REPORT OF THE DATA SUBGROUP
JULY 2011
MAINTENANCE ERROR DATA

EXECUTIVE SUMMARY

There is a very large amount of information on maintenance error available. Amongst this plethora of information are a number of data sets which are well structured and which have been collected consistently over a significantly long period of time. Substantial studies based on these data sets have been produced. Those studies have identified broad themes and trends which are frequently consistent across the studies. These common themes and trends amount to the strongest basis available for future action.

There are some aircraft systems and ATA Chapters which are at particular risk from human error in aircraft maintenance. Rule-based and knowledge-based tasks[1] in these areas multiply the risks unless mitigations are put in place. Some aircraft systems have increased likelihood of hazardous consequences if errors occur and reach the flight line or ramp undetected. Even well-intended violations further increase the risk.

Costs are poorly documented but even on conservative evidence there is economic justification for addressing those maintenance tasks which bear the greatest elements of risk for the organisation. The various studies which have been examined have sufficient agreement to identify those areas of risk clearly.

1 INTRODUCTION

Human factors in engineering maintenance is no longer a new or unexplored area, yet it is proving consistently difficult to manage. Training is now mandated and well accepted throughout the industry, and at all levels of responsibility we have a greater understanding of human performance, and of physiological and cognitive limitations than ever before. Yet the annual cost of maintenance errors remains huge, and the potential for major loss of life and equipment is generally agreed to be unacceptably high. It is often felt that there is no clear way ahead for maintenance organisations faced with severe financial and operational constraints, mainly because there is no undeniable cost benefit analysis.

That is not to say that there are no success stories, but a number of factors militate against positive action. Firstly, there is every possibility that the organisation which merely meets its legal obligations, and nothing more, will not have an accident. Secondly, most of the costs of any accident are invisible (and uninsured), and so become just another cost of doing business. Thirdly, managing error is a complex and all-embracing concept which is hard to define, understand and implement. Finally, even if the will and resources to minimise error exist, it is not immediately clear which areas of activity are most likely to show a return on investment, and much less so to identify those areas where there is a significant risk to life.

Some good data sets, collected over many years, do exist and some authoritative studies have been carried out using these data. It is evidence of their validity that from such disparate and varied maintenance events, each with its distinctive and particular circumstances, failures and shortcomings, that consistently strong common themes pervade the studies. This paper attempts to identify the available data sources, and to compare the best studies of the best data sets, to identify areas of common ground.

Where common themes are consistently identified, the industry ignores them at its peril. Globally, these factors will inevitably produce losses. For individual organisations, it is just a matter of time. This paper is intended to provide convincing evidence that 'do nothing' is no longer an affordable option.

2 DATA SOURCES

There is a very large amount of information on maintenance error available. Much of that information is objectively factual; it is genuinely data, albeit often not in the numerical sense. Most of the factual and objective information is anecdotal, in the form of case histories, and may fairly be considered to be useful data, although it lacks a numerical or statistical basis. There is, however, little that could be described as numerical data, and therefore an alternative approach is needed to identify the most effective error management measures.

Amongst this plethora of information are a number of data sets which are well structured and which have been collected consistently over a significantly long period of time. Substantial studies based on these data sets have been produced. Those studies have identified broad themes and trends which are frequently consistent across the studies. These common themes and trends amount to the strongest basis available for future action. A previous HFG:E paper (EMSG 2007) identified the world-wide data resources available.

3 REPORTS

3.1 CHIRP analysis of Maintenance Error Decision Aid (MEDA) data

The Confidential Human factors Incident Reporting Programme (CHIRP) is administered by the CHIRP Trust, an independent body which investigates voluntary reports, publishes de-identified information and conducts analyses. CHIRP-MEMS is largely based on MEDA data, but also contains other data sets. The analysis of data held by CHIRP has identified a number of areas of concern both by error type and by ATA Chapter number. CHIRP reports are periodically updated, and this report is also updated to reflect the most recent CHIRP data.

3.2 CAA Paper 2009/05 ‘Aircraft Maintenance Incident Analysis’

This study analysed a large selection of maintenance related events to large public transport aircraft (> 5,700Kg), to identify trends, themes and common factors. It breaks the events down by error type, and also by ATA Chapter. In addition, it contains an analysis of a number of high-risk incidents, where maintenance error posed a significant threat to the aircraft and its occupants.

3.3 ATSB Survey of Licenced Aircraft Maintenance Engineers (LAMEs) in Australia

This survey, published in 2001, was based on a survey of LAMEs in Australia conducted in 1998. 610 reports were evaluated. The report examined outcomes (but not severity), error types, the correlation between error types and outcomes, contributory factors and their relationship with error types, time of day and shift patterns, and mitigations.

An earlier Australian BASI study of incident reports used critical incident analysis techniques on reports obtained from LAMEs between 1993 and 1995. This report considered severity of outcomes, aircraft ‘area’ (akin to ATA Chapter) time of day and shift patterns, types of error (skill, rule, knowledge-based error types), local factors and organisational factors. It relied heavily on the Reason and SHEL models of human error.

3.4 Airbus Analysis of Operational Reliability Data.

Airbus operational reliability data are recorded in the Airbus In-Service Aircraft Information Management database, which contains more than 400,000 entries. These entries include ‘technical’ delays (15 minutes or greater) as well as more serious engineering related events. The reports are usually brief. Airbus selected some 6,500 of these reports for further analysis. While much of this data is difficult to compare for the purposes of this paper, Airbus have produced some ‘Maintenance Briefing Notes’ where some of the data has been broken down into useful categories.

3.5 Boeing Maintenance Occurrence Database Analysis

In-service problems reported to Boeing from 1970 through 1997 were analysed by the manufacturer to determine if human error could be assessed from the write-ups. The reported problems were largely from line maintenance, servicing, and ground operations. 18,209 reports were analysed, and 8,998 were found to be associated with human error. The data were broken down by aircraft type, ATA Chapter, and Boeing MEDA error categories. This study is not in the public domain and further details were not available.

3.6 MAA Flight Ops Review

The UK’s Military Airworthiness Authority[2] reported on its ‘Review of Air Safety Issues in Aircraft Maintenance and Engineering Activity in 2009/10’ in August 2010 (MAA 2010). This report used data from the Defence Flight Safety occurrence Report (D-FSOR) and Aviation Safety Information Management System (ASIMS) database. Of 4,721 reports of all types for the reporting year, 663 were essentially technical and 385 of these were considered to involve human factors in maintenance.

3.7 MIRCE Akademy study of UK military events

MIRCE Akademy analysed some 10,000 safety reports of all types from the UK's Defence Aviation Safety Centre (DASC) and identified 463 as being maintenance related. The reports were broken down by aircraft system, error type, contributing factors, design of tasks, procedures and equipment. The report discusses error detection, consequences, trends, and some specific instances.

3.8 NASA Air Safety Reporting System (ASRS) report

About 2% of ASRS reports are maintenance related. The report is an analysis of approximately 1,600 maintenance events recorded between 1996 and 2002. It examines shift working, MEL related errors, procedural errors, error types and contributory factors.

3.9 FAA 'Root Cause Analysis'

The FAA has completed many studies, one of which is the 2002 'Root Cause Analysis of Rule Violations by Aviation maintenance Technicians'. That paper discusses failure types, organisational and individual factors, and the effects of maintenance errors. Its most pertinent conclusion is that :

> *'ASRS data, Rule Violation data and Accident data indicate that maintenance errors stem from issues at both organizational as well as individual levels. Specifically, the issue of maintenance procedures/instructions is consistently prominent in all three databases. A detailed look at the maintenance procedures/instructions revealed that the problem lies in … …people having to make decisions in situations that they have never encountered before. …Under such circumstances, the mechanic is faced with a choice to either improvise or refuse to perform the job. When a job is not improvised correctly or an error is made during the improvisation process, a maintenance-related "event" is highly likely'.*

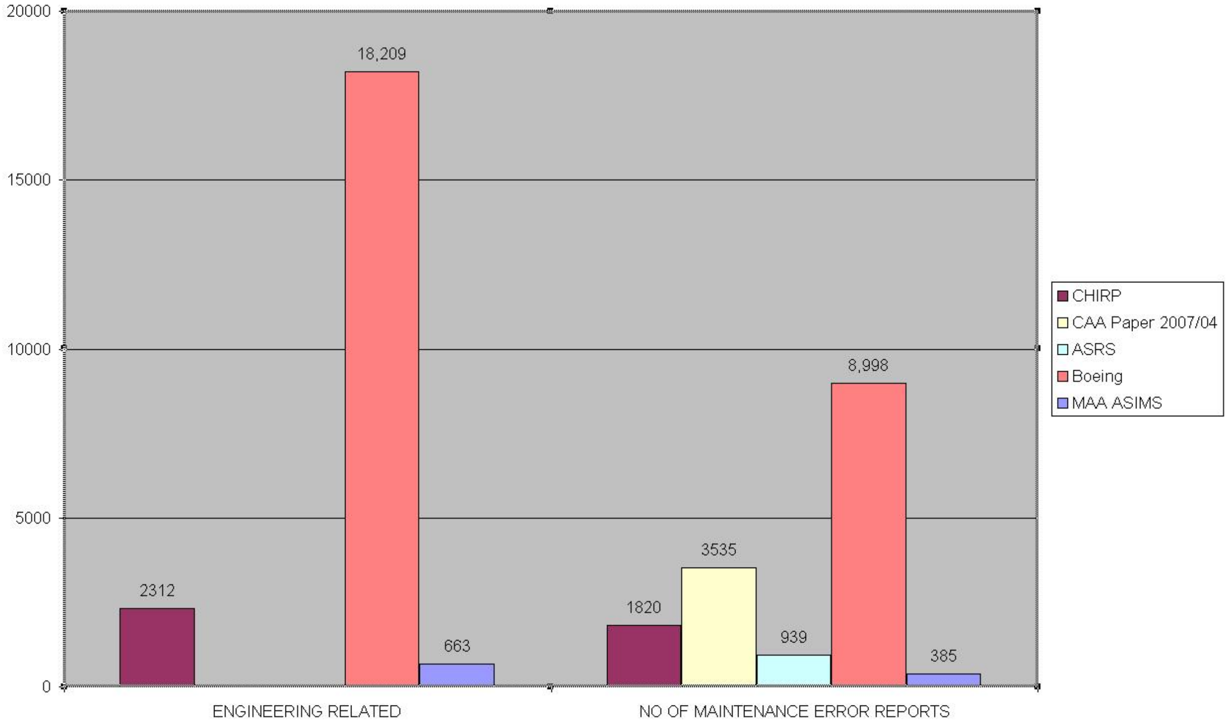
3.10 Defence Aviation Hazard Reporting & Tracking System (Australia)

The Australian DAHRTS military database contains casual factors derived from Air Safety Occurrence Reports. The contributory factors are categorised into 'Unsafe Acts or Conditions', 'Preconditions for Unsafe Acts', 'Deficient Supervision' and 'Organisational Influences'. While this makes comparison with other data sets problematic, examination of the subsets and their structure shows that skill, rule and knowledge-based errors are identified, as are routine and exceptional violations. 'Preconditions for Unsafe Acts' are Performance Shaping Factors. Thus some comparisons with other data can be made from this large and useful resource.

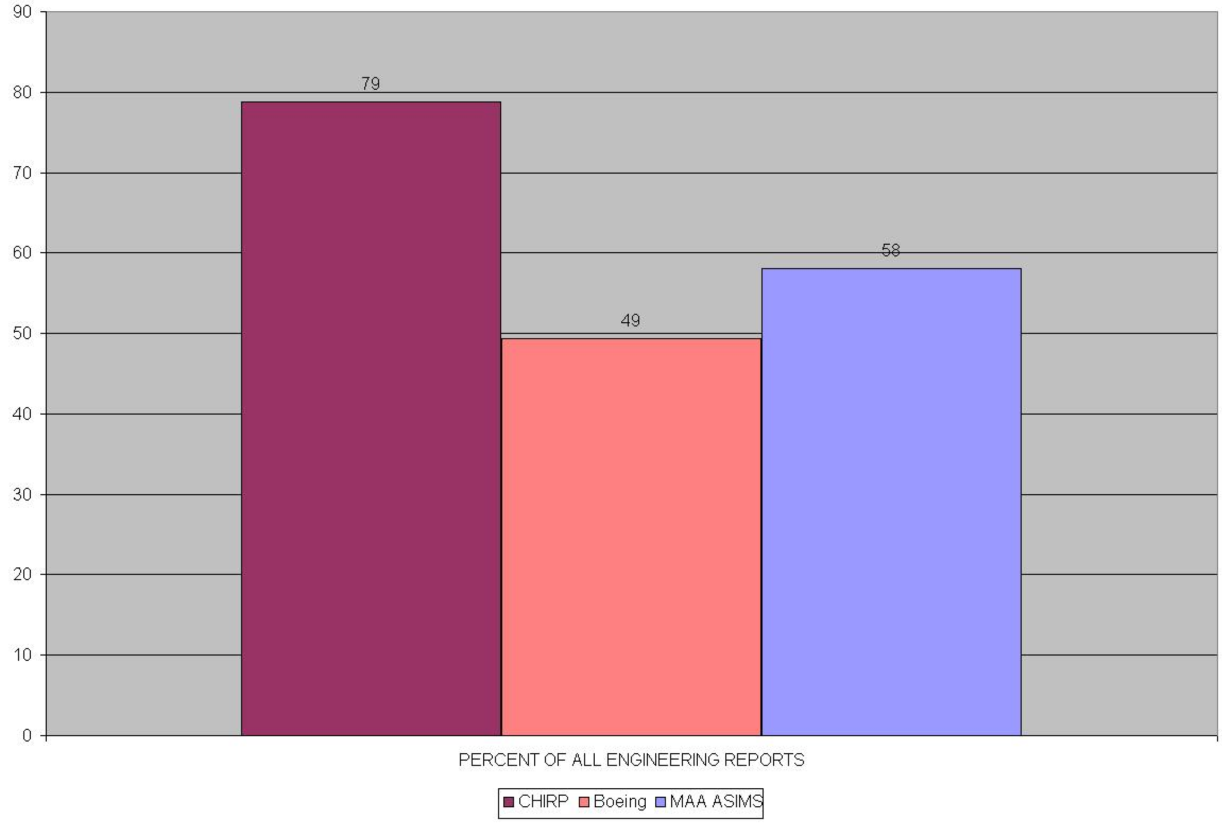
4 COMMON THEMES

These reports identify some common themes. Due to differences in reporting and analysis, it can be difficult to compare data from different data sets and different studies. However, some important conclusions can be drawn.

4.1 Maintenance error reports make up a significant proportion of all engineering-related Air Safety Reports



The above chart shows the number of maintenance error reports considered by each study. For CHIRP, MAA ASIMS and Boeing data it also shows the number of engineering-related reports from which these maintenance error reports were extracted. While it is often difficult to categorise many reports, making comparative data unavailable, similar proportions are believed to exist for the other data sets. For the CHIRP, MAA ASIMS and Boeing data, the percentages are shown below. Note that the Boeing data is the percentage of all technical delays, while the CHIRP data is the percentage of maintenance reports (excluding other non-maintenance technical reports). The MAA ASIMS data is the percentage of all technical reports.

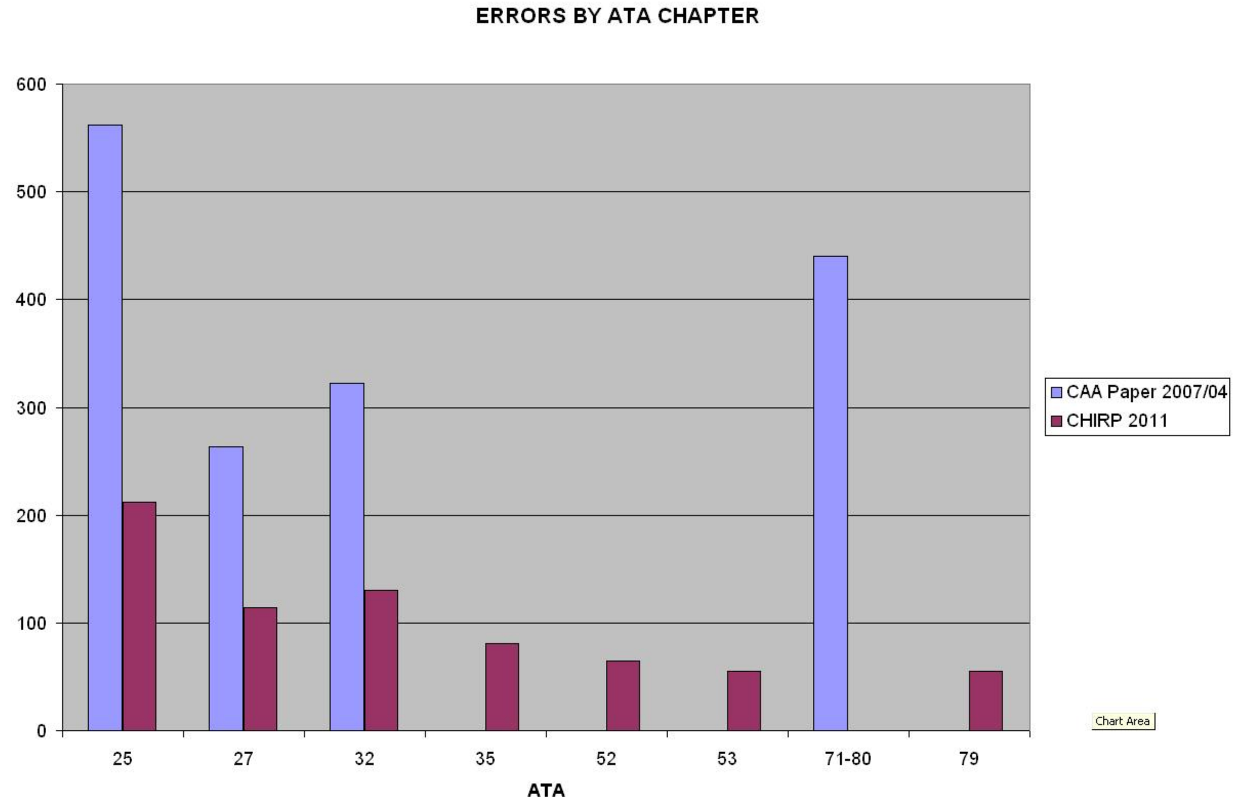


4.2 Certain ATA Chapters are especially vulnerable

The CAA study of 3, 982 MORs (CAA 2009) identified the top three ATA Chapters as ATA 25 (Equipment and furnishings), ATA 32 (Landing gear) and ATA 27 (Flying controls). However, combined powerplant ATA Chapters 71-80 came second only to Equipment and furnishings. The study also analysed a high risk subset of the MOR events, and there the top three became ‘Combined engine’ (ATA 71-80), Landing gear (ATA 32) and Flight controls (ATA 27).

The CHIRP study of MORs submitted between 2005 and 2010 (CHIRP 2011) identified ATA Chapters 25 (Cabin), 32 (Landing gear) and 27 (Flight controls) as being predominant, with Chapters 35 (Oxy), 52 (Doors) and 79 (Oil) in order of decreasing frequency.

The MAA Flight Ops Review categorised the technical reports by aircraft type and systems and subsystems. Although the data could not be directly compared with the ATA chapter system used for the CAA and CHIRP analyses, some similarities could be identified. Engine related reports, equivalent to ATA Chapters 71-80 combined, generated 21% of all reports. Propellers/rotors/transmissions generated 6.4%, landing gear 4.8% and flying controls 2.6%.



4.3 There are predominant error types, e.g. installation errors

The following chart shows the main error types evaluated by each report, and attempts to compare across the disparate taxonomies of the studies by colour coding similar error types identified in each study.

The Australian Transportation Safety Board (now the Bureau of Air Safety Investigations, BASI) survey (Hobbs & Williamson 2002(2)) found the top five errors in descending order to be: System operated unsafely during maintenance; incomplete installation; person contacted hazard; incorrect assembly; towing event.

The Airbus Maintenance Briefing Notes, based on a subset of the AISAIM database, identified 11 top error types, including installation, servicing, job set-up/preparation, inspection and repair, and further analysed the first three of these into subtypes. See the source document (Airbus (2008) for further details.

The CAA study (CAA 2009) of 3,982 Mandatory Occurrence Reports categorised error types differently but concluded that the three top error types were: Incorrect maintenance action (i.e. wrongly performed); Maintenance Control (i.e. failure of the management of the maintenance process); and Incomplete maintenance (unfinished, or not done at all). It identified failure to adequately control maintenance tasks and inadequate tool control as key Maintenance Control issues. Incorrect assembly was the most common error associated with ‘Incorrect maintenance action’.

The UK Confidential reporting scheme, CHIRP identified Installation error, Approved data not followed and Servicing error as the top three error types by a substantial margin during the period 2005-2010 (CHIRP 2011).

SOURCE	RANKING	ERROR TYPE
Airbus MBN June 2008	1	Installation
	2	Servicing
	3	Job set-up / preparation
	4	Pre-flight
	6	Slide
	7	Inspection
	8	Removal
	9	Test
	10	Repair
		NB Other categories were identified - see source document
BASI	1	System operated unsafely during maintenance
	2	Incomplete installation
	3	Person contacted hazard
	4	Incorrect assembly
	5	Towing event
CAA 2007	1	Incorrect maintenance action (i.e. wrongly performed)
	2	Maintenance Control (i.e. failure of the management of the maintenance process)
	3	Incomplete maintenance (unfinished, or not done at all)
CHIRP 2010	1	Installation error
	2	Approved data not followed
	3	Inspection error
Kanki & Hobbs	1	Incorrect installation
	2	Incorrect fault isolation
	3	Documentation problems
MEDA (NASA)	1	Incorrect servicing
	2	Documentation errors
	3	Wrong parts installed
Owen, Nicholas & Gill	1	Installation (48%)
	2	Transporting/driving (11%)
	3	Servicing (9%).
MAA Flight Ops Review	1	Ground Handling and Towing
	2	Procedures and Documentation
	3	Installation Errors
	4	Organisational Influences
	5	Supervision
	6	Other Preconditions
	7	FOD and Loose Articles

The NASA study of about 1,600 maintenance reports (Kanki & Hobbs) identified that, within Shift handover related errors, incorrect installation, incorrect fault isolation and documentation problems predominated. 44% of all ASRS reports described errors in information sources. The NASA study also considered MEDA data and found that the top outcomes were incorrect servicing, documentation errors and wrong parts installed.

Owen (2005) identified installation errors as most frequent, and most frequently damaging to the aircraft.

From 10,000 military incident reports, Owen, Nicholas & Gill identified military role equipment as the second most frequent area for errors; apart from this however the top three were Engine 17%, landing gear 13%, propeller 9%, and flying controls were 8% of all reports. Error types were; Installation 48%, transporting/driving 11% and servicing 9%.

The MAA Flight Ops Review identified the ‘Not So Magnificent Seven’ categories of common engineering flight safety events as, in order, Ground handling and towing; procedures and documentation; Installation errors, Organisational influences; Supervision; Other preconditions; and FOD and loose articles.

4.4 Errors are dominated by knowledge-based and rule-based errors

Aircraft maintenance relies heavily on rule-based and knowledge-based tasks, even though the majority of actions performed by the mechanic are skill-based. The skill based errors, though more frequent, are a much smaller percentage of the skill-based tasks undertaken, than are the rule or knowledge-based errors. In other words a rule or knowledge-based task, which by definition is more unusual and demanding, is much more likely to result in an error. Accordingly, by concentrating on reducing the number of rule-based and knowledge-based tasks, the greatest reduction in errors overall may be achieved . (Hobbs & Williamson 2002).

The NASA study (Kanki & Hobbs) found that violations, followed by knowledge-based errors, then (memory) lapses were the predominant error types. Violations were linked to management and supervision factors; knowledge-based errors related to inadequate procedures and training.

The Australian DAHRTS data confirms that nearly twice as many factors contributing to Air Safety Occurrence Reports were related to rule-based and knowledge-based errors, as opposed to skill-based errors. Given the preponderance of skill-based activities in aircraft maintenance, this underlines the importance of protecting rule and knowledge-based tasks.

4.5 Certain error types are associated with high-risk outcomes

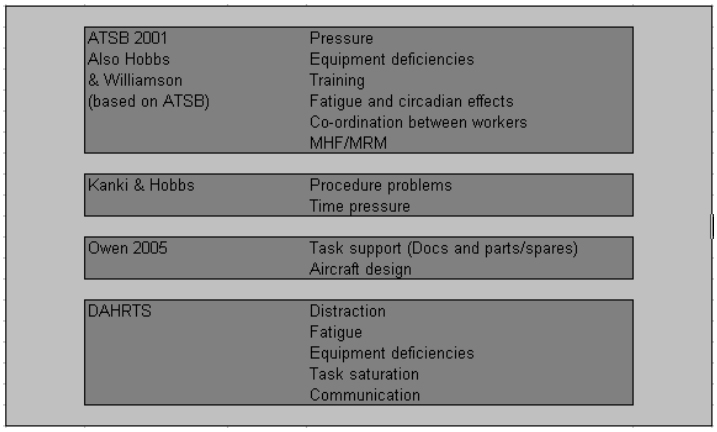
Hobbs and Williamson (Hobbs & Williamson 2002(2)) categorised errors as unintended, mistakes or violations after Reason *et. al.* and found that violations could combine with errors to generate adverse outcomes. Rates of violations had a direct and strong bearing on risk to the organisation, although skill-based errors were more commonly associated with staff injuries. Different intervention strategies are required for each type of action, but flight safety would be best improved by directing effort at reducing violations and the factors which cause them. Organisational-level issues need to be addressed.

The ATSB survey of 4,600 LAEs (ATSB 2001) identified memory lapses and procedural shortcuts as particularly important in the development of occurrences, and also suggested targeting these.

Owen, Nicholas & Gill found that the most frequent errors associated with flight operations consequences were Installation, Servicing and Fabrication (modification or construction errors).

4.6 There are common Performance Shaping Factors (PSF)

The Australian Transportation Safety Bureau (ATSB 2001) identified the following Performance Shaping Factors – Pressure; Equipment deficiencies; Training; Fatigue and circadian effects; Co-ordination between workers. Also MHF/MRM.



ATSB 2001 Also Hobbs & Williamson (based on ATSB)	Pressure Equipment deficiencies Training Fatigue and circadian effects Co-ordination between workers MHF/MRM
Kanki & Hobbs	Procedure problems Time pressure
Owen 2005	Task support (Docs and parts/spares) Aircraft design
DAHRTS	Distraction Fatigue Equipment deficiencies Task saturation Communication

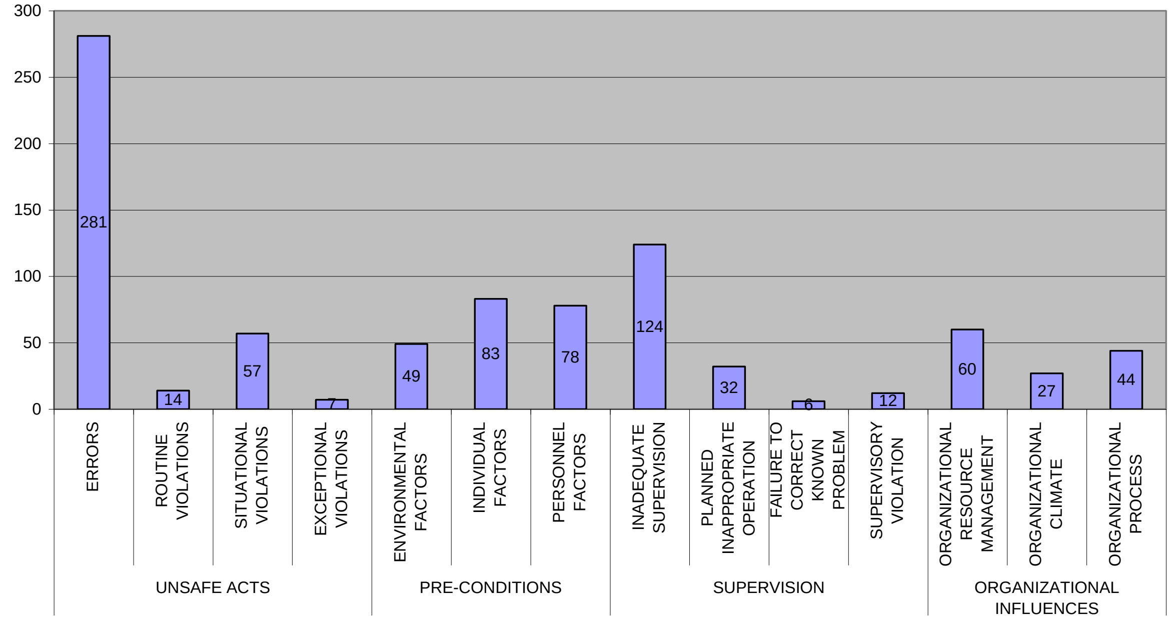
Hobbs & Williamson 2002(2), from the same data, identified identical Performance Shaping Factors.

Kanki & Hobbs identified Procedure problems and time pressure.

Owen (2005) identified Task support (Docs and parts/spares), and aircraft design.

The Australian DAHRTS database identified distraction, fatigue, deficient equipment, task saturation and communication as dominant Performance Shaping Factors.

The MAA Flight Ops Review analysed factors using the Human Factors Analysis and Coding System (HFACS) which is becoming widely accepted. An HFACS spectrum for all the occurrences categorised by the study as ‘Maintenance’ or ‘Other’ is shown below.



5 VIOLATIONS

The MAA Flight Ops Review HFACS spectrum draws attention to violations. It is important to understand that violations are frequently not culpable, but are often organisationally induced or even encouraged. They often combine with errors to produce adverse outcomes.

The DAHRTS report drew attention to violations as contributing factors, and like the MAA report distinguished between routine and exceptional violations. The incidence of violations as contributing factors was significantly high.

The FAA report 'Root Cause Analysis of Rule Violations by Aviation Maintenance Technicians' identified the pressure placed upon maintainers to complete the task, resulting in well-intentioned violations, and their consequences.

It is generally accepted that violations must be carefully considered before culpability is assumed. Routine violations are generally a problem of organisational/systemic origin. Exceptional violations may be culpable, but may also represent a genuine, if mistaken, attempt to achieve the best result for the organisation.

The most important aspect of violations is that they erode system defences which then allow errors to carry forward unchecked.

6 COSTS

Little information on costs was contained in any of these studies. However, the FAA (FAA, 1999) provides maintenance engineers with some estimates of costs of events arising from maintenance errors. For example, if the aircraft has left the gate and has to taxi back for rectification before departure, the average cost was around $15,000. The cancellation of a flight was estimated at an average $50,000. A typical ground damage incident, such as impact by a catering vehicle, cost $70,000. If an aircraft had to shut down an engine in flight and return, even if there is only trivial rectification required, the cost was estimated by FAA as around $500,000.

In 1992 GE Aircraft Engines estimated that maintenance error caused 20-30% of IFSDs, 50% of all flight delays due to engine problems and 50% of flight cancellations due to engine problems. Boeing estimated the associated costs at $9,000 per flight delay and $66,000 per cancellation, at today's values, averaged across the historic fleet.

Current figures from another major manufacturer makes the following assumptions for modern large wide-body civil aircraft:

In-flight shutdown and return - $700k to $1400k;
Cancellation - $200k to $400k;
Low speed aborted takeoff - $100k to $200k.

Where maintenance error results in consequences for flight operations, Owen, Nicholas & Gill identified a distribution as follows: IFSD 28%; Diversion 32%; Fuel dump 13% and precautionary landing 8%.

7 VALUE OF HUMAN FACTORS PROGRAMMES

The FAA has conducted a detailed study of human factors programmes globally, (Hackworth, *et al*, 2007). Particular reference is made to regulatory requirements in Europe and Canada, and to programmes in those areas and in the USA and Australia, as well as elsewhere globally. A large and highly experienced group of survey respondents formed the basis for the conclusions drawn on the effectiveness of HF programmes. The report summarises:

> *'This study reinforces the belief that maintenance human factors (MHF) programs are valuable and important, and there are a variety of such programs throughout the world... Regardless of the variety of international regulations of MHF, the industry reports that flight safety and worker safety are the primary reasons to have such programs.*
>
> *HF programs reduce cost and foster continuing safety and control of human error in maintenance. This survey found that the best targets of opportunity for improvement are use of event-data reporting, creation of a fatigue management program, and increased use of data as a means of tracking errors over time to justify the cost of HF programs'.*

8 CONCLUSIONS

There are particular aircraft systems and ATA Chapters which are at risk from human error in aircraft maintenance. Rule-based and knowledge-based tasks in these areas multiply the risks unless mitigations are put in place. Certain aircraft systems have increased likelihood of serious consequences if errors occur and reach the flight line or ramp undetected. Even well-intended violations further increase the risk.

Costs are poorly documented but on even conservative evidence there is economic justification for addressing those maintenance events which bear the greatest elements of risk.

The various studies which have been examined have sufficient agreement to identify clearly the areas where action would be most beneficial, from both cost and safety perspectives.

9 RECOMMENDATIONS

9.1 Controls to mitigate risks should be reviewed and strengthened when work is being carried out in vulnerable ATA Chapters. Those ATA Chapters (27, 32 and 71-80) identified where errors are both frequent and lead to high-risk events, should receive priority consideration.

9.2 Tasks which are rule-based or knowledge-based should be supported adequately by the internal (Planning and Quality) and external (Design Authority, Regulatory) functions.

9.3 Performance Shaping Factors should be evaluated for high-risk tasks, and where human performance is predicted to be reduced, mitigations should be devised and applied.

9.4 Aircraft design should embody error prevention and detection mechanisms such as forcing functions to reduce criticality and facilitate error recovery.

A P Simmons
For the RAeS HFG:E

Internal issues:
1st Issue 12 Jan 2009
2nd Issue 1 July 2009
3rd Issue 22 February 2010
4th Issue 18 January 2011
5th Issue 19 July 2011

Formal issue: awaited

References

Airbus (2008)
Maintenance Briefing Notes Reference : MAINT – HUM_PER_SEQ 03 – REV 01 –June 2008

ATSB (2001)
‘ATSB Survey of Licenced Aircraft Maintenance Engineers in Australia’, Australian Transportation Safety Board

CAA (2009)
UK Civil Aviation Authority Paper 2009/05 ‘*Aircraft Maintenance Incident Analysis'*

CHIRP (2011)
CHIRP ‘*Overview of CAA MOR maintenance data Jan 2005 – Dec 2010’*

EMSG (2007)
Engineering Maintenance Standing Group 'Data Sources' paper April 2007

FAA (1999)
Maintenance Resource Management Computer Based Training,
Human Error in Maintenance module, prepared under FAA contract DTFA01-94-C-01013 by Galaxy Scientific Corporation, Tucker GA. (On CD-ROM).

FAA ‘Root Cause Analysis’

Hackworth *et al*, (2007)
‘An International Survey of Maintenance Human Factors Programs’,
FAA Office of Aerospace Medicine, Washington DC

Hobbs & Williamson (2002)
‘Skills, Rules And Knowledge In Aircraft Maintenance Errors In Context’ (based on BASI study).

Hobbs & Williamson (2002(2))
‘Unsafe Acts and Unsafe Outcomes in Aircraft Maintenance’ (based on ATSB survey of 4,600 Licenced nechanics).

Kanki & Hobbs (200?)
‘Human Error Risks in Maintenance: Lessons from Confidential Incident Reports’
NASA Ames (ASRS data)

MAA (2010)
‘*UK Military Aviation Authority Flight Operations Review of Air Safety Issues in Aircraft Maintenance and Engineering Activity in 2009/10’* UK MAA

Owen (2005)
Airbus Maintenance Occurrence Database (MOD) Analysis

Owen, Nicholas & Gill (2006)
‘Maintenance Related Flight Safety Occurrence Analysis’ based on DASC data.

Appendix A

Bibliography

Alan Hobbs Ph.D. '*An Overview of Human Factors in Aviation Maintenance'* Aviation Research and Analysis Report – AR-2008-055 December 2008 ATSB TRANSPORT SAFETY REPORT

Phil Hall '*Maintenance Error Interventions'* RAeS HFG:E 2008

Dr. Adel A. Ghobbar†, Gunnar R. Ideler, and Philip M. van Meer; '*Aircraft Maintenance and Human Error Occurrences: A Combination of Multi-Taxonomy Classification Systems within Airline Operators'* Delft University of Technology, The Netherlands

Alan Hobbs, Barbara Kanki; '*Human Error Risks in Maintenance: Lessons from Confidential Incident Reports*' NASA Ames

FAA Office of Aviation Medicine, Washington, DC, '*Root Cause Analysis Of Rule Violations By Aviation Maintenance Technicians*', 2002

Alan Hobbs And Ann Williamson *'Skills, Rules And Knowledge In Aircraft Maintenance: Errors In Context*', Ergonomics, 2002 Vol 45 No 4 pp290-308

Alan Hobbs And Ann Williamson, '*Unsafe Acts And Unsafe Outcomes In Aircraft Maintenance',* Ergonomics, 2002 Vol 45 No 12 pp866-882

NOTES:

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[1] Academics recognise that tasks of different complexities are performed in different ways. Simple, well-practised tasks are performed using well-honed skills requiring little conscious thought. This is known as 'skill-based' working. When a task is less familiar, it is necessary to refer to a set of detailed instructions, and to follow those rules. This is known as 'rule-based' working and carries extra risk because of the lack of familiarity and the need to follow the rules closely. When the rules are unclear it is only possible to proceed by analysing the situation and applying knowledge. Although this is where the training and experience of a professional engineer comes into play, it is also a situation where that experienced individual is testing and learning. When engaged in 'knowledge-based' working, even experts are more likely to make errors.

[2] Following the Haddon-Cave Inquiry, the Nimrod Review Report recommended the establishment of a Military Aviation Authority in the United Kingdom.'