

Aircraft Maintenance Incident Analysis

CAP 1367



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Foreword

1. This report was originally intended to be released in 2013. This date was delayed because of the UK CAA having to carry out a review Offshore Helicopter operations in the North Sea. The UK CAA published CAP 1145 on the 20 February 2014. Some of the data which had been analysed as part of this paper was used to produce the Human Factors charts for the offshore operators in CAP 1145, Annex F. This resulted in CAP 1145, Action 30 which states that:

“The CAA will carry out a further review of Human Factors Maintenance Error data referred to in this report and publish the results to seek improvements in this important area.”

2. The research in this paper was carried out by the engineering specialist staff within the Confidential Human Incident Reporting Programme (CHIRP) using data recorded on the UK-MEMS database, supplemented by additional data on maintenance error events from reports in the CAA MOR database. The UK-MEMS database was established by CHIRP with CAA funding to provide a means of capturing the information from investigative reports into maintenance error events.
3. Further information on Maintenance Error Management Systems (MEMS) can be found in CAAIP Leaflet B-160, including the philosophy behind the reporting of maintenance errors and the actions required by organisation through their investigative processes. The CAA had also published two previous papers on Aircraft Maintenance Incident Analysis and these serve a useful background to this paper. The CAA Papers are available on the CAA web-site, reference CAA Papers 2007/04 and 2009/05.
4. A limited number of Part 145 organisations (23) have contributed the reports of their findings over the period to this database, and therefore the experience of all Part 145 organisations (in the order of 400 plus) is not necessarily captured by the UK-MEMS database alone. A preliminary analysis was presented by CHIRP to the CAA in 2009 which gave useful results but reflected only a partial analysis of the available data. Additional use has therefore been made of CAA MOR data, which perhaps better reflects the industry wide experience of maintenance error events.
5. In conjunction with the CAA’s high level HF Review, which is focused on reviewing the CAA’s strategy for HF matters across the aviation industry, and work to review and update the CAA guidance on Maintenance Error Management Systems, it was felt appropriate to carry out further work with

a view to publishing a further five year analysis over that contained in CAA Paper 2009/05.

6. Once again, this paper seeks to provide information on the common causes where maintenance error has been a contributory factor in incidents and occurrences reported to the CAA. The aim is to provide industry with a more up to date set of data which they can review and, where appropriate, use to complement their own analyses as part of their Safety Management Systems.

Executive summary

1. Maintenance Error continues to be one of the most obvious safety threats from an engineering or airworthiness perspective. Over the years, the evolution of aircraft design techniques, the use of new materials and using the learning from incidents and accidents has seen improvements in aircraft system design and component reliability. Whilst accidents due to airworthiness issues do happen they are relatively rare.
2. However, despite those improvements the system of performing maintenance remains vulnerable to the issues surrounding human factors. Humans are fallible and therefore errors and mistakes are still going to happen. It is through good training and competence assessment regimes and creating a culture that fosters good engineering practice that will reduce the likelihood of errors. The Organisation also needs to create an environment where engineers can concentrate on the task at hand without external pressures compromising the quality and integrity of the work by putting pressure on individuals to cut corners. It is these violations from process and procedures where both the individual and the organisation become exposed to accidents and incidents.
3. Training is essential as engineering skills and good practice does not materialise out of thin air. Everyone involved in aircraft maintenance should possess the necessary competence, including the required behaviours and attitudes to do the job. Procedural control is important as there is a reason why maintenance has to be done in a specific sequence. The quality of the work and the rigour with which the function checks are performed verifies the adequacy of the work that has been done. It is a continuum from start to finish and having multiple actors within the overall process it requires co-ordination and attention to detail.
4. The investigation of maintenance events is a valuable tool in the armoury for safety improvement. It allows us to look at what went wrong and why. The contributing factors of any incident are important so that we can identify interventions that will prevent, or at least minimise the chances of it happening again.
5. Human error is influenced by the individual's personal circumstances, frame of mind and approach to the job. There are many causes that lead to someone having a simple lapse in concentration that results in an error or a mistake. It is important therefore to look at corrective actions that will help the individual as well as the maintenance system.

6. Training on its own is not the solution to an issue. There is clear evidence that training is not an entirely effective way of eradicating error. It is the underlying culture and approach to safety that matters. That needs to be fostered through the organisation's values and strategic direction. The individual has to recognise that they are part of a team and that each has a role to play and standards to maintain. The unlicensed mechanic plays a vital role since it is at the point of 'doing' that many errors are made, as such, organisations need to focus on all members of staff to ensure they have the tools, training, procedures / processes and have the competence necessary to complete the assigned task consistently to a good standard.
7. That does not mean that supervision is un-necessary. It is the overall integration of the particular task and its effect on other tasks that are being worked in parallel that makes the role of the supervisor vital. It is the supervisor who manages the workload, task allocation and planning, whilst protecting individuals from external pressures and influences.
8. Senior management have an important role to create the right environment and system for people to work in. This includes providing sufficient resources, workable procedures, creating the right safety culture and a shared vision managing external pressures, providing serviceable tools and equipment. Without a system to manage human related risks maintenance errors will continue to occur.

Chapter 1

Introduction

- 1.1 Following a number of high profile maintenance error events in the early 1990's considerable work was done in looking at the issue of human factors (HF) and human performance within aircraft maintenance. It appeared that the growing complexity of aircraft technologies, the prevalence for carrying out maintenance during the night and the impact of the increased pressure on the commercial needs of the operation all had the potential to create an environment where the potential for error could exist.
- 1.2 As part of that HF focus, the need to make engineering staff aware of the potential pitfalls associated with human error and performance gathered some support. The concept of error investigation took hold and several schemes and basic investigative tools followed. However, identifying the root cause was one thing, knowing how to address it was something else.
- 1.3 This led to the introduction of HF training requirements for all maintenance staff, at both an initial and continuation training level. These requirements were introduced into JAR-145¹ and remain an essential element of the new EASA Part 145 rule. In addition, a syllabus of training was developed for licensed engineers and included as module 9 in Part 66². The Part 145 requirements were similarly enhanced by the provision of typical subjects for study in the associated guidance. To provide further guidance to JAR-145 organisations about their responsibilities regarding management of human factors the CAA published CAP 716³ in January 2002. This gave information on safety culture, error reporting, error management programme and training.
- 1.4 CAA Papers 2007/05⁴ and 2009/04⁵ reported on research into the common causes or factors associated with incidents attributable to maintenance error. The work in the earlier 2007 paper covered the periods from 1996 to 2005 with the later 2009 paper extending that analysis to include data from reports received during 2006.

¹ Introduced into JAR-145.A.30 and A.35 in Amendment 5

² JAR-66 was introduced in 1998 but was subsequently supported by the issue of CAP 715 – An introduction to Aircraft Maintenance Engineering Human Factors for JAR-66, January 2002

³ CAP 716 – Aviation Maintenance Human Factors (EASA / JAR 145 Approved Organisations) – guidance material on the UK CAA Interpretation of Part 145 Human Factors and Error Management Requirements, first issued January 2002

⁴ CAA Paper 2007/05 – Aircraft Maintenance Incident Analysis, December 2007

⁵ CAA Paper 2009/04 – Aircraft Maintenance Incident Analysis, July 2009

- 1.5 Almost 4000 MORs were analysed in the data set associated with these studies, primarily for aircraft above 5700 kgs MAUW. Those two analyses validated the chosen taxonomy and helped identify emerging themes or trends.
- 1.6 In 2005, the CAA had sponsored the setting up of a maintenance error database under the auspices of the Confidential Human Incident Reporting Programme (CHIRP)⁶ at their Farnborough offices. The purpose of this was to record information supplied by a number of pilot Part 145 organisations from their internal investigations into maintenance error events.
- 1.7 These investigations were part of the process assigned to the organisations' Maintenance Error Management System (MEMS), where error events or incidents were analysed in detail to establish the underlying causal factors, and associated root cause, with a view to using that learning to help reduce the future potential for similar errors. The whole purpose of the UK MEMS database was to collate and share the results of the investigations for the greater benefit of all organisations. In essence, the MEMS process readily forms a sub-set of an expected risk analysis and response mechanism under an organisation's Safety Management System (SMS).
- 1.8 The MEMS requirements are outlined in guidance contained in CAAIP Leaflet B-160 (previously Airworthiness Notice No. 71)⁷ and stem from the need for an approved organisation to have an internal investigation system under Part 145.A.60. This is a legally required element of the Part 145 approval as it falls under Regulation (EC) 2042/2003, as amended. All Part 145 organisations are therefore required to have such systems, whether working on whole aircraft or aircraft components. The content of Leaflet B-160 has recently been amended, in July 2012, to align MEMS policy with the latest EASA requirements and with the introduction of SMS that is now taking place.
- 1.9 In addition, organisations are required to make reports under the provisions of the CAA's Mandatory Occurrence Reporting (MOR) Scheme. This is enacted through the legal provisions of the UK Air Navigation Order and amplified through CAP 382. That document was also amended, in March 2011, to take account and enact into UK legislation the requirements of the European Directive on Occurrence Reporting, EU Directive 2003/42/EC. It should be noted that the revised MOR provisions require incidences of human factors or maintenance error to be reported to the CAA (reference

⁶ CHIRP is a charitable trust that had its roots in the Aviation School of Medicine and their interest in human performance issue relating to flight crew, subsequently extended to include aircraft maintenance engineers.

⁷ The MEMS guidance was first issued in March 2000.

CAP 382, Appendix B). It therefore lends itself to MEMS becoming a useful tool to follow up MORs and provide supplementary reports.

- 1.10 The purpose of this study, which was carried out by CHIRP on behalf of the CAA, was twofold. The first aim was to collate updated information on maintenance error related events and data up to the end of 2011 has been included in the study. The second element was to try and obtain information on the current safety threats from maintenance error and to try and determine if the current application of HF training is effective.
- 1.11 A copy of the database containing the analysed information, coded and classified by CHIRP, formed a deliverable to the CAA under this project. CHIRP staff collated and analysed the majority of the data upon which this paper is based and the CAA expresses its thanks to the CHIRP team for their efforts and diligence.

Chapter 2

The analysis of incident data

- 2.1 The CAA MOR data set analysed by CHIRP comprised 2733 maintenance occurrence reports covering the period from January 2005 to December 2011. This data set contained 2399 reports relating to large aeroplanes, 85 relating to large helicopters and 249 relating to small aircraft (below 5700 kgs). It is not known what proportion of the actual number of events across the industry this represents as it is wholly dependent upon reports being submitted to the CAA, despite the reporting of such incidents being mandated under the MOR scheme.
- 2.2 The following information for each CAA Occurrence Report was provided to CHIRP for them to analyse:
- Aircraft type;
 - Occurrence number;
 - Occurrence grade classification;
 - Occurrence date;
 - Operator / maintainer;
 - Aircraft manufacturer;
 - Event descriptor;
 - Pre-title;
 - Précis of the event and investigation;
 - ATA chapter.
- 2.3 Whilst this data set is slightly different from those used in the research under the previous CAA Papers, the key elements were still present and therefore it is believed that there remains a fair degree of consistency in the methodology for the data analysis and therefore in the results obtained.
- 2.4 There were notable differences between the data on the CHIRP-MEMS database and that supplied by the CAA from the MOR records system. In many cases, the reporting organisation provided basic information on the incident to the CAA to satisfy compliance with the MOR requirements but did then go on, at the end of the investigation to supply more detailed information to CHIRP for their MEMS database and subsequent analysis. Whilst the perceived need for individuals to restrict information reported to

the CAA is understood there is a confidential route available under the CAA MOR system⁸.

- 2.5 In some instances, the MOR system had a record of a report being made whilst there was no comparable information within the UK-MEMS database, and vice versa. CHIRP therefore took information from both sources to better populate the spreadsheet for a more complete analysis.
- 2.6 In the case of CAA supplied MOR data, the information provided was subject to the CAA's normal provisions regarding confidentiality of data⁹. The use of UK-MEMS data was further enhanced by the CHIRP protocols on dis-identifying personal data within their database. The data set therefore provided a suitable level of confidentiality for individuals whilst retaining enough markers within the data to allow analysis in accordance with the developed taxonomy.
- 2.7 Although the analysis and information in this review covers large aeroplanes, large helicopters and small aircraft the data has been analysed both collectively and independently so information on common themes for each sub-set is available. As in the previous CAA Papers this study concentrates on the larger fixed-wing transport aircraft in order to maintain a degree of consistency against the earlier data and findings wherever possible.
- 2.8 It was felt that the large helicopter population, with the increased complexity of such rotorcraft, merited study in its own right. Accordingly some separate analysis on that data set has been made to determine if there are sector specific trends that can be identified.
- 2.9 It was felt that small aircraft should be included and this also aligns with the work that CAA has done in creating a new General Aviation Unit. Statistical data and analysis for this additional sector has therefore been included in this paper. However, given the lack of information on GA aircraft, the results of the analysis can only be indicative, not necessarily wholly representative of the issues.

⁸ The MOR confidential route allows the CAA to have access to the reporter in order to follow up on the details of the incident without the reporter's identity being released to third parties. This allows the CAA to investigate the MOR if necessary without compromising the reporter. Anonymous reports are not accepted under the MOR system.

⁹ The CAA MOR scheme does have a confidential reporting provision within it where the identity of the reporter is kept confidential during any investigation. However, many individuals believe that this is not sufficient. In the early stages of the MEMS programme, the CAA agreed that the database would be held by CHIRP to allay some of the expressed concerns over confidentiality. The disclosure of data regarding individuals is covered by the CAA's compliance with the Data Protection Act.

Chapter 3

MEMS

Background

- 3.1 There is a considerable amount of general literature available on human error in the public domain and many documents published in recent years have been more focused towards aircraft maintenance in particular. This reflects the increasing interest in engineering related incidents.
- 3.2 The available literature includes developed and mature aircraft maintenance error taxonomies including the original outline of Boeing Maintenance Error Decision Aid (MEDA – Rankin et al, 2000), Human Factors Analysis and Classification System – Maintenance Extension (HFACS – ME – Weigmann and Shappell, 1997) and the baseline ICAO ADREP 2000 system. The basic philosophies behind these concepts have been refined in the light of experience and for example, in the case of MEDA, adapted to suit other aircraft maintenance applications such as workshops. A number of consultancies have also developed the original concept to suit a range of different scenarios and organisational capabilities.
- 3.3 The US FAA has also remained quite active in looking at HF issues in aircraft maintenance and their HF web-site, https://www.faa.gov/about/initiatives/maintenance_hf/, continues to provide a wealth of material that is worthy of scrutiny by those interested in the subject.
- 3.4 The original CAA guidance on MEMS¹⁰ referred to the need for a methodical and objective approach to error investigation, the adoption of a 'just culture' and the need to report and collate data across the industry to get the best learning out of the analysis. This guidance was re-issued as CAAIP Leaflet B-160¹¹. The latest changes provide alignment against the requirements for organisations to have an SMS and, following the learning experience since MEMS was first launched, also better indicates what is expected now within a functional MEMS process.
- 3.5 It is clear that many organisations have no formal error capture and investigative mechanisms, even some 10 years after MEMS was initiated. Whilst it is accepted that many such organisations are small and cannot

¹⁰ Originally Airworthiness Notice No. 71.

¹¹ Part of CAP 562 - Civil Aviation Airworthiness Inspections and Procedures (CAAIP)

afford the cost of dedicated staff to the task, it is naïve to think that errors simply do not occur. It is equally important for small organisations to recognise the safety issues associated with maintenance error as the company may be carrying out work on safety critical components. There is a need therefore to perhaps refocus attention among organisations to the need for policy and procedures in this area.

- 3.6 Even where organisations have put in place an effective MEMS system the extent to which detailed error investigations are conducted appears to have decreased based on recent submissions to UK-MEMS. This suggests that the industry's commitment to error investigation has waned. This may be because the benefits that can accrue from the identification of root cause and putting in place suitable corrective actions are not readily quantifiable, or industry is becoming complacent.
- 3.7 However, the risks arising from maintenance error continue and, if left unaddressed, will inevitably result in an aircraft incident and possibly the worst case scenario, a fatal accident. It is essential that organisations work proactively wherever possible to reduce or eliminate the potential for error. As with any system that does not result in an immediate and identifiable economic return the organisation has to believe that it is a valuable exercise. There is some truth in the phrase, 'if you think safety is expensive, try an accident'.

The UK-MEMS programme

- 3.8 When the CAA introduced requirements in 2000 for MEMS industry expressed concerns about the way in which the data may be misused, particularly if it was possible to identify the organisation, or more especially, the individuals concerned.
- 3.9 However, the CAA still saw benefits in the detail of the reports being collated and analysed periodically so that trends and common themes could be identified. This would help industry to capitalise their efforts and target them on coherent solutions.
- 3.10 The CAA established an agreement with CHIRP for them to set up a database to collate the data reported from the output of organisation MEMS investigations. This did not do away with the need to submit MORs in respect of incidents. It did, however, provide a continuing avenue for the detail behind the investigations to be dealt with by CHIRP as an independent body.
- 3.11 Despite subsequent attempts to roll the programme out across the UK industry, the UK-MEMS programme has failed to achieve wider penetration

into the UK industry beyond the 23 pilot organisations that have largely contributed from the outset of the initiative. There are some 460 UK organisations that hold Part 145 approval and therefore greater scope for reports to be made and analysed for the wider benefit of industry.

The UK-MEMS group

- 3.12 In order to support the UK-MEMS initiative within CHIRP, it was decided to establish an industry group to 'manage' the interface with the database and the general principles of error management within the industry. This activity of the group, UK-MEMS, was mainly focused upon the pilot scheme members. The terms of reference were aimed at helping develop policy relating to MEMS and engender better understanding of the issues among the members. A close liaison between Deputy Director - Engineering CHIRP¹² and the UK-MEMS group was also achieved.
- 3.13 The membership of the UK MEMS group has subsequently been expanded over the original members and now includes representatives from the major UK airlines, Qinetiq, the Military Aviation Authority and of course the CAA.
- 3.14 The discussions within the group have also expanded out from the original focus on MEMS to include wider discussions on fatigue, human performance issues and safety management systems.
- 3.15 The UK MEMS group does not represent all organisations that are required to have a maintenance error management system. This is an issue that the group has considered before, and are reviewing their constitution to widen their remit.
- 3.16 It would also be helpful to consider the group's terms of reference vis-à-vis being an expert group for MEMS to sit in collaboration with the UK CAA, as a CAA/industry committee, and offer advice on such matters as may be agreed. This will provide a more substantive basis for the group to act as the interface between industry and the regulator on MEMS issues.

¹² Deputy Director Engineering at CHIRP maintains the responsibility for Engineering related reports to CHIRP but also the UK MEMS database and consequently sits on the UK-MEMS Group.

Chapter 4

Methodology for the analysis

Background

- 4.1 The MOR data supplied by the CAA was collated and put into a spreadsheet. This ensured consistency of the data within the spreadsheet. The data was then analysed individually to determine the nature of the event, the underlying causes and any contributing factors.
- 4.2 The taxonomy used followed the general categories that had been developed in the earlier papers. However, in order to focus on certain particular issues the terminology does differ slightly. Comparisons can still be drawn between the earlier papers and this review and have been included where appropriate in this paper.
- 4.3 It is clear that the amount and quality of information reported to the CAA varies from organisation to organisation. In many cases an MOR will provide only superficial details of the event and the initial action taken to resolve the issue. Longer term actions, such as the subsequent amendment of procedures may not be reflected in the data filed against the MOR. This means that the analysis is limited to the information held. This may be something that needs to be addressed for future analysis.
- 4.4 It was also noted that the amount of information held under the UK-MEMS system varied and, more worryingly, has become more superficial in the last year or so. This may be simply the consequences of increased pressures on organisational resources committed to MEMS investigations. It may also reflect a shift in industry's perceived value of the MEMS process since, to date, there has been little feedback to the industry on information supplied under the scheme.

Taxonomy

- 4.5 It was also noted that the amount of information held under the UK-MEMS system varied and, more worryingly, has become more superficial in the last year or so. This may be simply the consequences of increased pressures on organisational resources committed to MEMS investigations. It may also reflect a shift in industry's perceived value of the MEMS process since, to date, there has been little feedback to the industry on information supplied under the scheme.

- MOR number from CAA database
- Error type (by analysis of the event)
- Date of the event
- Aircraft type (e.g. Boeing 757)
- Operator (where available)
- ATA chapter and sub-set (to help analysis by ATA system)
- Manufacturer (e.g. Boeing, Airbus)
- Primary error / key causal factor
- Aircraft category (e.g. large aeroplane, large helicopter)
- Pre-title (summary of the event)
- Précis (main content of the MOR report)

- 4.6 The data was entered into an Excel spreadsheet and set up so that the data streams, e.g. aircraft type, could be sifted and the information presented in different ways. This allowed maximum flexibility in carrying out a partial or selective analysis on the data to identify any particular themes of interest.
- 4.7 It was clear from the data held by CAA in its MOR database that there was a repeat of the experience from the two previous analyses. The low level of detail in the MOR maintenance occurrence reports determined the extent to which the data could be analysed. Once again, the use of the MEDA reporting and investigative tool would provide additional data that could be beneficial to identifying a more comprehensive approach to identifying safety interventions to respond to a maintenance error threat.
- 4.8 It is recognised however that the limited submission of data to UK-MEMS does not necessarily complement the MOR data. For an analysis to be comprehensive and reflective of the whole industry experience there needs to be more data submitted.
- 4.9 In addition to the core data supplied by the CAA, further parameters were added to the Excel database to identify the ATA Chapter, aircraft system and the maintenance error type. The background experience of the Deputy Director (Engineering) CHIRP ensured that some level of consistency of approach and categorisation was achieved in looking at the data.
- 4.10 A number of occurrences were removed from the data set, as in the previous analyses, as they were considered to fall outside the scope of the study as it related specifically to maintenance error events.
- 4.11 One point of interest during the analysis was to see whether the introduction of new European regulatory requirements in the form of Part M