

Aircraft Maintenance Incident Analysis

CAP 1367



Published by the Civil Aviation Authority, 2015

Civil Aviation Authority,
Aviation House,
Gatwick Airport South,
West Sussex,
RH6 0YR.

You can copy and use this text but please ensure you always use the most up to date version and use it in context so as not to be misleading, and credit the CAA.

The latest version of this document is available in electronic format at www.caa.co.uk.

Enquiries regarding the content of this publication should be addressed to:

Airworthiness,
Safety and Airspace Regulation Group,
Aviation House,
Gatwick Airport South,
West Sussex,
RH6 0YR

Contents

Contents.....	2
Foreword	4
Executive summary	6
Chapter 1.....	8
Introduction	8
Chapter 2.....	11
The analysis of incident data	11
Chapter 3.....	13
MEMS	13
Background	13
The UK-MEMS programme	14
The UK-MEMS group	15
Chapter 4.....	16
Methodology for the analysis.....	16
Background	16
Taxonomy	16
Baseline analysis results	18
Chapter 5.....	28
Detailed analysis for large aircraft	28
Large aircraft global statistics	28
Large aircraft maintenance error types.....	32
Aircraft type analysis	34
Chapter 6.....	40
Detailed analysis for small aircraft.....	40

Small aircraft global statistics	40
Small aircraft maintenance error types.....	43
Chapter 7.....	46
Detailed analysis for large helicopters.....	46
Chapter 8.....	48
Examples of maintenance error	48
Chapter 9.....	57
Summary.....	57
Chapter 10.....	59
Conclusions.....	59
Actions to the CAA	59
Recommendations to operators, PART M and PART 145 organisations	59

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

and Part 145¹³ had any effect. This introduced some new aspects to maintenance management procedures and the analysis was able to capture some events which appeared to be triggered as a result of the new requirements.

- 4.12 The previous reports, CAA Papers 2009/05 and 2007/04 had also identified a number of high risk occurrences. These were not drawn out in the CHIRP analysis of the data. Further work was however done to identify some events where there had been a higher safety risk and some of these have been included in a later section of the report to give an idea on how maintenance error can manifest itself.

Baseline analysis results

- 4.13 The resulting data set for the period covered 2733 events and these were analysed in accordance with the above taxonomy. The breakdown by aircraft category is shown in figure 1.

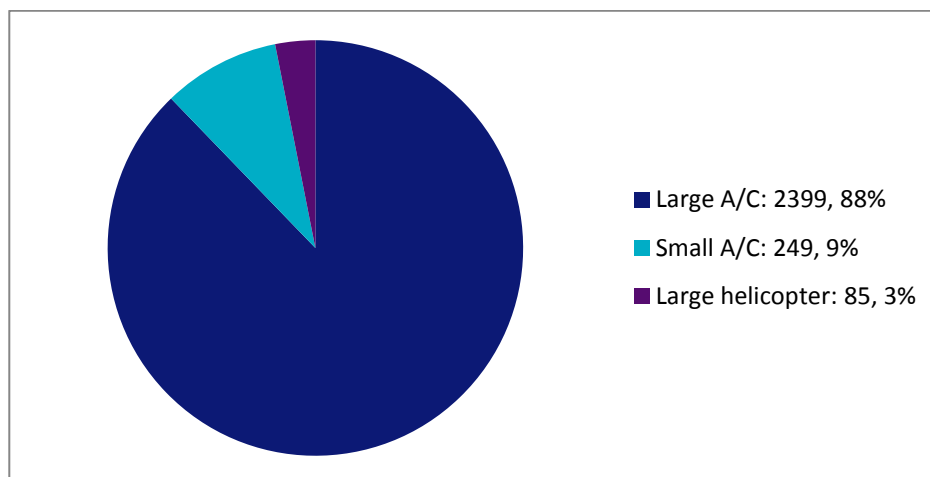


Figure 1: Overall breakdown of analysis

- 4.14 It can be seen that with 88% the largest proportion of events relate to large aeroplanes. This is not surprising as the 'mandatory' elements of the MOR scheme apply to these aircraft rather than the smaller, more General Aviation focused sectors.
- 4.15 Large helicopters, the bulk of which are operated in support of the North Sea oil industry or for search and rescue purposes made up only 3% of the data set. The total UK fleet of such helicopters is small in relation to the equivalent fixed wing fleet. Despite this, the relatively low level of reported events is surprising given the knowledge that there is a greater intensity of maintenance activities on such aircraft.

¹³ Part M and PART145 are included as Annexes 1 and 2 respectively to Regulation (EC) 2042/2003 as amended.

- 4.16 Small aircraft reported incidents, both aeroplanes and helicopters, contributed to only 9% of the total. It should be noted that it is not mandatory to submit reports for many events related to small aircraft so there are likely to be additional events that are not captured in the MOR data held by the CAA. The focus of this review is therefore understandably and predominantly related to large aircraft and those used for commercial air transport.
- 4.17 The data set broke down into events related to Part M – maintenance management issues and maintenance error events. The analysis is shown in figure 2. It can be seen that, whilst there were small variations in the balance between the two classes of events the proportion was relatively consistent across the aircraft categories. What is significant is the slightly larger proportion of Part M – maintenance management issues reported for large helicopters. Since these relate mainly to maintenance overruns on life limited components this is not surprising given the much larger number of life controls and overhaul periods prescribed for such aircraft. This can also be linked to errors introduced during the migration of data to new computer systems.

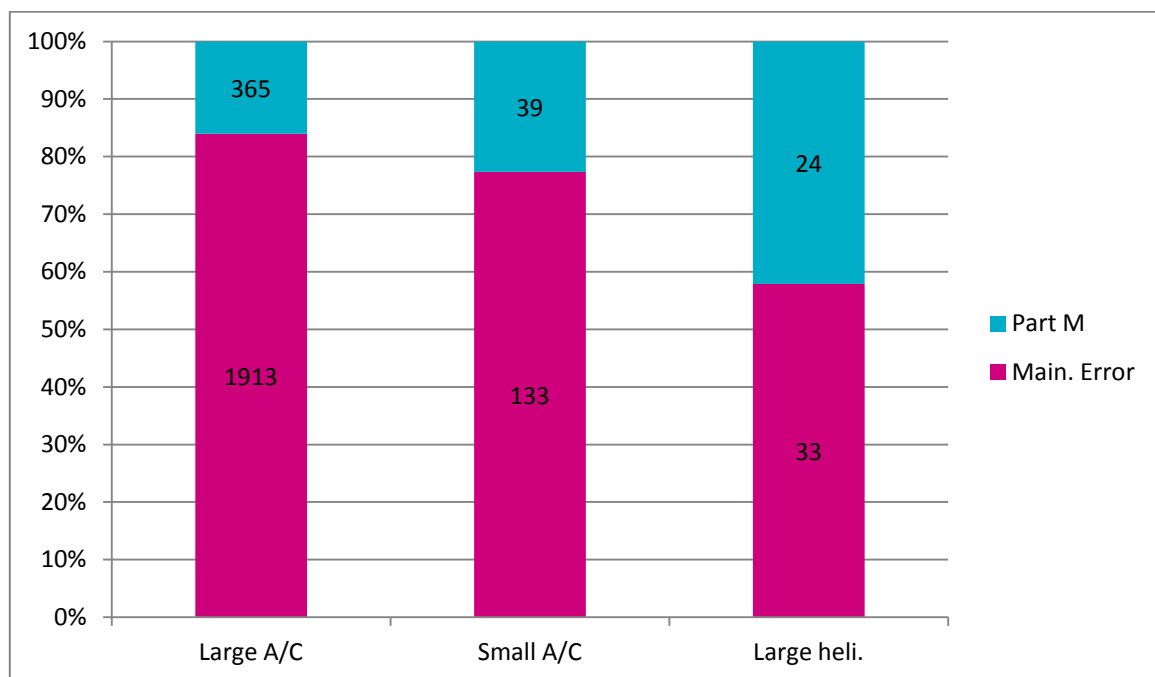


Figure 2: Breakdown of events, Part M vs maintenance error

- 4.18 The occurrences of maintenance error can be further analysed at a high level to show a correlation with the CAA classification of the MOR when received by the CAA. This is shown in Figure 3. The most significant MORs, typically involving accidents, are classified as category A with the lesser reports, usually closed on receipt by the CAA as category D.

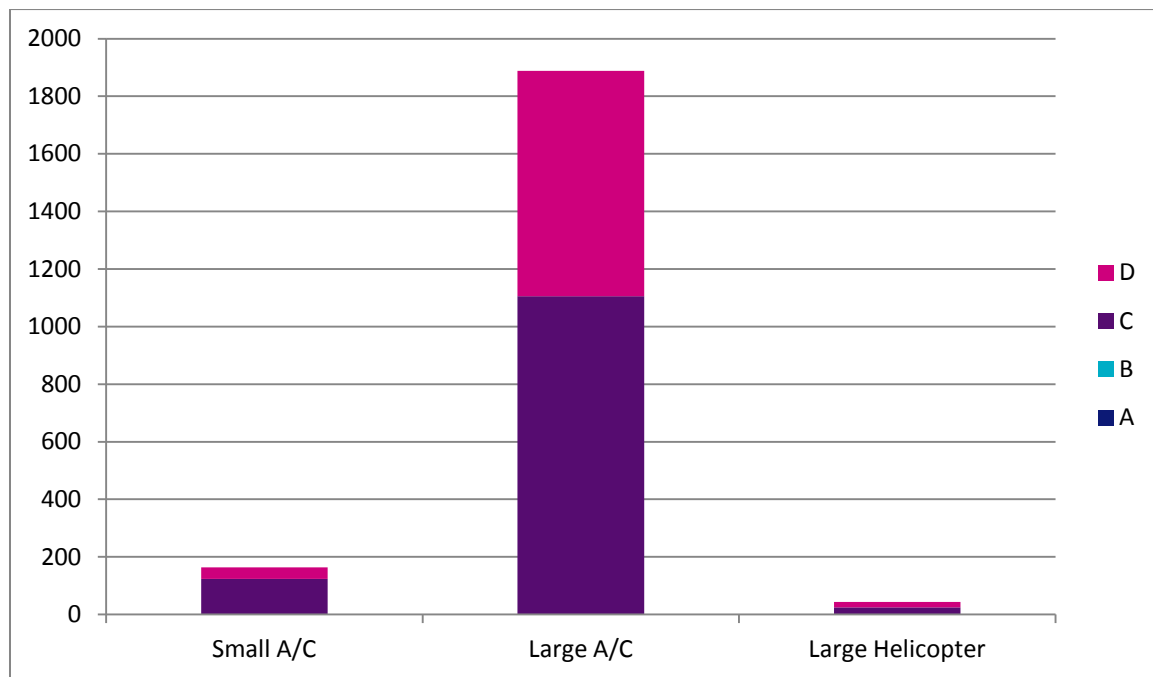


Figure 3: Maintenance error-risk distribution, all categories 2005-2011

- 4.19 It can be seen from this that the bulk of the maintenance related MORs are classified by the CAA as Category C. That does not mean they are not significant and many require CAA investigation of the circumstances surrounding the MOR.
- 4.20 There are two reasons for this. The first is to ensure that the operator or maintenance organisation is reacting properly to the occurrence. This will initially be to rectify the problem in order to return the aircraft to service. The secondary function will be to further analyse the event and determine the root cause in order to put in place corrective measures to prevent a reoccurrence.
- 4.21 By comparison, the further high level analysis of the Part M related errors yields the results shown in figure 4.

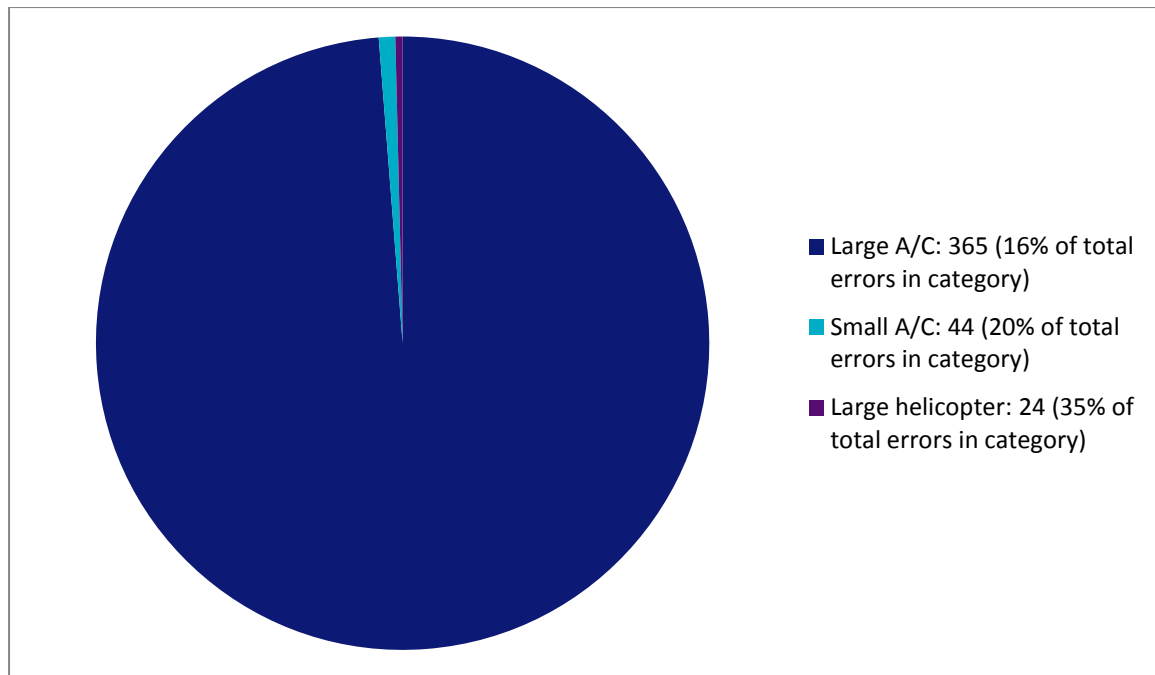


Figure 4: Distributions of Part M errors reported 2005-2011

- 4.22 Figure 4 shows that there were 433 reported Part M errors. Of these 303 (70%) related to overrun of overhaul lives, airworthiness directives or maintenance inspections called out as part of the Approved Maintenance Programme, of these approximately 40 reports indicated a non-compliance with an Airworthiness Directive. This is often a reflection of poor maintenance planning where due maintenance is not carried out and not re-planned within the appropriate timescale. In some instances the overrun is linked to a data entry issues. A more detailed review of the contributing causes also suggests that there may be some evidence of a conflict between the accomplishment of the work and commercial pressures to continue operating the aircraft.
- 4.23 A further 130 (30%) reports highlight errors in setting up the data in the first place. These errors are often simple transcription errors between the hard copy paperwork following maintenance and the electronic database used to manage the planning function. For example, inputting component life data following their fitment to the aircraft and forecasting next due tasks. Such errors can lead to an overrun if not detected by some other intermediate means, such as unscheduled component replacement or a detailed audit of the database.
- 4.24 The final baseline or high level category to pick up on is the number of reports that are attributable to manufacture and overhaul, see Figure 3.

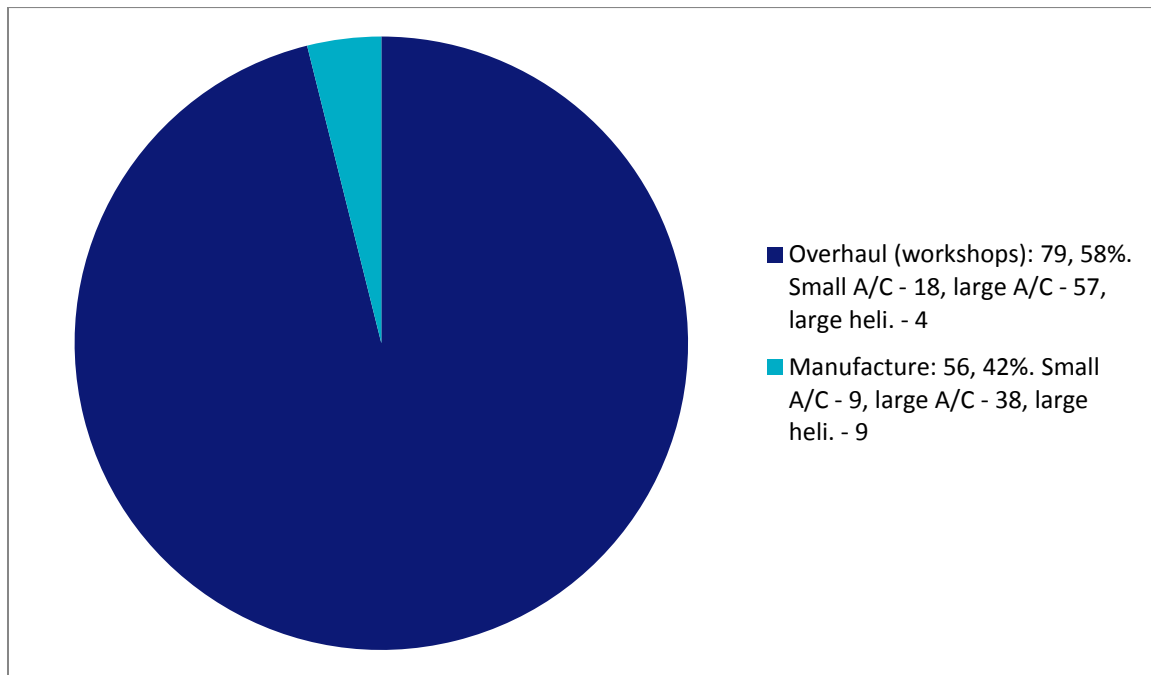


Figure 5: Distribution of events considered as manufacturer or overhaul errors, data 2005-2011

- 4.25 These are events which, following analysis of the underlying circumstances, are issues that have their roots in an error at the time of manufacture or which are attributed to an overhaul agency and not therefore a direct error within the operator's system. Both of these failures can involve human error but the fact that they occurred in third party organisations clouds the available data and the ability to mine the data and find the underlying root causes.
- 4.26 Manufacturing error should be captured within the production and inspection system. Any deviations should be the subject of design concession but the assembly of complex components is no different from the maintenance activity that ultimately can give rise to maintenance error, e.g. mis-assembly, incorrect parts fitted etc.
- 4.27 It is logical that as much attention should be given to such errors but the current requirements under Part 21¹⁴ do not require an error management or capture system in the same way that Part 145 does. This is perhaps something that EASA ought to consider for future amendments to Part 21.
- 4.28 The manufacturing and overhaul events together constitute 135 events or approximately 4.9% of the total reported MORs. It is interesting to note that not all of the manufacture events are down to a physical error. Many are due to technical authorship errors in the approved data. The distribution over the period from 2005 – 2011 is shown in figure 6.

¹⁴ Part 21 forms part of Regulation (EC) 16702/2003 as amended.

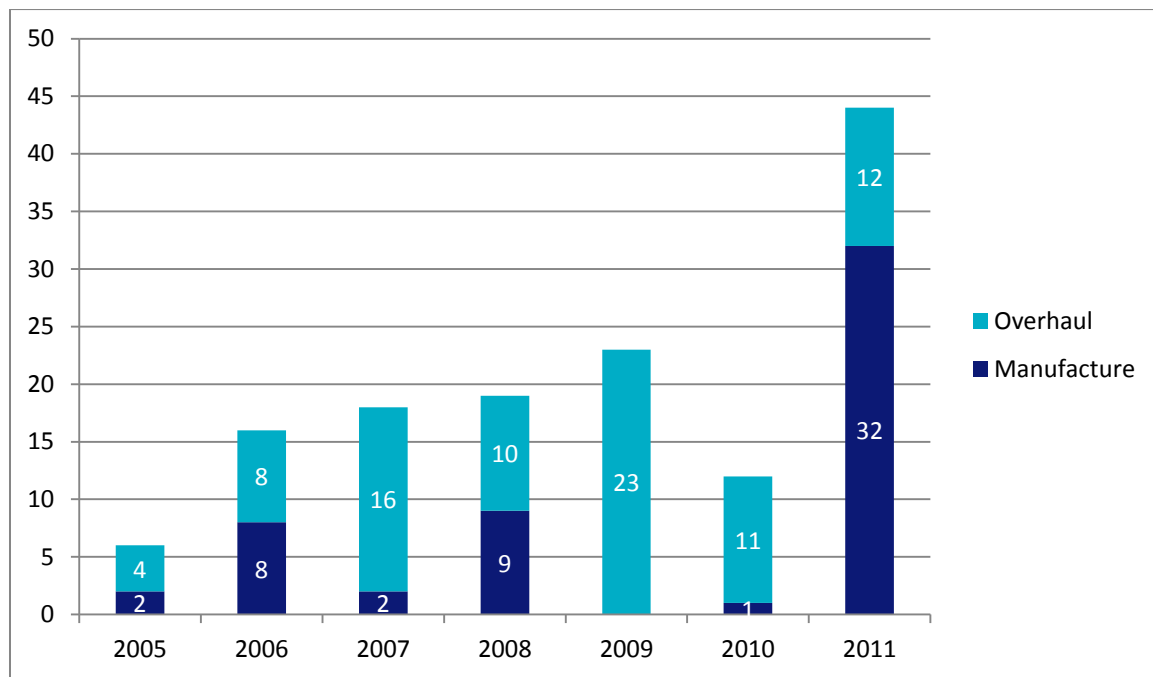


Figure 6: Error reports attributable to manufacture or overhaul

- 4.29 It is clear that the inclusion of manufacture or production events in the data suggests these activities should indeed also be considered in the context of the application of an error management system. The potential for an incident or accident is equally as significant as for maintenance activities.
- 4.30 The overhaul function, since it is another form of maintenance activity, is already covered by the need to have a MEMS process under Part 145. However, many organisations do not have the formal investigative tools, such as MEDA, in place and therefore some additional focus may need to be made in order to address maintenance error within those organisations. These issues will be considered further by CAA in conjunction with EASA.
- 4.31 The number of maintenance related MORs received each year is shown in figure 7. It can be seen that the overall reporting levels are fairly consistent.
- 4.32 No explanation can be made for the apparent decrease in reporting in 2010 although it is recognised that the overall level of industry activity, in terms of aircraft operation had decreased as a result of the global financial crisis. The increase in reports for 2011 perhaps reflects increasing ‘commercial’ pressure and the resulting impact of manpower reductions increasing the risk of an error being made.
- 4.33 The increasing trend noted in Part M reflects the introduction of the Part M requirements in 2005 and the learning curve associated with the transition to the new structure. Further detail on the typical error causes is given in later Chapters.

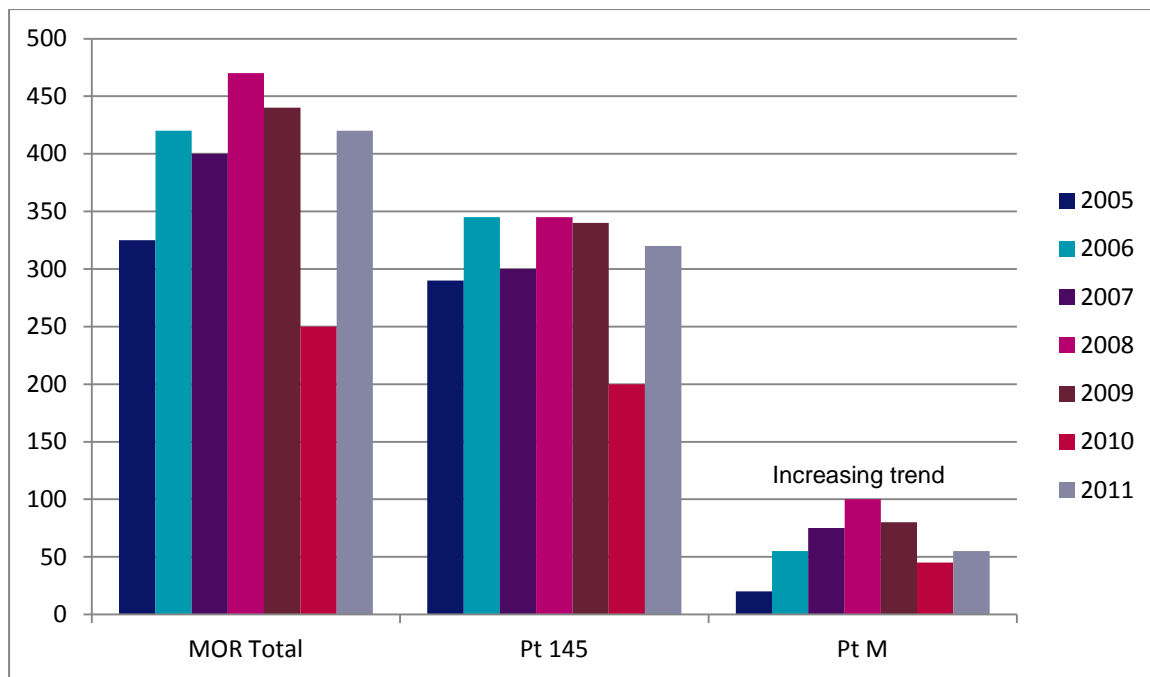


Figure 7: Maintenance MOR reporting levels 2005-2011

4.34 The high level analysis allowed identification of maintenance errors by ATA Chapter, presented graphically in Figure 8.

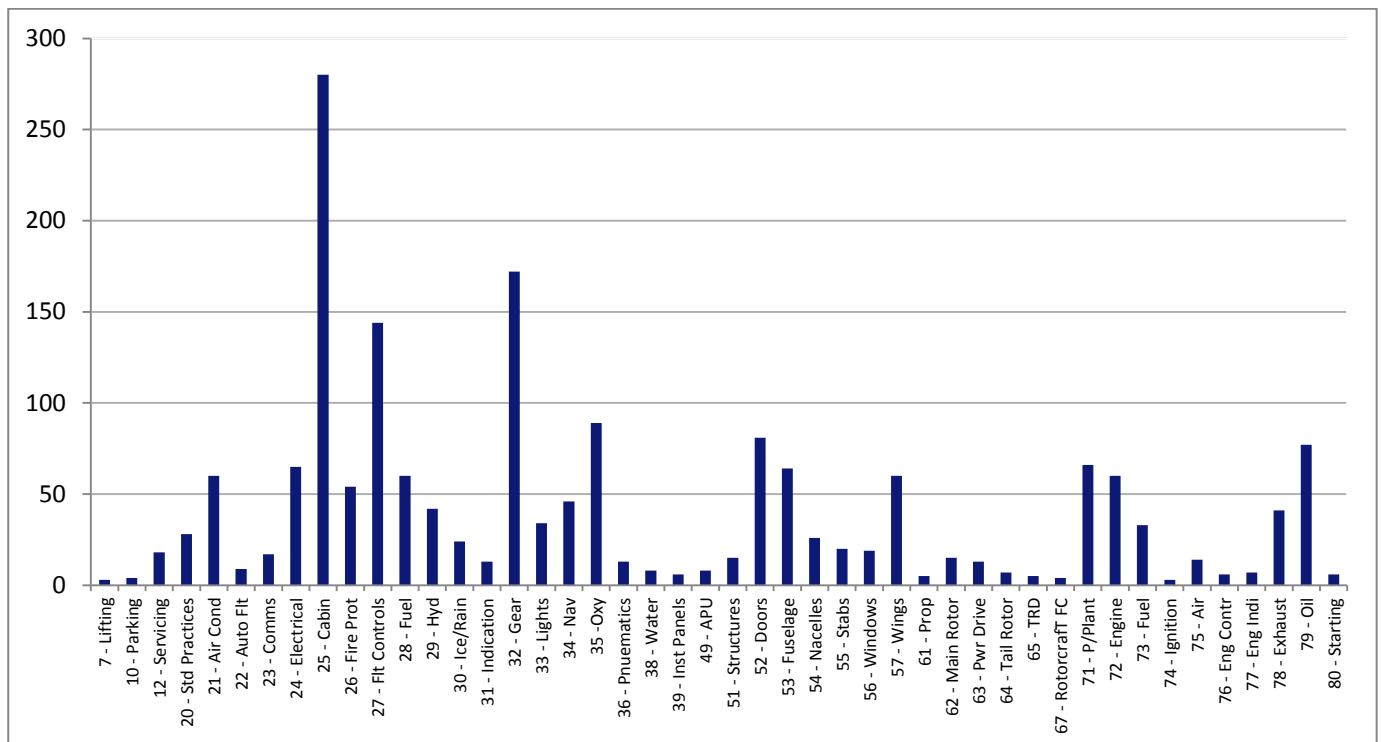


Figure 8: Global maintenance error events by ATA chapter

- 4.35 From this it can be seen that the main ATA Chapters that appear to attract a maintenance error events are:

ATA 25 cabin / safety equipment	11%
ATA 32 landing gear / undercarriage	8%
ATA 27 flight controls	6%
ATA 35 oxygen	4%
ATA 52 doors	3%
ATA 79 engine oil	3%

- 4.36 That does not mean that errors do not occur in the other areas of maintenance activity. Most ATA Chapters have seen some incidence of error. It is interesting to note that Chapter 25 covers a variety of maintenance tasks, ranging from seat installation and condition to the installation of safety equipment. There is a significant difference in the potential safety threat if an error is made fitting the wrong style of cushion to incorrectly fitting an emergency escape slide to a door. This will be discussed further in Section 5.

- 4.37 Figure 9 shows the change in reporting trends over the period analysed. Although there is some variation year on year the overall figures for these ATA Chapters is fairly consistent with the exception of ATA Chapter 25, Cabin/Safety Equipment. There is no obvious explanation identifiable in the MOR data for the apparent reduction in the number of incidents for ATA 25. It can only be concluded that the incidents are not being reported as they ought to be or tasks not read as frequently.

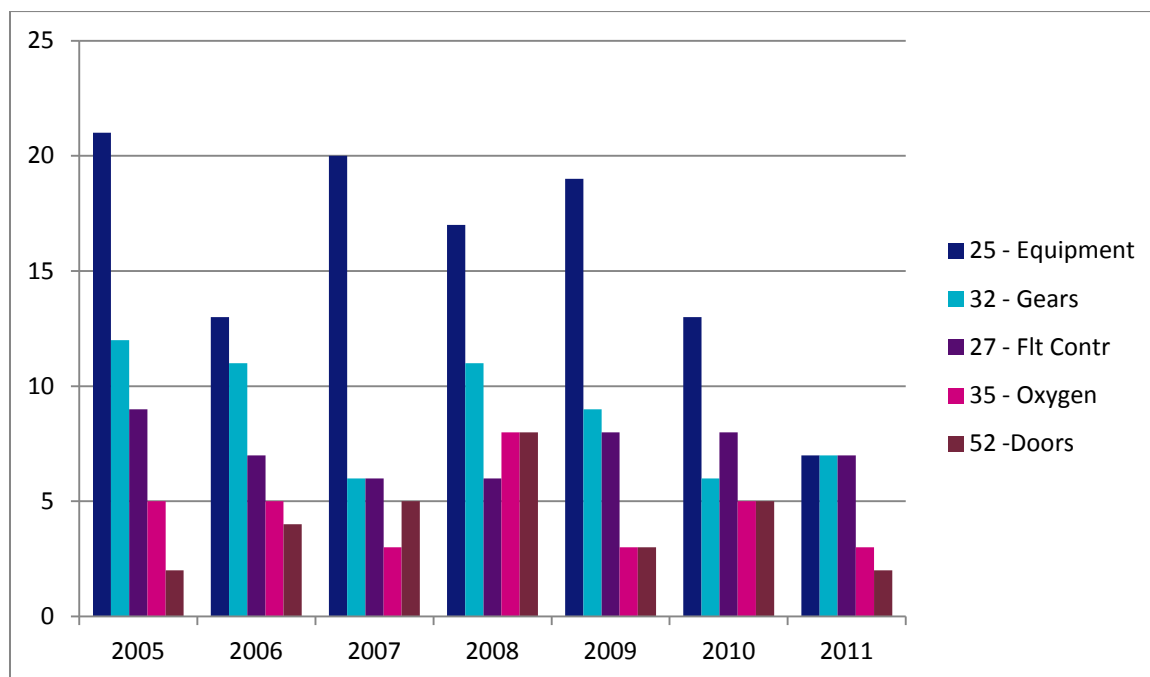


Figure 9: Reporting trends primary ATA chapters as % of total yearly maintenance error MOR

4.38 The more detailed analysis of the root cause of the events is also able to be derived. This is shown in Figure 10 for the global data set.

4.39 The 100% figure represents 2108 MORs overall, 1890 for large aircraft, 174 for small aircraft and 44 for large helicopters.

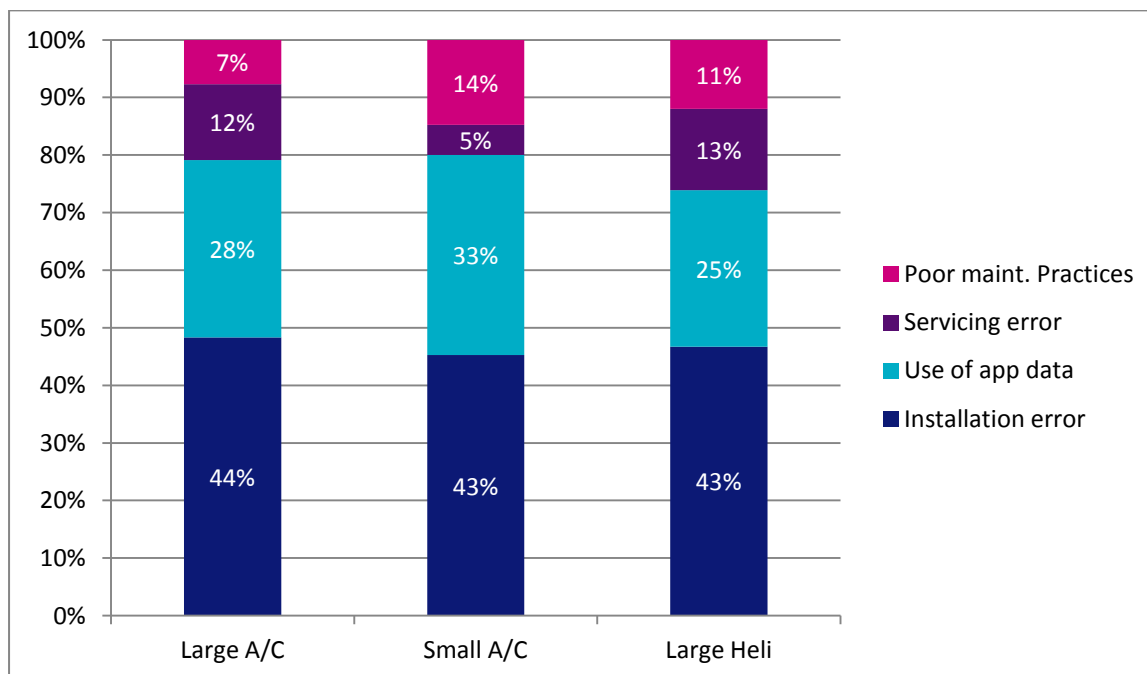


Figure 10: Maintenance error distribution comparison, common categories 2005-2011

4.40 From these figures it can be seen that the most likely error type is 'incorrect installation'. The next highest is the use of approved data, or rather the

likely lack of it. Incorrect installation includes failure to fit all required components (e.g. seals or spacers), incorrect routing of electrical cables and incorrect applied torque. 'Use of approved data' includes the proper use of approved data such as the maintenance manual, service information or repair drawings.

- 4.41 Again, Figure 11 shows the change in reporting trends for maintenance error types over the period analysed. Although there is some variation year on year the overall figures for these ATA Chapters is also fairly consistent with the exception of 'Installation Error'.

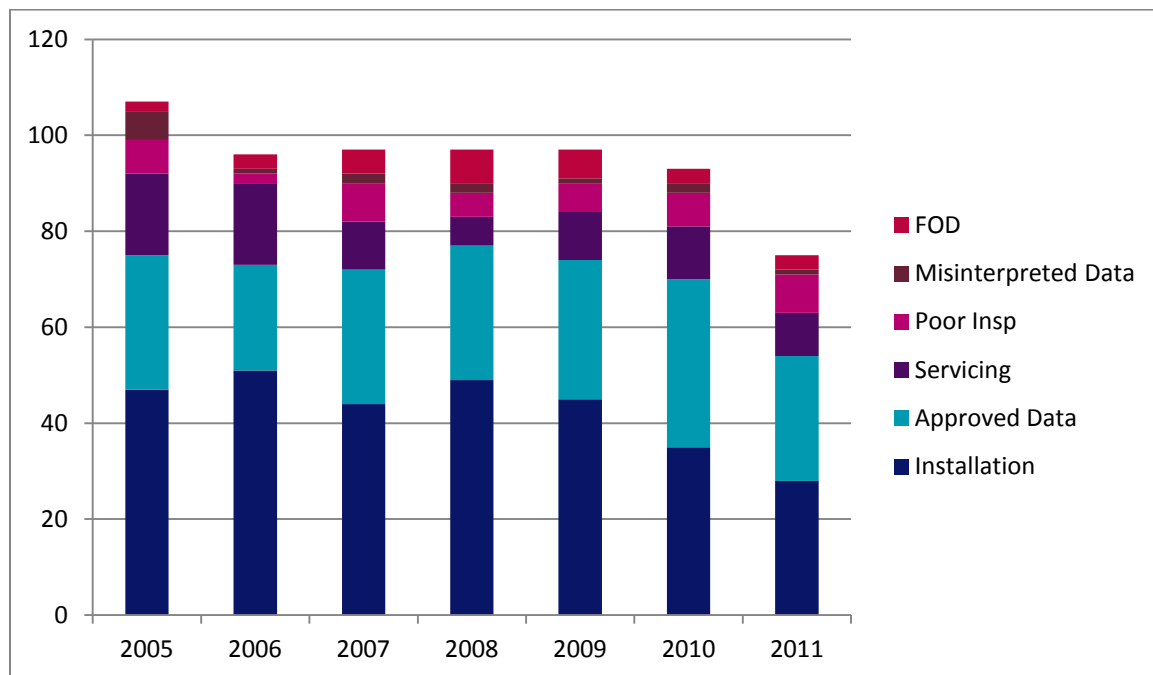


Figure 11: Key maintenance error types as % of total each year, all aircraft categories

- 4.42 There is no obvious explanation identifiable in the MOR data for the apparent reduction in the number of incidents for installation error other than the possibility that internal inspection is catching the error before release to service. This would mean that the events are still happening but, despite being caught, are not being reported as required under the CAA MOR scheme and the European Directive on Occurrence Reporting.

Chapter 5

Detailed analysis for large aircraft

Large aircraft global statistics

- 5.1 Following on from Section 4, further detailed analysis was carried out on the large aircraft data. This allowed certain trends and themes to be identified which clearly suggest some areas to be explored by companies to address the root cause. The analysis was also carried out such that some information as regards aircraft type could be collated and presented.
- 5.2 As mentioned previously, the analysis identified a significant discrepancy between the number of maintenance event MORs reported to the CAA and the submission of MEDA data to UK-MEMS. This is understandable given the fact that not all Part 145 organisations are necessarily aware of UK-MEMS or the need to contribute to the database. Figure 12 shows the relevant results. It should be noted that the MOR data set covers the period 2005 to 2011 whilst the MEDA data (UK-MEMS) shows a wider period from 1998 to 2006. Whilst this is not wholly representative of a like for like comparison it does suggest that the UK-MEMS system could have produced much more information of value to the industry had it received information on all of the events?
- 5.3 This represents the MOR total of 1890 as noted in 4.3.27 above. There were 584 MEDA events.
- 5.4 Those 1890 MORs can be broken down by ATA Chapter and the results are shown in Figure 13.

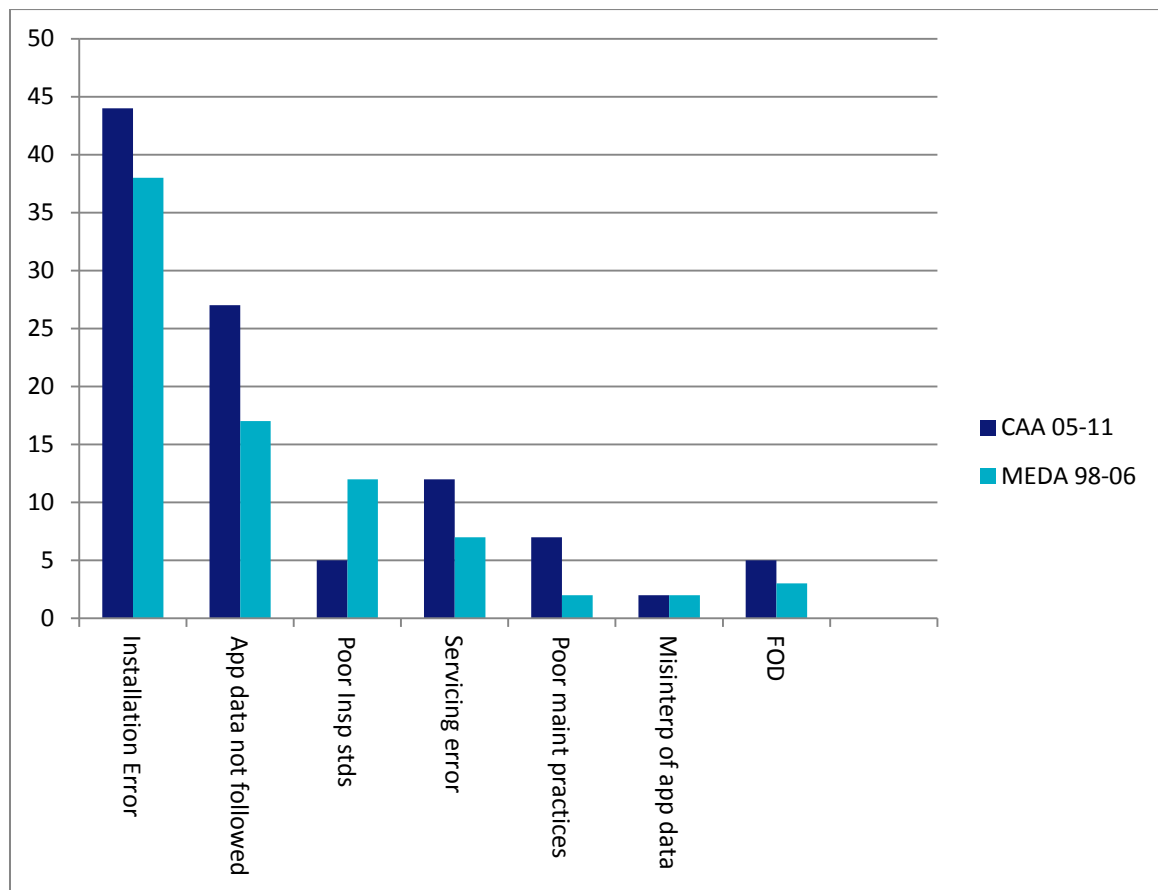


Figure 12: Comparison of CAA MOR and MEDA maintenance event analysis, large aircraft, shown as % of total

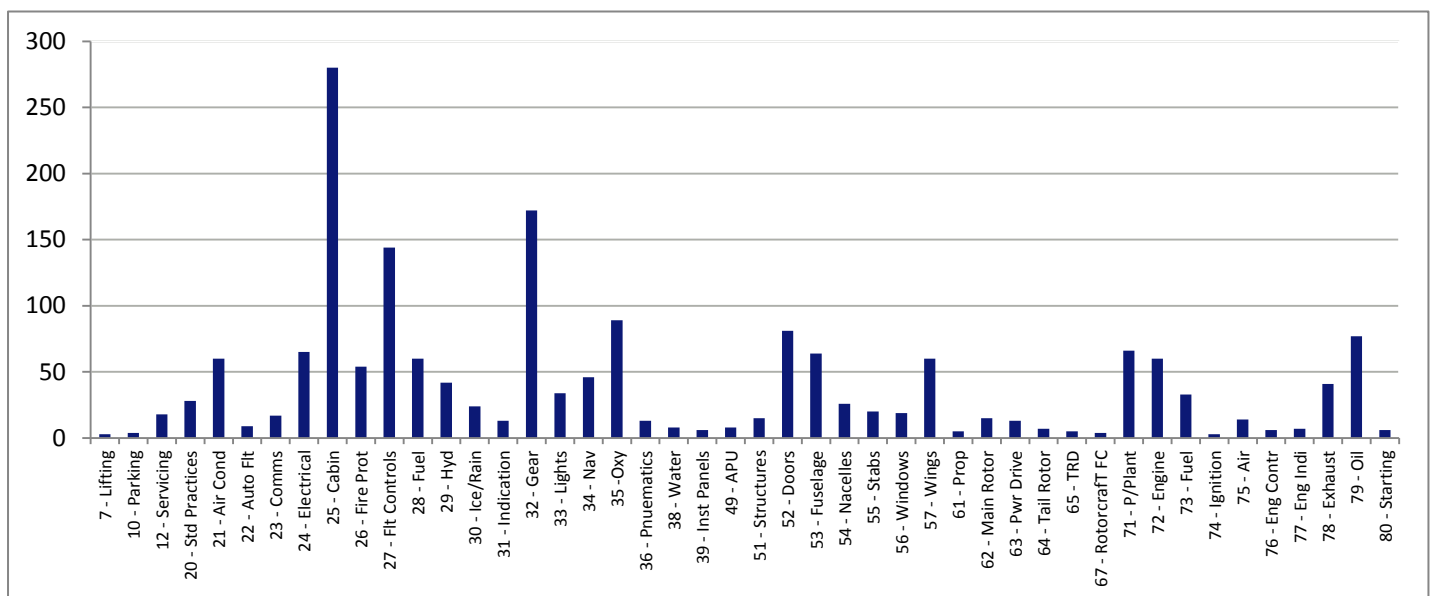


Figure 13: Breakdown of maintenance error MORs by ATA chapter, 2005-2011

- 5.5 Once again, the top six ATA Chapters can be identified and the percentage of MORs shown against the total maintenance error number. These are:

ATA 25 cabin / safety equipment	14%
ATA 32 landing gear / undercarriage	8%
ATA 27 flight controls	7%
ATA 35 oxygen	5%
ATA 52 doors	4%
ATA 79 engine oil	3%

- 5.6 This, not unsurprisingly, reflects the data presented in figure 8 and paragraph 4.3.23 above. The figures for ATA 25 are slightly higher reflecting the more complex and voluminous cabin configurations on large aircraft. There is simply more to go wrong. Similarly ATA 35 and ATA 52 are up slightly.

- 5.7 A closer analysis of ATA 25 shows the following as typical maintenance errors:

- Cabin sidewall trim not fitted properly
- Emergency door slide not connected
- Emergency door slight transit pins in place
- Passenger seats not in correct configuration
- Passenger seats not connected to seat rail
- Incorrect passenger oxygen masks found fitted
- Life raft found time expired
- P2 seat harness, incorrect shoulder assembly
- Emergency path lights found covered in tape
- Mountain bolts found missing from cabin attendant's seat
- Galley incorrectly installed
- Seat belts incorrectly installed
- Seat rows partially blocking emergency exit
- Roll of masking tape left in oven causing smoke

- 5.8 For ATA 32 the following were typical of the error events:

- Hydraulic brake pipes cross connected
- MLG fairing failed due to incorrect rigging
- Wrong main wheel bearing grease seal and retainer

- Main wheel heat shield bolts missing
- Main wheel fitted without spacer
- Gear failure messages due to tachometer not refitted
- Brake pedal bellcrank assemblies incorrectly fitted
- Incorrect and excessive grease caused brake fire
- Gear failed to retract, pins still fitted
- Incorrect tyre type fitted to wheel caused foul on retraction
- Incorrect brake steering control unit fitted, steering failure
- Incorrect brake steering control unit fitted, steering failure
- Incorrect installation of the NLG door connecting rods, fouled structure
- MLG shimmy damper found disconnected with blanks fitted

5.9 For ATA 27 the following were typical of the error events:

- Elevator feel pressure pipes damaged / disconnected
- Ailerons heavy due to lost motion device not correctly rigged
- Elevator manual rigging incorrect leading to uncontrollable dive
- Incorrect installation of rudder limiter actuator
- Loose screw caused elevators to jam (FOD)
- Boeing 747 rudder trim unit fitted to Boeing 767
- RH spoiler cable failed. LH cable outside of wear limits
- Alternate flap switch safety locked with heavy gauge lock wire
- Rudder trim actuator to indicator wiring crossed
- Range of elevator movement reduced due to incorrect installation
- Stabiliser trim hydraulic motor incorrectly assembled during overhaul
- Flap roller failure due to incorrect shimming
- Incorrect flap control unit fitted

5.10 In many of the cases reported in paragraphs 5.7 to 5.9 the number of incorrect installation examples bears out the belief that this is the biggest error threat. Whilst the ramifications of errors on flying control system are more readily apparent to the flight crew, the same is not true of items such as door slides being incorrectly installed. The consequences of a door slide not operating correctly during an emergency evacuation are equally of concern as the in-flight problems that errors can lead to.

Large aircraft maintenance error types

- 5.11 It is clear from the supporting data behind the reports that in many cases the engineer concerned did not use the latest available manuals or approved data to carry out the task. This highlights a cultural issue where, due to the information perhaps not being readily available, the engineer reverts to basic engineering skills. This does not, however, cater for critical dimensions or tasks when carrying out rigging etc.
- 5.12 Figure 14 provides an illustration of the MOR maintenance error types for the period 2005 – 2011. This tends to speak for itself.

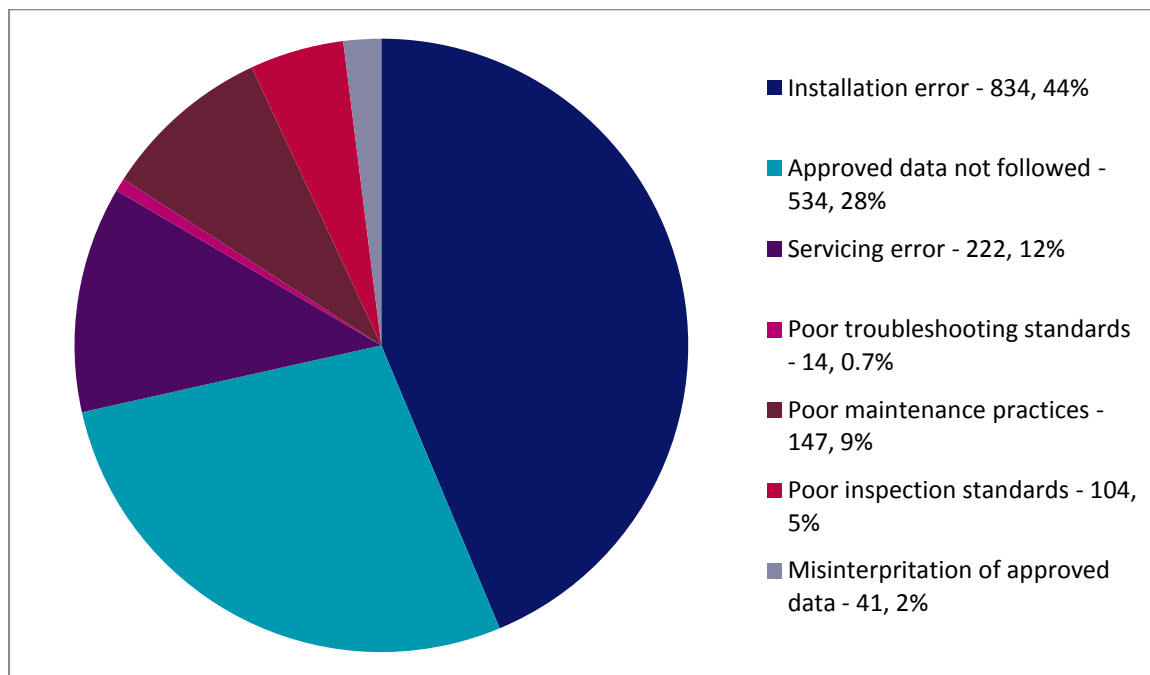


Figure 14: MOR maintenance error types 2005-2011

- 5.13 This clearly shows that installation error and not following approved data collectively represent around 72% of the reported events. The failure to use approved data is, of course, a key underlying causal factor in the case of incorrect installation events.
- 5.14 Of the 834 events relating to installation error the following list represents a broad analysis of the associated factors (a few random events are not included):

Instruction non-adherence	325 events
Poor inspection	158
Wrong part fitted	96
Part not fitted	73

- | | | |
|--|--------------------------|----|
| | Wrong orientation | 54 |
| | Cross connection | 35 |
| | Poor insp. (independent) | 33 |
| | Poor insp. / test | 32 |
| | Panel detached in flight | 13 |
| | Wrong location | 10 |
- 5.15 This shows that there is a mixture of underlying factors that can contribute to incorrect installation. In the analysis for this review, it is possible that there were more than one factor present in the lead up to the error being made, e.g. multiple elements. However, in order to simplify the presentation the key underlying factor has been used.
- 5.16 Of the 534 incidents where approved data was not followed the following list gives an indication of the key underlying factor that contributed to the event:
- | | |
|--------------------------------|------------|
| Approved maintenance manual | 181 events |
| Procedures | 131 |
| Minimum equipment list | 119 |
| Structural repair manual | 49 |
| AD / SB | 27 |
| Approved maintenance programme | 9 |
| Illustrated parts catalogue | 6 |
| Wiring diagram manual | 6 |
- 5.17 This shows that there is some diversity of document that is used to refer to when carrying out maintenance. It also highlights the different potential failure paths during line and base maintenance. For example, the Minimum Equipment List (MEL) is not used much during base maintenance but is crucial on the line.
- 5.18 The number of events relating to servicing error totalled 222 incidents. This represents some 12% of the total and the key ATA Chapters affected are shown below:
- | | |
|-----------------------|-----------|
| ▪ ATA 79 engine oil | 43 events |
| ▪ ATA 32 landing gear | 23 |
| ▪ ATA 35 oxygen | 17 |

- ATA 29 hydraulics 11
- 5.19 The vast majority of engine oil incidents related to overfilling of the engines during servicing. Whilst this may appear to be innocuous it is known that this can lead to fumes in the cabin and is a subject that has been of concern over recent years. Other events include incorrect filters being installed and magnetic chip detector plugs not being fitted (loose in engine cowl).
- 5.20 Poor maintenance practices (147 or 9%) also revealed some indications of the lack of attention paid by engineers whilst carrying out work or possibly organisational issues such as distraction.
 - Foreign objects 78 events
 - Unrecorded work 14
 - Aircraft damage 10
- 5.21 It is surprising the number of foreign objects that are left on aircraft, despite it being general practice to carry out a loose objects and cleanliness check after all maintenance. The loose objects found include torches, spanners, rags and individual bolts or bags of bolts. Where the tool is left adjacent to a flying control system there is a real risk of a control restriction occurring at some point so the actual safety threat can be significant. There should be no reason for work going unrecorded as every engineer, whether licensed or not has an obligation to record any disturbance or defect found.

Aircraft type analysis

- 5.22 Whilst the generic analysis of MOR data gives an indication of potential areas where human error can occur in maintenance the specific design characteristics of different aircraft can also be quite influential. For example, flight control design is fundamentally the same but with the introduction of fly-by-wire systems the supporting software infrastructure can be quite different as far as operating philosophy goes. It is important that any analysis also attempts to account for any type specific data that may suggest an area to pay particular attention to.

Figure 15 provides an indication of the reporting trends as a percentage of the total maintenance error MORs by aircraft type, for the main aircraft types in UK service.

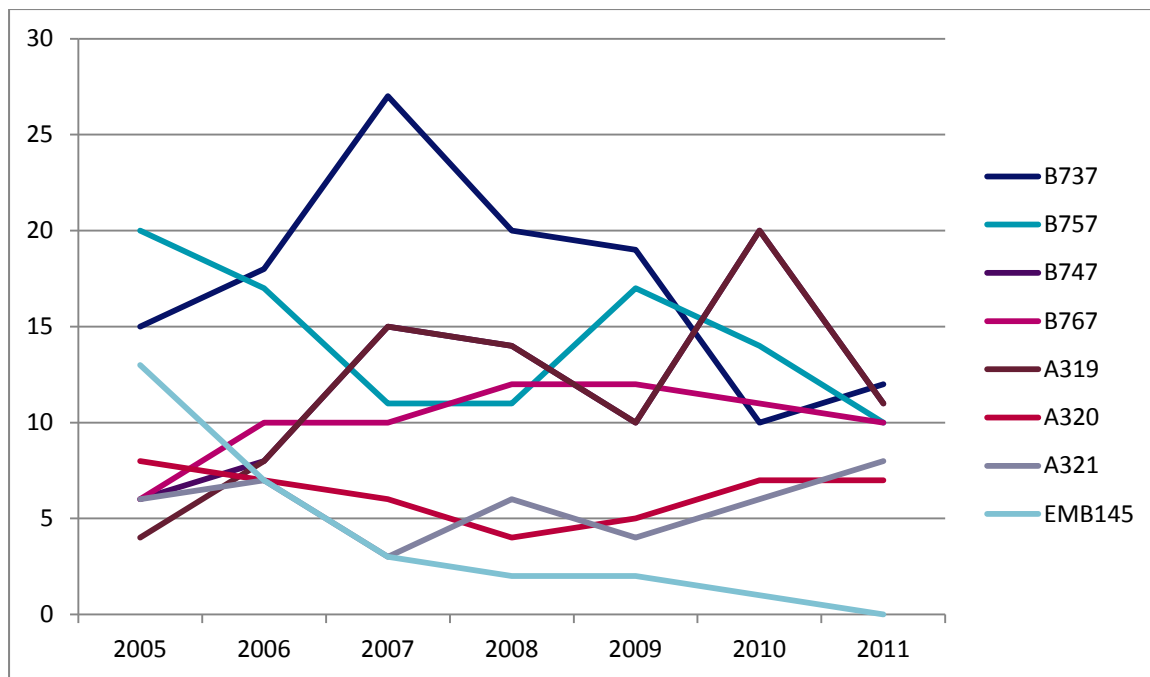


Figure 15: Reporting trends as % of total M/E MOR by type

- 5.23 It is difficult to understand exactly why the trends spike as shown in figure 14. For example, the Boeing 737 fleet was reduced as the Airbus A319 type was introduced into service. The increasing MOR trend may be a reflection on the lack of engineering commitment to a type that was being run down. Likewise the increasing spike for the Boeing 747 in 2010 perhaps reflects the stand-down of some aircraft due to over-capacity or alternatively a more intensive scheduling without ample time to carry out maintenance. However, without looking at the specific details against a particular operator these reasons are purely speculative.
- 5.24 What may provide a better indication of the prevalence of an aircraft type to maintenance error is a look at the errors relating to key ATA Chapters for specific aircraft types. Figure 16 shows the ATA Chapters for each type where there are 6 errors or more reported. This information has again to be considered in context. The data covers all aircraft of that type within the UK register so a more numerous aircraft type such as the Boeing 737 will give rise to larger numbers of error reports. However, what is of use is to look at the ATA Chapters for each type to see the proportion of maintenance errors shown for each ATA Chapter.

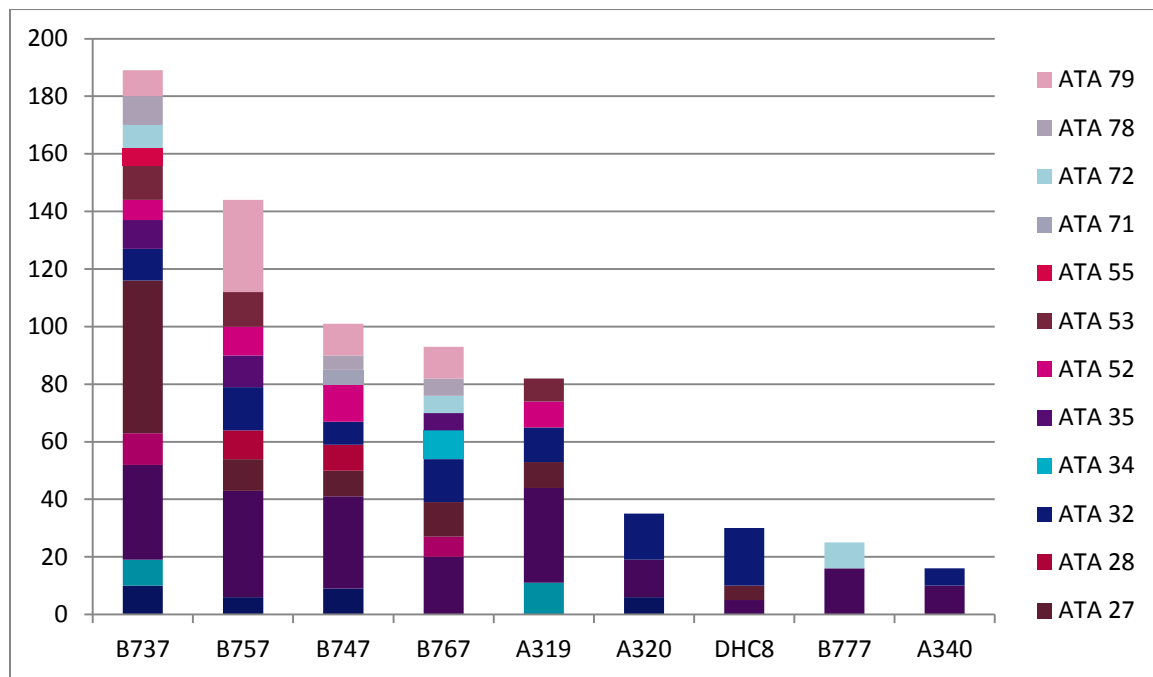


Figure 16: Top 9 aircraft types / ATA (large aircraft category) 2005-2011, 6 errors or more identified in each ATA chapter

- 5.25 For most aircraft types, the incidence of errors for ATA Chapter 25 is noticeable. What is also noticeable is that the Boeing 737 appears to suffer a lot of errors relating to flying controls. Analysis of the actual reports shows that elevator, flap and configuration warning issues were of note. The Boeing 757 suffers from errors related to Chapter 79, engine oil. This reflects a known issue with overfilling of the engines. It has been identified that a number of organisations were found not to have been following the manufactures recommendations and had not being topping up the engine oil correctly. The DHC-8 has seen its fair share of undercarriage issues.
- 5.26 As noted in paragraph 5.3.4 the raw data is of little value in determining the relative risk unless it can be standardised. By taking into account aircraft utilisation data a Maintenance Error rate per flight can be derived. The resulting figures are shown in figure 17.

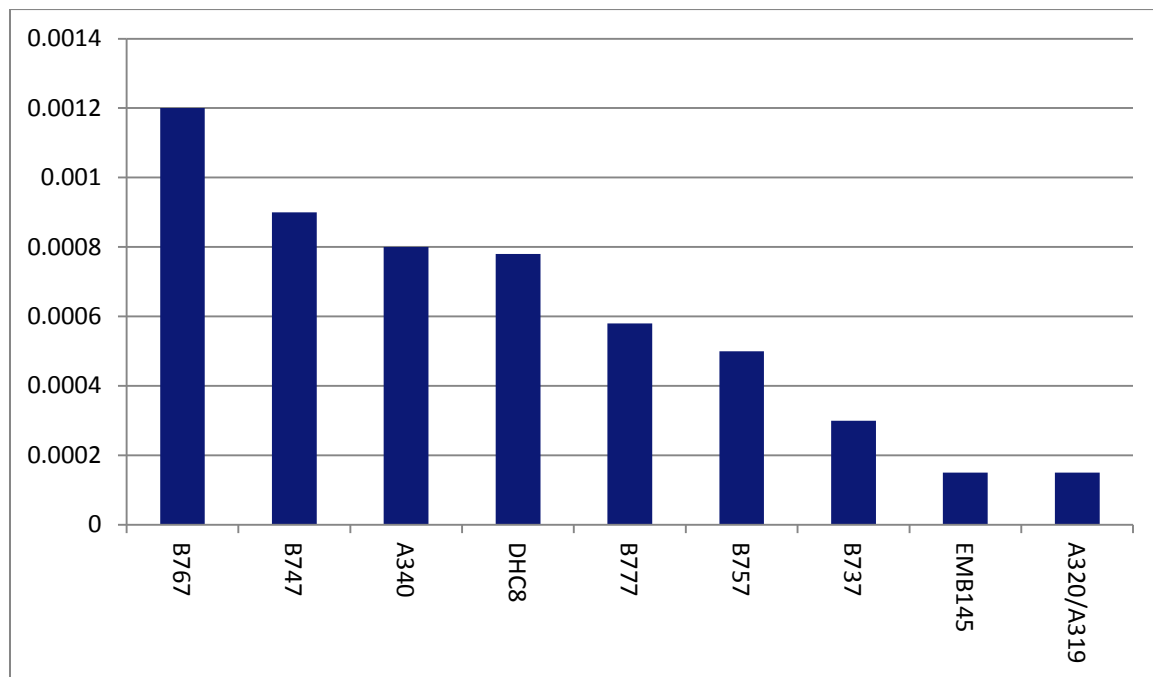


Figure 17: Maintenance MOR rate per flight by aircraft type

- 5.27 This gives a better, although not perfect, view of the relative likelihood of an occurrence for various types. However, the information does not account for the stage of the aircraft's useful life that the graphs represent. Obviously for an aircraft that is at a mid design life point or nearing end of useful design life, it will be more maintenance intensive. There will therefore be a greater likelihood of a maintenance error taking place unless suitable mitigation is put in place.
- 5.28 The depth of analysis also precludes identification of any social and environmental issues that may affect the likelihood of error. Shift patterns and cumulative fatigue may impact an engineer's ability to make the correct engineering judgements or open up the possibility of a lapse in attention during critical inspections. Is the engineer really taking in what it is he or she is seeing?
- 5.29 From an environment perspective, the organisation's circumstances can determine influencing factors.
- 5.30 Financial pressures could lead to a shortage of readily available spares, a need to cut back on recruitment and training. These could compromise the engineering system, if the risks are not identified and managed appropriately.
- 5.31 Aircraft flight scheduling, whilst serving passenger's interests in terms of flight availability can often do nothing to balance out the needs of engineering to ensure that ample time is given to address airworthiness issues. A tight schedule often does not give any realistic time between

flights in order to address defects that may arise. The pressures of the denied boarding compensation requirements simply exacerbate this pressure to keep the aircraft in service. An intensive day time schedule also limits the aircraft's availability for maintenance, pushing what can be intensive engineering checks and inspections into the night time period where there are different human performance issues to contend with.

- 5.32 Weather too is a factor not to be dismissed lightly. Whilst some maintenance can be accomplished on the line environment there are still times when the prevailing weather is such that logic dictates that some form of refuge, e.g. hangar etc, is needed in order to avoid the potential human performance issues with adverse weather.
- 5.33 To identify the implications of these factors a much more detailed maintenance error and reporting culture must be fostered. The data available from the current system simply is inadequate to give that level of granularity in the analysis.

Type	2005	2006	2007	2008	2009	2010	2011
A319	157610	218469	260852	304849	333897	344435	384032
A320	106970	107015	104290	94239	110227	124035	141918
A340	9476	10643	13368	14220	13523	12959	12981
B 737	292309	259421	254560	230056	152750	119178	111785
B 747	39939	40344	44697	44083	40434	34191	35093
B 757	108357	107301	109916	97774	78387	70800	70160
B 767	32787	33919	36318	30307	27095	28192	28269
B 777	28130	28951	28768	28308	28635	30632	31757
DHC8	26164	30082	18248	13645	15966	13967	6705
EMB145	71327	74607	69838	53812	27449	22834	25201

Table 1: Annual utilisation (flight hours) by selected aircraft type

- 5.34 Figure 18 uses the cumulative fleet number of flights from 2005 – 2011 to present the data. Table 1 show the actual yearly breakdown of flights for the types. This allows a trend analysis to be developed and this is shown in Figure 16.

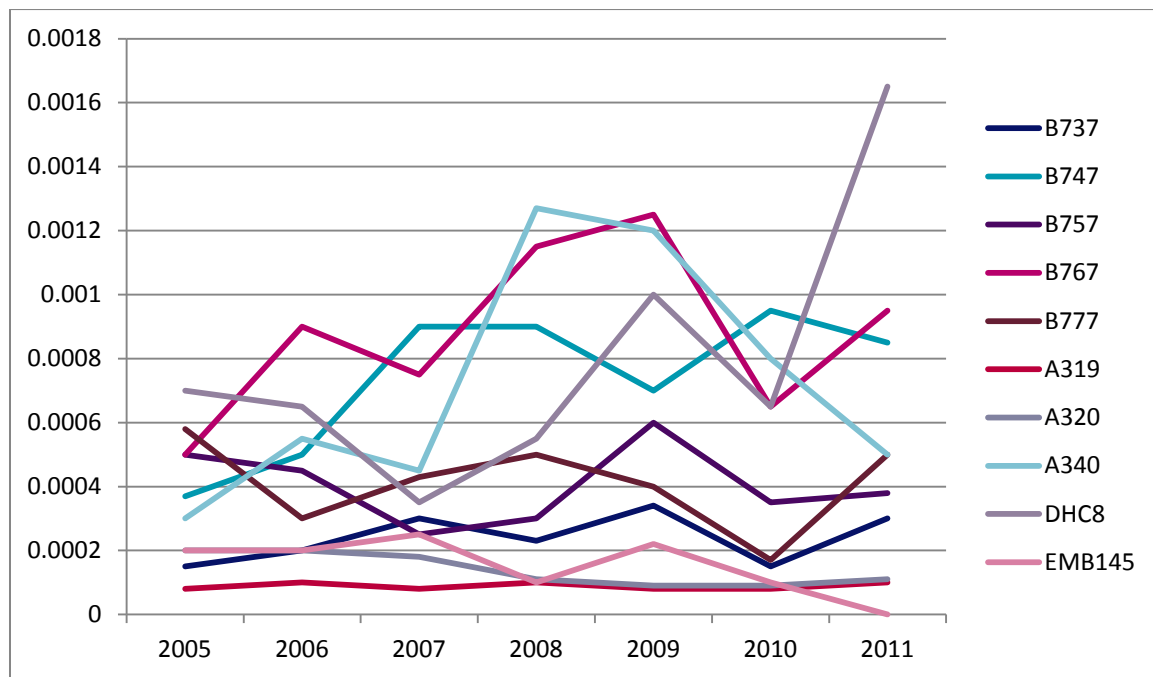


Figure 18: Maintenance MORs / flight for selected aircraft types

- 5.35 This is more useful as it indicates aircraft where a developing trend is identified, or vice versa, an improving trend. This can often be reconciled against a detailed understanding of the issue that the aircraft type is experiencing. By a combination of the two, organisation can identify a strategy to try and contain the likelihood of maintenance error on that aircraft type, in relation to the particular ATA Chapter or actual component where there are known issues. This strategy can then be fed into the engineering and maintenance system by internal notices to engineers and staff and through the medium of continuation training.

Chapter 6

Detailed analysis for small aircraft

Small aircraft global statistics

- 6.1 As for Section 5, some analysis was carried out on the small aircraft data. There was more of an issue here regarding the availability of data as the CAA MOR scheme is generally regarded as not being mandated for General Aviation (GA) or small aircraft, other than turbine engines.
- 6.2 The analysis that has been carried out can therefore only be indicative of what lies within the data set that was looked at. The lack of maintenance error data and the absence of MEMS processes in many, if not all, GA oriented organisations maintaining small aircraft means that many events will go unreported. During the review of MOR data for another project¹⁵, a review of the Regulatory Approach to Recreational Aviation, it was identified that inconsistency in the way the data was classified upon receipt meant that it was difficult to extract accurately the data which may have been reported that covered maintenance errors. However, without carrying out a full review of each MOR the inconsistent classification of MORs cannot be addressed. The following analysis is therefore not comprehensive or conclusive.
- 6.3 Figure 19 shows the global data for the small aircraft category. A total of 174 events were analysed ranging across a range of fixed wing aircraft such as the DHC-1 Chipmunk to BN-2 Islander and smaller rotary wing types such as the Robinson R22 to the Sikorsky S76. Fixed wing was responsible for 98 of these events (some 56%) with the remaining 76 events (44%) relating to rotary wing. Proportionally however there are far more small fixed wing aircraft than rotary wing so it tends to reinforce the belief that there are fewer reports on large helicopters than there ought to be.

¹⁵ Some 22500 MORs relating to GA/Recreational Aircraft were reviewed as part of the RA2 programme.

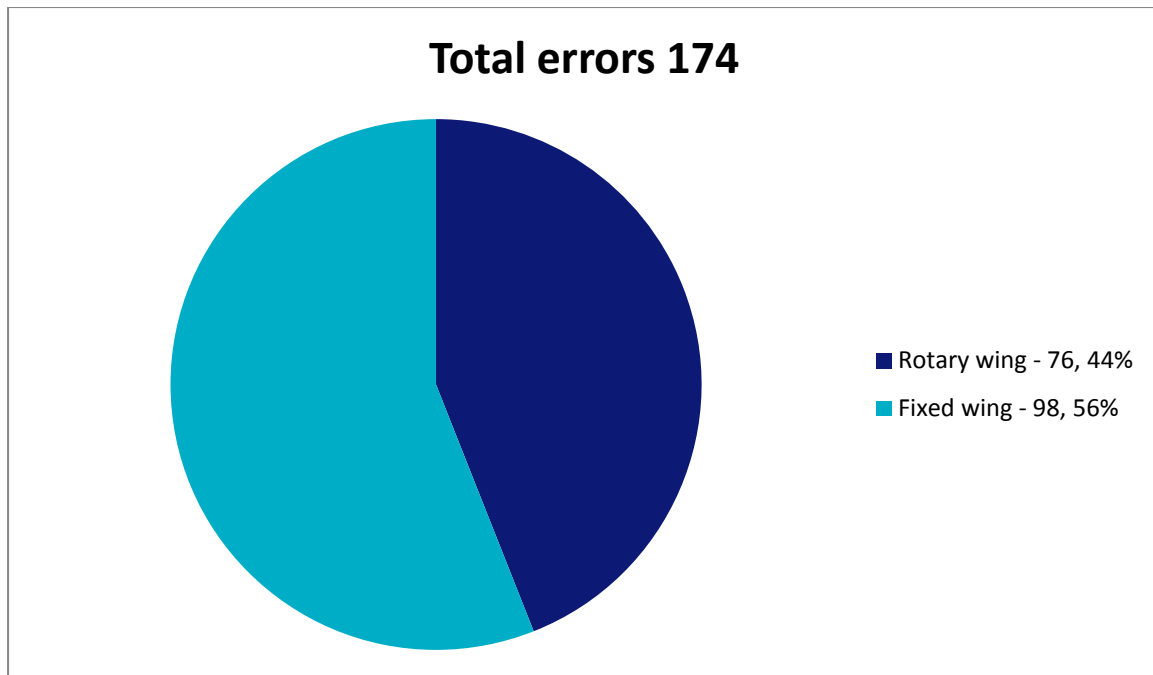


Figure 19: Global MOR data for maintenance error, small aircraft

- 6.4 Obviously small aircraft are not as complex as their larger counterparts. Systems tend to be simpler in design with less redundancy and system protection. This means that they can be more prone to the effects of maintenance error.
- 6.5 Figure 20 shows the breakdown by ATA Chapter. It should be noted that not all small aircraft manufacturers use the ATA Chapter system for defining and coding maintenance activity. In the analysis of the data, CHIRP assigned the relevant ATA codes to the report in order to provide some consistency of analysis and to provide a comparison against large aircraft if anyone was interested.

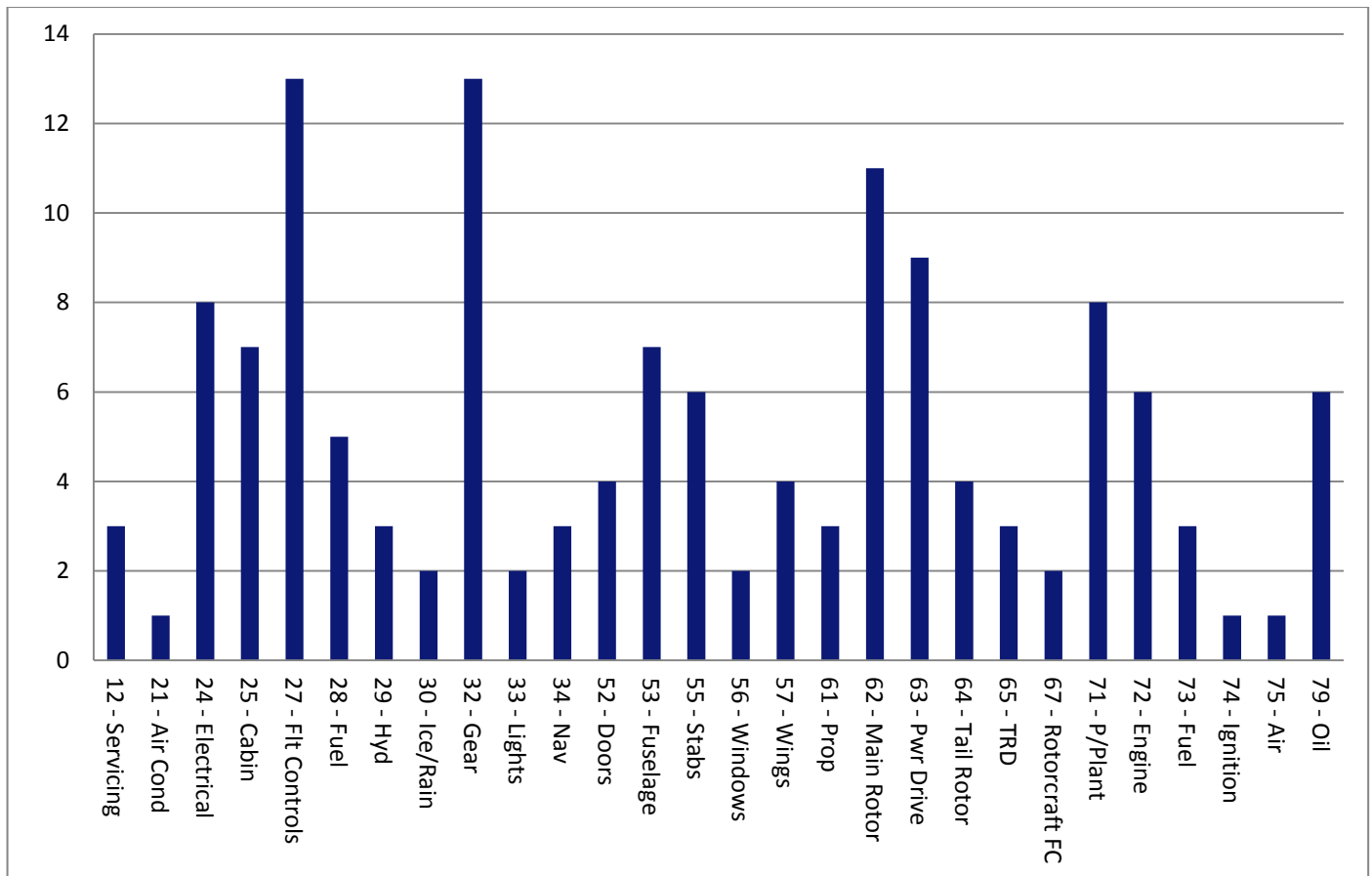


Figure 20: Breakdown by ATA chapter, small aircraft

6.6 The 6 top ATA Chapters can be shown as a percentage of the total reports as follows:

- Chapter 32 – Landing Gear 7% (13 events)
- Chapter 27 – Flying Controls 7% (13 events)
- Chapter 62 – Main Rotor 6% (11 events)
- Chapter 63 – Power Drive 5% (9 events)
- Chapter 71 – Powerplant 4% (7 events)
- Chapter 24 – Electrics 4% (7 events)

6.7 Problems and errors on landing gear or undercarriage systems (ATA Chapter 32) amounted to some 7% of the reports. Looking at the source data, many of these events were attributable to poor lubrication, incorrect rigging, excessive wear in retraction mechanism and incorrect tyre fitting causing it to foul on the structure during retraction.

6.8 Flying Controls (ATA Chapter 27) shows instances of control being incorrectly installed (reverse sense) despite duplicate inspections having been performed. The incorrect installation of bellcranks, cable routing and improper use of tools during installation (leading to subsequent component

failure due damage) are also evident. There were also two incidents where the flying control cables were excessively worn and two incidences of loose object (rag and loose screw) where the controls were stiff to operate.

- 6.9 There were four events where the engine cowl partially detached in flight as the cowl was not properly fastened.
- 6.10 On the electrical side (ATA Chapter 24) the issues found were incorrect routing of wiring, improper installation of battery box cover causing a short and unapproved parts used in repair/overhaul of starter motor.

Small aircraft maintenance error types

- 6.11 In a similar manner to the analysis of maintenance error types for large aircraft, as shown in paragraph 5.2.2. and Figure 14, Figure 21 provides that information for the small aircraft category.

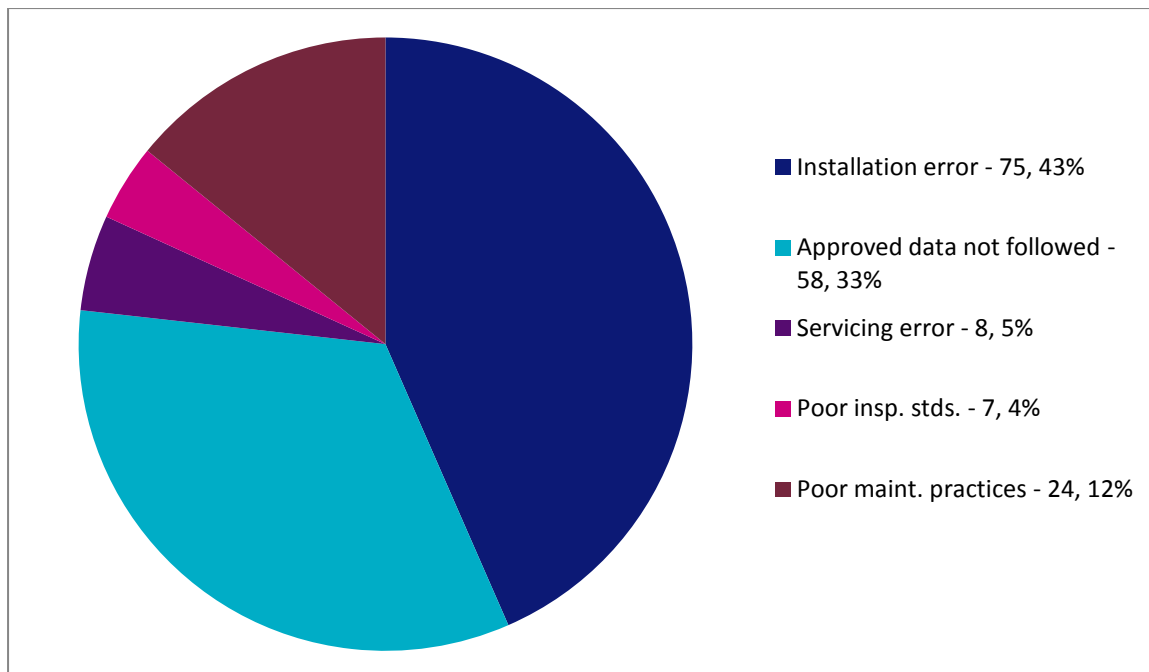


Figure 21: MOR maintenance error types 2005-2011, small aircraft

- 6.12 Whilst, based on the limited data available, Installation Error was similar in proportion to large aircraft, the percentage of Approved Data not Followed (33% against 28%) and Poor Maintenance Practices (14% against 9%) for small aircraft is higher than for large aircraft. This may well be a reflection on the culture of small aircraft maintenance, the lack of organisational focus on quality control and the absence of training available for new entrants. However, without carrying out an individual re-assessment of each MOR the actual reasons cannot be determined.

6.13 Once again a more detailed analysis of the maintenance error types can be obtained through the analysis. This is shown in Figure 26. In this case, it appears that the primary error type was 'approved data not being followed'. This accounted for 58 events out of the total of 174 occurrences or around 33%. These break down into the following causal factors related to non-adherence:

▪ Procedures	21 events
▪ AMM	20
▪ AD / SB	6
▪ IPC	4
▪ AMP	3
▪ SRM	3
▪ WDM	1

6.14 The lack of adherence to procedures and the maintenance manual (AMM) are statistically the highest. However, many small organisations do not have formal procedures as such. This may be a reflection that the MORs received were submitted by organisations that are large enough to have developed procedures to manage their maintenance activity.

6.15 Installation error is also a cause for concern, as was the case for large aircraft. In this case it accounted for 75 events or 43% of the total (for large aircraft the figure was 834 events or 44% of the large aircraft total). For small aircraft this breaks down into the following causal factors:

▪ Instruction non-adherence	18 events
▪ Wrong part fitted	14
▪ Poor inspection standards	12
▪ Wrong orientation	10
▪ Poor insp. stds. (duplicate)	9
▪ Cross connection (duplicate – 2)	5
▪ Part not fitted	4
▪ Panel detached	2
▪ Wrong location	1

6.16 It is interesting to note the extent to which the wrong part has been fitted and the incorrect orientation on fitting. However, poor inspection of the final task and failure of the duplicate inspection process to detect errors are dominant causes, as is the case for large aircraft.

- 6.17 With regard to poor maintenance practices, this accounted for 24 events or some 14% of the total. The detailed data suggested the following were the key elements:
- General standards 13 events
 - FOD 10
 - Unrecorded work 1
- 6.18 The fact that general standards and foreign or loose objects being found suggest that there is inadequate inspection and supervision within the maintenance process. This may be attributable to the relatively low number of licensed engineers involved in the process and the absence of final inspection procedures.

Chapter 7

Detailed analysis for large helicopters

- 7.1 The number of maintenance related MORs for large helicopters was substantially smaller than it was for large aircraft. This is in part a reflection of the smaller size of the large helicopter fleet but there is a question as to the number for reports on record, given the differing technologies and more complex systems.
- 7.2 A total of 44 MORs were analysed and the results are presented in this section. Once again, the analysis by CHIRP correlated the available information from the UK MEMS database with the CAA MOR record.
- 7.3 The breakdown of the MORs by ATA Chapter is shown in figure 22.

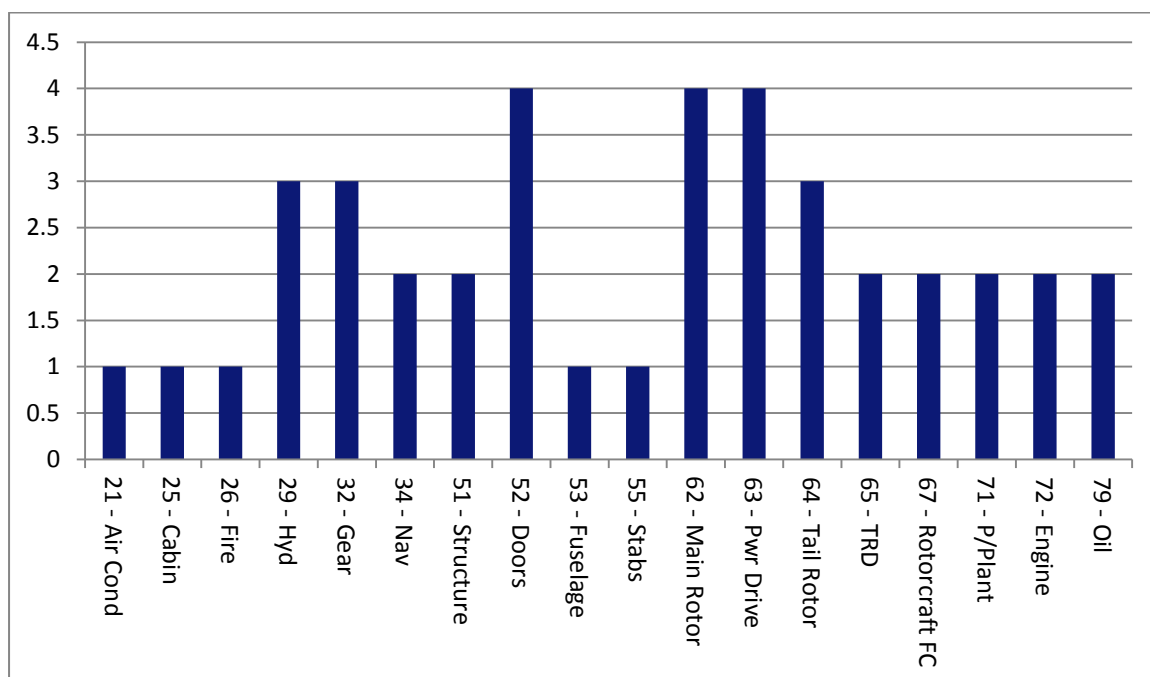


Figure 22: Breakdown of large helicopter maintenance MORs by ATA chapter

- 7.4 It can be seen that there are a few ATA Chapters that show a higher level of maintenance error events. These include:
- Chapter 52 – Doors 9%
 - Chapter 62 – Main Rotor 9%
 - Chapter 63 – Power Drive Train 9%
- 7.5 At a secondary level of interest we can see issues within:

- Chapter 29 – Hydraulics
- Chapter 32 – Landing Gear
- Chapter 64 – Tail Rotor

7.6 The remaining incidents are spread over the other primary systems.

7.7 The numbers are not large but do suggest that the greater potential for error is present where the systems are more complex.

7.8 A further more detailed breakdown of the maintenance error types is shown in Figure 23.

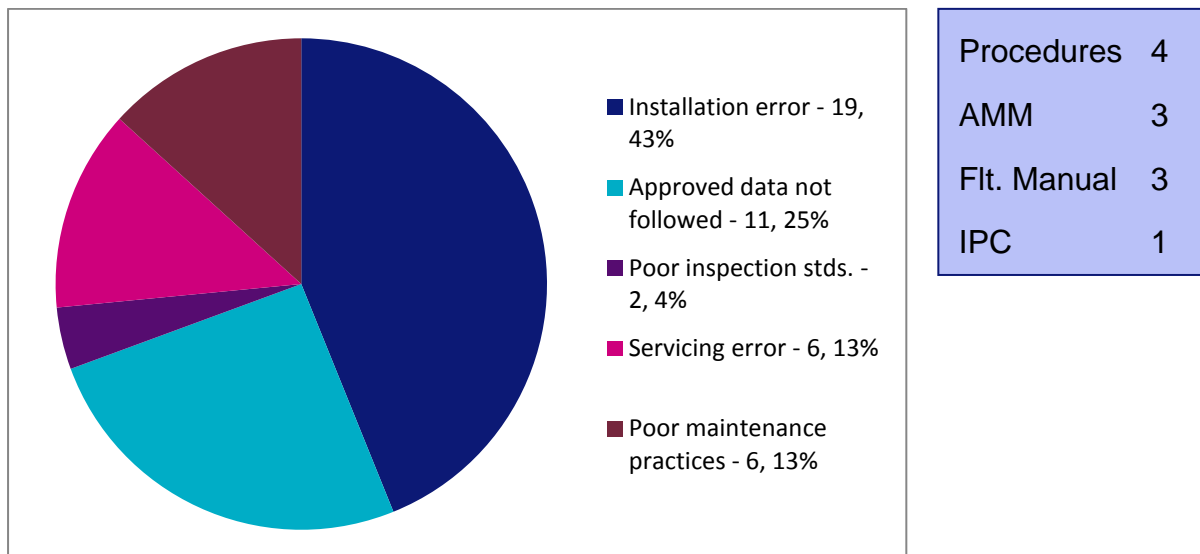


Figure 23: Large helicopter MOR maintenance error types

7.9 The highest proportion of error as shown in Figure 21 relates to incorrect installation. This accounted for some 43% or 19 of the 44 events. The more detailed breakdown of these events was as follows:

- Wrong part fitted 5
- Instruction non-adherence 4
- Wrong orientation 4
- Part not fitted 2
- Poor inspection standards 2
- Panel detached 2

7.10 As can be seen the number of events is not high and therefore has no real statistical significance. However the underlying causes still have some similarity with the issues shown for large aircraft and the issues should not be discounted. The low number of reports may simply be a lack of reporting under the MOR scheme.

Chapter 8

Examples of maintenance error

- 8.1 The following examples are typical of reports received under the CAA MOR system relating to maintenance errors. The MOR report is summarised in each case along with the CAA closure recommendation. However, that is only part of the issue. The company that experienced the event is required, under Part 145.A.60 and their MEMS programme to carry out the investigation and establish the root cause.
- 8.2 Having identified the problem and the root cause, the organisation will then be expected under their Part 145 approval to put in place corrective actions. This can be one or a combination of actions ranging from better enforcement of supervision of tasks, additional inspections on complex tasks to retraining of the staff.
- 8.3 In the examples shown, the MOR number and aircraft type are not shown as, for the purposes of this report, the key issue is to encourage engineers and organisations to think about the issue, what could have caused it and consider whether they too are exposed to the risk of a similar occurrence.
- 8.4 It is recognised that any corrective actions that may be proposed will possibly differ from organisation to organisation. The reason for this is that, despite the aircraft maintenance manual requirements being the same, different modification and equipment configuration standards can result in differences. It is essential therefore that organisations look at how any event, whether arising internally to their operation or relating to a potential learning experience in another operator, is considered in the appropriate context.

Example 1

- 8.5 Date 07/2011: ATA Chapter 25 - Equipment-Furnishings

Event description: When the aircraft was put in for a routine maintenance inspection all four escape slide inflation bottles were found to have safety pins still installed.

Implications: In the event of an evacuation being required, the slides would not inflate and this would slow down the safe evacuation of passengers and crew. It also increased the potential risk of injury if passengers and crew were forced to jump from the doorway.

Investigation: It was clear that upon installation the pins had not been removed. The organisation looked back into the records to see when the slides were last removed and installed. From this it was possible to identify the engineers involved in the task and the certifying engineer who cleared the job. The event was clearly caused by a maintenance error, a lapse in concentration. However, if the task was performed by an unlicensed mechanic then there is a question over that individual's competence in relation to the task and the need to ensure the appropriate maintenance instructions were followed. There is also a clear issue about the supervision and application of the relevant inspection standards by the certifying engineer. Given the safety significance of the error the engineer clearing the work should have ensured that the system was fully operational. With the door covers installed the pins could not be seen.

Corrective actions: The human factors identified in this event can possibly be attributed to organisational factors regarding staffing levels and work processes and procedures not being adequately followed. The mechanics performing the work failed to discharge their obligations to following the AMM. The certifying engineer failed to ensure the system was functional before release. Was this a case of 'blind stamping', certifying without inspection in the belief that the mechanics would have done the job properly? A fleet check carried out by the operator did not reveal any other instances of incorrect installation. In order to try and prevent similar occurrences in future the operator decided to instigate stage sheets for multiple installation/removal tasks to allow engineers to document the task stages.

Commentary: Whilst the job itself is relatively straightforward, the importance of the final operational status should have been considered by the engineers performing the work. Adopting a system for secondary inspection would add another level of assurance that the system was indeed fully operational on release to service. However, the issue of using tasks cards that simply calls for slide replacement due, perhaps, to the slide being time expired opens up a potential area for error, if the task card is not broken down into the constituent sub-tasks. Ideally, there should be scope for a clear inspection requirement and final clearance to refit the cover. In this case, if such a requirement existed the certifying engineer did not physically inspect the work before clearing the task.

8.6 Date 08/2010 ATA Chapter 78 – Exhaust

Event description: During a walk around inspection the flight crew noticed an anomaly in the bypass duct of the right hand engine. With the C duct open damage was found to the heat shield, apparently caused by a boroscope plug being missing.

Implications: The missing plug meant that hot engine gases were not contained as designed and had the potential to escape and cause heat damage to components on the engine. Up to the time the issue was noted, the engines overheat warning system and/or fire warning system did not activate.

Investigation: The boroscope plug was missing and therefore allowed gases to escape. Further engineering investigation revealed that the heat shield was actually missing. Hot gases had impinged upon the thrust reverser structure causing some heat damage and distortion. Investigation found that the aircraft had been subject to a boroscope inspection some three days earlier by a contracted maintenance organisation. The maintenance organisation carried out a MEDA investigation and found that, due to other commitments, the primary contracted organisation could not accomplish the work. The task was therefore contracted by the operator to another boroscope inspection organisation. This led to some management issues with regard to check planning and call out of the work.

Planned access to the proposed hangar was not possible due to another aircraft check overrunning so gaining access to an alternate hangar resulted in the check commencement being delayed, significantly reducing the available period for the task to be completed. This also meant that the usual facilities and support were not available. The work pack, as supplied by the operator was incomplete and this required the check supervisor to spend additional time sorting out the issue. Staged inspection sheets were not provided and as the plug removal and fitment was carried out by two different mechanics the opportunity to ensure that all disturbed plugs were refitted was compromised.

Corrective actions: There were several actions proposed following investigation into this event. These included improvement in check planning by the operator, the interface with the contracted maintenance organisation, management and operator/third party interface issues, the need for stage inspection sheets and improved supervision of third party work.

Commentary: There are a number of issues clearly identified in the MEDA investigation and therefore no single root cause. The absence of stage inspection sheets meant that there was a lack of clarity about what plugs had been disturbed. The change of location and the consequent delay in the check commencement brought about pressure to complete the required work in a shorter allotted time. This, the use of an independent third party to do part of the work (the boroscope) and the incomplete worksheets meant that the check supervisor was distracted and not able to perform as expected.

Example 3

8.7 Date 09/2011 ATA Chapter 32 – Landing Gear

Event description: The LH nose wheel tyre was found to be worn to limits. On jacking the aircraft to replace the wheel the wheel assembly was found to be excessively loose with an axial and radial movement of about half an inch.

Implications: The excessive movement appears to have potentially increased the wear rate of the tyre. However, there was clear potential for the movement to change the loading of the wheel and bearing assemblies and this could have led to bearing failure. In similar events previously recorded this has led to damage to the axle and in the extreme case the wheel departing the aircraft.

Investigation: On investigation the wheel outer bearing retention circlip was found to be missing and the wheel nut on removal was found to be less than hand tight. This suggested that there was an issue regarding the application of the correct torque when the wheel was fitted. It was not possible to determine whether the circlip was fitted at the last tyre and/or bearing replacement.

Corrective Actions: The organisation was able to check back through the records to the last wheel change. However, it was not possible to prove conclusively that the wheel had not been fitted properly. Likewise, the organisation was able to trace back to the last wheel/bearing change but again there was no conclusive evidence to suggest that the work was not done properly in the workshop. The only possible action was to highlight the event to the engineers.

Commentary: This example shows the need to ensure as the end user that the part to be fitted is indeed serviceable. Checks to ensure that it has not suffered any transit damage is the most obvious issue to be considered. However, in many cases wheels are supplied as ready to fit assemblies and do not require the bearings to be swapped over between wheels. Although the engineer fitting the wheel should have been able to rely upon the workshop having done the work properly the final responsibility for ensuring that the wheel was indeed in the correct configuration for fitment lay with the engineer installing it on the aircraft. This shows the importance of having the competence to determine that the bit to be fitted is what it should be.

Example 4

8.8 Date 11/2011 ATA Chapter 73 – Fuel Control

Event description: Following an FCU replacement, on starting during the engine post-task function checks the right hand engine did not control and continued to accelerate past normal idle. Engine shut down to prevent overspeed.

Investigation: The maintenance organisation had changed the FCU on both left and right hand engines on the night shift. During the following day shift the organisation carried out the post-task functions checks. The left engine started and operated normally. The right hand engine continued to accelerate beyond idle and, showing no signs of stopping, was shut down when around 80% was achieved. The rigging of the FC was checked and found satisfactory. A second start attempt was made with the same fault present. The FCU was removed and inspected whereupon a small plastic drive shaft was found to be missing. The driveshaft was found still attached to the old FCU and was transferred. Subsequent engine run carried out without problem.

Corrective action: The fact that the ground run was carried out and found the defect is some mitigation against the failure to transfer the driveshaft during replacement of the FCU. The AMM procedure was clear about the shaft being in place. However, a simple comparison between the unit being removed would also have highlighted the anomaly. The issue was followed up with the relevant staff.

Commentary: This example shows the need for vigilance when carrying out replacements. Following the AMM procedure will help reduce the potential for such errors but the mechanic/engineer involved should still be aware of the need to verify that the relevant seals, shafts and attaching hardware are available and serviceable. It shows the value in carrying out the ground runs to verify correct engine operation. In this case, the engineer was able to shut the engine down without damage.

Example 5

8.9 Date 10/2011 ATA Chapter 27 – Flying controls

Event description: After departure a control restriction was felt during a turn to the right to the required heading. Increased force in the control input achieved the required turn. Further incidences of control restriction noted during the next few turns but the aircraft remained controllable. Aircraft returned.

Implications: There was clear scope for the control restriction to become worse and affect the controllability of the aircraft.

Investigation: The investigation revealed that the aircraft had a history of autopilot trimming issues for about a month. A deferred defect had been raised noting the autopilot as being unserviceable. The post incident analysis suggested there may be an issue with the aileron servo actuators. Further analysis of the previous history showed that the previous reports in the technical log implied that there were similar control restrictions, not autopilot problems. On this occasion, the restriction was evident on the ground with the autopilot disengaged. The aileron PCU was changed. The autopilot roll servo was replaced as a precaution. In addition, the aileron hinge bearings were replaced. Restriction was no longer evident. No subsequent reports.

Corrective action: The defect was analysed and components replaced to re-establish the system's serviceability. Follow up action on aileron PCU strip revealed no defects. Roll servo actuator strip report likewise showed no defects. Manufacturer suggested there was a possibility of ice build up on a control cable adjacent to a detached recirculation fan. The area was inspected but no defect with the recirculation fan could be seen. The operator's reliability monitoring system will continue to review the system operation.

Commentary: Troubleshooting in this case failed to identify a root cause. The absence of reported defects following receipt of the component strip reports does not help. The report suggests that the fault, which is suspected as having been present for some time, may have not been properly reported in the technical log. This could mean that the opportunity to resolve the issue at an earlier date may have been missed. This highlights the importance of clear reporting in the aircraft's technical log of the symptoms seen when pilots find a defect.

Example 6

8.10 Date 10/2011 ATA Chapter 29 – Hydraulic systems

Event description: On selecting flap 1, left hydraulic system pressure warning illuminated followed by left hand quantity warning. Crew declared PAN call and following some further checks made an approach and landed safely.

Implications: Loss of hydraulic fluid, loss of pressure and potential compromise of certain system operation.

Investigation: On investigation after landing, a split in a hydraulic flexible hose was found in the left hand main landing gear wheel well. This pipe ran from the left system filter/case drain module and the relief valve assembly. It was noted that the hose was poorly supported with a single 'P'

clip and was free to move. A temporary repair was carried out using flexible hoses and the left system replenished. An ADD was raised to include re-inspection at each daily check.

Corrective action: Noting the temporary repair carried out the aircraft was returned to service. The MOR record notes that the operator's quality assurance department appears to have authorised for replacement of the pipe not to exceed the next A check. Further investigation into the replacement pipe showed that a rigid pipe should have been installed.

Commentary: Although the temporary repair used flexible pipes as a short term measure in accordance with a provision in the AMM it seems that the flexible pipe that failed had been installed for some time. With the discovery that there should have been a rigid pipe in that position there is a question as to how the flexible came to be installed in the first place and why the aircraft records did not subsequently require replacement by the proper rigid pipe.

Example 7

8.11 Date 01/2010 Chapter 28 – Airframe Fuel

Event Description: The aircraft arrived with approximately 16 Tons of fuel in the number 2 main tank. The cockpit indication showed a 'hard past zero' empty indication.

Implications: Suspected indication problem giving erratic/incorrect readings.

Investigation: The initial checks carried out on the wiring confirmed there was an open circuit in the tank harness. When entry was gained to the tank to make repairs it became evident that work had been carried out on the harness. A number of defects were found including incorrect routing of the wiring resulting in a number of taut cables. The harness was only partially secured and in addition was really too short placing undue strain on the wiring and connections. A number of wires, including the fly leads had been cut but remained attached and there was some wiring that, despite being redundant had been left in the tank. Following these discoveries the rest of the aircraft was inspected with a number of further defects being found.

Corrective Actions: Work was carried out to rectify the defective wiring and the fuel tank harness was replaced. Detailed review of the aircraft records failed to reveal where the fuel tank wiring was carried out. It was not therefore possible to establish the root cause beyond the clear

application of incorrect working practices and failure to follow approved data and repair data.

Commentary: Given the more recent focus on fuel tank wiring and EWIS requirements the defects found in this instance are a cause for concern. It is clear that the work had been done by an approved maintenance organisation but, as it was not possible to establish when the work had been done and the aircraft had transferred between registers, it could not be determined what approval had been involved. However, given that the manufacturer's continuing airworthiness requirements, approved maintenance manual and the wiring diagram manuals applying equally under any of the approvals there was no cause for these deficiencies to have been present. This demonstrates the need to ensure that work carried out has been done properly, which may mean supervising the approved maintenance organisation working with an operator's engineering staff. It also shows the need to ensure that maintenance is up to scratch when an aircraft is brought onto the UK register.

Example 9

8.12 Date 04/2010 ATA Chapter 28 – Airframe Fuel

Event Description: A fuel leak was evident from the right hand wing surge tank panel.

Implications: Fuel leak with the attendant loss of fuel and fire risk.

Investigation: On removal of the access panel for re-sealing, an incorrect panel was found fitted to in the right hand main fuel tank. The access panel houses the surge tank over pressure relief valve. With it being fitted in the wrong position, the surge tank relief valve ended up being fitted in the right main tank rather than the surge tank. This altered the design of the fuel vent and surge system with the attendant implications on system operation. The panels had been transposed during a maintenance check inspection five months previously. The aircraft had suffered a fuel leak some two months later. This was rectified by a re-torque of the attachment screws on the leaking panel. The next day saw a further fuel leak and air turn back. This was put down to a surge valve problem and the pressure relief valve was reset.

The aircraft pressure relief valve was replaced the following day and the surge tank inlet scoop inspected. The float valve was also replaced. Although the aircraft was then operated for a couple of months a further fuel leak occurred. This led to the discovery of the incorrectly located panels.

Corrective Action: The panels were relocated to their correct positions and fuel system checks carried out. Two investigations were completed by the airline's safety department and the engineering organisation. A number of recommendations were made. Documentation was changed including updating of the AMM by the manufacturer.

Commentary: It is interesting to note that the problem was originally the result of inadequate control of fuel tank closure and system reinstatement following the maintenance check. When the original fuel leak was reported the engineers looked to simply re-torque the panel screws. There was no consideration of whether the panels were correctly positioned, based most likely that they had been fitted correctly at the time. It is of concern that further work was then carried out following the next fuel leak and air turn back where there was a question over the operation of the pressure relief valve and the surge tank inlet. This should have, but failed to, detect the incorrect positioning of the panels. It was not until a further leak some two months later that the anomaly was discovered.

This event shows the importance of staged inspections and a thorough check of panel installation following maintenance. In this case, it is apparent that the leak did not really happen until the fuel system was filled to a certain level. Given the variable nature of the aircraft operation the appearance of the defects, e.g. a leak, may not happen until sometime after the work was done. A similar situation was noted by AAIB in the investigation of a Boeing 777 centre tank access panel being left uninstalled following maintenance. This resulted in a heavy fuel leak following take off. The criticality of panels being installed correctly is also highlighted in the AAIB report of a Boeing 757 where the flap panels were left off, leading to lateral control difficulties in flight.

Chapter 9

Summary

- 9.1 The information above from the analysis of the CAA maintenance error related MORs gives a clear indication of the potential areas to be considered. This is useful information for any engineering organisation or operator wishing to look at potential safety risks and develop safety strategies to address them.
- 9.2 The examples given are a snapshot of some MORs giving additional detail and an indication of what the investigation revealed. It is clear from the examples that the MOR system does not always have much information relating to the actions taken or what the company may have done to try and prevent a reoccurrence.
- 9.3 Where applicable, under an organisation's SMS there is an inherent obligation to identify risks and put appropriate mitigation in place. More than that, there is a need to become a learning organisation, looking at the risks within other organisations that may have been identified in accident investigations or through reports made under the CAA MOR scheme. An organisation that looks simply at its internal issues leaves itself open to the hazards that others have already fallen foul off.
- 9.4 There are some fundamental issues that need to be borne in mind. The operator has an obligation to manage the airworthiness and maintenance requirements of its aircraft fleets. Whilst Part M covers this in part there may be a need to exercise some form of oversight of the contracted Part 145 organisation that actually performs the maintenance to ensure that what is expected is what is delivered, in terms of both content and quality.
- 9.5 The Part 145 organisation has an obligation to ensure the competence (knowledge, experience, behaviours and attitudes) of the staff performing the work, whether licensed or not. In addition, it is important that there is an appropriate balance of supervisory and inspection staff to ensure that the work is progressed in controlled manner and that the required quality of work is achieved.
- 9.6 The analysis shows there is scope for concern about how often maintenance staff fail to follow the correct procedures, maintenance manual processes such that incorrect installation or incomplete installation is the undesirable consequence. This can impact aviation safety as well as damaging an organisation's reputation.

- 9.7 There is a need for maintenance error management systems (MEMS), not least because Part 145 requires it, which allows the organisation to look at continuous improvement but if the organisation pays only lip service to it the organisation could well be guilty of corporate failings. In the event of an accident this could compromise any defence the organisation may wish to put forward. Corporate manslaughter and corporate killing are real business risks if an organisation fails to meet its obligations¹⁶.
- 9.8 It is hoped that the information in this CAA paper will help organisation to develop a strategy to minimise the likelihood of any maintenance error and the resulting compromise of the operator's flight safety programme.
- 9.9 It became clear during the Offshore review that there is still a need to decrease the number of maintenance errors and also improve the maintenance standard within organisations. The review of the MOR data and events showed that errors are still occurring at a concerning rate. It is therefore clear that a programme of initiatives is needed to reduce the likelihood of significant events occurring in the future. To address this issue CAP 1145 Action 31 states:
- "The CAA will form an Offshore Maintenance Standards Improvement Team with the offshore helicopter operators with the objective of reviewing the findings at Annex F to the CAA Strategic Review of the Safety of Offshore Helicopter Operations and making proposals to achieve a step change in maintenance standards."*
- 9.10 During the establishment of the Action 31 Improvement Teams, it was clear that these issues were not specific to the Helicopter maintainers and management organisations and were equally applicable to the fixed wing organisations. This review will be published as a separate report.

¹⁶ Corporate Manslaughter and Corporate Homicide Act 2007

Chapter 10

Conclusions

It is clear from the report and from a number of AAIB reports, during the same period, that maintenance Human Performance is still a casual/contributory factor, in a significant number of events. Therefore the following actions/recommendations are made:

Actions to the CAA

1. The CAA should continue to carry out a periodic review of occurrences to identify the maintenance error event trends, to follow on from this 2005 to 2011 report.
2. The CAA should work with operators to provide guidance on how to identify best practice to identify and reduce the likelihood of errors occurring and the impact on aircraft safety.
3. The CAA should develop a method of ensuring that maintenance staff are fully aware of the their responsibilities in the following areas:
 - Correctly recording and signing off work;
 - Identifying and carrying out safety critical tasks or independent / duplicate inspections;
 - The importance of following procedures, maintenance instructions, reporting and investigating errors;
 - Improving tool and debris control.

Recommendations to operators, PART M and PART 145 organisations

Organisations should ensure that all of their staff should be made aware of and discuss relevant areas of this report during their continuation training or briefing sessions that focus on the above actions. They should review their procedures, working practices and highlight any occurrences where contributory factors have resulted in an installation error.