RISKS ASSOCIATED WITH AIRCRAFT MAINTENANCE IN EUROPEAN COMMERCIAL AIR TRANSPORT

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INTRODUCTION & CONTENT

• Background, two MSc projects, why?
• Analysis of Maintenance Related European Occurrence Reports (2012-2016)
  • Initial analysis
  • Taxonomies
  • Custom taxonomy
  • Validating the method
  • Conclusions
• Analysis of Maintenance Related Global Accidents & Incidents (2003-2017) & future plans

• Goals for today:
  • Explain why recategorising 3912 incident reports may have been a useful exercise.
  • Collect more data: PollEv.com/ICSC
What do you think the most significant risk in continuing airworthiness / maintenance domain is? (In no more than one sentence or short phrase)

Respond at PollEv.com/icsc

“Limited handover if maintenance errors”

“Time pressure”

“From my experience with the RNAF, I would say the gap between the way it should be done and the way it is done by the maintenance personnel”

“Standardization”

“The legislative change throughout the industry and the (blurry) line between theory and practicality (therefore misinterpretation)”

“Drifting away from original design assumptions.”

“Disconnect between managerial decision making and management versus production pressure demands faced by engineers forced to make ends meet”
What do you think the most significant risk in continuing airworthiness / maintenance domain is?
(In no more than one sentence or short phrase)

"Manage the change/ re-integrate the system after maintaining it"

"Error design, updating systems, frequency of maintenance"

"Maintenance engineer fatigue"

"Time and money"

"Incident reporting"

"Lack of resources"

"Unclear maintenance instructions"

"Fatigue"

"Lack of understanding by front line staff as to why they need to report incidents?"
BACKGROUND

- Fortunately, accidents caused by maintenance errors are relatively rare.
- Incident reports, both mandatory and voluntary, are gathered in the European Central Repository (ECR).
- Analysis of this data is used to produce Annual Safety Reports (ASR).
- The 2016 review showed that Aircraft Maintenance (1318 incidents) was related to all key risk areas.
EASA ANNUAL SAFETY REVIEW 2017

Source: Annual Safety Review 2017 available @
https://www.easa.europa.eu/sites/default/files/dfu/209735_EASA_ASR_MAIN_REPORT_3.0.pdf
1 - CAT AEROPLANES SAFETY RISK PORTFOLIO

Key Risk Areas

- Loss of Control Accidents
- Runway Excursions

(7) Aircraft Maintenance
TWO INDEPENDENT / INTERTWINED MSC RESEARCH PROJECTS

Cranfield Safety & Accident Investigation Centre

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3912 incident reports from the European Central Repository (2012-2016)

Less detail in the data but more volume for trend analysis

112 Accidents & Serious Incidents from ASN & Skybrary databases (2003-2017)

More detail in the data but still challenging
THE CHALLENGE

- Thesis project was set up, using a download from the ECR that included raw (anonymous) data for 7158 incident reports (2012-2016), in the end 3912 were used.
- Aim was to see if this data could be used to:
  - Find a top-10 of safety issues in aviation maintenance
  - Compare this to previous analysis
- Steps:
  1. Initial analysis on the download.
  2. Background research into maintenance errors, possible taxonomies.
  3. Structuring and analysing the data.
  4. Develop a taxonomy that fits the brief for this project.
  5. Evaluate the taxonomy and validate the method.
1. INITIAL ANALYSIS

- Practical issues: 3 different worksheets, 2 categorisations (Outcomes and Causal & Contributory, or ‘event type’, factors), line numbers in the three sheets did not match up due to multiple categories per incident.
- Excel workbook was built so that the data from three sheets could be collated on one page, with options to either exclude the incident record, or categorise it.
1. INITIAL ANALYSIS - CONTINUED

- A large percentage of reports could not be used (68% of 3912 reports). Main reasons:
  - Narrative is empty (28%)
  - Language not in English (21%)
  - Not enough information in narrative (8%)
  - Incident is not related to maintenance (5%)

22/07/2014 Airbus A330
According to the report(s) received by FCAA, incorrect defect logging procedures were used.

03/08/2014 Boeing 757
When a crew member reached for the handle on the entrance door on station two to close the door, and stepped out on the stair outside it started to move away from the aeroplane.
EXISTING TAXONOMY IN REPORTS

- Four-level breakdown covering everything under the sun, useful?
  - Operational (Level 1) and Aircraft Maintenance (Level 2) is used in 5046 of 14055 ‘event type’ records (on average, two categories are used per incident) or 36%.
  - Out of these, 2704 include a level 4 category, the other 46% only use three levels of categorisation.
- Selecting Equipment (Level 1) allows the user to select a whole range of possible failures, structured using the ATA system. 25% of categorisations use this option but only 6.5% (out of all records) use this to level 4, which provides the best level of detail.

| ATA | Level 4 used | Level 2 | 14055 records |
2. POSSIBLE TAXONOMIES

- Several options:
  - CAA paper 2009/05 (developed for analysing MORs)
  - CAP 1367 (modified from above)
  - MEDA (Boeing tool to investigate maintenance events)
  - HFACS-ME (US Naval Safety Center, to investigate HF causes in maintenance events)

- The first two looked promising, but turned out to be restricted in the level of detail available.
- Both MEDA and HFACS are more suited to an immediate investigation than a retroactive analysis of reports. As both require selection of causes rather than facts, it may not fit a reporting system either.
2. POSSIBLE TAXONOMIES

- Points to keep in mind for a good taxonomy (Wiegman & Shappell, 2001):
  - Reliability
  - Comprehensiveness
  - Diagnosticity
  - Usability
  - Validity
- In this case the taxonomy had to work well in two situations:
4. CUSTOM TAXONOMY

1. Base the taxonomy on familiar descriptions and the maintenance process (level 1):

   - Maintenance documentation
   - Parts supply/tracking/life limits
   - Tools
   - Job access/job set-up
   - Working practices
   - Troubleshooting
   - Lubrication/servicing
   - Inspection/testing
   - Installaiton/Removal
   - Modification/Repair
   - Activation/deactivation
   - Job close-up

2. Make sure that there is sufficient level of detail in the second level (67 different options provided).

The purpose was to categorise what went wrong, most reports do not allow analysis of the causes.
4. CUSTOM TAXONOMY

- Ideally, a taxonomy creates separate categories where one report fits into a single category only.
- This turned out to be impossible without sacrificing comprehensiveness.

01/04/2013 Boeing 737
After replacement of HMU on L/h engine, the engine actuator test was performed with the fuel spar valve closed, not in accordance with the maintenance manual. Then an engine idle run was performed and the aircraft was returned to service. The actuator test without fuel supply may have been the reason for the engine fuel pump failure.

04/04/2013 Boeing 737
C/B for FWD door area heater found open. T/S revealed that connectors to heater M2174 on R FWD overwing exit were incorrectly connected.

07/05/2013 ATR 42
Engineer was tasked with changing the unserviceable T6 thermocouple from L/h engine. Upon removing the cover plates to gain access, it was found that the thermocouple was missing.

17/05/2013 Boeing 737
Data plates attached to engines using rivets drilled into fan case flanges. Modification documentation calls for 20 gauge locking wire.
5. VALIDATING THE METHOD

A survey showed that:

- In a significant percentage of cases, the same level 1 category was selected (51% of 138 cases).
- In 31% of the 138 cases, the level 2 classification was also the same.
- Looking at just the 51% from the first graph, for 61% of these cases, the level 2 category matched with the original selection during this project.
5. VALIDATING THE METHOD

- Opinions about the level to which the classification described the incident showed a significant preference for the new taxonomy.

**Comparison between opinions about ECR classification and new taxonomy**

- 1 - Not At All
- 2 - To a Small Degree
- 3 - To a Moderate Degree
- 4 - To a Considerable Degree
- 5 - To a Great Degree
Based on the categorisation used in this project, the most frequently occurring issues are:

| No. | Issue                                                                                           | Number of Incidents | Percentage |
|-----|-------------------------------------------------------------------------------------------------|---------------------|------------|
| 1   | 10.7 Installation/removal incorrect                                                           | 199                 | 16.2%      |
| 2   | 1.10 Defect deferred with incorrect procedure/reference/follow up                             | 111                 | 9.0%       |
| 3   | 1.3 Scheduled tasks overdue                                                                  | 74                  | 6.0%       |
| 4   | 13.2 Tools/parts/FOD left behind                                                              | 63                  | 5.1%       |
| 5   | 13.1 Close up not performed correctly                                                         | 54                  | 4.4%       |
| 6   | 10.3 Part incorrect                                                                           | 51                  | 4.1%       |
| 7   | 6.4 Incorrect procedure used or procedure applied incorrectly                                | 50                  | 4.1%       |
| 8   | 10.5 Installation/removal incomplete                                                           | 42                  | 3.4%       |
| 9   | 11.5 Repair not carried out IAW AMM/SRM/other instructions                                     | 38                  | 3.1%       |
| 10  | 3.2 Parts supplied with incomplete/incorrect modification, configuration or condition.         | 37                  | 3.0%       |

(Simmons/RAeS, 2011)
Considering the limited resources and budgetary constraints, which one of the following categories of occurrences would you further investigate and propose mitigation actions as a priority?

- Installation / Removal incorrect: 16.2%, 30%
- Defect deferred with incorrect procedure/reference/follow-up: 9.0%, 40%
- Scheduled tasks overdue: 6.0%, 25%
- Tools/parts/FOD left behind: 5.1%, 5%
- Close up not performed correctly: 4.4%
ANALYSIS OF MAINTENANCE RELATED GLOBAL ACCIDENTS & INCIDENTS

A Contemporary Analysis of Aircraft Maintenance-Related Accidents and Serious Incidents

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ABSTRACT: Aircraft maintenance has been identified as a key point of concern within many high risk areas of aviation; still being a casual/contributory factor in a number of events. The purpose of this study is to investigate the nature of aircraft maintenance-related accidents and serious incidents for 2003-2017, to provide a modern-day understanding to the critical areas of concern, in addition to exploring the key risk areas. To achieve this, a dataset of maintenance-related accidents and serious incidents was compiled and then qualitatively analysed by thematic template analysis. This allowed for the development of an appropriate taxonomy, MxFACS, which was used to code these occurrences. The coded output was then evaluated by subject matter experts, and an inter-rater concordance value determined to assure research rigour. Subsequently, the occurrences were evaluated in terms of their relationship to fatal accidents, creating a picture of the associated risk. The most frequent maintenance occurrence consequences were found to be runway excursions and air turnbacks, with the most common associated events being related to engine and landing gear. The greatest maintenance factor issues were inadequate maintenance procedures and inspections not identifying defects. In terms of fatalities, collision occurrences were the most prominent consequence, engine-related events were the most significant event type, and inadequate maintenance procedures were the most concerning maintenance factor. The study’s findings may be used in conjunction with existing risk analysis methodologies and taxonomies to aid in a Safety-II approach to understanding where barrier weaknesses lie within maintenance safety management systems, allowing stakeholders to better develop future targeted action or oversight.
Review of Accidents & Serious Incidents – CODED OUTPUT

**Level 1 - Occurrence**
- Consequence
  - Runway-related occurrence: 18
  - Diversion or Air Turnback: 13
  - Collision: 8
  - LG-related occurrence: 7
  - Landing-related occurrence: 4
  - Structural damage: 4
  - Fire: 2
  - Depressurisation: 2

**Level 2 - Associated Event System / Component**
- Engine: 38
  - Landing gear: 4
  - Flight controls: 4
  - Electrical power: 4
  - Instrumentation and indication: 4
  - Steering: 1
  - Structure: 1
  - Fuel: 1
  - Insulation: 1
  - Pressurisation: 1

**Level 3 - Maintenance Factors**
- Inadequate maintenance: 53
  - Incorrect maintenance: 16
  - Inspection: 12
  - AMM: 9
  - Organisational: 8
  - Oversight: 5
  - Check: 5
  - Overhaul: 3
Level 1 - Occurrence Consequence

- Runway-related occurrence: 23
- Diversion or Air Turnback: 22
- Collision: 18
- LG-related occurrence: 15
- Landing-related occurrence: 13
- Structural damage: 8
- Fire: 7
- Depressurisation: 4
- Cabin fume event: 1
- In-flight shutdown: 1

Review of Accidents & Serious Incidents – CODED OUTPUT
Review of Accidents & Serious Incidents – CODED OUTPUT

Level 2 - Associated Event System/Component

- Engine: 38
- Landing gear: 4
- Flight controls: 4
- Electrical power: 4
- Instrumentation and indication: 4
- Steering: 1
- Structure: 1
- Fuel: 1
- Insulation: 1
- Pressurisation: 1
- Windscreens: 1
- Workload: 1
Review of Accidents & Serious Incidents – CODED OUTPUT

Level 3 - Maintenance Factors

- Inadequate maintenance: 59
- Incorrect maintenance: 17
- Inspection: 17
- AMM: 16
- Organisational: 10
- Oversight: 8
- Check: 3
- Overhaul: 3
- Airworthiness directive: 2
- Human Factors: 3
- FOD: 33

Level 2 - Associated Event
- Engine
- Landing gear
- Flight controls
- Electrical power
- Instrumentation and indication
- Steering
- Structure
- Fuel

Level 1 - Occurrence
- Runway-related occurrence
- Diversion or Air Turnback
- Collision
- LG-related occurrence
- Landing-related occurrence
- Structural damage

Review of Accidents & Serious Incidents – CODED OUTPUT
Review of Accidents & Serious Incidents – RESULTS

Level 1 Fatal Accident Relationship
- 18, 606, 11
- Ø = n occurrences with fatalities

Number of Occurrences
- Runway-related occurrence
- Diversion or Air Turnback
- Collision
- LG-related occurrence
- Landing-related occurrence

Level 2 Fatal Accident Relationship
- 44, 232, 8

Number of Occurrences
- Engine
- Flight controls
- Instrumentation and indication
- Structure
- Insulation, Pressurisation and Windscreen
- Landing gear
- Electrical power
- Workload
- Steering
- Fuel

Level 3 Top 9 Fatal Accident Relationship
- 32, 209, 6

Number of Occurrences
- Inadequate maintenance procedures
- Operator's inadequate maintenance oversight
- Non-airworthy component released into service
- Inspection does not identify defect
Review of Accidents & Serious Incidents – RESULTS

Level 1 Fatal Accident Relationship

- Runway-related occurrence
- LG-related occurrence
- Fire
- Diversion or Air Turnback
- Landing-related occurrence
- Depressurisation
- Structural damage
- Collision
- Cabin Fume Event and IFSD

Number of Fatalities vs Number of Occurrences

Ø = n occurrences with fatalities
Review of Accidents & Serious Incidents – RESULTS

Level 3 Top 9 Fatal Accident Relationship

- Inadequate maintenance procedures
- Non-airworthy component released into service
- Overhaul not undertaken
- Incorrect component installed
- Inspection not undertaken
- Operator’s inadequate maintenance oversight
- Inspection does not identify defect
- Regulator’s inadequate maintenance oversight
- Incorrect installation

Number of Fatalities vs. Number of Occurrences

Ø = n occurrences with fatalities
Which one of the event categories should be the focus of attention as a priority? (#total accidents, #fatalities, #fatal accidents)

- Inadequate maintenance procedures (32, 209, 6) - 21%
- Operator's inadequate maintenance oversight (14, 391, 6) - 29%
- Inspection does not identify defect (16, 115, 3) - 7%
- Non-airworthy component released to service (9, 111, 3) - 14%
- Incorrect installation (15, 155, 2) - 14%
- Incorrect component installed (8, 169, 2) - 7%
- Inspection not undertaken (5, 107, 2) - 7%

Respond at PollEv.com/icsc
CONCLUSIONS

• Next to installation errors, the process for deferring defects and the job-close up phase could use some attention.

• The search continues for causes, or the ‘why’ behind these errors:
  • CHC Safety & Quality Summit
  • DGAC maintenance safety network advisory group
  • Next IFA event (Nov 2018)

• Several recommendations were made to improve the data quality for ECR reports.

• Several opportunities for additional research are available based on this project and the material used.

• For now, the tip of the iceberg is very small, or invisible. Is it hiding in the fog?
IMPROVING THE USEFULNESS OF REPORTS

- Insist on a narrative with sufficient detail when submitting a report.
- Modify the ‘event types’ taxonomy to shift maintenance related categories to a higher level in the taxonomy.
- Separate the ATA breakdown from the contributory causes taxonomy. Focus on the ‘what’ before insisting on listing causes.
- Regular analysis of the reports in the ECR to evaluate their usefulness.
- Inform the reporters in the industry about how to submit a report for maximum usefulness.
FURTHER RESEARCH

• Evaluate the narratives for the two high scoring categories to see if HF issues can be identified.
• Interview subject matter experts to see if the safety issues identified in this report are recognised.
• Further work on the taxonomy to avoid ambiguity in the descriptions of the categories.
• Use better descriptions of the taxonomies in the CAA papers to compare the results.
• Evaluate whether the input method for submitting reports to the ECR has an influence on the level of detail submitted.
THANK YOU FOR YOUR TIME AND ATTENTION