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‘Fragmentation of Information’ in International Data Gathering from Aircraft Fume Events

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ABBREVIATIONS

APU	Auxiliary power unit
BAe	British Aerospace
BFU	German Federal Bureau of Aircraft Accident Investigation
EASA	European Union Aviation Safety Authority
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
MOR	Mandatory occurrence reporting
PF	Pilot flying

ABSTRACT
This paper describes fragmentation of information problems in relation to information dissemination from bleed air contamination reports on aircraft. Chemical contamination of the bleed air supply system may cause crew impairment and can negatively impact flight safety. By comparing and contrasting official investigation reports with other information sources, the validity of the available information is scrutinized. The results display a lack of centralized data about fume events. Additionally, there is inconsistency between data from different sources. Fragmentation of information makes it difficult for pilots and decision makers to accurately assess the extent of the problem.

INTRODUCTION

The design of jet aircraft incorporates a bleed air system, which provides medium to high-pressure air bled from the compressor section, prior to the burning chamber of the engines and the auxiliary power unit (APU). One of the main purposes of bleed air is to provide pressurization and air conditioning to the cockpit and cabin air. There are three ways that jet engine oil can contaminate the bleed air, being the air that is bled from the engine compressor stages to the cabin air that is delivered to passengers and crew: (i) by design: jet engines need minimal seal clearance to operate and thereby permit low level oil leakage into the aircraft cabin during normal flight operations; (ii) by seal bearing failure or minor systems failures, including worn seals; and (iii) maintenance irregularities or design deficiency.[1] This paper deals with the effects of the latter two categories, when noticeable amounts of jet engine oil or even externally ingested hydraulic fluid contaminate the aircraft occupants’ breathing air. In recent years, there has been growing concern about the health and flight safety implications from such contaminations, which are commonly called fume events, or alternatively named cabin air contamination events. Fume events are hard to objectify in the absence of sensors and in the absence of safe limits for the specific chemical mixture from aircraft engine oil. Yet, many aircraft accident safety investigations identified oil leaks after crews reported health effects ranging from minor health effects, from impairments up to full pilot incapacitation. In several cases, health effects on passengers were reported.[2]

Reporting and learning from occurrences

Since the introduction of bleed air technology, there have been reports of pilot impairment and incapacitation,[3–5] whereby the subsequent technical troubleshooting revealed the presence of jet engine oil or hydraulic fluid in the bleed air. However, the exact causative toxicologic mechanism is not known, which has allowed some aviation stakeholders to publicly doubt whether flight safety can even be affected by cabin air contamination.[6] In the light of the number of reports and the degree of impairments described, doubting a causal link seems questionable and not in line with the duty of care one usually finds in flight safety matters. However, there is no global repository for fume event reports and the lack of access to one central database produces uncertainty in the absence of the exact toxicological explanation.

Aviation reporting schemes are designed to learn in hindsight from the sum of cases that happen elsewhere, even if they happen beyond the operational boundaries of a particular airline, or across national borders. There are different levels on which regulators and aircraft accident investigation agencies react to pilot reports. At the initial level, pilot reports are gathered in national databases. At the second level, serious incidents will additionally escalate into an official investigation. Finally, if specific safety trends emerge, aviation authorities can decide to investigate further with summary reports or react by adapting the regulations.

The typical transparency produced by aircraft accident investigation disclosure is combined with 'share-your-experience' incentives from airlines and aviation authorities. Such incentives are intended to inform pilots about the risks they face by learning from similar previous incidents and accidents. The feedback loop that consists of reporting on the one hand and redistribution of information and mitigation on the other hand, encourages and rewards pilots for speaking up. Aviation reporting schemes and subsequent information dissemination have set a positive example for many other industries. Yet, in the case of fume events, as can be concluded from the findings of this paper, the existing 'share-your-experience' mechanisms suffer from what safety science calls an organization without a memory. Organizational memory loss happens when there are barriers to successful learning from incident reporting or, when the perceived lack of learning and the absence of change in practice might eventually further decrease the willingness of operators to contribute to incident reporting.[7]

Organizational uncertainty

There is a difference between intentionally produced organizational uncertainty and uncertainty as the result of unintentional mechanisms. Although there are several documented studies in relation to fume events where aviation stakeholders contributed to manufactured uncertainty, aligned with intended corporate or individual benefits, it is not unlikely that at the same time airline managers and airframe manufacturers were simply unaware of the many reports and their severity from previous decades, and thereby themselves became a 'victim' of organizational memory loss.[6,8,9] As opposed to manufactured uncertainty, unintentional organizational uncertainty has earlier been labelled 'structural secrecy' by Diane Vaughan's analysis of the Challenger space shuttle disaster.[10] Her analysis was eventually issued as the book 'the Challenger Launch Decision', which described how a known criticality with the space shuttle O-ring seals during cold weather operations was not communicated to all NASA participants. With Vaughan's focus on sociological and organizational factors, she refuted the conventional explanation of a mere engineering and accountability problem, which was the earlier conclusion from the officially appointed Rogers Commission. As a part of structural secrecy, Vaughan described the principle of 'fragmentation of information' where within NASA, specific actors held technical information that the Challenger launch would not be safe and even warned against it, yet this information did not reach the team tasked with the launch decision. This breach of information flow eventually led to the explosion of the Challenger during its launch. Since Vaughan's seminal work, safety scientists have often examined whether 'structural secrecy' and 'fragmentation of information' can be recognized in other disasters. The aim of this paper is to show signs of the memory loss of a system as a whole in relation to fume events and show that fragmentation of information is a mechanism at play that leads to structural secrecy.

METHODS

The methodology of this paper consists of a desktop exercise, which re-iterates some findings from a previous Master's thesis about the topic of competing discourses in aircraft cabin air quality, written for the MSc 'Human Factors and System Safety' at Lund University, Sweden.

Information from the different levels of pilot report management as discussed in section 'Reporting and learning from occurrences' were studied. The most important level to learn about the origin and severity of an aviation safety topic are aircraft accident investigation reports, because these investigations result from pilot reports, which have been escalated because of serious incidents or accidents.

A collection of all obtainable incident reports between 1996 and 2017 was the starting point of this desktop exercise. A total of 55 reports was retrieved from aircraft accident investigation units. National databases do not normally provide easy access for the general public. The UK Mandatory Occurrence Reporting (MOR) scheme provided easy access until rules of access changed recently. Therefore, the global collection of 55 investigation reports could be compared and contrasted with information from the UK national database containing those reports that did not escalate to an investigation.[11] Finally, a German summary report from the Federal Bureau of Aircraft Accident Investigation about the topic of cabin air contamination was consulted in relation to its evaluation of technical findings.[12] The German study covered occurrences of cabin air quality caused by bleed air contamination or alternative cabin air contamination sources (e.g. electrical fumes or galley-generated smells). For this paper, the data about the technical findings of suspected bleed air contamination events from incident reports was tabulated and compared against information from secondary information sources and checked for credibility and consistency.

RESULTS

The first sub-section in Results covers all investigation reports that could be identified in a 21-year period globally. The second covers some qualitative data from the same collection of reports. The third covers a UK collection of mandatory occurrence reports that did not escalate into an investigation. The fourth compares findings about a German BFU summary report and an airline report.

Investigation reports

The retrieval of incident reports was not a straight-forward task. Looking through national databases and websites from national aircraft accident investigation branches using generic search terms such as smells, engine oil, fumes, fume events, smoke, haze, cabin air quality, and cabin air contamination gave fewer reports than those already retrieved by the author of this paper through other sources. Eventually, a network of scientific colleagues writing on this topic proved to be a more valuable source of available reports than national accident investigation accessible databases. Hence, there is no structured and systematic method for retrieving incident reports on the topic of cabin air contamination. Consequently, there is no way to make certain that the list of reports used in this paper is exhaustive.

The 55 investigation reports collected for this study between 1996 and 2017 were produced by a total of only 11 countries, of which Australia is the only non-European country to investigate the issue. The UK only produced half of the reports worldwide, 27 out of 55. The fact that entire continents or countries are not represented in the investigations is remarkable, because the literature and mandatory occurrence reports have described the same problems all over the world and in relation to all popular aircraft models with comparable frequency and gravity.[8,13,14] One earlier study collected a total of 87 fume events in a single US airline during the 2-year period 2009-2010.[2] Those US events have no relation to the collection of incident reports from this conference proceeding. From these 87 events in the US, emergency medical care was required after 27 flights and follow-up medical care after 43 flights. Mechanical records confirmed that oil contaminated the air supply on 41 of the 87 suspected fume events.[2] However, not a single National Transportation Safety Board (NTSB) (US aircraft accident investigation branch) investigation about these US events could be retrieved by the author of this paper.

The 55 investigation reports from this study were analyzed for mechanical correlation with bleed air contamination. The distribution of technical findings is depicted in Figure 1.

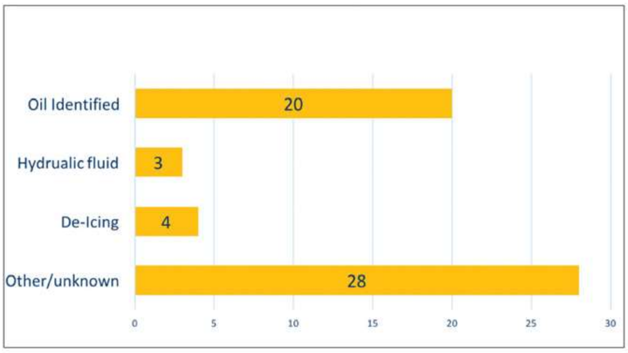

Figure 1— Distribution of technical findings from suspected bleed air contamination from incident reports

From the 55 incident reports that were analyzed, 27 reports were able to identify the presence of oil leaks or aviation fluids. The majority were engine or APU oil leaks. Only-three discovered hydraulic leaks and another three identified de-icing fluid. Despite narrative descriptions of troubleshooting difficulties, mentioned in this collection of reports, the cause-effect relationship between the reports and the numerous identified oil leaks establish a pattern for half of the cases. A further statistical analysis remains impossible, because there was no comparable method of investigation among the reports.

The majority of the remaining reports in the category other/unknown could not identify a cause for reported smells, fumes, smoke, and/or symptoms. Only few of the reports searched for alternative conclusions. Some provided non-falsifiable conclusions, such as the possibility of residual oil contamination of the ducts from previous fume events.[15] Such probable causes were not counted as a positive result in the positive identifications of bleed air contamination, so the positive identifications for engine oil and aviation fluid as depicted in Figure 1 remain a conservative count. The only positive verifiable alternative finding, which was not attributable to pyrolyzed engine oil, hydraulic or de-icing fluid, was provided by metallic parts from turbine blade fatigue that created smoke in the cabin. Even in this case bleed air design was responsible for the smoke entering the cabin, but it was still counted under the 'other/unknown category' from Figure 1.[16]

Some reports hypothesized other possible sources, in the absence of hard proof, such as the widespread misuse of a toilet-cleaning agent for floor cleaning in one investigation, although such misuse could not be identified on this particular flight.[17] A further report found the source of contamination to have resulted most likely from a chemical within the forward toilet servicing.[18] These are examples of non-falsifiable hypotheses. This is also true for reports that have described the possibility of a physical-psychological related reaction in the absence of evidence of bleed air contamination. A German BFU report described possible contributing factors to be physiological and psychological effects on both crew members of massive smell development whose origin and spread could not be determined.[19] The report counted 72 pages and looked into a multitude of sources but stated that a provable answer why two pilots became affected at the same time cannot be given.[19] The investigation did not start until one year after the facts.

Investigation reports reveal a much wider history of events

Some reports from the collection in 'Investigation Reports' refer in their side marks to a much wider history of events. A report from the year 2005 describes how a Dash-8 filled with smoke due to a fatigue cracking of the compressor, allowing an oil leak into the bleed air.[20] The final report found that fume events still happened frequently, and the investigation attributed the majority of these cases to oil leaks:

"A search of the CAA database revealed that in the three-year period to 1 August 2006 there had been 153 cases of fumes, abnormal odor or smoke or haze in the flight deck and/or cabin of UK registered public transport aircraft of various types. Details on a number of the cases were limited but the available information suggested that around 119 of the cases had probably resulted from conditioned air contamination. This had commonly been caused by oil release from an engine, APU or air conditioning unit or ingestion of de-icing or compressor wash fluid by an engine or APU, with consequent smoke

and/or oil mist in the conditioned air supply to the fuselage. It appeared that in many of the cases the crew members had found it difficult or impossible to establish the source of the contamination."[20]

The excerpt above reveals that in a 3-year period, the UK aircraft accident investigation branch attributed 119 cases of fume events to conditioned air contamination for the UK only. Considering the fact that the Federal Aviation Administration (FAA), European Aviation Safety Agency (EASA), and the International Civil Aviation Organization (ICAO) have warned of the possible impact on flight safety,[21,22] this substantial number of previously unknown events mentioned in a side comment is reason for concern. Another even larger series of occurrences was revealed in the final report of a Swedish investigation when BAe systems, the airframe manufacturer of an aircraft involved in a specific incident, was asked about previous problems and uncovered a whole series of previous events, exclusively on the BAe 146, in their description to the investigators.[23] Their frequency and safety impact explained in the report was significant:

"The aircraft manufacturer continuously follows-up submitted reports of disturbances from operators of the BAe 146 type of aircraft. The following information has been provided by the manufacturer. During the period from June–92 until January-01 a total of 22 cases were reported where the flight crew's capacity had been impaired. Of these, seven have been judged as serious since they affected flight safety negatively. During the period from January-96 until September-99, 212 reports were submitted by a specific airline to the aircraft manufacturer concerning tainted cabin air. Of these, 19 reports concerned the impairment of the crew's capacity. Seven of the reports were submitted directly by the crewmembers. From another 36 operators of the aircraft type a total of 227 occurrences relating to contaminated cabin air were reported during the period from May-85 until December-00. Of these, 11 reports concerned the impairment of the crew's capacity".[23]

It is remarkable to see that hundreds of events, several of them with an impact on flight safety, were already recorded before the millennium. But none of this information was communicated to the pilots affected by the flight under investigation. The pilots were not trained to react to and handle a fume event. The fact that the crew members only recognized the significance of what they were being exposed to until it was too late, whereas hundreds of similar incidents with the same aircraft model preceded it, confirm the premise of this article about a system without a memory. Organizational memory loss is created by fragmentation of information where extensive information is available to one side of the system (the manufacturer) but not to the actors that need to manage such events (the pilots). As the captain of the SE-DRE investigation testified: *"[we] didn't realize that we were being intoxicated before we were really ill".*[24] *"Once I began to feel ill, things happened extremely quickly. If I hadn't managed to get my oxygen mask on in 15 seconds, I would never have succeeded in getting it on. I was so ill that I couldn't even lift an arm".*[24]

UK mandatory occurrence reporting

Mandatory occurrence reporting (MOR) contain pilot narratives and possibly also technical findings. They are gathered by the national aircraft accident investigation branch, but usually not disclosed to the public as is the case with investigation reports. They provide the second information source for this study. A MOR collection of events from the UK over a 5-year period from 2001 until 2005 produced 37 identified cases of engine oil leaks and an additional 26 APU or engine oil overfillings out of a total of 227 suspected fume events with varying impact.[11] This creates a higher number of technical identifications of bleed air contamination over a 5-year period for a single country than the entire number of globally collected incident reports with a full investigation over a 21-year period from the 'Investigation Reports' section.

In 57 out of 227 UK MOR reports from this section, health symptoms of varying degree were reported. One particular case, where the captain collapsed after landing is provided below. The narrative from this report revealed a double pilot impairment, leading to subsequent identification of an oil leak. The problem was already identified by the mechanics before departure, but the repair was deferred. The wording from the report is as follows:

"A strong smell of engine oil / fumes entered the flight deck during descent. The Captain became affected very quickly, felt very ill, was unable to concentrate and could not monitor the First Officer who was PF [Pilot Flying]. Nr1 engine bleed immediately switched off, with no further smell noted. Oxygen used, resulting in the Captain feeling better, but he deteriorated quickly again when oxygen was removed. PF landed the aircraft. After landing, the Captain collapsed in the rear galley."

The root cause was found to be lower modification state seals, which allowed some engine oil into the ECS [Environmental Control System]. The seals were replaced and the system purged. An improved seal had been available which was being installed at engine shop visits. It was not however available in stock at operators main base.[11]

Most countries do not make their mandatory occurrence reporting system accessible to the public. The UK allowed easy access until recently. From this UK MOR collection example, it becomes clear that both oil leaks and overfillings are frequent and the effects can be detrimental for flight safety. It also reveals that incident reports are not the only source of information that should be consulted as mandatory reporting schemes can easily outnumber technical findings gathered in incident investigations.

BFU study versus internal troubleshooting

The German Federal Bureau of Aircraft Accident Investigation (German official abbreviation: BFU) started a retrospective study after a series of German occurrences happened from which one received widespread media attention. The retrospective analysis covered an 8-year period from 2006 until 2013.[25] Root causes were adopted from technical causes transmitted by the operators and scrutinized in those cases were the BFU initiated an investigation. The BFU could only attribute a small portion to engine oil, APU oil, hydraulic or de-icing fluid from a total of 663 findings. The sum of the table however only contains 659 events, from which engine oil or hydraulic and de-icing fluid are distributed as follows:

- Engine (not specified): 13
- Engine oil overfill: 3
- APU (Oil and De-icing fluid): 24
- Hydraulic and fuel lines: 9

Remaining categories with the remaining specify avionics fan, ECS fan, fire electrical systems, external contamination, coffee machine, oven, bird strike, etc.

If one adds all the oil leaks and hydraulic leaks for this 8-year period, the sum becomes 40. Note that the category APU merges oil and de-icing contamination. It should also be noted that the category of unsolved cases (undetermined/not known/none) represented the biggest part of the data totaling 431 cases.

The German Pilots Association Vereinigung Cockpit obtained an internal airline analysis from 167 technical logbook entries in relation to fume events from an airline staff member. They were collected over a 1.5 year-period and analyzed in 2009. The year 2009 falls within the 8-year range of the BFU study set up to collect all events. The incidents of the internal analysis should therefore also be reflected in the BFU study. In the document received by Vereinigung Cockpit, airline maintenance identified oil deposits in 58 cases, with the APU being the main culprit. This is a conservative estimate, because in 79 of the cases a mandatory service bulletin, which initiates a maintenance investigation after a fume event has not been performed. From these figures it becomes clear that one mid-size airline has collected more positive findings of engine and APU-related oil contaminations (58) after fume events in 1.5 years than the entire German airline industry has reported in an eight-year period to the BFU (40). Therefore, the statistics about technical root causes for fumes from the BFU report from 2013 cannot be maintained. It cannot be traced if these occurrences where within the 663 events already reported and their root causes were not transmitted or whether these occurrences were simply not transferred to the BFU and should be added to the total. In both cases they would alter the total distribution of root cause findings considerably and question the validity of the rest of the figures. The positive identification of confirmed engine oil related problems would be more than double. One should be mindful that the biggest category of events in the BFU study was labeled undetermined / not known / none, covering 431 cases, which shows that the quality of data is insufficient for actual statistical conclusions. The airline analysis repeats a lack of data problem as the mandatory maintenance inspection was not performed in approximately half of the cases.

DISCUSSION

Some of the effects on crews from the mandatory occurrence reports narratives contained descriptions from health impairments that were substantial. The gravity of health effects on crews can therefore not be established as the commonly accepted trigger to start an investigation. In some of the full incident investigations health effects were completely absent, whereas in some of the mandatory reports without a full incident investigation report they had a negative impact on flight safety. Neither was the positive identification of an engine oil or hydraulic leak a commonly accepted trigger that escalates a pilot report into an investigation. From the analysis of all obtainable investigation reports it becomes clear that some countries do not investigate fume events at all, not even when jet engine oil leaks are confirmed, and both crew and passengers required emergency medical assistance.[2] Thus, there is a lack of a common basis to investigate fume events.

A recent paper from Shehadi, with the specific aim to characterize nature and frequency of the issue in order to collect meaningful monitoring data, approximates that 2 to 3 contaminated bleed air events per day happen in the US.[13] A similar situation is to be expected in other areas of the world. Although the impact from fume events and their severity varies greatly, worst case outcomes reported full incapacitations or serious impairments from which the subsequent troubleshooting identified the presence of oil in the bleed air. The fact that ICAO, the FAA and EASA have warned about the possible negative effects on flight safety creates enough reason for a more centralized collection about frequency, severity and technical correlation of fume events.

Flight crews that seem to rely the most on critical safety information are often uninformed about the existence and/or effects of fume events. This is supported by other authors that have revealed that many crew members are still not familiar with the issue.[26] Although this confirms the fragmentation of information effects, it is not clear if this uncertainty mainly belongs to the category of manufactured uncertainty, which is intended, or structural secrecy, which is the unintended consequence of opaque or broken organizational structures. Both types of uncertainty are intertwined and will amplify each other. Manufactured uncertainty in relation to fume events has already been provided in earlier studies.[6,8,9]

Structural secrecy in the case of fume events is facilitated by the lack of a centralized repository. Fragmentation of information is among other things revealed by the fact that side-remark accounts contain hundreds of previous undisclosed events, or by the fact that internal airline analyses are not integrated in summary reports meant to map the problem. This creates structural uncertainty when studying fume events frequency and severity.

CONCLUSIONS

Fume events can create a serious risk to flight safety. The information gathered by aircraft accident investigation branches from the different sections of this paper should be better communicated to the pilot community by share-your-experience incentives. This paper focused on informational shortcomings in the reporting information collection and feedback system. However, technical solutions such as sensors to objectify the origin and severity of fume events should not be overlooked in conjunction with the above-mentioned organizational improvements.

Fragmentation of information effects not only influence pilots, but also have an effect on the decisions from aviation authorities. Top decision makers tend to rely on signals as a shortcut, "a way of isolating bits of 'telling' information from what is available".[10] It is therefore also beneficial for regulators to update their variety of information sources and be aware of inconsistencies in outcomes from different information sources. This paper can help to achieve that goal.

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