, and glare from the daylight.

d) Equipment design issues: Evaluates the equipment that uses controls: ease of control, intuitiveness of controls, and labelling of controls for consistency and readability.

e) Access equipment: Evaluates ladders and scaffolds for safety, availability and reliability.

Maintenance phase

f) Documentation: Considers the physical handling of documents and the environmental conditions affecting their readability, i.e. weather and light.

g) Communication: Deals with communication issues between co-workers and supervisors, and whether or not suggestions by AMEs are taken into consideration.

h) Task lighting: Looks at the overall lighting available to the AME for completing the task. Evaluates points such as light levels, whether personal or portable lighting is used, and whether the lighting equipment is causing interference with the work task.

i) Thermal characteristics: Examines the current conditions of thermals in the environment in which the task is being performed.

j) Operator perception: Considers operator perceptions of the work environment during the current season and during the other three seasons.

k) Auditory characteristics: Determines if the sound levels in the current work environment will cause hearing loss or interfere with tasks or speech.

l) Electrical/pneumatic equipment: Examines availability of any electrical/pneumatic equipment, whether the equipment is working or not, and ease of using the equipment in the work environment.

m) Access equipment: Looks at availability of ladders and scaffolds, whether the equipment is working or not, and ease of using the equipment in the work environment.

n) Hand tools: Evaluates the use of hand tools, whether or not the hand tools are designed properly to prevent fatigue and injury, and usability by both left- and right-handed people.

o) Force exertion: Examines forces exerted by the AME while completing a maintenance task. Posture, hand positioning and time duration are all accounted for.

p) Manual material handling: Uses NIOSH 1991 equation to determine if the AME is handling loads over the recommended lifting weight.

q) Vibration: Checks amount of vibration an AME encounters for the duration of the task. Determines if there are possible detrimental effects to the AME because of the exposure.

r) Repetitive motion: Considers the number and frequency of limb angles deviating from neutral while performing the task. Takes into consideration arm, wrist, shoulder, neck and back positioning.

s) Access: Looks at physical access to the work environment; whether it is difficult or dangerous, or if there is conflict with other work being performed at the same time.

t) Posture: Evaluates different whole-body postures the AME must assume in order to perform the given task.

u) Safety: Examines the safety of the work environment and what the AME is doing to make it safer, e.g. the use of personal protective devices.

v) Hazardous materials: Lists the types of chemicals involved in the maintenance process, whether or not the chemicals are being used properly, if disposal guidelines are being followed, and if the company is following current requirements for hazardous material safety equipment.

Post-maintenance phase

w) Buy-back: Measures how useful the feedback of information is to the AME and whether or not this buy-back is from the same individual who assigned the work.

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Appendix G to Chapter 3

DOCUMENT DESIGN FOR AIRCRAFT MAINTENANCE

1. INTRODUCTION

Written communication is at the very heart of AME work. Therefore, ensuring that documents are both usable and are actually used are keys to a successful maintenance error reduction programme.

Note.— In this appendix "procedures" means all the documentation likely to be used in the control and/or recording of work on the aircraft or its components, e.g. company procedures, aircraft maintenance manuals, worksheets, and job or task cards.

2. CONTENTS

2.1 Investigation of maintenance-related incidents has shown that many procedures are poorly written or presented. While it is important that the manufacturers' data are incorporated accurately within the procedures, this information can be presented well or poorly, depending upon the skill of the procedure writer and the extent to which the procedure is revised based on experience and practice.

2.2 The following guidelines, based on the U.K. CAA document *Aviation Maintenance Human Factors* (CAP 716), are intended to assist operators and maintenance organizations in the production and amendment of procedures:

- Ensure procedure design and changes involve maintenance personnel who have a good working knowledge of the tasks;

- Validate all procedures and changes to those procedures before use, where practicable;

- Ensure procedures are accurate, appropriate and usable, and that they reflect best practice;

- Take into account the level of expertise and experience of the user; where appropriate, provide an abbreviated version of the procedure for use by experienced AMEs;

- Take into account the environment in which the procedures are to be used;

- Ensure that all key information is included without the procedure being unnecessarily complex;

- Where appropriate, explain the reason for the procedure;

- Ensure that the order of tasks and steps reflect best practice, with the procedure clearly stating where the order of steps is critical and where the order is optional;

- If the order of steps is not already dictated, consider ordering the steps according to logic or space (e.g. working around the aircraft sequentially, as with a pilot's checklist), as opposed to alphabetical or ATA chapter order;

- Group steps into "chunks" and plan for interruptions. Train staff to complete a "chunk" of steps before allowing themselves to be interrupted, and design the procedure in such a way that it can be marked when and where an interruption occurs;

- Ensure consistency in the design of procedures and use of terminology, abbreviations, references, etc.;

- Where possible, try to ensure that a complete procedure or chunk of information is on one page. Where a procedure runs to more than one page, make this clear;

- Include clear titles at the top of each page and section of the procedure. Where the procedure has been changed, highlight this change where appropriate (with a line or the letter "R" at the side of the page), and note the revision date at the bottom of the page;

- Avoid cross-referencing where possible. This may require steps to be repeated in several places (note: the drawback of this is that any changes have to be made in several places also);

- Logical flow should be clear, using a flow chart if necessary. If procedures include options and branches, care should be taken that the path through the procedure is clear, especially if the user is required to return to an earlier point in the procedure after having actioned a set of steps. This can be particularly important in troubleshooting;

- Group associated steps on the page; separate non-associated steps on the page. Use blank lines or spaces appropriately;

- Use emphasis (e.g. italics and bold) consistently. Avoid overuse of upper case for emphasis; lower case is easier to read. Avoid overuse of italics, reserving this for single words or short phrases only, or for notes. Boxing is useful to distinguish very important steps or chunks from less important steps or chunks;

- A diagram or photograph can be very useful and can communicate large amounts of information efficiently. However, care must be taken with their use, ensuring:

  — it is correct (a diagram of a similar piece of equipment which is not exactly the same can cause more confusion than help);

  — it photocopies well (if photocopying is likely to take place);

  — the fine detail can be read in the lighting conditions under which it will be used;

  — it is orientated and labelled appropriately; and

  — the diagram/photograph is clearly linked with a procedure/step;

- Insert warnings and notes into the procedure wherever necessary, without unduly detracting from clarity, to ensure safe and accurate performance;

- Consider the use of warnings, cautions or notes to highlight important points and steps where errors are likely (information from the internal error management scheme should identify error-prone procedures and steps);

- Distinguish between directive information, reference information, warnings, cautions, notes, procedures and methods;

- Use cautions and warnings directly above the text to which they refer or, where this is inappropriate, clearly link the text and the warning or note. Use notes after the related text;

- Cautions, warnings and notes must be on the same page as the text to which they refer;

- Where practical, build in check boxes into the procedure to enable and encourage the user to check off steps as they are completed;

- Clearly link the check box with the associated step, e.g. using dotted lines;

- Allow enough space if information needs to be entered;

- Stress the importance of clear handwriting if written information needs to be handed over to another person;

- Ensure that printing/copy quality is good, and that there are enough printers, copiers, etc.; and

- Provide training on the use of technology to access and print procedures and maintenance data.

3. INFORMATION READABILITY

The following guidelines on readability are based on the FAA/AAM *Human Factors in Aviation Maintenance and Inspection,* 1997 Phase VII Progress Report, Chapter 4, Appendix B, entitled "The Documentation Design Aid (DDA) Development" by C. G. Drury, A. Sarac and D. M. Driscoll. The PC version of the complete DDA is included on the FAA Human Factors CD-ROM (1998) and Web site: www.hfskyway.com.

Typographic layout

Page size

- Use a standard paper size. In Canada and the United States, use 8-1/2 x 11 inches. In the rest of the world, use A4.

Page layout

- Use a single column layout as this is easier for lower-level readers and does not affect more experienced readers.
- For 8-1/2 x 11 inch paper, use a left margin of 1.5 inches and allow at least 1.0 inch for all other margins. The ideal line length is 10 to 12 words, or about 6 to 7 inches.
- Label each page with a subject heading at the top.
- Number each page sequentially placing the numbers at the lower right corner, 0.5 inches above the bottom edge of the page and not extending into the right margin.
- There is no need to end every page at the same point, i.e. the baseline can vary from page to page.

Justification

- Use left justification, i.e. typing lines up at left edge only. Centre and right justification is distracting and can slow reading speed.

Paragraphs and indentation

- Use modified block style with two space indentation for subdivisions.
- Label each heading and sub-heading sequentially, i.e. 1., 1.1, 1.1.1, etc.
- Within a heading, keep paragraphs below half a page in length, to help the reader's concentration.
- Leave one blank line between paragraphs.
- Do not indent the start of each paragraph.

Spacing

- Use 1:2 space ratio between sentence spacing and paragraph spacing.
- Use one blank line to separate all paragraphs and headings.
- Use one space after commas, colons and semicolons.
- Use two spaces after periods, question marks and exclamation marks.

Typeface (font)

- Use the typefaces (fonts) which have a relatively large height, are moderately expanded, solid rather than delicate looking, and have fairly uniform type colour, for example, Times Roman, Century Series, New Gothic, or Helvetica. Times Roman is the most common font style and the least fatiguing to proofreaders due to its easy readability.
- Keep the font consistent throughout the document and between documents.

Type size (font size)

- Use sizes between 9 and 12 points for ease of reading. The best size for most uses is 11 or 12 points.

Emphasis

- Keep a consistent use of emphasis throughout the document and between documents.
- To emphasize a single word, use bold (most preferred), underlining, italics or all capitals (least preferred).
- To emphasize a lengthy passage, use bold or underlining. Avoid CAPITALS or italics as they slow reading and reduce comprehension.
- Use only one or two emphasis techniques within a document to increase comprehension. Bold and underlining are good choices.

- Do not overuse emphasis techniques as it causes confusion and reduces comprehension.

Responses

- If you are using a check box following the related instruction, do not use a large gap between the check box and the instruction.
- Avoid the use of a sign box with “Not Required” or “XXXXX” if the user of the document is not responsible for the instruction accomplishment.
- Use a consistent check box design throughout the document if it is possible.
- Give enough space if you are expecting any answer from the user.

Colour

- Avoid regular use of colour in illustrations. Use distinctive shading patterns within black line images instead of colour.
- Coloured paper does not photocopy well.
- Black ink on white paper is recommended.

Pagination

- Avoid use of any reference back to previous text.
- Avoid references to other sections of the document as far as possible. Unavoidable cross references must be precise and unmistakable.
- The page should act as a naturally occurring information module, i.e. it should contain an appropriate number of tasks and avoid carryover of task across pages.
- Each task that begins on a page should also end on that page.
- Minimize the routing; in other words, do not route the user from page to page since it can cause serious defects.

Letters, numbers and words

Letters and numbers

- Use lower case letters instead of upper case in the text since lower case letters are much easier to read because they have more distinguishable shapes (ascenders and descenders). Note that upper case letters occupy more space (40 to 45 per cent more than lower case letters) and reduce the reading speed by 13 to 20 per cent.
- Use mixed-case headings and sub-headings instead of all capitals to improve readability.
- Avoid hyphens which merely indicate word division at the end of a line.
- In series of words or statements which present mutually exclusive choices, making the “or” explicit throughout the series enhances comprehension.
- Avoid using Roman numerals since they are not easy to read and can cause confusion.
- Use Arabic numbers followed by a period for each item in your list if you should use numbers. If not, you can use a bullet or dash to get the attention of the user.
- Do not enclose the number in parentheses.
- Use a conventional (ATA style) dash-number breakdown such as chapter-section-subject-page (e.g. 26-09-01-02).

Words

- Avoid using different terms for the same object.
- Use precise, unambiguous and common words, with which the user of the document is familiar, throughout the document for consistency. (AECMA Simplified English is a suitable guide.)
- Do not use many prepositions; they cause the user to read slowly.

Abbreviations

- Use only known acronyms and proper nouns.
- Avoid abbreviations. If you have to use abbreviations, then:
  - — Use them consistently; and
  - — Use the first few letters to remind the reader of the word.
- Provide a glossary if the users need one.

Writing well

General considerations on writing

- Try to achieve a balance between brevity, elaboration and redundancy of information.
- Complement verbal material by appropriate pictorial representation.
- Adapt the format of instruction to the characteristics of the respective task.
- Write clear, simple, precise and self-explanatory instructions.
- Minimize the writing requirement for the users of the documents.
- Summarize the main ideas of lengthy prose passages in a section before the text since it aids in learning the context.
- Use adequate information in the instruction steps.
- Text should be written in a consistent and standardized syntax.
- Text should be as brief and concise as practicable.
- Use a logical structure of sentences and paragraphs since they are easier to understand and remember. Logically place:
  - — General before specific provisions;
  - — Important before lesser provisions;
  - — Frequent provisions first; and
  - — Permanent before temporary provisions.

Sentences

- Use simplified language (e.g. AECMA Simplified English) as much as possible.
- Use short sentences instead of long ones since short sentences are easier to read and understand.
- Use definite and affirmative sentences in the active tense instead of using negative forms and passive tenses since the active voice increases comprehension.
- Use sentences with personal pronouns since they increase comprehension and the reader's motivation.
- Sentences with many subordinate clauses are difficult to comprehend.
- Use action verbs because they are easier to read and understand.
- Do not use sentences with a long noun string, since they are hard to understand.
- Use sentences complete with the necessary "who" and "which" words to clarify the relative clauses. This should avoid ambiguity and ease reading.
- Use third person for definitions as follows:

  "The torsion link assembly transmits torsional loads from the axle to the shock strut."

- Use second person imperative only for operational procedures as follows:

  "Check the oil level."

- Ideas expressed in positive terms are easier to understand.
- State directly what you want to say without excess or unnecessary words since the sentences with unnecessary words are harder to understand and take longer to read.

Lists and tables

- Data and information presented in the tables facilitate understanding and comparison.
- In lists and tables, do not leave blanks within a line greater than half an inch or five spaces.
- Group the lines in lists and tables according to content.
- Do not group more than five lines together.
- Separate the groups in the list and table by spacing.
- Write the list of items in parallel construction since that way is easier to read and remember.
- List a series of items, conditions, etc. rather than displaying them in a series separated by commas.
- Avoid using compound questions and statements.
- Minimize the logically related question as much as possible.
- Construct the questions in a way which requires minimum memory use from the user of the document.

Graphic information

- Place the visual item in the text of a document near the discussion to which it relates. If it is not possible, place the visual item in an appendix, label the item and refer to it.
- Use a clear title with a figure or a table number on the line directly below all illustrations.
- Use the same title for illustrations as corresponding text subject title.
- Use either a horizontal-landscape format with the top of the illustration at the binding edge or vertical layout to present graphic information for ease of reading and cross-reference consistently.
- Adequate text must be supplied to support illustrations, not vice versa.
- Draw illustrations in a size and line weight such that they can be used without any rework for the production of material for screen projection in a training environment.
- Illustrations should have limited information in order to avoid a cluttered appearance. The presentation should be self-explanatory.
- Use illustrations as the primary source of information transfer.
- Present all spatial information in graphical format instead of in textual format.
- Label each table and figure with an Arabic numeral, such as Table 1 and Figure 1.
- Use simple line drawings, which are superior in most cases.
- Use a consistent format for figure layout and numbering.
- Use illustrations whenever they will simplify, shorten or make the text easier to understand.
- Do not use complicated reference numbers for figures, e.g. T07-40423-001.
- Avoid use of perspective part drawings as figures.
- The figure views should be as the user sees it.
- Use standard and correct technical drawing terminology, e.g. avoid use of terms “section” and “view” interchangeably.
- Reference all tables and figures in the text by the numbers.
- Use bar charts to make accurate comparison of numerical data whenever possible.
- Line charts (or graphs) help to understand trends and allow accurate comparison between two or more numerical values.

Printing and copying quality

- Check the toner box regularly to have consistent copy quality.

- Make sure that no major image degradation occurs with reproductions of originals.

- Use paper which has a reflectance of at least 70 per cent.

- Use low visual acuity and large type size if user is going to use the document under low illumination levels.

- Readers prefer matt paper to medium or glossy paper.

- High opacity paper is preferable.

- Use black ink on white paper since it is more effective than white ink on black paper.

- Develop and implement standards for changing printer ribbons, toner boxes, etc. to ensure a consistent print quality at all times.

4. ORGANIZATIONAL ISSUES

- Allow the prospective users of work cards to participate in the design of the document.

- Check every individual instruction by testing it in the field situation.

- If your document is going to include multiple copies, colour can be a useful processing aid.

- Have a feedback system so that users are aware of how to correct an erroneous entry.

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Appendix H to Chapter 3

POSSIBLE FATIGUE MANAGEMENT INTERVENTIONS

1. INTRODUCTION

1.1 Interventions to minimize the effects of fatigue can be taken by both the individuals themselves and AMO management.

1.2 Individuals, such as the certifying staff in a maintenance organization, have an obvious responsibility for their own fitness for work. That fitness can be impaired by various factors such as illness, prescribed drugs, non-prescribed drugs (legal or non-legal), eyesight, fatigue and sleep. Some States have passed legislation to regulate these aspects.

1.3 Management and those in supervisory roles in a maintenance organization also have responsibilities for their staff and the environment in which they work.

2. STEPS TO MINIMIZE EFFECTS OF FATIGUE

The United Kingdom Civil Aviation Authority document *Aviation Maintenance Human Factors* (CAP 716) suggests the following steps in order to minimize the effects of fatigue on personnel when working shifts:

- Avoid excessive working hours;
- Allow as much regular night sleep as possible;
- Minimize sleep loss;
- Give the opportunity for extended rest when night sleep has been disrupted;
- Take into account reduced physical and mental capacity at night;
- Take into account individual circumstances;
- Provide organizational support services;
- Give opportunity for recovery;
- Rotate shifts towards the biological day, i.e. rotate to later rather than earlier shifts;
- Minimize night shifts through creative scheduling;
- Provide longer continuous rest periods when the week includes more than two night shifts;
- Allocate more critical tasks during day shifts when staff are likely to be more alert;
- Make appropriate (additional) checks on work performed by a night shift; and
- Break down lengthy repetitive tasks into smaller tasks, with breaks in between.

3. RECOMMENDATIONS FOR "GOOD PRACTICE"

3.1 The report on "Work Hours of Aircraft Maintenance Personnel" by Professor Simon Folkard (2002) includes recommended guidelines for "good practice" in the scheduling of working hours and the scheduling aspects of a risk management programme. The guidelines are based primarily on a review of literature on the impact of work schedules on health and safety. In addition, they take into account the results of a large-scale survey of licensed British AMEs who worked both inside and outside of the United Kingdom. The objectives of the recommendations are to minimize build-up of fatigue over periods of work, to maximize dissipation of fatigue over rest periods and to minimize sleep problems and circadian disruption. The recommendations are summarized in the following paragraphs.

Daily working hour limits

3.2 There is good evidence that risk increases over the course of a shift in an approximately exponential manner such that shifts longer than about 8 hours are associated with a substantially increased risk. It was therefore recommended that:

Recommendation No. 1: No scheduled shift should exceed 12 hours.

Recommendation No. 2: No shift should be extended beyond a total of 13 hours by overtime.

Recommendation No. 3: A minimum rest period of 11 hours should be allowed between the end of a shift and the beginning of the next, and this should not be compromised by overtime.

Breaks

3.3 There is evidence that fatigue builds up over a period of work and that this can be, at least partially, reduced by the provision of breaks. It would thus seem prudent to recommend limits on the duration of work without a break and on the minimum length of breaks. It should be recognized that work demands may prevent the taking of frequent short breaks. In the light of this and the findings on the provision of breaks from the survey, two limits were thus recommended, namely:

Recommendation No. 4: A maximum of 4 hours work before a break.

Recommendation No. 5: A minimum break period of 10 minutes plus 5 minutes for each hour worked since the start of the work period or the last break.

Weekly working hour limits

3.4 Fatigue accumulates over successive work periods and it is thus necessary to limit not only the daily work hours, but also the amount of work that can be undertaken over longer periods of time. The aim here is to ensure that any accumulation of residual fatigue is kept within acceptable limits and can be dissipated over a period of rest days. In the light of this and of the findings from the survey, the following recommendations were made:

Recommendation No. 6: Scheduled work hours should not exceed 48 hours in any period of 7 successive days.

Recommendation No. 7: Total work, including overtime, should not exceed 60 hours or 7 successive work days before a period of rest days.

Recommendation No. 8: A period of rest days should include a minimum of 2 successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off). This limit should not be compromised by overtime.

Annual limits

3.5 Some residual fatigue may accumulate over weeks and months despite the provision of rest days, therefore, annual leave is important. There is, however, little evidence to indicate what might be considered an ideal number of days of annual leave. It was therefore recommended that:

Recommendation No. 9: Wherever possible, the aim should be for a total of 28 days of annual leave. This should not be reduced to less than 21 days of annual leave by overtime.

Night shift limits

3.6 There is good objective evidence that risk is increased at night relative to the morning/day shift. There is also good evidence indicating that risk increases in an approximately linear fashion over at least four successive night shifts, such that it is higher on the fourth night shift than on the first night shift. However, given the increased risk on 12-hour shifts relative to 8-hour shifts, it would seem prudent to take account of shift duration in recommendations for limiting successive night work. It is also the case that a single night's sleep following a span of night shifts may not fully dissipate the fatigue that may accumulate over a span of night shifts. There is also published evidence that later finish times to the night shift can result in shorter day sleeps between successive night shifts. In the light of these considerations and the findings of the survey, the following recommendations were made:

Recommendation No. 10: A span of successive night shifts involving 12 or more hours of work should be limited to 6 for shifts of up to 8 hours long, 4 for shifts of over 8 hours to 10 hours long and 2 for shifts of over 10 hours. These limits should not be exceeded by overtime.

Recommendation No. 11: A span of night shifts should be immediately followed by a minimum of

2 successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off) and this should be increased to 3 successive rest days (i.e. 83 hours off) if the preceding span of night shifts exceeds 3 (or 36 hours of work). These limits should not be compromised by overtime.

Recommendation No. 12: The finish time of the night shift should not be later than 0800 hours.

Limits on morning/day shifts

3.7 There is good objective evidence that an early start to the morning/day shift can result in a substantial truncation of sleep. The extent of this truncation depends on the time at which the individual has to leave home, which in turn is largely determined by the start time of the shift. It is also the case that a balance needs to be achieved between later starts to the morning/day shift and earlier finishes to the night shift with a view to maximizing the sleep duration between both types of shifts. In the light of this and the findings from the survey, the following recommendations were made:

Recommendation No. 13: A morning or day shift should not be scheduled to start before 0600 hours and, wherever possible, should be delayed to start between 0700 and 0800 hours.

Recommendation No. 14: A span of successive morning or day shifts that start before 0700 hours should be limited to 4, immediately following which there should be a minimum of 2 successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off). This limit should not be compromised by overtime.

Notice of schedule

3.8 There is no objective evidence that the number of days' notice given of a schedule affects risk or fatigue, but it was perceived by respondents to the survey as influencing risk. It was therefore recommended that:

Recommendation No. 15: Whenever possible, aircraft maintenance engineers should be given at least 28 days' notice of their work schedule.

Additional recommendations

3.9 The Folkard report then makes the following further recommendations for "good practice" which should form a major part of a comprehensive risk management programme:

Recommendation No. 16: Employers of aircraft maintenance personnel should consider developing risk management systems for the control of fatigue.

Recommendation No. 17: Educational programmes should be developed to increase the awareness of aircraft maintenance personnel to the problems associated with shift work. In particular, it is important to draw their attention to the objective trends in risk with a view to increasing their vigilance at points when risk may be high despite the fact that fatigue may not be. It is also important to provide information on how to plan for night shift work and to give guidance on the health risks which seem to be associated with shift work, particularly at night.

Recommendation No. 18: Aircraft maintenance personnel should be required to report for duty adequately rested.

Recommendation No. 19: Aircraft maintenance personnel should be discouraged or prevented from working for other commercial organizations on their rest days and, hence, from exceeding the proposed recommendations on work schedules despite their implementation by their main employer.

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Appendix I to Chapter 3

MAINTENANCE PROGRAMME APPLICATION — PLANNING

1. Planning is vital to the successful application of a maintenance programme not only from a Human Factors viewpoint but also to ensure operational and economic efficiency. The primary aim should be to ensure that there are adequate appropriately qualified and alert personnel, tools, equipment, material, maintenance data and facilities at the right place and at the right time for the scheduled (and, as far as is possible, the unscheduled) tasks.

2. The purpose of this appendix is to highlight some (but not necessarily all) of the Human Factors issues which should be taken into account in the planning process, such as human performance limitations when working shifts and long hours. The U.K. CAA document entitled *Aviation Maintenance Human Factors* (CAP 716) has been used as a reference.

3. Depending on the amount and complexity of work generally performed by the maintenance organization, the planning system may range from a very simple procedure to a complex organization including a dedicated planning department in support of the production function. Planning has two aspects: first, logistics planning for availability of parts and materials and, second, production planning which has the following two complementary elements:

- scheduling the maintenance work ahead to ensure that it will not adversely interfere with other maintenance work as regards the availability of all necessary personnel, tools, equipment, material, maintenance data and facilities; and
- organizing the maintenance teams and shifts during maintenance work and providing all necessary support to ensure the completion of maintenance without undue time pressure.

4. The planning system and procedures should consider, as a minimum, the following:

- logistics and inventory control;
- coordination with internal and external suppliers, etc.;
- square meters of workshop and/or hangar accommodation;
- hangar and/or workshop availability;
- estimation of man-hours;
- availability of man-hours;
- preparation of work; and
- scheduling of safety-critical tasks during periods when staff are likely to be most alert, and avoiding periods when alertness is likely to be very low, such as early mornings on night shifts.

5. It is considered best practice for the maintenance organization to have a maintenance man-hour plan showing that there are sufficient staff to plan, perform, supervise, inspect and quality monitor the organization. In addition, the organization must have a procedure to reassess work intended to be carried out when actual staff availability is less than the planned number for any particular work shift or period.

6. It is important that planners have Human Factors training in order to better appreciate how good or bad planning can potentially affect human performance and, ultimately, safety and airworthiness.

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Appendix J to Chapter 3

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Chapter 4

REPORTING, ANALYSIS AND DECISION MAKING

4.1 INTRODUCTION

4.1.1 The ADAMS project report examined organizational learning to improve safety and reliability and reported the following:

> "Organisations are frequently condemned to making the same mistake again and again. More seriously, it is often the case that several serious incidents have to occur before effective preventive measures are taken. How can an organisation learn to reduce the risk of similar incidents happening again?"

In response to its own hypothetical question, the report continues as follows:

> "There are a number of preconditions which have to be established if effective learning is to be achieved:
>
> - a common goal of maximising learning from problems, errors and failures
> - accountability for putting the lessons into practice
> - using safety information to greatest effect
> - closing the loop from audit or investigation to implementation and review of recommendations."

4.1.2 In summary, the ADAMS report recommends the collection, analysis and use of event data. Although it is important that reports cover events having serious consequences, such occurrences are relatively infrequent. Therefore, for reports to be more effective, they should also include those events which have minor consequences and which occur more often.

4.2 OBJECTIVES

The objectives for a reporting system need to be clearly defined. The following are suggested as guidelines for AMOs and operators that have an error management system:

- To openly investigate maintenance errors in order that the contributing factors and root causes can be identified and to make the organizational system resistant to similar errors;
- To provide an environment in which maintenance errors may be openly investigated without fear of punitive action (see 4.3.7 of this chapter);
- To ensure that the reporting system or systems complement, not supplant, any existing State accident or incident reporting system which is intended for compliance with Annex 13 — *Aircraft Accident and Incident Investigation*; and
- To use the following definition of a maintenance error in the context of the reporting system: An occurrence when the maintenance system, including the human element, of an AMO or an operator fails to perform in the manner expected in order to achieve its safety objectives. The investigation using this definition demands consideration of the system failings (in the AMO and/or operator) as well as the error committed by the person.

4.3 ERROR REPORTING

4.3.1 Annex 13 requires all States to have legislation requiring accident and incident reporting. In addition, Annex 6 calls for legislation to require operators to report service difficulties to the State of Registry. Furthermore, there are some unavoidable events having operational significance (e.g. technical delays, cancellations and in-flight engine shutdowns) that are not legally required to be reported externally; however, the AMO or operator concerned frequently investigates these events, although most often only to assign responsibility for them. At an even lower level, there are events without operational significance that only rarely are reported or investigated, for example, the omission of an oil filler cap which, by chance, is noticed and corrected before flight. In order to gain a better understanding of the problems and factors that contribute to errors, these less significant events should be investigated by either the AMO or operator before a similar occurrence contributes to an accident or incident.

4.3.2 Clearly, it is important to examine not only what happened to cause these lower level events, but also why they happened in order to determine the root causes. In his book *Managing the Risks of Organizational Accidents,* Professor James Reason calls these low-level events “near-misses”. He defines a near-miss as “any event that could have had bad consequences, but did not”. He further explains that these events can range from a partial penetration of the defences, which can provide useful pro-active information about the resilience of the organizational systems, to those events which missed being catastrophic by a hair’s breadth, which can provide useful reactive information.

4.3.3 The ability of the AMO or operator to gather information on near-misses depends on the willingness of those involved to make a formal report. However, even if they are willing to do so, they may be unable to give a detailed, useful account of the contributing factors due to lack of knowledge of upstream processes or lack of appreciation of the significance of local workplace factors. For example, they may be accustomed to working with substandard equipment and hence not see this as a factor. Similarly, if the task subject to a report was regularly not supervised when it should have been, the lack of supervision at the time of the event may not be seen as the problem.

4.3.4 While the reporting difficulties outlined in the previous paragraph are real, so are the advantages. Professor Reason calls reports on near-misses “free lessons” and lists a number of their advantages, which are summarized below:

- Proper analysis and action taken can improve the system’s defences and help to prevent some more serious events in the future;
- Reporting shows how apparently small defensive failures can line up and thereby create more serious events;
- Lesser events occur more frequently and hence can yield the numbers required for more penetrating statistical analyses; and
- Wide promulgation of events and the statistics can be a reminder to all levels of the organization of the hazards which confront the system.

4.3.5 Persuading people to report or confess events involving their own errors is not an easy task. There is a natural desire for the people involved to forget that the incident ever happened. Their first concern is likely to be the possibility of bringing trouble upon themselves or their colleagues. In addition, they may not see the value of the report and, perhaps, may doubt if any management corrective action will result. Despite these disincentives, several highly successful programmes exist. Professor Reason identifies the key factors for the success of these programmes as follows:

- Indemnity against disciplinary proceedings — as far as possible;
- Confidentiality or de-identification;
- Separation of the collecting body from the body with the authority to impose disciplinary procedures or sanctions;
- Rapid, useful, accessible and intelligible feedback to the reporting community; and
- Ease of making the report.

He goes on to say that the first three items are, of course, designed to foster a feeling of trust. He also states that the rationale for any reporting system is that valid feedback on the local and organizational factors which can promote errors is far more important than assigning blame to individuals.

4.3.6 It is important for the State aviation regulatory body to encourage the development of a safety culture within the AMO and operator organization. This safety culture should encourage trust and open lines of communication between management and the workforce. A fundamental concept that can help to achieve this culture is an immunity-based internal reporting and investigation system for maintenance errors. Such a system should be non-punitive and should investigate events and disseminate information only for the purposes of continued flight safety. An example of an internal reporting system developed by industry is the Boeing Maintenance Error Decision Aid (MEDA). This reporting system is briefly described in Appendix A to this chapter. One State has formally encouraged AMOs to adopt the concept which it calls a "Maintenance Error Management System" (MEMS) while another State has developed guidance material for establishing what it calls an "Aviation Safety Action Program" (ASAP). Information on the programmes of these two States is reproduced in Appendix B to this chapter.

4.3.7 Confidential, independent, non-punitive human error reporting systems have been established over the past two decades by some States for both flight and ground crew. Experience with these systems has generally been favourable, but they are a supplement, not a substitute, for good reporting systems managed by the AMO, operator and the State aviation regulatory body. However, these confidential systems can provide much valuable information for use in training and awareness programmes, as well as the early identification and correction of risks. Examples of two immunity statements issued by States are shown in Appendix C to this chapter.

4.3.8 In some cases a maintenance error may cause an occurrence, incident or accident which falls within the category of being legally reportable. If the subsequent investigation reveals a breach or violation of regulations, then the State aviation regulatory body should have a policy in relation to prosecution or sanctions against those persons or bodies having committed the breach. In some States, for example, there is a statutory obligation to prosecute violators. In other States that have discretion over prosecution of violators, a range of sanctions is available which can be graded to suit the circumstances of the particular case. In some States, the tradition is for the aviation regulatory body to encourage AMO and operator compliance by influence or attempts to influence. This influence can include a graded set of sanctions, which can be threatened and/or imposed, such as the suspension or restriction of licences or certificates. In order to ensure that the reporting responsibilities of organizations and individuals are not inhibited by the possibility of punitive action, some States have promulgated their policies in respect of immunity and confidentiality. An example of one such statement issued by a State is shown in Appendix D to this chapter.

4.3.9 AMO managers sometimes believe that the State aviation regulatory body expects them to take a clear disciplinary position with their staff who commit violations. However, in many cases this belief is implicit and may not be well founded. The ADAMS project report suggests that disciplinary systems can be more effective in influencing the general climate of acceptable behaviour than in changing the individual. To achieve this influence, an AMO or operator disciplinary system needs to be seen as follows:

- To be independent, transparent and fair;
- To be routinely and universally enforced; and
- To have proper process and proportionality in the sanctions, taking into account mitigating circumstances.

The ultimate sanction for any employer is to dismiss someone who is perceived to be an "unsuitable" employee. However, this action raises the question as to why the person was appointed to that particular position, which questions earlier AMO/operator management decisions to employ the person in the first place or to continue to employ the person.

4.3.10 The State aviation regulatory body should, therefore, not expect punitive action to be taken against individual employees where the investigation reveals that the error was an unpremeditated or inadvertent lapse. However, the organization may well consider such action justified if, for example, the persons concerned:

— Intended to cause deliberate harm or damage;

— Knowingly violated procedures that were readily available, workable, intelligible and correct;

— Have been involved previously in similar lapses;

— Have attempted to hide their lapse or their role in the event; and/or

— Acted with substantial disregard for aircraft safety.

4.3.11 The focus of any investigation must be on why the error occurred. This is the common feature of all the various Human Factors "tools". The characteristics of some of the currently available systems for investigation and analysis were tabulated as part of an industry assessment of the FAA AAM research reports included on the FAA *Human Factors in Aviation Maintenance and Inspection* CD-ROM. The table is reproduced in Appendix E to this chapter.

4.4 INVESTIGATION, ANALYSIS AND STANDARDS

4.4.1 Establishment of the reporting environment is only the first step towards a system which meets the objectives defined in 4.2 of this chapter. To be effective, all parts of the system must be directed towards a goal of maximizing learning to improve quality and reliability in order to reduce the risk of maintenance errors.

4.4.2 The investigation of maintenance errors by AMOs and operators must look for the contributing factors that they can manage within their organization. Measures that involve telling people to "be more careful" have only limited effectiveness. Human error can only be reduced to a point, not eliminated altogether. Professor Reason states that "the difficulty has been to discriminate between the truly bad behaviors and the vast majority of unsafe acts to which the attribution of blame is neither appropriate nor useful. Nevertheless there is an interface between discipline and Human Factors and this interface must be well understood by all concerned if the event investigations are to be effective."

4.4.3 The primary goal of any maintenance error investigation by an AMO or operator is to extract from the incident the lessons that can be learned to help prevent similar incidents in the future. Investigations that merely satisfy a regulatory requirement or apportion blame are inappropriate and will not lead to learning by the organization.

4.4.4 There are normally five phases that an AMO or operator follow in the conduct of an investigation of what appears to be a maintenance error incident:

1. What happened? — establishing basic information about the incident and its consequences;

2. What happened? — constructing the event sequence;

3. Why did it happen? — identifying the errors and failures;

4. Why did it happen? — identifying the contributory factors; and

5. How can it be prevented in the future? — making recommendations.

4.4.5 The five phases in 4.4.4 describe a logical progression through the investigation process by first establishing the facts of the incident and the sequence of events before attempting explanations and making recommendations. The basis of the "what happened?" phase of the investigation should be the task documentation and interviews with the personnel concerned and the witnesses. The "why did it happen?" phase should first comprise the error(s) and/or failure(s) and then the contributory factors. The "how can it be prevented in the future?" phase should focus on the recommendations. The final report should consist of various sections with narrative and associated factual data.

4.4.6 Incident investigators in AMOs and operators should have an aviation technical background with knowledge of the aircraft, engine or equipment involved in the incident. This background should enable them to analyse the technical aspects of the event, analyse and classify the technical causes and recommend actions to prevent a recurrence. However, when it comes to investigating human or organizational failures, they will need other skills such as an inquiring mind and good interpersonal skills as well as a suitable guide to conduct this aspect of the investigation and analysis. There are a number of suitable guides available from various industry or regulatory sources. As an example, the ADAMS project report guide is reproduced in Appendix F to this chapter.

4.5 CLOSING THE LOOP — MANAGING ERROR

4.5.1 Organizational learning from incidents is perhaps the most difficult task of error management. There are numerous case studies that can help, and an examination of these reveals the following characteristics:

- Several attempts and time may be necessary to achieve an adequate solution for change;

- Validating the change is a critical step in the change process and should involve those who actually perform the task; and

- Monitoring and reviewing the effectiveness of the changes on a continuous basis is essential.

4.5.2 Completion of the investigation report, with its associated recommendations for change, is only the starting point of a management process in the organization to reduce the probability of another similar occurrence in the future. If these changes are to be effective they must:

- Be implemented;
- Be directed towards eliminating the factors identified as the cause; and
- Be free from adverse side effects, which create additional or compensatory problems.

4.5.3 Investigating, reporting and implementing appropriate changes may not be sufficient to prevent similar incidents. There may be some more general or fundamental weakness in the systems of the organization. For this reason it is important to collect data from a number of incidents in order to identify any possible pattern of events. The data must be collated in such a way as to display any possible trend, pattern or relationship between different types of incident or event. These displays should then be used as part of a proactive error management system to identify areas which are vulnerable to error.

4.5.4 Plans for the future should include having organizational learning for safety on an industry-wide basis in order to help organizations to learn from the mistakes of others and to avoid making the same ones themselves. Ideally, an international database (such as the Global Aviation Information Network (GAIN)) should have sufficient detailed incident information to assist preventative interventions in AMOs and operator organizations worldwide.

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Appendix A to Chapter 4

ERROR REDUCTION, ELIMINATION AND PREVENTION

1. INTRODUCTION

The Boeing Maintenance Error Decision Aid (MEDA) is one of several useful Human Factors "tools" for AMOs and operators to use in the investigation of errors. The major objective of MEDA is to provide a standardized process for analysing maintenance errors and the contributing factors to those errors, and developing possible corrective actions. MEDA identifies the following four broad error prevention strategies:

- error reduction/elimination;
- error capture;
- error tolerance; and
- audit programmes.

2. ERROR REDUCTION/ELIMINATION

2.1 The most often used and most readily available error prevention strategies are those that directly reduce or eliminate the contributing factors to the error. Examples include increasing lighting to improve inspection reliability and using Simplified English to reduce the potential for misinterpretation. These prevention strategies aim to improve task reliability by eliminating any adverse conditions that have increased the risk of maintenance error.

2.2 Often the individual error investigation does not yield contributing factors with strong linkages to the error under investigation. Sometimes the effect of certain contributing factors is not fully understood until a number of events are investigated with the same contributing factor(s) related to them. The difficulty for the front-line manager performing an investigation is the pressure to take action resulting from a single-event investigation. The dilemma, however, is how to decide on a prevention strategy when there are no clearly identifiable contributing factors leading to the error. What if the error had safety implications? Somehow, the error must be addressed. Two additional types of error management strategies are available to address error.

3. ERROR CAPTURE

3.1 Error capture refers to tasks that are performed specifically to catch an error made during a maintenance task. Examples include a post-task inspection, an operational or functional test, and a verification step added to the end of a long procedure. Error capture is different from error reduction in that it does not directly reduce the human error. For example, adding a leak check does little to reduce the probability of a mis-installed chip detector. It does, however, reduce the probability that an aircraft will be dispatched with a mis-installed chip detector. This is why most regulatory authorities require a subsequent inspection of any maintenance task that could endanger safe operation of the aircraft if performed improperly.

3.2 While error capture is an important part of error management, new views point to a general overconfidence in the error-capturing strategy to manage maintenance error. In theory, adding a post-task inspection will require two human errors to occur in order for a maintenance-induced discrepancy to make it on to a revenue flight. In recent years, however, there has been a growing view that the additional inspection to ensure the integrity of an installation will adversely impact the reliability of the basic task. That is, humans consciously or subconsciously relax when it is known that a subsequent task has been scheduled to capture any errors made during the primary task. It is not unusual to hear an airline manager say that the addition of an inspection did little to reduce the in-service experience of the error.

4. ERROR TOLERANCE

4.1 Error tolerance refers to the ability of a system to remain functional even after a maintenance error. The classic illustration of this is the 1983 Eastern Airlines L-1011 aircraft's loss of all three engines due to O-rings not installed on the chip detectors. As a strategy to prevent the loss of multiple engines, most regulatory authorities granting extended range operations by twin-engined aeroplanes (ETOPS) approval prohibit the application of the same maintenance task on both engines prior to the same flight. The theory is that even if a human error is made, it will be limited to only one engine. This was not the case in the Eastern Airlines L-1011 aircraft shutdown of all three engines. One type of human error, the same incorrect application of a task applied to all three engines, nearly caused the aircraft to be lost.

4.2 Another example of building error tolerance into the maintenance operation is the scheduled maintenance programme for damage tolerant structures (allowing multiple opportunities for catching a fatigue crack before it reaches critical length).

4.3 Error tolerance, as a prevention strategy, is often limited to areas outside the control of the first-time investigator. However, it is important for the first-line supervisor or interviewer to be aware of this type of prevention strategy and to consider it when it may be the best way to effectively deal with the error.

5. AUDIT PROGRAMMES

Audit programmes refer to an approach that actually chooses not to directly address the error. In other words, by not directly trying to reduce/eliminate the error or increase the tolerance for the error, the organization chooses to do something else. What this can include is a high-level search of the organization to see if something can be done that will serve as a prevention strategy. Examples of these types of strategies are independent audit programmes and special investigation training. Airlines typically implement audit projects or programmes as a quick fix in response to errors. Yet, these programmes are rarely effective over the long term in reducing error because the short-term awareness that results from them wears off, and the organization is not able to achieve any long-term change.

6. THE MEDA PROCESS

The overall MEDA process is as follows:

- *Event:* an event occurs, such as a return to the gate or an air turn back.
- *Decision:* after correcting the problem and returning the aircraft to service, the operator decides if the problem was maintenance related — if yes, the operator performs a MEDA investigation.
- *Investigation:* the operator uses the MEDA results form to perform the investigation. This identifies the type of error that caused the event, the contributing factors to the error, and a list of possible corrective actions.
- *Corrective actions:* the operator reviews, prioritizes and then implements actions to avoid or reduce the likelihood of similar errors in the future.
- *Feedback:* the operator provides feedback to the maintenance workforce. This informs them that changes have been made to the maintenance system based on the MEDA process.

7. SUMMARY

Boeing states that the MEDA process is available to customer airlines to help improve the management of maintenance error events within their operations. In addition, it claims that operators using MEDA have made improvements to their maintenance systems that enhance economics and operational efficiency.

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Appendix B to Chapter 4

MAINTENANCE ERROR MANAGEMENT SYSTEMS

Extracts from two documents are reproduced below as examples of the current practice by State aviation regulatory bodies to encourage AMOs and operators to establish internal reporting systems which have a level of indemnity granted by the State or the regulatory body.

Example 1: Extract from U.K. CAA Airworthiness Notice No. 71, Issue 1, dated 20 March 2000, on Maintenance Error Management Systems (MEMS)

"Maintenance Error Management Systems

"1 INTRODUCTION

"1.1 Given the worldwide commitment to reducing the fatal accident rate, the CAA has, as one of its Human Factors initiatives, undertaken to reduce the number of maintenance errors and to mitigate the consequences of those which remain. CAA seeks to provide an environment in which such errors may be openly investigated in order that the contributing factors and root causes of maintenance errors can be addressed using a system that would complement, not supplant, the two current systems for reporting maintenance errors (MORS and CHIRP).

"1.2 The already well established Mandatory Occurrence Reporting (MOR) scheme exists in order that significant safety issues are brought to the notice of the CAA. However, the MORs scheme is not intended to collect and monitor the normal flow of day-to-day defects/incidents etc. which, in remaining an industry responsibility (CAP 382, para 5.4.5), forms an important part of the overall operational safety task. This Notice concerns, primarily, those events which fall below the MOR criteria but which, nevertheless, are important for an organisation to understand and control. However, the principles described in this Notice may also be applied by an organisation to their own internal investigation of incidents meeting the MOR criteria (Note: organisations will still be required to report MORs to the CAA).

"1.3 The Confidential Human Factors Incident Reporting Programme (CHIRP) scheme provides an alternate reporting mechanism for individuals who want to report safety concerns and incidents confidentially. However CHIRP should not be considered as an alternative to implementing a MEMS scheme. A MEMS and CHIRP perform different functions albeit acting towards the same ultimate aim, i.e. improved flight safety.

"1.4 Maintenance errors with serious consequences such as accidents or incidents are routinely investigated by organisations, CAA or Air Accident Investigation Branch. Operationally significant events (e.g. technical delays, cancellations, in-flight shutdowns etc.) which are not legally required to be reported externally are frequently investigated by organisations but too often only to apportion responsibility for the event. Below these levels are events without operational significance which may rarely be investigated (e.g. the omission of an oil filler cap which, by chance, is noticed and corrected before flight). In order to gain a better understanding of the problems and factors which contribute to errors it is necessary to investigate these and operationally significant events before they possibly contribute to or cause an incident or accident in the future.

"1.5 It is important to examine not just *what* happened, but *why* it happened, in order to determine the root causes and problems.

"2 MAINTENANCE ERROR MANAGEMENT SYSTEM

"2.1 With the issue of this Notice, the CAA is declaring its policy on Maintenance Error Management

Systems (henceforth referred to as MEMS) such that maintenance organisations, in particular those maintaining large commercial air transport aircraft, are encouraged to adopt the concept.

"2.2 Prevailing industry best practice has shown that a MEMS should contain the following elements:-

- Clearly identified aims and objectives
- Demonstrable corporate commitment with responsibilities for the MEMS clearly defined
- Corporate encouragement of uninhibited reporting and participation by individuals
- Disciplinary policies and boundaries identified and published
- An event investigation process
- The events that will trigger error investigations identified and published
- Investigators selected and trained
- MEMS education for staff, and training where necessary
- Appropriate action based on investigation findings
- Feedback of results to workforce
- Analysis of the collective data showing contributing factor trends and frequencies

"2.3 The aim of the scheme is to identify the factors contributing to incidents, and to make the system resistant to similar errors. Whilst not essential to the success of a MEMS, it is recommended that for large organisations a computerised database be used for storage and analysis of MEMS data. This would enable the full potential of such a system to be utilised in managing errors.

"2.4 For the purpose of this Airworthiness Notice a maintenance error is considered to have occurred when the maintenance system, including the human element, fails to perform in the manner expected in order to achieve its safety objectives. The human element includes technicians, engineers, planners, managers, store-keepers — in fact any person contributing to the maintenance process. The foregoing definition differs from that of a human error as it demands consideration of the system failings (e.g. inadequate staffing, organisational factors, tooling availability, ambiguous manuals etc.) as well as the error committed by a person.

"3 CAA ASSURANCES

"3.1 It is recognised that the success of a MEM programme is dependent on full and free investigation without fear of action by the CAA. Accordingly, the CAA gives the following assurances:-

"3.1.1 The CAA will not approve a MEMS even when included in the approved Exposition. Should a MEMS be included in an Exposition, it will not be subject to auditing as part of CAA regulatory oversight of that organisation. Any interest shown in an organisation's MEMS is purely one of a desire to work with industry to enhance safety.

"3.1.2 The CAA will not require any organisation or individual to make available to the Authority any specific reports that are submitted under a MEMS, other than information normally reported to the Authority via the MOR scheme.

"3.1.3 If an Organisation, in the interests of improving safety, voluntarily elects to share with the CAA the details of a specific occurrence reported under MEMS, or the results of its investigation, the CAA will:-

(a) not disclose the name of the person submitting the MEMS report, nor of a person to whom it relates, nor pass on a MEMS report to a third party, unless required to do so by law or unless the person(s) concerned authorises such disclosure.

(b) take all reasonable steps possible to avoid disclosing the identity of the reporter or of those individuals involved in the occurrence, should any follow-up action arising from a MEMS report be taken.

(c) not, as its policy, institute proceedings in respect of unpremeditated or inadvertent breaches of the law or requirements which come to its attention only because they have been reported under the MEMS scheme, except in cases involving dereliction of duty amounting to gross negligence or recklessness. Such an assurance is similar to that provided under the MOR scheme.

"4 MEMS CODE OF PRACTICE

"4.1 The CAA encourages organisations to adopt the following code of practice regarding a MEMS:-

"4.1.1 Where an occurrence reported via MEMS indicates an unpremeditated or inadvertent lapse by an employee, as described below, the CAA would expect the employer to act reasonably, agreeing that free and full reporting is the primary aim in order to establish *why* the event happened by studying the contributory factors that led to the incident, and that every effort should be made to avoid action that may inhibit reporting.

"4.1.2 In the context of error management it is considered that an unpremeditated or inadvertent lapse should not incur any punitive action, but a breach of professionalism may do so. As a guideline, individuals should not attract punitive action unless:

(a) the act was intended to cause deliberate harm or damage.

(b) the person concerned does not have a constructive attitude towards complying with safe operating procedures.

(c) the person concerned knowingly violated procedures that were readily available, workable, intelligible and correct.

(d) the person concerned has been involved previously in similar lapses.

(e) the person concerned has attempted to hide their lapse or part in a mishap.

(f) the act was the result of a substantial disregard for safety.

'Substantial disregard', for this purpose, means:-

- In the case of a certification authorisation holder (e.g. licensed engineer or Certifying Staff) the act or failure to act was a substantial deviation from the degree of care, judgement and responsibility reasonably expected of such a person.

- In the case of a person holding no maintenance certification responsibility, the act or failure to act was a substantial deviation from the degree of care and diligence expected of a reasonable person in those circumstances.

The degree of culpability would vary depending on any mitigating circumstances that are identified as a result of the MEMS investigation. It follows that any action taken by the organisation would also be on a sliding scale varying from corrective measures such as retraining through to dismissal of the individual.

"4.1.3 In the case of incidents investigated via a MEMS, irrespective of whether or not such incidents were brought to the knowledge of the CAA, the CAA expects an organisation to address the problems which contributed to these incidents. The organisation should, where possible, implement appropriate measures to prevent the problem from re-occurring, or alternatively monitor future occurrences, according to the degree of risk and likelihood of reoccurrence. A supporting database is useful in these circumstances in helping to assess the frequency of occurrence and any associated trends.

"4.1.4 The CAA would expect that identified safety issues would be acted upon. If the CAA becomes aware, by whatever means, that a significant safety problem existed and was not being addressed, it reserves the right to take appropriate action.

"**NOTE:** The statement by an organisation that an incident is undergoing, or has undergone, a MEMS investigation, without any additional information provided to explain why the incident occurred, would not normally be an adequate basis for an MOR closure.

"4.1.5 Organisations are encouraged to share their MEMS results with the CAA and with other maintenance organisations. It is hoped that by sharing such data the CAA and industry can jointly develop a better understanding of maintenance error causation and develop more focused human factors strategies. However, it is appreciated that some information in a MEMS may be considered sensitive to the organisation affected, and may need to be disidentified before being shared with other organisations. …"

Example 2: Extract from U.S. FAA Advisory Circular (AC) No. 120-66B, dated 15 November 2002, on the Aviation Safety Action Program (ASAP)

"AVIATION SAFETY ACTION PROGRAM (ASAP)

"1. PURPOSE

"This Advisory Circular (AC) provides guidance for establishing an air transportation Aviation Safety Action Program (ASAP). The objective of the ASAP is to encourage air carrier and repair station employees to voluntarily report safety information that may be critical to identifying potential precursors to accidents. The Federal Aviation Administration (FAA) has determined that identifying these precursors is essential to further reducing the already low accident rate. Under an ASAP, safety issues are resolved through corrective action rather than through punishment or discipline. The ASAP provides for the collection, analysis, and retention of the safety data that is obtained. ASAP safety data, much of which would otherwise be unobtainable, is used to develop corrective actions for identified safety concerns, and to educate the appropriate parties to prevent a reoccurrence of the same type of safety event. An ASAP is based on a safety partnership that will include the FAA and the certificate holder, and may include a third party, such as the employee's labor organization. To encourage an employee to voluntarily report safety issues, even though they may involve the employee's possible noncompliance with Title 14 of the Code of Federal Regulations (14 CFR), enforcement-related incentives have been designed into the program.

a) Information obtained from these programs will permit ASAP participants to identify actual or potential risks throughout their operations. Once identified, the parties to an ASAP can implement corrective actions in order to reduce the potential for reoccurrence of accidents, incidents, and other safety-related events. In order to gain the greatest possible positive benefit from ASAP, it may be necessary for certificate holders to develop programs with compatible data collection, analysis, storage, and retrieval systems. The information and data, which are collected and analyzed, can be used as a measure of aviation system safety.

b) An ASAP provides a vehicle whereby employees of participating air carriers and repair station certificate holders can identify and report safety issues to management and to the FAA for resolution, without fear that the FAA will use reports accepted under the program to take legal enforcement action against them, or that companies will use such information to take disciplinary action. These programs are designed to encourage participation from various employee groups, such as flight crewmembers, mechanics, flight attendants, and dispatchers.

c) The elements of ASAP are set forth in a Memorandum of Understanding (MOU) between the FAA, certificate holder management, and an appropriate third party, such as an employee's labor organization or their representatives. …"

Note.— Please refer to FAA AC No. 120-66B for the complete text on the ASAP together with a sample MOU and an ASAP MOU checklist.

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Appendix C to Chapter 4

IMMUNITY/CONFIDENTIALITY STATEMENTS

As examples of current practice by State aviation regulatory bodies where confidential Human Factors reporting systems have been established, two extracts of immunity/confidentiality statements are reproduced below.

Example 1: U.S. FAA Aviation Safety Reporting Program (ASRP)

The FAA Aviation Safety Reporting Program is described in FAA Advisory Circular (AC) No. 00-46D dated 26 February 1997 and utilizes the National Aeronautics and Space Administration (NASA) as a third party to receive reports. The AC includes the following section on "Enforcement" which describes how the immunity concept applies to pilots, controllers, flight attendants and maintenance personnel making incident reports:

"9. ENFORCEMENT POLICY.

"a. The Administrator of the FAA will perform his/her responsibility under Title 49, United States Code, Subtitle VII, and enforce the statute and the FAR in a manner that will reduce or eliminate the possibility of, or recurrence of, aircraft accidents. The FAA enforcement procedures are set forth in Part 13 of the FAR (14 CFR Part 13) and FAA enforcement handbooks.

"b. In determining the type and extent of the enforcement action to be taken in a particular case, the following factors are considered:

(1) nature of the violation;

(2) whether the violation was inadvertent or deliberate;

(3) the certificate holder's level of experience and responsibility;

(4) attitude of the violator;

(5) the hazard to safety of others which should have been foreseen;

(6) action taken by employer or other government authority;

(7) length of time which has elapsed since violation;

(8) the certificate holder's use of the certificate;

(9) the need for special deterrent action in a particular regulatory area, or segment of the aviation community; and

(10) presence of any factors involving national interest, such as the use of aircraft for criminal purposes.

"c. The filing of a report with NASA concerning an incident or occurrence involving a violation of 49 U.S.C. Subtitle VII, or the FAR is considered by FAA to be indicative of a constructive attitude. Such an attitude will tend to prevent future violations. Accordingly, although a finding of violation may be made, neither a civil penalty nor certificate suspension will be imposed if:

(1) the violation was inadvertent and not deliberate;

(2) the violation did not involve a criminal offense, or accident, or action under 49 U.S.C. Section 44709 which discloses a lack of qualification or competency, which is wholly excluded from this policy;

(3) the person has not been found in any prior FAA enforcement action to have committed a violation of 49 U.S.C. Subtitle VII, or any

regulation promulgated there for a period of 5 years prior to the date of occurrence; and

(4) the person proves that, within 10 days after the violation, he or she completed and delivered or mailed a written report of the incident or occurrence to NASA under ASRS. …"

Example 2: U.K. Confidential Human Factors Incident Reporting Programme (CHIRP)

In the United Kingdom, an independent charitable trust is responsible for the Confidential Human Factors Incident Reporting Programme. The following statement is published by the CAA in Aeronautical Information Circular No. 47/2001 dated 31 May 2001:

"CONFIDENTIAL HUMAN FACTORS INCIDENT REPORTING PROGRAMME

"1 The United Kingdom Confidential Human Factors Incident Reporting Programme (CHIRP) was introduced in 1982 to provide professional pilots with the opportunity to report their experiences on a strictly confidential basis, in a similar manner to that afforded by the Aviation Safety Reporting System in the United States. The Programme has been extended subsequently to include civilian air traffic controllers, maintenance engineers, approved maintenance organisations and approved design and production organisations. In 1999 the Programme was extended further to provide a similar service to the UK General Aviation communities. It is proposed to make the Programme available to cabin crew members w.e.f. [with effect from] 1 July 2001 on a trial basis.

"2 The principal aim of the Programme is to seek to identify Human Factors related causes of incidents that would not be reported through other systems, but which may, if analysed and compared with similar experiences, lead to changes in procedures or design or permit others to learn from the reporter's experience.

"3 Human Factors is a term covering all of the human elements of people in man-machine systems. It is not confined to the traditional design and utility of equipment and workplaces, but also covers aspects of manpower, organisation, management, communication, skills and training.

"4 Following an independent review of CHIRP in 1994, it was determined that the Programme should be augmented to reflect the increased focus on Human Factor related causes of aircraft accidents. Accordingly, in 1996 a full-time Director was appointed and the Programme was established as a company limited by guarantee and registered as a charity. The charity, 'The CHIRP Charitable Trust', receives a Grant of Funding from the CAA Safety Regulation Group, but is independently managed by a Board of Trustees. …

"This structure ensures the continued independence and confidentiality of the system.

"5 CHIRP supplements other reporting systems, including the CAA Mandatory Occurrence Reporting Scheme. The submission of a CHIRP report does not fulfil the statutory obligations under the Air Navigation Order for mandatory reporting. When a requirement to submit an MOR exists but the reporter wishes to use a confidential system, the confidential Mandatory Occurrence Reporting Scheme may be used, details of which are contained in CAP 382. However, if the MOR scheme or other reporting channels do not meet the specific need then a report to CHIRP should be considered.

"6 CHIRP reports are handled on a strictly confidential basis, but it is possible that an incident reported to CHIRP may also be reported independently to the CAA by a third party. The CAA gives an assurance that its primary concern is to secure free and uninhibited reporting through CHIRP and that it will not be its policy to institute proceedings in respect of unpremeditated or inadvertent breaches of the law that are the subject of a CHIRP report and which come to its attention from such a third party report, except in cases involving dereliction of duty amounting to gross negligence.

"7 All reports received will be acknowledged. All personal details are returned to the reporter as soon as all relevant details of the report have been confirmed. Reports are then collated, analysed and retained on a confidential database. Before any information is made available to third party agencies and other reporting safety schemes, reports are technically disidentified to ensure that the reporter's identity cannot be inferred. If an appropriate level of technical disidentification is not possible, report data is not released.

"8 Selected reports/extracts are published on a quarterly basis in a newsletter titled FEEDBACK and distributed to the principal user groups. A separate news-sheet titled GA FEEDBACK is also published and distributed quarterly to GA pilots.

"9 In the case where a report to CHIRP appears to identify a definite hazard, immediate action will be taken to resolve the issue without breaching the confidentiality of reporters.

"10 The continued success of the Programme depends entirely on the quality of the reports submitted. All aircrew, air traffic controllers and engineers are urged to support the Programme.

"11 Report forms are distributed with each issue of FEEDBACK. …"

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Appendix D to Chapter 4

INCIDENT REPORTING — SANCTIONS POLICY STATEMENT

As an example of current practice by State aviation regulatory bodies in cases where organizations and individuals are required to submit a report on a serious flight safety-related incident, this appendix reproduces a policy statement regarding confidentiality and sanctions below:

Example: U.K. CAA Civil Air Publication (CAP) 382 entitled "The Mandatory Occurrence Reporting Scheme"

"Statement by the Chairman of the CAA

"Confidentiality of Reports

"It is fundamental to the purpose of the Scheme that the substance of reports should be disseminated where necessary in the interest of flight safety. Without prejudice to the proper discharge of its responsibilities in this regard, the Authority will not disclose the name of the person submitting the report or of a person to whom it relates unless required to do so by law or unless, in either case, the person concerned authorises disclosure.

"Should any flight safety follow-up action arising from a report be necessary, the CAA will take all reasonable steps to avoid disclosing the identity of the reporter or of those individuals involved in the reportable occurrence.

"Assurance Regarding Prosecution

"The CAA gives an assurance that its primary concern is to secure free and uninhibited reporting and that it will not be its policy to institute proceedings in respect of unpremeditated or inadvertent breaches of the law which come to its attention only because they have been reported under the Scheme, except in cases involving dereliction of duty amounting to gross negligence.

"Action in Respect of Licences

"The CAA has a duty to vary, revoke or suspend a licence as appropriate if it ceases to be satisfied that the holder of the licence is competent, medically fit and a fit person to exercise the privileges of the licence. If an occurrence report suggests that the licence holder does not satisfy these requirements, it will take appropriate licensing action. For example, if the report indicates that the licence holder requires further training, it may suspend his licence until he has undergone such training. If a report should indicate that the licence holder may not be a fit person to exercise the privileges of his licence, the fact that he has reported the occurrence will be taken into account in determining his fitness and will weigh heavily in his favour. Although the CAA recognises that, in practice, licensing action may be regarded as having a punitive effect, there can be no question of action being taken by the CAA on a licence as a punitive measure. The purpose of licence action is solely to ensure safety and not to penalise the licence holder. In all such cases, when considering what action to take, the CAA will take into account all relevant information about the circumstances of the occurrence and about the licence holder which is available to it.

"Possible Action by Employers

"Where a reported occurrence indicated an unpremeditated or inadvertent lapse by an employee, the CAA would expect the employer to act responsibly and to share its view that free and full reporting is the primary aim, and that every effort should be made to avoid action that may inhibit reporting. The CAA will, accordingly, make it known to employers that, except to the extent that action is needed in order to ensure safety, and except in such flagrant circumstances as are described under the heading 'Prosecution' above, it expects them to refrain from disciplinary or punitive action which might inhibit their staff from duly reporting incidents of which they may have knowledge.

"Protection of the Interests of the Licence Holder

"It is recognised that where a licence holder is a member of an association or trade union he is at liberty to inform that association or union of any prosecution or action by the CAA in respect of his licence, and seek their assistance.

"At any hearing conducted by the CAA, in respect of a licence held by a member of an association or trade union, a representative of that body may accompany the licence holder and address the CAA on his behalf.

"Sir Roy McNulty
Chairman of the CAA
March 2003"

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Appendix E to Chapter 4

A REVIEW OF MAINTENANCE ERROR INVESTIGATION AND ANALYSIS SYSTEMS FOR POSSIBLE USE BY AN AMO, OPERATOR OR STATE

Table 4-E-1 looks at the characteristics of different error investigation and analysis systems for possible use by an AMO, operator or State. Two different kinds of systems are reviewed. First is whether the system relies upon self-reporting to the State aviation regulatory body and, second, whether it is intended for the AMO to investigate known events. For example, the Aviation Safety Reporting System (ASRS) is entirely a self-reporting system from an individual to the FAA. Conversely, the Maintenance Error Decision Aid (MEDA) is designed as a tool for use by the AMO to investigate internal events. The material is an extract from a table in the FAA *Human Factors Guide for Aviation Maintenance.*

Table 4-E-1. Review of maintenance error investigation and analysis systems

Name	*Characterization*	*Owner*	*Scope of Investigation*	*Investigative Approach*	*Structured Data Analysis*	*Structured Prevention Strategy Development*	*Structured Monitoring and Feedback*
Aviation Safety Reporting System (ASRS)	Event Reporting, Analysis and Immunity	NASA and FAA	Inadvertent FAR [Federal Aviation Regulation] Violations	Self-reporting	Graphical and Narrative Search	None	Event Trending
Maintenance Error Decision Aid (MEDA)	Error Investigation Methodology	Boeing	Maintenance Error-induced On-aircraft Discrepancies	Assigned Investigators	None	None	None
Tools for Error Analysis in Maintenance (TEAM)	Error Analysis	Galaxy Scientific Corporation	Maintenance Error-induced On-aircraft Discrepancies	Assigned Investigators	Graphical and Narrative Search	None	Event Trending
British Airways Safety Information System (BASIS)	Error Investigation, Analysis and Action Item Tracking	British Airways	Maintenance Error-induced On-aircraft Discrepancies	Assigned Investigators	Graphical and Narrative Search	None	Risk Trending
Managing Engineering Safety Health (MESH)	Event Precursor Identification and Analysis	University of Manchester	Not Event Driven — Regularly Scheduled Input Instead	Technicians and Managers Periodically Self-reporting	Graphical Analysis	None	Precursor Trending
Aurora Mishap Management System (AMMS)	Event Investigation, Analysis and Corrective Action	Aurora	Determined by Customer	Assigned Investigator	Single Event, Graphical, and Narrative Search	Prevention Strategy Builder	Event and Cost Trending
Voluntary Disclosure Program (AC-120-56)	Event Corrective Action/ Immunity	FAA	High Visibility FAR Violations	Organizational Self-reporting	Single Event Focus	None	None
Aviation Safety Action Program (ASAP) (AC 120-66B)	Partnership and Immunity	FAA	FAR Violations	Airman Self-reporting Followed By Group Investigation	Single Event Focus	None	None

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Appendix F to Chapter 4

INVESTIGATION OF THE HUMAN FACTORS ASPECTS OF A POSSIBLE MAINTENANCE ERROR INCIDENT

1. INTRODUCTION

This appendix provides general guidelines for the conduct of an investigation of what appears to be a maintenance error incident. It is assumed that the technical aspects of the first two phases of the investigation dealing with "what happened?" have already been completed. The following text is based on the ADAMS report, Appendices 13 and 14.

2. PHASES 3 AND 4: WHY DID IT HAPPEN?

2.1 Having established as systematically and thoroughly as possible what happened preceding an incident, the next task is to explain why it happened. This should be divided into a two-step process:

- Identifying and classifying the errors and failures; and
- Identifying the contributory factors.

Identifying and classifying the errors and failures

2.2 The best way to identify errors and failures is to examine each event in the event sequence and decide if it could have contributed to the incident either through a maintenance error, a failure to prevent an error, or a failure to capture the error before the incident. The value of having an event sequence is that it enables examination of multiple errors and failures within each incident.

2.3 Classifying errors and failures can help to clarify exactly how an event contributed to an incident. Categorizing error types also provides useful information for analysis of multiple incidents in a database. The ADAMS report contains a reporting form (described in more detail in the attachment to this appendix) that has been designed to aid the user in this task. In particular, Section 2 of the ADAMS form provides an error/failure classification scheme. The initial classification is called "General Erroneous Performance", for example, whether a task was omitted or performed on the wrong part. Following this is the "Specific Erroneous Performance" classification which details the type of maintenance action that was being performed, for example, wiring, installation and attachment, and the specific error, for example, wired incorrectly and incorrect parts installed.

2.4 The narrative in the report in this phase of the investigation should clearly identify which events in the sequence are considered to involve errors or failures. Often only one event will fall into this category. The text should indicate what type of error was involved. If several error events occurred, a table of these events and their corresponding error types could be useful.

Identifying the contributory factors

2.5 Identifying the type of error(s) that occurred does not explain the incident nor does it suggest how it could be prevented. There is often little that can be done directly about an error except to issue warnings or cautions of the following nature: "Please do not install incorrect parts." More useful action can result when the factors which contributed to the error are identified. The ADAMS reporting form provides a classification system spanning a range of external and internal contributory factors (in Sections 3 and 4 respectively of the form).

2.6 Five major types of external factors are included: task factors, task support, environmental factors, socio-organizational factors and personal factors. The investigator's task here is to determine what specific aspects of the physical, social or organizational environment or of the person's physical or mental state influenced the person to make an error. Internal factors include factors such as "attention failure" and "interpretation failure".

2.7 Sometimes these factors are obvious and easy to decide upon, such as if the wrong parts were used because they were stored incorrectly. Other factors call for some judgement on the part of the investigator. Fatigue and stress, for instance, are common experiences in the maintenance industry. The investigator has to make a judgement if the fatigue or stress actually influenced the individual to make the error. With regard to internal factors, the investigator has to rely to a large extent on the reports of the people involved to classify them.

2.8 The error classification principles, such as those in the ADAMS reporting form, tend to focus on errors by hands-on personnel and the local factors that contributed to the error. Many local contributory factors have their roots in management failures, but these failures are often missed because they are not included in the classification systems.

2.9 A thorough investigation should include an assessment of possible management failures. An investigator conducting such an assessment should address each of the local contributory factors with the following question: "Was the influence of this factor a result of a management failure?", using the "management error" outline to highlight possible links.

2.10 The narrative of this section of the report should describe the contributory factors separately for each action/event in the sequence. There should also be a summary list of contributory factors for the whole incident, with the contributory factors numbered for easy reference and organized in order of priority. The implications of some contributory factors are obvious and need no justification, such as when wrong part numbers were listed in the procedure. Other contributory factors may need some explanation, such as when the boring or mundane nature of a task is judged to be contributory to a lapse of attention.

2.11 Conceptually, it is important to keep the error classification distinct from the classification of contributory factors. However, in the text itself, it is often more helpful if they are described together. In this case, the distinction can be clarified by use of a table such as Table 4-F-1.

3. PHASE 5: HOW CAN IT BE PREVENTED? — MAKING RECOMMENDATIONS

3.1 The final part of the report should describe how such an event can be prevented in the future. Often excellent work in investigation and identification of contributory factors can be squandered when translated into vague and general recommendations with no designated responsible person, no timescale for implementation and no system for reporting back. To be effective, a recommendation should have the following characteristics:

- Be specific and actionable. This means that it should be possible to unequivocally determine whether the recommendation has been implemented or not. Thus, instead of recommending: "Engineering to look into procedures", it would be better to say: "Engineering to prepare a report on possible alternative inspection procedures which would reduce the likelihood of missing panels remaining undetected";

Table 4-F-1. A sample table of events, errors and contributory factors (CFs)

Events	*Errors*	*Contributory Factors (CFs)*
1. Refitting panels; one panel not refitted.	Part not installed.	Local CFs: a) Poor communication between shift teams. b) Time pressure due to not enough time being allocated to the task. Management failures: a) Time not allocated to shift handover briefings.
2. Pre-flight check; missing panel not noticed.	Inspection inadequate.	Local CFs: a) Visual access partially obstructed. b) Attention distracted — task interruption.

- Be assigned to a responsible person/department;

- Have an explicit system of accountability. Accountability requires that within a designated time frame, evidence of, or an output from, actioning the recommendation should be provided to a designated person. Each organization needs to consider who this designated person should be and the sanctions they should have at their disposal for failure to implement the recommendation; and

- Be linked, referenced or coded in order to indicate the incident report out of which it arose, the recommendation number and the person/department responsible for action.

3.2 An important issue for companies to resolve is how prescriptive to make recommendations. Should investigators identify problems for others to solve, or should they prescribe solutions for those problems? The answer clearly depends on the nature of the problem, and the relative competence and organizational position of the investigator and the responsible person/department, but it is also a policy decision for the company as to how much authority to give the department which conducts incident investigation. Aside from the policy issues, on a pragmatic level, recommendations should be pitched between the extremes of "letting people off the hook" and presuming to know other people's jobs better than they do.

3.3 Developing recommendations is the task of translating the identified contributory factors into preventative actions. Note that it is contributory factors, not errors, that are relevant. Errors do not translate directly into recommendations, and attempts to make them do so are dangerous since they bypass understanding why they occurred. Typically, such attempts result in crude and ineffective recommendations such as: "Issue a safety bulletin instructing engineers not to leave tools behind in the aircraft". Whereas an attempt to understand the contributory factors could lead to better procedures for tracking tools, new designs for toolboxes that make missing tools more obvious, etc.

3.4 "External factors" are generally the easiest contributory factors to make into recommendations — being external, there are more obvious and direct ways of changing them. For example, if the wrong bolts were used because they were not stored in the correct place (a "task support" problem), then parts storage and checking procedures may need to be revised.

3.5 "Internal factors" are much more "in the head" and often have less obvious implications for solutions. Generally, preventative actions will entail changing external factors to make the internal failures less likely. For example, "distraction of attention" during pre-flight checks could lead to a reorganization of the line mechanic's duties so that the checks are not interrupted by other duties.

3.6 Organizational failures and management errors are particularly difficult to translate into recommendations because investigators are often reluctant to appear as if they are telling their managers how to do their jobs. Also, investigators with long operational experience can come to see certain aspects of the operation as unchangeable and, therefore, may not even consider a recommendation in that area.

3.7 When appropriate recommendations are not obvious, instead of abandoning the attempt, it is often worthwhile conducting a creative problem-solving exercise. A major problem with being creative is that people tend to think of the disadvantages of ideas before they have even considered them. The following simple two-step process, which can be carried out individually or in a group, helps to circumvent this problem:

1. Brainstorming. Think of as many ways as possible to solve the problem without regard to economic, political or operational constraints; and

2. Consider how these creative solutions could be reconciled with these constraints.

4. COMPLETION

Having completed the report, with its analysis of the event sequence, the errors and contributory factors, and its recommendations, the investigator's role is over. The onus is on the managers responsible for the incident information system to ensure that the good work is not wasted and that the report is used to initiate a process of organizational learning and change, rather than used as a mere historical record in the filing cabinet.

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Attachment to Appendix F to Chapter 4

SUGGESTED AMO HUMAN FACTORS INVESTIGATION REPORTING FORM

(Based on the ADAMS Reporting Form)

1. The AMO should use a report form designed to aid the user in identifying all the factors that are relevant to the occurrence that has happened. The expected user will be an AME, a quality assessor or an accident investigator. Some knowledge of Human Factors is necessary in using the form, and, of course, knowledge of maintenance engineering is likely to be required to fully assess the problems. The following paragraphs suggest the kind and sequence of information that should be included.

2. The reporting form should address all those types of maintenance occurrences which have an operational consequence, for example, flight delays, incidents and accidents. Occurrences are generally promoted by a chain of events, which may involve different people, times and places. Events are considered as erroneous maintenance performance which contributed to the occurrence.

3. The form is used to collect data on the events which promoted the occurrence and on their contributory factors so that preventative methods may be taken to avoid similar occurrences in the future. The aim is not to place blame on one particular person or group of people.

4. The report format is structured according to six major sections, namely:

- Section 1: General Information;
- Section 2: Erroneous Performance;
- Section 3: External Factors Influencing Performance;
- Section 4: Internal Factors Influencing Performance;
- Section 5: Narrative Description; and
- Section 6: Conclusions and Recommendations.

Section 1: General Information

5. This section should only address descriptive and background information related to the occurrence and to the events which contributed to the occurrence itself.

Part A, Background Information

6. This area should be devoted to general information related to the operator and the aircraft involved in the occurrence. Reference numbers are assigned to the report to make identification easier in case there is a database. The analyst who fills in the report is identified as well, so that this person can be contacted in case of further analysis about the same occurrence.

Part B, Occurrence

7. This part should simply define when and where the incident happened and what the consequences were. The local setting and time sequence of the occurrence, the operational consequences and the nature of fault should be reported. The consequences should be described.

Part C, Event(s)

8. This area should consider the different errors and events which led to the occurrence. This area is particularly relevant in the maintenance domain because maintenance errors are often not identified at the time error is made. This part should look back to when the different events happened. It is likely that there was more than one person involved in the event and also that a series of events happened which caused the actual occurrence. All the people who could be considered to be involved in the different events should be listed here against their job description.

Section 2: Erroneous Performance

9. This section should focus on how the events manifested themselves and should address the erroneous actions which were involved in the events.

Part A, General Erroneous Performance

10. This part should capture the identification of the error, with no attempt to interpret its causes/contributory factors. The focus is on the "active error" of each event and not on the causes. Again, different errors may have contributed to the final occurrence, so more than one item may be identified as causing the problem.

Part B, Specific Erroneous Performance: Aircraft System and Parts

11. This area should also record the identification of the error, but it should go much deeper in the description of the error itself.

Part C, Specific Erroneous Performance: Documentation

12. This area refers to erroneous performance related to information and documentation. As before, this area should describe the actual event/error as it manifested itself, with no attempt to analyse why it happened.

Section 3: External Factors Influencing Performance

13. Section 3 should include the factors which contributed to the erroneous performance. In particular, it should focus on the external factors which influenced performance. Here, the person or people who were involved in the initial causes need to provide information so that this section may be completed. Other people who support operations may also need to be asked about their involvement in the occurrences leading up to the event.

Part A, Task Factors

14. This area should look at the completion of the tasks that led to the occurrence — how familiar the task was to the person and characteristics of the task. It should record the features of the task that adversely influenced the performance and contributed to the error. A task, for example, could be characterized as being very repetitive; in some circumstances, this monotonous aspect of the task could contribute to promote an error.

Part B, Task Support

15. This area should look specifically at the supporting tools for the tasks that adversely influenced the performance and contributed to the error. How the tools were used at the time of the operations which led to the occurrence should be considered. The categories should be as follows: "Tools and Equipment", "Documentation and Procedures", and "Technology and Parts". If a factor is relevant, even if it occurs in everyday practice, it should be included in the evaluation.

Part C, Environmental Factors

16. As for the previous two areas (Parts A and B), this area should also address the factors which adversely influenced the performance and contributed to the event, but it should focus on the factors related to the environment, such as "weather" and "floor/ramp surface", and should consider the human body position required for a task. Indication should be provided if the effects seemed to have affected performance of the task.

Part D, Socio-Organizational Factors

17. This area should address latent errors at the managerial (socio-organizational) level which led or contributed to the event. It should also help to identify broad possible corrective actions, for example, training (insufficient training contributed to event) and communication (poor communication practices, lack of communication tools, etc.).

Part E, Personal Factors

18. These items refer to contributory factors that are related to the person(s) involved in the event, for example, physical and mental state.

Section 4: Internal Factors Influencing Performance

19. This section concerns internal factors which influence performance. It should mainly refer to the

"psychological error mechanism", that is the human cognitive process in which the error took place. The factors should be considered under the following headings:

- Attention failure;
- Detection/perception failure;
- Memory failure;
- Interpretation failure;
- Judgement failure;
- Assumption;
- Execution failure; and
- Rule violation.

These may be difficult to assess, and it will involve thinking back to how the events of the occurrence happened. The different items may not all be relevant in any one specific case, but it may be necessary to read through each factor to ensure that a full understanding is gained of each factor listed. The factors refer to basic thought and how the normal processes of thought may have affected the task.

Section 5: Narrative Description

20. A narrative description is required in this section. The data reported in the form would be nearly meaningless without a narrative description which highlights the time sequence and logical relationship among the different events and factors involved in the occurrence. Any comments may be written in this section whether or not they have already been covered in the form. The greatest level of detail should be given here. This section gives an opportunity for investigators to explain the events and occurrences in their own words.

Section 6: Conclusions and Recommendations

21. From the investigation, the investigator should draw logical conclusions which identify both the cause and the reasons for the incident. The recommendations should identify the corrective actions needed to reduce the probability of an incident from a similar cause.

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Appendix G to Chapter 4

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Chapter 5

TRAINING

5.1 INTRODUCTION

5.1.1 The ADAMS project report includes the following statement on the need for Human Factors training:

> "Developing competence in 'human factors' implies that, at all levels of the organisation, the ability to manage people effectively becomes second nature. Every aspect of a human-centred management system requires human-factors competence to make it work. Human factors training should support achieving the goals of a self-regulatory system, through the planning, organisation and actual performance of operations and the cycle of monitoring feedback and improvement in those operations."

Training at all levels is therefore a key factor in the success of a programme in an organization to reduce the rate of human errors during aircraft maintenance activities. It is also required as a result of Amendment 23 to Annex 6, Part I, in 1998.

5.1.2 Some early training in Human Factors for aircraft maintenance used Crew Resource Management (CRM) training as a model. However, in its early days, CRM was not universally accepted by the flight crew target population as it was perceived to lack linkage to the real world of the flight deck. Hence, CRM has now developed such that it is more integrated with normal flight deck skills. This integration also enables CRM skills to be observed and assessed as part of line operations (both real and simulated). As a result, acceptance of CRM and its training by flight crews has been enhanced. There is a need to learn from this experience and to recognize that the target population is different. Hence, it may be that CRM is not automatically an appropriate model for AMEs and other maintenance personnel.

5.2 BACKGROUND AND RESPONSIBILITIES

Training needs and scope

5.2.1 The Human Factors training requirements in Annex 6 may present some problems for training institutions, operators and AMOs. In the case of technical training for maintenance personnel, there is a wide international consensus as to training requirements, methods, objectives and course content. However, a similar consensus as to the appropriate focus for Human Factors training in aviation maintenance is only starting to emerge.

5.2.2 There are different perspectives in this matter. A central problem for many States is the difference in international practices regarding the application to such training of physiology, ergonomics, and the social/behavioural sciences. Additional differences relate to the relative importance accorded to knowledge and skills training. Perspectives on training content and strategies can also be strongly influenced by different cultural and social practices.

5.2.3 Associated with these contrasting perspectives are different approaches to aviation safety problems. Some specialists favour a broad, industry-wide systems approach to analysis and remedial action, while others prefer to focus on specific problem areas. Some authorities believe that the most effective action takes place at the point of aircraft and procedure design and thus feel that any action at the level of individual operational personnel is misplaced. Others see line management within the aviation industry as providing an appropriate focus for implementation of change. Thus, airline operators and maintenance organizations vary considerably in the practical emphasis they allocate to operational aspects of Human Factors.

5.2.4 In many countries, further problems derive from a lack of suitable resources, including appropriately trained physiologists, psychologists, ergonomists, aircraft maintenance specialists, managers and legislators. Furthermore, some national authorities are proactive in the pursuit of their regulatory activities, while others are not.

5.2.5 This short review of possible sources of difficulty underlines the potential for confusion and misunderstanding at both the national and international levels. The resulting uncertainty and lack of definition have sustained inaction in this field over many years. However, given the need to respond to the Annex 6 requirement for maintenance personnel education in human performance, the industry must now move forward, while bearing these potential difficulties in mind.

5.2.6 Responsibility for the standards of a course, intended to meet Annex 6 requirements, rests with the maintenance organizations that perform maintenance on the aircraft. These organizations may choose to develop a suitable training course themselves or select it from an appropriate training institution which can meet the standards they require.

5.2.7 Responsibility for the standards of a training course, intended to meet Annex 1 requirements, normally rests with the State aviation regulatory body and training organizations that perform the training. Details of the syllabus, guidance and standards for training to meet Annex 1 standards are not included in this manual.

5.3 TRAINING NEEDS AND OBJECTIVES

5.3.1 The first step in determining the training needs and objectives is to define the target audience. There is a viewpoint which considers that all AMO personnel do not need the same knowledge or skills. This view would, for example, consider that only a limited knowledge of Human Factors would be required for senior management personnel and, hence, only background information would be provided to them. Supervisors and AMEs, on the other hand, would be considered as needing specialist knowledge. Experience to date suggests that similar baseline knowledge and competencies are required for all categories of maintenance organization personnel, in particular:

- Management personnel (senior, middle and supervisory);
- Accident/incident investigators;
- Personnel who certify aircraft and components for release to service;
- Instructors for Human Factors and some technical topics;
- Planning and maintenance programme engineers;
- AMEs and mechanics;
- Quality personnel (Quality Assurance and Quality Control);
- Stores department staff;
- Purchasing department staff;
- Ground equipment operators; and
- Contract staff in any of the above categories.

In addition, Human Factors trainers themselves will need a greater depth of knowledge, and specialist modules may be needed for other specific categories of personnel. Some training organizations have achieved very good results by training, as a group, a balanced mix of these categories of personnel.

5.3.2 In order to gain acceptance by trainees and to succeed, the Human Factors training for maintenance personnel needs to be based on sound, practical task-related principles. In particular, Human Factors training for maintenance personnel must:

- Be seen as valuable by the target population, from top management through to AMEs;
- Be able to demonstrate that it has made a real and measurable difference;
- Be responsive to feedback from recipients so as to improve the syllabus, instructors, and training techniques; and
- Reflect the differences in skill and background between the flight crew and AME populations (see Appendix A to this chapter).

5.3.3 The skill and background of the target audience should determine the philosophical direction of the training. This direction will influence the design of the training courseware and the priority accorded to Human Factors elements in the activities and performance assessment. In order to develop an appropriate training philosophy, the topics requiring attention are:

- The roles to be given to theoretical and practical, or experience-based, learning activities. This will prove to be a most important dichotomy in practice, so clarity is essential;

- The integration of knowledge-based training into briefing, debriefing and practical exercises;

- The role of training activities which promote experience-based learning, e.g. group exercises such as role playing; and

- The required skills, knowledge and attitudes.

5.3.4 When determining training objectives, techniques and training activities, it is often useful to divide the learning task into appropriate subcategories such as "memorizing", "understanding", "doing", and "attitudinal aspects" and to identify the post-training competency, or command of the subject matter, expected of the trainees within each category. These four categories or domains of trainee competence may be characterized as follows:

1. *Knowledge-based (memorizing):* This covers factual knowledge and may include memorizing appropriate procedural information. Suitable teaching and assessment techniques are currently used in the theoretical and procedural training of maintenance personnel. This category will sometimes overlap with other categories such as comprehension.

2. *Comprehension-based (understanding):* This covers the understanding of relevant general principles and theory. Comprehension is often essential in order to achieve competency. This category will sometimes overlap with other categories such as knowledge.

3. *Skill-based/technique-based (doing):* This covers the skills that are essential for maintenance personnel. Maintenance personnel are routinely expected to acquire and display certain skills and techniques, which must be exercised in a suitable fashion, in the appropriate context and at the correct time. In aviation, psychomotor and procedural skills have traditionally received the most attention; in the case of human performance training, some additional skills are necessary, such as the development of appropriate communication skills; and

4. *Attitude-based:* Attitudes play an important part in determining overall performance. Philosophical aspects relating to operational practices, desirable professional attributes and dispositions conducive to good professionalism can be considered under this heading. The process of corporate/professional induction and socialization can also be considered under this heading for those organizations involved in the *ab initio* training of aircraft maintenance personnel. Attitudes have been strongly emphasized by a number of Human Factors specialists, who have noted the role of appropriate attitudes in implementing and sustaining safe and effective maintenance practices.

5.3.5 Appendix B to this chapter identifies training needs and topic objectives categorized into knowledge, skills and attitudes to be used in the design of Human Factors training programmes for various categories of maintenance personnel. Additional specialized elements can then be added for particular categories of personnel, e.g. a module on document design for planning engineers who write task cards.

5.4 IMPLEMENTATION AND SYLLABUS DEVELOPMENT

Selection of the trainers

5.4.1 The selection and education of those who will deliver training programmes in human performance have been matters of concern in some States. The reason for this concern is perhaps because of the understandable idea that only a trained psychologist can deal with subjects related to human behaviour. In their daily activities, however, instructors deal with and teach, for example, subjects related to aerodynamics without being aeronautical engineers, to meteorology without being meteorologists, to power plants without being mechanics, and so on. There is no reason why this line of logic cannot be applied to the teaching of human performance.

5.4.2 Instructors of aviation maintenance engineer training are among the obvious individuals capable of teaching human performance to the various categories of personnel in an operator or AMO. If instructors are thoroughly familiar with the contents of the proposed programme, whether through formal training or self-education, they should be able to fulfil the training objectives.

Alternatively, specialists in Human Factors will be in a good position to teach human performance, but only if they are themselves able to relate their knowledge in a practical manner to aviation and the aircraft maintenance operational environment. Appendix B to this chapter includes reference material which instructors may find useful.

Development of the syllabus

5.4.3 Conventional techniques such as instructional systems design can be used for development of the syllabus using the objectives in Appendix B to this chapter.

5.5 TRAINING DELIVERY TECHNIQUES

Training materials, techniques and educational technologies

5.5.1 A division can be made between training hardware, training strategies/techniques and the actual training courseware. It is anticipated that the better Human Factors training courses will make creative and imaginative use of the available resources.

Training delivery strategies and techniques

5.5.2 Associated with the new training hardware is an increasing differentiation of training methods, many of which utilize modern instructional technology. Thus, for instance, the merits of interactive media and the effectiveness of video feedback in training are now widely recognized. At the other extreme, valuable learning experiences in Human Factors can arise from the use of suitable group exercises such as role playing where trainees work on real or fictitious incident data to identify the errors and possible solutions. Such activities depend on careful and time-consuming preparation, but they are inexpensive and can be highly effective.

Training courseware

5.5.3 The content of training courseware will clearly depend on training objectives, time, equipment and available resources. Courseware should be prepared so as to explicitly include Human Factors points for consideration during briefing and debriefing. While the essential focus of Annex 6 requirements is on the provision of Human Factors knowledge, the training of preference will best achieve this when practical operational skills are also addressed during instructional design and development. The choices made at the courseware design stage will help to define the relevant instructor/trainee learning activities.

5.5.4 It is recommended that approximately 15 to 30 hours is the time required to properly present Human Factors training similar to that developed from the syllabus objectives in Appendix B to this chapter.

5.6 ASSESSMENT

5.6.1 Assessment of trainees on a regular basis is very much a part of aviation industry practice and provides one means of both determining training effectiveness and demonstrating that individuals meet agreed standards. Decisions as to suitable and productive means of maintenance personnel assessment will be an important influence in the courseware design. While traditional methods of assessment have unquestioned value in measuring factual knowledge and various aspects of comprehension, an alternative form of performance appraisal is generally considered essential when judging the results of experience-based learning activities.

5.6.2 Training activities in groups are considered to be especially good training techniques because they concentrate on the skill development needs of trainees, while avoiding the negative learning connotations associated with the checking/testing environment. While there may be no international consensus as to the best means of addressing the difficult issue of human performance training evaluation (and trainee performance appraisal), it is clearly important that the general issues discussed above are fully understood by trainers and instructional designers. Such an understanding will help prevent premature moves to assessment and testing in circumstances where they could prove counterproductive to longer-term learning needs.

5.7 TRAINING THE REGULATOR

5.7.1 In addition to having suitable background experience and qualifications, the maintenance inspectors from the State aviation regulatory body should have Human Factors training to a level at least comparable to their counterparts in industry. This should ensure that they are properly equipped to audit and assess industry compliance with the State requirement that implements Annex 6.

5.7.2 The curriculum of training for the State maintenance inspectors should cover at least all the items proposed in the training objectives in Appendix A to this chapter. It is suggested that the knowledge should be at Level 2 or higher as shown in Appendix B to this chapter.

5.7.3 In some States, it may be decided that the aviation regulatory body should perform the training for industry. In this case, the training of those inspectors who actually deliver the training should be at Level 3.

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Appendix A to Chapter 5

SKILL AND BACKGROUND DIFFERENCES BETWEEN CRM AND MRM

Some of the differences that exist between Crew Resource Management (CRM) and Maintenance Resource Management (MRM) are listed in Table 5-A-1. Training styles and emphasis should reflect these differences (see also Chapter 5, 5.3.2).

Table 5-A-1. Skill and background differences between CRM and MRM

Topic	*CRM*	*MRM*
Human Error	Flight crew errors are often classified as active failures as the consequences are usually immediate.	AME errors are usually classified as latent failures, when public safety is considered.
Human Factors Training	CRM training emphasizes psychomotor aspects because of the immediate effects of mental workload, reaction time, etc.	MRM training emphasizes the system's perspective of maintenance operations. It stresses social and organizational factors.
Communication	Flight operations communications are mostly "face to face" within the cockpit and immediately interactive with ATC.	Maintenance operations communications are mostly "non-face to face" via technical manuals, work cards, Service Bulletins, advertisements, etc. Hence, the AME is deprived of the non-verbal cues that are present for flight crews.
Team Composition	Flight crews tend to be homogenous by nature. Crew members generally have similar education and experience to each other.	AMEs tend to be diverse in their education and prior experience both from each other and from flight crew. Team skills training is therefore more difficult.
Teamwork	Flight crew team size is small and all members are located in the same small working space. CRM emphasis is therefore on team skills within the crew (intra-team).	AMEs tend to work in large teams on disjointed tasks spread over a large hangar area. There is also multi-team activity where each team has its own responsibilities. MRM emphasis is therefore on team skills between teams (inter-team).
Situation Awareness	The flight environment changes quickly and sets the scene for active failures. CRM is therefore tailored to avoid those errors. LOFT simulations provide simulated cues to improve future situation awareness.	The maintenance environment can be hectic, although it changes slowly relative to flight operations. AMEs must have the situational awareness to extrapolate the consequences of errors over hours, days and weeks. The MRM awareness cues taught must therefore be specifically tailored to suit this environment.

Topic	*CRM*	*MRM*
Leadership	As with teamwork, the leadership skills in CRM often focus on intra-team behaviours (i.e. “how to lead the team”) as well as “followership” skills. Inter-team interaction is somewhat limited during flight.	In maintenance organizations, supervisors or team leaders are frequently intermediaries between many points of contact in different departments or sections. AME leaders must therefore be skilled not only in intra-team behaviours (for their own teams) but also in handling team “outsiders” (personnel from other shifts, departments or work groups, etc.). These “outsiders” also vary widely in experience, mannerisms, etc. The MRM programme must take these issues into account.

Note.— Reference FAA Maintenance Resource Management Handbook, *Chapter 1.*

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Appendix B to Chapter 5

HUMAN FACTORS TRAINING NEEDS AND OBJECTIVES

1. INTRODUCTION

1.1 This appendix provides information on the needs and objectives for training course designers in respect of the training of maintenance organization personnel. Maintenance organizations vary widely in both scope and size; therefore, they must decide on the detailed allocation of overall objectives to jobs and the level of skill or knowledge required as appropriate.

1.2 Some of the information in this appendix is adapted from the ADAMS *Human-Centred Management Guide for Aircraft Maintenance.*

2. TARGET POPULATION

2.1 The various categories of aircraft maintenance personnel within operators or AMOs who are required to have Human Factors training are listed in Chapter 5, 5.3.1. In addition, the maintenance inspectors in the State aviation regulatory body require Human Factors training to a level at least equal to their counterparts in industry (see Chapter 5, 5.7).

2.2 The training needs and objectives suggested in this appendix assume that trainees have training and experience in their specific job disciplines as follows:

- Managers and supervisors are experienced and have leadership and management training;
- Planners and engineers are very familiar with aircraft documentation and the working conditions and environments of personnel performing aircraft maintenance work;
- Instructors and trainers understand instructional techniques and have experience in the working environment where the subject is to be applied;
- Investigators and auditors have experience and training in identifying, recognizing and analysing problems or causal factors related to Human Factors;
- AMEs have technical training and experience on the aircraft or components that they maintain; and
- Inspectors from the State aviation regulatory body are experienced in their regulatory inspection tasks and understand the working conditions, the personnel and environment of the appropriate AMO, aircraft or component maintenance work.

3. TRAINING NEEDS

3.1 The primary objective of Human Factors training is to give all the above categories of personnel an understanding of how and why error is avoided when maintenance work is being performed. Each category is exposed to, or creates the potential for, the risk of making an error. Human Factors training should therefore be adapted to suit the particular categories so that they can identify and avoid the potential opportunities for errors. Detailed training objectives are shown in Table 5-B-1. Specific training needs for the various categories of the target population identified above are listed in the following paragraphs (3.2 to 3.8).

3.2 Managers and supervisors need knowledge on how working conditions influence the performance of personnel that plan and perform maintenance work on aircraft and their components. They need to be able to apply this knowledge and understand how their decisions and behaviour influence the attitudes of the personnel in the organization and their ability to perform their work with the minimum of potential risk of error. Aspects that are direct management responsibilities, e.g. capital investment, budgets and accounting, may seem distant from where the actual work is done but, in fact, have a significant impact on the size and competence of the workforce and its ability to perform safe and reliable work.

3.3 Supervisors need to be aware of the local factors that present the potential for error. They should know how working conditions and the availability of correct tools and equipment can affect the attitude of the maintenance personnel and their approach to their work. Supervisors should be able to recognize and identify trends which indicate Human Factors-related risks.

3.4 Planners and engineers have a key role in the avoidance of Human Factors-related error. They must be able to write instruction documents that are not only technically correct but easy to read, understand and are not ambiguous or open to interpretation. They need to understand how their decisions, instructions, documents and other directives can influence the performance and results of work done on the aircraft or its components in workshops, hangars and ramp areas. It is therefore important that they understand the practical aspects of the work of maintenance personnel.

3.5 Instructors and trainers should ideally have a thorough understanding of the fundamentals of Human Factors as well as knowledge and experience from working in the particular environment (for example, workshops, hangars and ramp areas). They must be able to explain the fundamentals of Human Factors theory and possess theoretical knowledge to a level where they can illustrate with examples as well as facilitate discussions.

3.6 Investigators and auditors need to be able to identify, recognize and analyse problems or causal factors related to Human Factors. The investigator must be able to identify contributory Human Factors when investigating incidents. An auditor must be able to recognize potential Human Factors-related risks and report on these risks before they cause an error-related incident and become a subject for the investigator.

3.7 AMEs are the last link in the safety chain, and their training objectives are to understand why and how they may inadvertently create an unsafe condition when performing maintenance tasks. It must be possible for them to detect situations where there is the potential for making direct mistakes themselves. They must also be able to detect a built-in error in working instructions or information, and identify faulty equipment. They must understand how the working environment and one's own personal situation affects job performance.

3.8 Inspectors from the State aviation regulatory body need a similar level of knowledge as managers and supervisors.

4. TRAINING OBJECTIVES AND LEVELS

Table 5-B-1 lists the training objectives for all categories of maintenance organization personnel. The levels of Human Factors skill, knowledge or attitude should be as follows (where Levels 2 and 3 assume that the objectives of earlier levels have been met):

Level 1: A familiarization with the principal elements of the subject. On completion of the training, a trainee should be able to meet the following objectives:

- Be familiar with the basic elements of the subject;
- Be able to give a simple description of the whole subject using everyday words and examples; and
- Be able to use typical Human Factors terms.

Level 2: A general knowledge of the theoretical and practical aspects of the subject. On completion of the training, a trainee should be able to meet the following objectives:

- Understand the theoretical fundamentals of the subject and be able to give a general description of the subject with typical examples;
- Read and understand literature describing the subject; and
- Be willing and able to apply Human Factors knowledge in a practical manner.

Level 3: A detailed knowledge of the theoretical and practical aspects of the subject. On completion of the training, a trainee should be able to meet the following objectives:

- Know and understand the theory of the subject and its interrelationships with other appropriate subjects;
- Be able to give detailed explanations of the subject using theoretical fundamentals and specific examples;
- Be willing and able to combine and apply subject knowledge in a logical, comprehensive and practical manner; and
- Be able to interpret results from various sources and apply corrective action as appropriate.

Table 5-B-1. Training syllabus objectives

Note.— The training syllabus objectives are listed under ten topic headings. Each topic is identified as follows:

— *(S) = Skill;*
— *(K) = Knowledge; and*
— *(A) = Attitude.*

1. General introduction to Human Factors:

- Achieve a basic understanding of the meaning of the term "Human Factors" (K).
- Recognize the contribution of Human Factors to aircraft accidents (K).
- Understand the goal of Human Factors training (K).
- Appreciate the need to understand and address Human Factors (A).
- Become reasonably familiar with some of the well-known incidents and studies of incident data where Human Factors have contributed. Understand why these incidents occurred (K).

2. Safety culture and organizational factors:

- Achieve a good understanding of the concept of "safety culture" (K).
- Understand the meaning of "organizational aspects of Human Factors" (K).
- Appreciate the importance of a good safety culture (A).
- Identify the elements of a good safety culture (K).

3. Human error:

- Appreciate that human error cannot be totally eliminated; it must be controlled (K).
- Understand the different types of errors and their implications, and avoiding and managing error (K).
- Recognize where the individual is most prone to error (K).
- Have an attitude likely to guard against error (A).
- Achieve a reasonable practical knowledge of the main error models and theories (K).
- Understand the main error types and how they differ from violations (K).
- Understand the different types and causes of violations (K).
- Avoid violating procedures and rules and strive towards eliminating situations which may provoke violations (A).
- Achieve a good understanding of well-known incidents in terms of errors leading towards the incidents (K).
- Appreciate that it is not errors themselves that are the problem but the consequences of the errors if undetected or uncorrected (A).
- Understand the different ways of reducing errors and mitigating their consequences (K).

- Have a basic understanding of the main Human Factors concepts and how these relate to risk assessment. Note: This has management applicability (K).

4. Human performance:

- Recognize the effect of physical limitations and environmental factors on human performance (K).
- Appreciate that humans are fallible (A).
- Achieve basic knowledge of when and where humans are vulnerable to error (K).
- Recognize where self or others suffer and ensure this does not jeopardize aviation safety (A).
- Understand how vision and visual limitations affect the trainee's job (K).
- Recognize the need to have adequate (corrected) vision for the task and circumstances (K).
- Be aware of the health and safety best practice regarding noise and hearing (K).
- Appreciate that hearing is not necessarily understanding (A).
- Obtain a basic familiarity with the key terms used to describe information processing (i.e. perception, attention and memory) (K).
- Achieve a basic understanding of the meaning of attention and perception (K).
- Understand the dimension of situational awareness (K).
- Develop ways of improving situational awareness (S).
- Achieve a basic understanding of the different types of memory (sensory, short-term, working, long-term) and how these may affect the person at work (K).
- Appreciate that memory is fallible and should not be relied upon (A).
- Appreciate that claustrophobia, fear of heights, etc. may affect the performance of some individuals (A).
- Understand what motivates and demotivates people in maintenance (K).
- Appreciate the need to avoid misdirected motivation (cutting corners) (A).
- Develop a willingness to admit when feeling unwell/unfit and take steps to ensure this does not affect the standard of work performed (A).
- Recognize the basic concepts and symptoms of stress (K).
- Develop different techniques and positive attitudes to cope with stress (S).
- Recognize the need to manage workload (K).
- Develop methods to manage workload (S).
- Understand how fatigue can affect performance especially with long hours or shift work (K).
- Develop ways of managing fatigue (S).
- Develop a personal integrity not to work on safety critical tasks when unduly fatigued (A).
- Appreciate that alcohol, drugs and medication can affect performance (A).

- Understand the effects of sustained physical work on overall performance, especially cognitive performance in maintenance (K).
- Be aware of examples of incidents where repetitive tasks and complacency were a factor (K).
- Develop ways of avoiding complacency (S).

5. Environment:

- Achieve a basic appreciation of how the physical and social environment can affect human performance (K).
- Appreciate the importance of sticking to the "rules" even if others do not (A).
- Appreciate the importance of personal integrity (A).
- Appreciate the importance of avoiding placing peer pressure on others (A).
- Develop assertive behaviour appropriate to the job (S).
- Achieve a basic understanding of the concepts of stress and stressors as related to the maintenance environment (K).
- Recognize the dangers of cutting corners (K).
- Recognize the dangers of applying inappropriate deadlines (K).
- Recognize the dangers of self-imposed supervisor and manager time pressures (K).
- Understand the basic contributors to workload (K).
- Develop planning and organizing skills (S).
- Understand the basic concept of circadian rhythms as this relates to shift work (K).
- Be familiar with best practice regarding working hours and shift patterns (K).
- Develop strategies to manage shift work (S).
- Be aware of the health and safety guidance concerning noise and fumes (K).
- Be aware of the effects of lighting on performance (K).
- Be aware of the effects of climate and temperature on performance (K).
- Be aware of the health and safety guidance concerning motion and vibration (K).
- Be aware of the implications of own actions on other parts of the maintenance system (K).
- Be aware of the health and safety guidance concerning hazards in the workplace (K).
- Understand how to take into consideration the available manpower when scheduling, planning or performing a task (K).
- Develop ways of managing distractions and interruptions (S).

6. Procedures, information, tools and practices:

- Appreciate the importance of having available the appropriate tools and procedures (A).
- Appreciate the importance of using the appropriate tools and following the procedures (A).
- Appreciate the importance of checking work before signing it off (A).

- Appreciate the importance of reporting irregularities in procedures or documentation (A).
- Understand the factors that affect visual inspections (K).
- Develop skills to improve visual inspections (S).
- Appreciate the importance of correct logging and recording of work (A).
- Be aware that norms exist and that it can be dangerous to follow them (A).
- Be aware of instances where the procedures, practices or norms have been wrong (K).
- Appreciate the importance of having a good standard of technical documentation in terms of accessibility and quality (A).
- Learn how to write good procedures reflecting best practice (S).
- Learn how to validate procedures (S).

7. Communication:

- Recognize the need for effective communication at all levels and in all mediums (K).
- Understand the basic principles of communication (K).
- Develop skills, and correct verbal and written communication appropriate to the job and the context within which it is to be performed (S).
- Have detailed knowledge of some incidents where poor handover has been a contributory factor (K).
- Appreciate the importance of good handover (A).
- Learn how to carry out a good handover (S).
- Appreciate the importance of information being kept up to date and being accessible by those who need to use it (A).
- Appreciate that cultural differences can affect communication (A).

8. Teamwork:

- Understand the general principles of teamwork (K).
- Accept the benefits of teamwork (A).
- Develop skills for effective teamwork (S).
- Believe that maintenance personnel, flight crew, cabin crew, operations personnel, planners, etc. should work together as effectively as possible (A).
- Encourage a team concept, but without devolving or degrading individual responsibility (A).
- Understand the role of managers, supervisors and leaders in teamwork (K).
- Develop team management skills for appropriate personnel (S).
- Develop decision-making skills based on good situational awareness and consultation where appropriate (S).

9. Professionalism and integrity:

- Understand what is expected from individuals in terms of professionalism, integrity and personal responsibility (K).
- Understand the person's responsibility to keep standards high and to put this into practice at all times (A).
- Accept the personal responsibility to keep up to date with necessary knowledge and information (A).
- Achieve a good understanding of what is error-provoking behaviour (K).
- Appreciate the importance of avoiding the type of behaviour which is likely to provoke errors (A).
- Appreciate the importance of being assertive (A).

10. The maintenance organization's own Human Factors programme:

- Achieve an in-depth understanding of the structure and aims of the company's own Human Factors programme, for example:
  - — The Maintenance Error System (K).
  - — Links to the Quality and Safety Management Systems (K).
  - — Disciplinary reporting and a just culture (K).
  - — Top-level management support (K).
  - — Human Factors training for all maintenance organization staff (K).
  - — Actions to address problems (K).
  - — Good safety culture (K).
- Appreciate the importance of reporting incidents, errors and problems (A).
- Understand what types of problems should be reported (K).
- Understand the mechanisms of reporting (K).
- Understand the organization's policy and the circumstances under which disciplinary action may be appropriate and when not appropriate (K).
- Appreciate that the person will not be unfairly penalized for reporting or assisting with disciplinary investigations (A).
- Understand the mechanisms of incident investigation (K).
- Understand the mechanisms of actions to address errors (K).
- Understand the mechanisms of feedback (K).

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Appendix C to Chapter 5

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Chapter 6

REGULATORY POLICY, PRINCIPLES AND SOLUTIONS

6.1 INTRODUCTION

6.1.1 For many years, Annex 6 has specified requirements for ensuring that flight crew operate aircraft in accordance with Human Factors principles, taking into account normal human performance. In 1998, Amendment 23 to Annex 6, Part I, included similar Human Factors requirements for the following aspects of aircraft maintenance activities:

- The design and application of the maintenance programme — 8.3.1; and

- The training of maintenance personnel in an AMO — 8.7.5.4.

6.1.2 State regulations should therefore be amended or adopted to include these Human Factors requirements for maintenance activities. This manual provides suitable guidance to States and their regulatory bodies in this respect.

6.2 REGULATORY POLICY AND OBJECTIVES

6.2.1 The primary objective of introducing State regulations relating to Human Factors is to reduce aircraft accidents and incidents due to errors during maintenance. There is also the obligation on the State, as a signatory to the Chicago Convention, to implement and enforce regulations in conformity with Annex 6.

6.2.2 The State aviation regulatory body should develop a policy for the issue of regulatory material intended to ensure that appropriate maintenance Human Factors interventions are introduced by all its operators and associated aircraft maintenance organizations.

6.2.3 The first, and perhaps most important, policy consideration is how detailed and prescriptive the regulations need to be in order to achieve a satisfactory level of Human Factors interventions. Policy makers should bear in mind that in recent years, non-prescriptive programmes have been initiated in several States and have successfully achieved implementation in a significant number of their operators and maintenance organizations. However, Annex 6 requires 100 per cent implementation, and it is too early to tell if persuasion alone is sufficient to achieve this requirement. The State should consider this aspect carefully and strike the balance between the detailed regulation and persuasion best suited to its national legal and cultural circumstances.

6.2.4 A second important policy consideration is to determine which entity is the most appropriate to "target" for Human Factors regulations. In a State where all operators perform their own maintenance, the answer is simple as only one party exists. However, in many States, operators contract maintenance to other organizations, and one possible solution would be to address all the regulations to the operator which would then require compliance by the maintenance organization. The operator would then need to perform a Human Factors audit of this maintenance organization and require compliance before work was started. A more practical and balanced solution would be to address the regulations regarding practical Human Factors application to the maintenance organization. Human Factors regulations associated with the design of the maintenance programme itself would then be addressed to the operator.

6.2.5 A third policy consideration is to establish the level of Human Factors interventions necessary to produce a satisfactory result. Annex 6 provides no details of the required level, but it is suggested that it will depend on factors such as:

- Size, management structure and policies of each individual industry organization;

- Levels of Human Factors experience, training and education in the workforce of both industry and the aviation regulatory body;

- The current level of Human Factors knowledge and implementation in industry;

- Accidents and incidents where maintenance error is known to be a causal factor; and

- National culture and legal system.

6.2.6 The regulatory policy should assume that the maintenance inspectors of the State aviation regulatory body will normally monitor compliance by the State's aviation industry as part of their process of supervision. This policy will require that these inspectors have appropriate Human Factors training. Alternatively, a State may wish to consider using Human Factors specialist inspectors provided that it is satisfied as to their level of aviation maintenance experience and knowledge.

6.3 REGULATORY PRINCIPLES

6.3.1 The legal status of the regulations and/or other guidance material issued by the State aviation regulatory body for implementation of Human Factors should be clear and preferably consistent with other existing State material. This clarity will help to produce consistent implementation across the various industry organizations and will also guide the State's maintenance inspectors in their approach to monitoring compliance.

6.3.2 The "spirit" of the regulations must be seen as just as important as specific compliance with what is actually written. The use of non-regulatory guidance materials and, perhaps, face-to-face briefing is recommended to enhance and explain Human Factors, its pitfalls and potential benefits.

6.3.3 The regulations and guidance material should clearly identify the body or individual responsible for compliance and/or action. For example, the assumption in Annex 6 is that responsibilities are assigned as follows:

- The operator is responsible for developing the maintenance programme in order that it observe Human Factors principles;

- The State aviation regulatory body is responsible for evaluating and, when satisfied that it meets the appropriate requirements, approving the maintenance programme submitted by the operator;

- The operator is responsible for ensuring that the AMO apply the programme in such a way as to observe Human Factors (i.e. that the AMO facility, staff and procedures observe Human Factors principles);

- The AMO is responsible for the standards of Human Factors training given to its staff; and

- The State aviation regulatory body is responsible for evaluating the maintenance organization and, when satisfied, approving it as an AMO.

6.3.4 The Human Factors regulations should not inhibit the practice (for commercial or facilitation reasons) of contracting some of the industry tasks and activities between the parties concerned. For example, some operators contract the task of developing and/or maintaining the maintenance programme to the AMO. The State may, of course, tacitly accept such an arrangement provided that the operator can demonstrate that the final document meets the requirement of observing Human Factors principles.

6.3.5 The Annex 6 requirement for the AMO to train its staff in Human Factors principles is clear, and appropriate guidance is included in Chapter 5 of this manual.

6.3.6 The Annex 6 requirement for the operator's maintenance programme addresses two aspects: first, the design of the programme and, second, the application of the programme. In practice, the operator designs the maintenance programme to be applied in the AMO and, hence, its facility, procedures and work instructions must observe Human Factors principles. Although the operator can have total control over the design of the maintenance programme, it has much less direct control over the maintenance organizations that perform maintenance work on its aircraft or its components.

6.3.7 Whatever the balance of tasks and activities between the operator and the maintenance organization, it is the operator that remains responsible to ensure that its aircraft are maintained in an airworthy condition (Annex 6, Part I, 8.1.1, refers). The operator must therefore be confident that the AMO observe Human Factors principles. The operator should consider this aspect, and if necessary, it should confirm this, perhaps by an audit, both before and during the maintenance contract.

6.4 DESIGN OF THE MAINTENANCE PROGRAMME

6.4.1 The State regulations (or the change to existing regulations) to include Human Factors should recognize that some documents which are used by the AMO for application of the maintenance programme may not necessarily observe Human Factors principles. For example, the continuing airworthiness documents issued by the Type Certificate (TC) holder are not specifically required by Annex 8 to observe Human Factors principles. It may be, however, that industry standards, such as those issued by ATA, do result in satisfactory documents. The operator should therefore consider if it is necessary to perform detailed "Human Factors checks" on the following publications:

- The maintenance manual (i.e. the TC holder's recommendations on how to perform tasks);
- Information issued as a Service Bulletin or Service Letter (i.e. what changes or special inspections to make as a result of service experience); and
- The AMO maintenance control manual in respect of topics which define the procedures that control the application of the maintenance programme.

When these Human Factors checks or internal company reporting systems (post-event) reveal a text that does not properly observe Human Factors principles, the operator should report this to the originator and consider the need to transcribe it so that it does observe Human Factors principles when it is applied by the AMO.

6.4.2 Annex 6, Part I, 11.3.1, requires that the operator's maintenance programme contain the following information:

> "maintenance tasks and the intervals at which these are to be performed, taking into account the anticipated utilization of the aeroplane."

Following the issue of Amendment 23 to Annex 6, Part I, the operator has the additional responsibility of designing a programme that observes Human Factors principles and providing this information in such a way that it can be applied by the AMO while observing Human Factors principles.

6.4.3 The design of a maintenance programme has two aspects: first, the definition of actual work tasks and, second, the design and presentation of the programme document itself.

6.4.4 The actual maintenance work tasks and activities defined in the maintenance programme should take into account the following factors:

a) The type of operation: short or long sectors which require different scheduling of tasks, e.g. a short-sector operation may break down the tasks into "packages" which can be performed overnight, whereas the long-sector operation requires a minimum of scheduled tasks over the operating days or weeks followed by a much larger maintenance work "package";

b) The geographical area of operation: e.g. operation in a high or low latitude with very short or long winter daylight hours where the high latitude will necessitate scheduling all tasks into a hangar to protect personnel from cold and to provide good lighting;

c) The operator's or AMO's experience in operating or maintaining the aircraft type: e.g. personnel who are new to a particular type of aircraft are likely to require more time to perform tasks than those with considerable experience;

d) The standards of aircraft type training provided to operating and maintenance personnel: e.g. personnel who have received a minimum level of training on the aircraft type are likely to require more time to perform tasks than those with more comprehensive training;

e) The standard of competency of the AMO, its associated procedures and quality system: e.g. manpower planning should suit not only the actual tasks during a particular shift but also the actual available manpower; and

f) The standard of competency of the operator's organization and its associated procedures for the operation of the reliability programme (if applied to the aircraft type): e.g. an operator with a good standard of data collection, analysis and organization structure is likely to be able to take faster and better corrective action. As a result, the airworthiness of individual aircraft is likely to be higher.

6.4.5 The design of the operator's aircraft maintenance programme document should observe Human

Factors principles. Chapter 3, 3.10, of this manual contains suitable guidance material for this.

6.5 APPLICATION OF THE MAINTENANCE PROGRAMME

The State regulations or other equivalent material should be written so that application of the operator's programme by the AMO will have the following results:

- Task instructions from the approved maintenance programme that can be either easily and accurately understood directly by AMEs or can be easily and accurately transcribed for them;
- Hangar or workshop environment and facilities that observe Human Factors principles;
- Procedures, instructions and practices that enable the AME (and other AMO staff) to apply the maintenance programme consistently and correctly and to release an aircraft or component that meets the type design and is in condition for safe operation; and
- All maintenance personnel having Human Factors knowledge and skills appropriate to the assigned tasks and responsibilities.

Note.— All holders of AME licences that are compliant with Annex 1, Amendment 161, (5 November 1998) or later should have Human Factors knowledge and skills appropriate to the licence category and scope. However, this standard may not always be sufficient to meet either the standards intended by Annex 6 or those of the AMO in particular cases.

6.6 POSSIBLE REGULATORY SOLUTIONS

6.6.1 Annex 6, Part I, requires that the operator provide a maintenance control manual accepted by the State (8.2.1) and employ a person or group of persons to ensure that all maintenance is carried out in accordance with the manual (8.1.4). The contents of the maintenance control manual are specified in Annex 6, Part I, 11.2. The State aviation regulations are therefore required to specify this standard as a minimum. However, paragraph 11.2 does not include a reference to Human Factors, and State regulations should require this to be included.

6.6.2 The Annex 6 requirement for AMO personnel to be trained in human performance can be met by a requirement for the approval of a maintenance organization which specifies this training for various categories of AMO staff. A suggested curriculum for such training is shown in Chapter 5, Appendix A. Recognition of an AME licence or certificate that has included Human Factors training may not necessarily be sufficient. The AMO and the State aviation regulatory body are responsible for this determination.

6.6.3 If the State aviation regulatory body considers that the actual aviation industry Human Factors situation in its State is satisfactory, there is an option for the regulations to be drafted to reflect actual practice. A suggested format for a questionnaire to establish the current level of industry knowledge and implementation of maintenance Human Factors is shown in Appendix A to this chapter.

6.6.4 In the case where an aviation industry sector has a known or demonstrated weakness, the State could decide to regulate that aspect directly. For example, rather than the operator ensuring that the AMO apply its programme in such a way as to observe Human Factors principles, the State approval requirements for an AMO could include topics such as:

- The establishment and promulgation of a company-wide aviation safety policy;
- The establishment in the AMO of a maintenance error management system as one element of a "safety culture";
- A specific shift handover procedure which reflects industry "best practice";
- Planning of manpower, parts, tools and work to take into account the fatigue and pressure effects on human performance;
- Duplicate or specific required inspections of critical points or tests;
- Avoidance of inspection and sign-off on completion of tasks by non-authorized personnel; and
- Company procedures to be written and implemented to take into account Human Factors principles.

6.6.5 Chapter 3 of this manual suggests several interventions likely to be beneficial, and these topics could be used as the basis of a regulatory programme to address the Human Factors issues. For example:

- Organizational interventions;
- Communication and MRM;
- Inspection and quality systems;
- Human error management;
- Error capture;
- Environmental interventions;
- Ergonomic interventions;
- Documentary interventions;
- Fatigue interventions; and
- Some simple interventions.

These topics should be introduced in an appropriate place in existing regulations or guidance material.

6.6.6 One group of signatory States gathered evidence from programmes introduced by industry on a voluntary basis. This evidence showed that Human Factors programmes do make a significant contribution towards improved aviation safety and reduced maintenance errors. As a result, these States were able to identify detailed reasons to change their joint regulations for the approval of maintenance organizations. Their reasons and some examples of the changes developed for their regulations are summarized in Appendix B to this chapter.

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Appendix A to Chapter 6

SUGGESTED INDUSTRY QUESTIONNAIRE

The following is a suggested questionnaire for the State aviation regulatory body to send to an AMO or operator to obtain selected information on its knowledge and implementation progress with Human Factors in aircraft maintenance and inspection. The questionnaire is adapted from the FAA *Human Factors in Aviation Maintenance and Inspection* CD-ROM.

Section 1. General Information

Date: ______________________ Name: ______________________________

Organization name and address: ____

____

Type of Organization (circle only one):

Airline Operator, Repair Station, Approved Maintenance Organization (AMO)

Years of experience in:

— Human Factors: ______________

— Aircraft maintenance: __________

Section 2. Purpose of this Questionnaire

The purpose of this questionnaire is to enable the State aviation regulatory body to assess the following:

- Current status of maintenance Human Factors programmes in your organization; and
- Your knowledge of aviation maintenance Human Factors research products and guidance material.

Section 3. Current Status of Human Factors Maintenance Programmes in Your Organization

PART A

Please add comments at the end of the section.	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
a) Our maintenance Human Factors programme is implemented and active; OR b) We are planning a Human Factors programme for maintenance personnel. c) We have an active Human Factors training programme being delivered to maintenance personnel; OR d) We are planning Human Factors training for maintenance personnel. e) Our organization has at least one person with full-time responsibility for maintenance Human Factors. f) Our organization has a high interest in maintenance Human Factors.					

PART B

Please add comments at the end of the section.	*Yes*	*No*	*Not Sure*
a) We use posters such as the “Dirty Dozen” somewhere in our organization. b) We use Human Factors information from the following sources: — FAA Human Factors CD-ROMs — CAA Human Factors Handbook — Hard copy reports — Web sites — Conferences — Other (Please identify.)			

PART C

Please add comments at the end of the section.	*Yes*	*No*	*Not Sure*
a) We have sent people to specialized Human Factors courses.			
b) We have brought in consultants to deliver Human Factors courses.			
c) We have a formal Human Factors maintenance error reporting system;			
OR			
d) We are planning a formal Human Factors maintenance error reporting system.			
e) We have a formal discipline system that acknowledges the importance of maintenance error reporting.			
f) We have data from our maintenance error reporting system:			
— showing how Human Factors-related errors raise costs			
— showing how Human Factors interventions lower costs			
g) We have conducted a Human Factors audit of our maintenance organization.			
h) We plan to conduct a Human Factors audit. (Please state timescale.)			
i) We plan to use the FAA Document Design Aid (DDA). (Please state timescale.)			
Explanations, comments or suggestions for Section 3:			

Section 4. Your Knowledge of Human Factors Research and Development Information and Products

PART A

Please add comments at the end of the section.	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
a) I am knowledgeable about Human Factors conditions that existed 10 years ago.					
b) I am knowledgeable about Human Factors conditions that existed 5 years ago.					
c) I am knowledgeable about Human Factors conditions that exist today.					

PART B

Please add comments at the end of the section.	*Yes*	*No*	*Not Sure*
a) I have received a CD-ROM from the FAA concerning aviation maintenance Human Factors.			
b) I have received the U.K. CAA Human Factors in Aircraft Maintenance Handbook or CAP 716. (Please state which.)			
c) I have received Human Factors in aircraft maintenance information from another source. (Please identify.)			
d) Representative(s) from my organization has attended aviation maintenance Human Factors conferences. Please state which:			
0 – 3 times			
4 + times			

PART C

Please add comments at the end of the section.	*Yes*	*No*	*Not Sure*
Have you implemented aviation maintenance Human Factors research products/interventions? (Please comment.)			
Explanations, comments or suggestions for Section 4:			

Section 5. The Value of Various FAA Human Factors Research Products

Please rate your familiarity and value of the following FAA Human Factors research products:

Please add comments at the end of the section.	*Low*	*Medium*	*High*	*N/A*
a) Document Design Aid (DDA) — Familiarity — Value				
b) Software for maintenance ergonomics audit (ERNAP) (1996) — Familiarity — Value				
c) *Human Factors Guide for Aviation Maintenance* (Web site version) (1998) — Familiarity — Value				
d) The www.hfskyway.com Web site (1996–1998) — Familiarity — Value				
e) What is the overall value of the FAA maintenance Human Factors research programme?				
Explanations, comments or suggestions for Section 5:				

Section 6. Perceived Requirements for Aviation Maintenance Human Factors Products

Please indicate your agreement or disagreement with the following:

Please add comments at the end of the section.	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
My organization needs maintenance Human Factors support in the following areas:					
a) Training Materials: — Hard copy training — Computer-based training (CBT) — Web-based training b) Job Aids: — New technology hardware for the aircraft maintenance environment — New technology software for the aircraft maintenance environment (e.g. scheduling, work flow, process automation and electronic publications) — Information on how to conduct internal Human Factors audits c) Information: — Web site on *Human Factors in Aviation Maintenance and Inspection* — Annual CD-ROMs on *Human Factors in Aviation Maintenance and Inspection* — Annual hard copy update on *Human Factors in Aviation Maintenance and Inspection* — Conferences — Advisory Circulars (or other guidance material) for Human Factors					
Explanations, comments or suggestions for Section 6:					

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Appendix B to Chapter 6
SUGGESTED REGULATION TEXT

1. INTRODUCTION

This appendix summarizes some of the recent changes to regulations for the approval of a maintenance organization made by the European Joint Aviation Authorities (JAA). These changes are stated to be based on industry best practice and sound scientific research. They attempt to apply some of the good Human Factors principles already established in flight operations and air traffic control to the aircraft maintenance industry. The JAA further state that the proposal is intended to comply with Annex 6, Part I, Amendment 23.

2. CHANGES TO REGULATIONS

2.1 The following paragraphs list reasons some States found to change their regulations and suggest some regulatory and guidance texts which States may consider for use in their own regulations. These have been adapted from the associated JAA material.

Design/maintenance interface

2.2 *Reason:* Inaccuracies, ambiguities, etc. in airworthiness instructions or information can lead to maintenance errors or encourage deviations. Indirectly, they may also encourage or give good reasons to maintenance personnel to deviate from these instructions.

2.3 State regulations and advisory and explanatory material should be in place to require that inaccurate, incomplete and ambiguous maintenance procedures, practices, information or maintenance instructions contained in the maintenance data used by personnel be notified to the responsible organization (usually the type certificate (TC) holder).

2.4 The following are suggested State texts:

Regulation: The AMO must establish procedures that ensure that any inaccurate, incomplete or ambiguous procedures, practices, information or maintenance instructions contained in the maintenance data used by maintenance personnel be recorded and notified to the applicable TC holder responsible for the data.

Advisory material: The procedures should ensure that when maintenance personnel discover inaccurate, incomplete or ambiguous information in the maintenance data, they record the details. The procedures should then ensure that the AMO notify the problem to the TC holder in a timely manner. A record of such communication to the TC holder should be retained by the AMO until such time as the TC holder has clarified the issue, perhaps by amending the maintenance data.

Safety culture

2.5 *Reason:* A safety culture within an organization makes an important contribution to reducing maintenance errors. Recognizing that it is impractical to write a requirement demanding a safety culture, the State should include requirements and guidance material that call for the elements that would enable one to flourish.

2.6 State regulations should be in place to require:

a) The maintenance organization to establish and publish the organization's safety policy;

b) Identification of the accountable manager (or Chief Executive Officer) of the maintenance organization as the person responsible for establishing and promoting this safety policy; and

c) An "Internal Occurrence Reporting System" which consists of a closed loop occurrence and safety hazard reporting, recording and investigation system.

2.7 The following are suggested State texts:

Regulation 1: The AMO must establish a safety and quality policy for the organization. This policy is to be included in the AMO procedure manual.

Regulation 2: The accountable manager (or Chief Executive Officer) is responsible for establishing and promoting the required safety and quality policy.

Procedural non-compliance

2.8 *Reason:* Failure to comply with good maintenance procedures is more a matter of education, safety culture and discipline. However, the effects of compliance with poor procedures can be minimized by focusing the requirement on a system that ensures during drafting that procedures are accurate, appropriate and reflect best practice.

2.9 A revised regulation should be in place to require that Human Factors principles be taken into account when establishing and writing procedures. Advisory and explanatory material should recommend, among other things, the involvement of the end users in writing the procedures, the verification and validation of the procedures, and an effective mechanism for reporting errors and ambiguities and for changing and updating the procedures.

2.10 The following is a suggested State text:

Regulation: The AMO must establish procedures acceptable to the State taking into account Human Factors and human performance to ensure good maintenance practices and compliance with all relevant requirements in this regulation which must include a clear work order or contract such that aircraft and aircraft components may be released to service in a safe condition and in accordance with regulations.

Shift and task handover

2.11 *Reason:* This is a routine process that repeatedly appears as a causal factor in aircraft accident and incident reports.

2.12 A requirement should be in place to specifically require a shift and task handover procedure acceptable to the State. Advisory and explanatory material should describe the best practice based on current knowledge and scientific research.

2.13 The following are suggested State texts:

Regulation: When it is required to hand over the continuation or completion of a maintenance action for reasons of a shift or personnel changeover, relevant information must be adequately communicated between outgoing and incoming personnel in accordance with a procedure acceptable to the State.

Advisory material: The primary objective of the changeover information is to ensure effective communication at the point of handing over the continuation or completion of maintenance actions. Effective task and shift handover depends on three basic elements:

- The outgoing person's ability to understand and communicate the important elements of the job or task being passed over to the incoming person;
- The incoming person's ability to understand and assimilate the information being provided by the outgoing person; and
- A formalized process for exchanging information between outgoing and incoming persons and a place for such exchanges to take place.

The referenced procedure should be specified in the AMO procedure manual.

Fatigue

2.14 *Reason:* The adverse effect of human fatigue on maintenance errors is a well-established fact.

2.15 A regulation should be in place to require the organization's planning procedures to take into account the limitations of human performance, focusing on the fatigue aspect. Advisory and explanatory material should include guidance using known best practice and research material.

2.16 The following are suggested State texts:

Regulation: The planning of maintenance tasks, including the organizing of shifts, must take into account human performance limitations.

Advisory material: Limitations of human performance, in the context of planning safety-related tasks, refer to the upper and lower limits and variations of certain aspects of human performance (circadian rhythm/24-hour body cycle) which planners should be aware of when planning work and shifts.

Duplicate inspections

2.17 *Reason:* Error capturing forms an important element of the safety net in the approved maintenance organization. Duplicate inspections may be a means of capturing maintenance errors but not necessarily the only means.

2.18 A regulation or advisory material should be in place to recommend that duplicate inspections be considered as a possible means of error capturing and to provide additional guidance as to the circumstances where this may be necessary.

2.19 The following is a suggested State advisory or regulatory text:

Advisory or regulatory material: Procedures should be established to detect and rectify maintenance errors that could, as a minimum, result in a failure, malfunction or defect endangering the safe operation of the aircraft. The procedures should identify the method for capturing errors, and the maintenance tasks or processes concerned. A typical procedure could include the performance of duplicate inspections where the task or process is performed by one suitably qualified person and then independently checked and verified by a second suitably qualified person, or the inclusion of an additional functional or leak check.

In order to determine the work items to be considered, the following maintenance tasks, in addition to any existing State requirements for capturing errors, should be reviewed for their criticality and vulnerability to error:

- Installation, rigging and adjustments of flight controls;
- Installation of aircraft engines, propellers and rotors;
- Overhaul, calibration or rigging of components such as engines, propellers, transmissions and gearboxes;
- Previous experiences of maintenance errors, depending on the consequence of the failure; and
- Information arising from the State occurrence reporting system required by Annex 8.

Planning of tasks, equipment and spare parts

2.20 *Reason:* The absence of effective planning can contribute towards increased work pressure. This pressure itself may lead to deviation from procedures. Deviation from procedures is well known as a contributing factor in many aircraft incidents.

2.21 A regulation should be in place to clarify the objective of good planning. Advisory and explanatory material should include further guidance on elements to consider when establishing the planning procedure.

2.22 The following are suggested State texts:

Regulation: The AMO must have a system appropriate to the amount and complexity of work to plan the availability of all necessary personnel, tools, equipment, material, maintenance data and facilities in order to ensure the safe completion of the maintenance work.

Advisory material:

a) Depending on the amount and complexity of work generally performed by the maintenance organization, the planning system may range from a very simple procedure to a complex organizational set-up including a dedicated planning function in support of the production function.

b) For the purpose of meeting the State maintenance organization approval regulations, the production planning function should include two complementary elements:

   - scheduling the maintenance work ahead to ensure that it will not adversely interfere with other maintenance work as regards the availability of all necessary personnel, tools, equipment, material, maintenance data and facilities; and
   - during maintenance work, organizing maintenance teams and shifts and providing all necessary support to ensure the completion of maintenance without undue time pressure.

c) When establishing the production planning procedure, consideration should be given to the following:

- logistics;
- inventory control;
- square metres of accommodation;
- estimation of man-hours;
- availability of man-hours;
- preparation of work;
- hangar availability;
- coordination with internal and external suppliers, etc.; and
- scheduling of safety-critical tasks during periods when staff are likely to be most alert.

Signing off tasks not seen or checked

2.23 *Reason:* Recent research has proved that many maintenance tasks are signed off but have not been seen or checked by authorized personnel. This has the potential to lead to incomplete maintenance.

2.24 A regulation should be in place to explain the meaning of "sign-off" and the need to self-check or inspect the task before signing it off.

2.25 The following is a suggested State text:

Advisory material: A "sign-off" is a statement by the competent person performing or supervising the work that the task or group of tasks has been correctly performed. A sign-off relates to one step in the maintenance process and is therefore different to the release to service of the aircraft. In order to prevent omissions, every maintenance task or group of tasks should be signed off. To ensure the task or group of tasks is completed, it should only be signed off after completion. Work by non-competent personnel (i.e. temporary staff, trainees, etc.) should be checked by authorized personnel before they sign off. The grouping of tasks for the purpose of signing off should allow critical steps to be clearly identified. The referenced procedure(s), if applicable, should be specified in the AMO maintenance procedure manual.

Competence in Human Factors

2.26 *Reason:* In order to ensure that Human Factors principles are effectively applied within the organization, maintenance personnel must be competent to apply such principles.

2.27 A requirement should be in place to establish the competence of maintenance personnel including managers. That "competence" should include the ability to apply Human Factors principles. Advisory and explanatory material should specify initial and continuation training as a means to ensure and maintain that "competence". (See Chapter 5 of this manual.)

2.28 The following are suggested State texts:

Regulation: The competence of personnel involved in maintenance management and/or quality audits must be established and controlled in accordance with a procedure and to a standard acceptable to the State. In addition to the necessary expertise related to the job function, competence must include an understanding of the application of Human Factors and human performance issues related to that person's function in the organization.

Advisory material: With respect to the understanding of the application of Human Factors and human performance issues, maintenance, management and quality audit personnel should be assessed for the need to receive initial Human Factors training, and in any case, all maintenance, management and quality audit personnel should receive continuation training. This should concern to a minimum:

- Holders of posts, such as managers or supervisors;
- AMEs, certifying staff, technicians, mechanics and engineers;
- Technical support personnel, such as planners, engineers and technical record staff;
- Staff with special skills, such as welders and NDT personnel;
- Quality control and quality assurance staff;

- Human Factors trainers;
- Technical trainers;
- Purchasing department staff;
- Ground equipment operators; and
- Contract staff in the above categories.

Miscellaneous

2.29 *Reason:* For consistency, definitions should meet international standards.

2.30 The existing State regulations should include the definitions of "Human Factors principles" and "human performance" which are taken from Annex 6.

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Appendix C to Chapter 6

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