COMPETING DISCOURSES IN AIRCRAFT CABIN AIR CONTAMINATION: HOW TO DEFINE A PROBLEM

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Abstract

In the scientific literature and in the media there is a growing concern about toxins in aircraft originating from the air conditioning system as a result from pyrolised jet engine and hydraulic oil, and more recently also de-icing fluid. Many crews have reported long-term neurological and respiratory health effects, but also acute impairment or even incapacitation while performing their flight duties. Several incident reports described that pilots had cognitive impairments that interfered with flight safety. Numerous incident/accident and technical investigations have revealed oil leaks, after crew reported such impairments. Engine and hydraulic oils contain known neurotoxins, which are suspected to cause these impairments. Single-case investigations and summary reports have repeatedly defined this as a threat to flight safety. Nevertheless, there are diverging views on the actions that are needed.

Pilots have no warning or detection systems to either identify or dismiss a contaminated bleed air event, although it is a requirement that warning devices should be installed to warn pilots for any unsafe situation that needs corrective action. This unsettles crews in their decision-making and produces diversion costs for airlines in the case of false negatives when the only possible reaction is a diversion landing.

The aim of this study is to deliver a more abstract definition of the problem space, by analysing the issue of cabin air contamination not only by its final effects, but also by the complex interactions that are involved when accepting the identification problems for crews and incident investigators. This thesis will explore some reasons behind the competing discourses on flight safety, but also investigate the mechanisms that enable such divergent interpretations and which effects are further created by it. The central question is which signals the system has generated in relation to cabin air contamination and how the effects of contaminated bleed air on aircraft have been interpreted and defined.

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LIST OF ABBREVIATIONS

AAIB – Aircraft Accident Investigation Branch
AAIU - Air Accident Investigation Unit (Ireland)
AD - Airworthiness Directive
AFA - The Association of Flight Attendants-CWA
AOM - All Operator Message
AMC - Acceptable Means of Compliance
ASR – Air Safety Report
ASIR - Air Safety Incident Report
ATSB - Australian Transport Safety Bureau
BASI - Australian Transport Safety Bureau name before 1999
BFU – Bundesstelle für Flugunfalluntersuchung - German Federal Bureau of Aircraft Accident Investigation
CAA – Civil Aviation Authority (UK)
CS- Certification Specifications
CASA – Civil Aviation Safety Authority (Australia)
COT - Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment
ECS – Environmental Control System
EASA - European Aviation Safety Agency (EU aviation regulator)
FAA – Federal Aviation Administration (US aviation regulator)
FODCOM - Flight Operations Department Communication
IATA - International Air Transport Association
ICAO – International Civil Aviation Organization of ICAO
MSDS – Material Safety Data Sheet
NOTOP - Notice to Pilots
NTSB – National Transportation Safety Board
PIC – Pilot In Command (Captain)
SIL – Service Information Leaflet
SDR – Service Difficulty Report
SHK – Statens Haverikommission - Swedish Accident Investigation Authority

LITERATURE REVIEW AND FACTUAL BACKGROUND

Technical Introduction

The design of jet aircraft incorporates a bleed air system, which provides medium to high-pressure air "bled" from the compressor section of the engines and the Auxiliary Power Unit (henceforth: APU). One of the main purposes of bleed air is to provide pressurization and air conditioning to the cockpit and cabin air. (Mann, Eckels, & W. Jones, 2014) The air from the engines is taken unfiltered from the compressor stages just prior to the burning chamber. (Baker et al., 2013; Hecker et al., 2009; S. Michaelis, 2010) Both jet engine oil and hydraulic oil contain neurotoxins. (Marsillach et al., 2011; Schopfer, Furlong, & Lockridge, 2010; Winder & Balouet, 2002). Jet engines leak small amounts of engine oil by design during normal operation, (BAe Systems, 2007; Boeing, 2006, 2010; S. Michaelis, 2016) ;(CASA as stated in: S. Michaelis, 2010, p. 519) Greater amounts can leak due to mechanical or maintenance issues. Mechanical problems that were identified as the cause of these incidents are associated with oil contamination of the air compressor stages of the engine and the APU (BAe Systems, 2008; C. van Netten & Leung, 2001). In addition the possibility of hydraulic fluid contamination of the APU air intake has also been recognised (ASHRAE, 2013; Schindler et al., 2013; Solbu et al., 2010). Air conditioning contamination happens as a consequence of such leaks into the air conditioning system, which is entirely fed by either compressed APU or engine air. The normal temperature from the air taken at the compressor stages varies between aircraft models and phases of flight, but can reach 420°C (BFU, 2014).

At temperatures exceeding 270°C laboratory tests showed that the toxicity of jet engine oils is seriously increased (Paciorek, Nakahara, & Kratzer, 1978; Treon et al., 1955; Treon, Cleveland, & Cappel, 1954). By gradually heating the engine oil, Van Netten showed that heating of the oils produces volatile compounds that are not present in the oil itself (C. Van Netten & Leung, 2000, p. 282). This is the result of thermal degradation (pyrolysis), which alters the original chemical structure of the engine oil compared to the cold product. Neer repeated the test with Mobil Jet II, the most frequent used oil in civil aviation and reconfirmed the predictable thermal degradation behaviour of this jet engine oil (Neer, 2012; Neer et al., 2011).

The same concerns exist for hydraulic or de-icing fluids (Neer, 2012), which are sometimes ingested by the air-intakes (SAE Aerospace, 2008). Aviation hydraulic oils also showed pyrolysis effects under laboratory conditions (C. Van Netten, 2000). Some tests found evidence on aircraft for such thermal degradation products by analysing the aircraft's filters (Vasak, 1992 as cited in: Vakas, 2007). The Defence Science & Technology Laboratory of the UK Ministry of Defence analysed cabin air supply ducts of a BAe 146 aircraft (CAA, UK, 2004), in response to a Civil Aviation Authority request also found thermal degradation products. It stated that "the ducts were contaminated with a carbonaceous material containing chemicals entirely consistent with the pyrolysis products of aircraft engine oil" (CAA, UK,, 2004, ch2: p.3), but the same report also describes "that there are over 40 difference chemicals contained in all breakdown products and many have no published toxicity data, so it is not possible to be certain whether any of these products contributed to, or are the sole cause of the recorded incidents" (CAA, UK,, 2004, p. vi). According to the material safety data sheets (MSDS) both engine oil (Boeing, 2007; Mobil Oil Corp., 1999), and hydraulic oil (Solutia Inc., 2007) contain known neurotoxins and thermal degradation processes can produce additional ones as described above. Although some marker compounds are defined and their likelihood to cause symptoms in the levels identified at the time of measurements is low (CAA, UK,, 2004), the complete cocktail is unknown. Furthermore, no fume events were observed on any of the flights that were subject of air monitoring studies performed so far (V. Harrison & Mackenzie Ross, 2015, p. 3).

EASA commissioned a study in 2015 to bring clarity about possible pyrolysis by-products from jet engine oil (EASA, 2015). Results can be expected early 2017. This indicates that even if there are confirmed toxins in the fluids, there still is a toxicological knowledge gap to be filled.

Incident reports have described difficulties due to cognitive impairment in relation to contaminated bleed air. Also respiratory symptoms in relation to inhaling hydrocarbons on-board aircraft have been described (Burdon & Glanville, 2005). Although in many cases engine oil leaks were identified and impairment and even incapacitations due to cabin air contamination was stated as the most probable cause, the investigations often remained inconclusive about the exact causative mechanism (AAIB, 2004b; BASI, 1999; BFU, 2014; SHK, 2001), which should pose no surprise considering the toxicological knowledge gap. At the same time oil leaks with regular intervals have been documented (AAIB, 2004b; CAA, UK, 2011) and a flight safety issue in relation to these leaks has been confirmed by aviation industry, studies and reports (BFU, 2014; CAA, UK, 2002; FAA, 2004; IATA, 2015; NRC, 2002; SAE Aerospace, 2005; SUST, 2016). As an Australian evidence review panel in 2009 accurately summarized it: "The immediate effects of exposure to contaminated air have been well documented but debate continues about causation, diagnosis and treatment of long-term effects." (CASA, p. ii).

In addition to the flight safety acknowledgments there is also some debate, which is mainly marked by diverging views on risk mitigation measures. There is also strong disagreement about the long-term health effects. Reported symptoms are headaches, burning eyes and throat, light headedness, nausea, dizziness, disorientation, blurred vision and numbness (S. Michaelis, 2010; C van Netten, 1998) . The triaryl phosphates that are present in the engine and hydraulic oils have a highly variable presenting symptomatology. Some see this, what is known as 'a-typical' symptomatology, as a reason to dismiss a strict causality (de Ree et al., 2014), but to others a wide variety of different symptoms is a priori a logic pattern to expect (Howard, 2014), supported by the fact that the neurological symptoms reported are similar to those reported among workers in other industries exposed to triaryl phosphates (Schulte, 1996, Krebs, 1995, as cited in; Hecker et al., 2014, p. 6). Triaryl phosphates are not the only chemicals of concern. Other neurotoxins such as xylene or toluene have been confirmed (Winder & Balouet, 2002). Flight crews have reported that they permanently lost their health and that their medical licenses were revoked after experiencing reported incidents with either oil leaks identified or what flight crews reported as oil fume incidents. (Abou-Donia, Abou-Donia, ElMasry, Monro, & Mulder, 2013; Burdon, 2011; Murawski, 2009; Parliament of the Commonwealth of Australia, 2000). In relation to fume events scientists have described symptoms, which are accounted to central nervous system deficiencies Van Netten, 2005 (Burdon, 2011; Burdon & Glanville, 2005; Marsillach et al., 2011; Schindler et al., 2013; Schopfer et al., 2010). Reports with opposed conclusions can be found in the literature. Some concluded that albeit know neurotoxic components in the fluids, the concentrations of target compounds such as organophosphates (triaryl phosphates) or hydrocarbons are estimated to be too low to cause such effects (Cranfield University, 2011; de Ree et al., 2014). Some reports in answer to public concerns doubt a causal relationship exists (EPAAQ, 2012) and others even state that there is insufficient evidence to justify further epidemiological research on chemical of concerns such as organophosphates (COT committee, 2007, p. 23). Scientifically opposed to this are the concerns in relation to known health and safety effects from acute and low level doses of the chemicals contained in the engine and hydraulic oils Van Netten, 2005 (C. Van Netten, 2000; C. Van Netten & Leung, 2000). Additionally there are repeated concerns that the information provided on the warning labels and Material Safety Data Sheets understate the hazards (Vakas, 2007; Winder & Balouet, 2002, p. 1). A lack of systematic and consistent epidemiological data (COT committee, 2007; S. Michaelis, 2010, pp. 754-755; NRC, 2002; Vakas, 2007, p. 155) is at least one common critique both ends of the debate, although used for different conclusive reasoning.

In addition to the flight safety debate, health and safety issues have repeatedly caused public concerns, especially from flight crews, followed by governmental or scientific panels for several decades around the world. The panels and reports partially came with difference conclusions. Vakas (2007) and Michaelis (2010) each devoted entire PhD's on the selective use of evidence in respectively the Australian Senate inquiry and the global issue.

To scientifically assess the conflicting opinions from the above-mentioned literature, I turned to the original sources, rather than their scientific assessment in the literature which is often plagued by corporate interests (S. Michaelis, 2010; Vakas, 2007) and different definitions of flight safety. This was also needed because the debate identifies many knowledge gaps in the current toxicological understanding of the chemicals under concern that make conclusive answers impossible (V. Harrison & Mackenzie Ross, 2015; van der Veen & de Boer, 2012). What was missing from the literature was a more conceptual understanding of how safety is constructed and navigated in different ways by different authors. I therefore needed qualitative data as close as possible to the phenomenon. The current knowledge gap could be filled by a more abstract identification of the diverging views in relation to the interpretation of the signs from an acknowledged, but not fully understood flight safety issue. Therefore, I started reading the information from the incident reports themselves and investigated the level of public protection provided by the applicable regulations. The initial literature review thus generated more reading and more references that will further unfold throughout this thesis.

RESEARCH QUESTION

The literature and incident reports have repeatedly described the effects of bleed air contamination by jet engine and hydraulic oil on health and safety as described in the technical introduction. Occurrences of bleed air contamination and its associated risks are well recognised in the technical and academic literature. Despite an extensive body of acknowledgment of these risks (Cf. technical introduction and following thesis chapters), there are competing discourses about the exact causative mechanism. This has influenced the debate about the correct assessment of the impact on flight safety.

Earlier research and committees have identified that the signs in relation to cabin air contamination and its effects on flight safety where not treated as such until specific events have triggered a retrospective attention to events that happened earlier (S. Michaelis, 2010; Parliament of the Commonwealth of Australia, 2000). Previous authors have also described the difficulty from crew reports to become recognised as signals of acceptable evidence (S. Michaelis, 2010; Vakas, 2007) to the regulators. While studies initiated by the regulator came with reassuring conclusions about the thresholds of identified toxins (CAA, UK,, 2004; Cranfield University, 2011), there is general agreement that several toxicological and epidemiological knowledge gaps remain unanswered (de Boer, Antelo, van der Veen, Brandsma, & Lammertse, 2015; V. Harrison & Mackenzie Ross, 2015).

These knowledge gaps allow a large degree of ambiguity in the way the problem is defined. Two competing discourses in the literature draw the attention. Both come to different conclusion about the protective measures that could be taken.

This thesis looks at the different problem definitions of the interpretation of the signals created in the history of bleed air contamination.

This question can be divided into several sub-questions. What is the conceptual definition that emerges from the incident reports conclusions and recommendations? How does the regulator define the problem? Which signals are taken into account for the conceptual definition?

The central research question that provides an answer to all of these questions is:

'Which signals are generated in relation to cabin air contamination and how were they interpreted in relation to flight safety?'

The corresponding phenomena that will be investigated in this research is which signals were accepted into the safety assessment and how these are interpreted to define the problem.

This thesis will make some statistical analysis where needed, but mostly it will study the qualitatively interpretation of the issue. Therefore, I will also investigate if there is a qualitative relationship between managing and understanding the phenomenon. By answering these different aspects of the questions, I will try to get a better understanding of the problem space according to investigation reports and from a regulator perspective.

RESEARCH METHODOLOGY

Author's personal statement and action research

Many years ago, I was an active airline pilot and I flew the aircraft model BAe146/AVRO RJ. I regularly experienced fume events in the form of very strong smells, although I was never made aware of the risks or any incident reports concerning fume events. They produced a very peculiar smell that could become very intense. Often these fumes were transient during flight when making power changes, and even more often they appeared after starting the APU[1] for the first flight of the day during flight preparations. From the very beginning the captains in my company, who flew this model longer than I did, and our mechanics confirmed that this was the smell of burnt jet engine or APU oil. This was said to be quite typical for this aircraft model. At that time, I would compare it to the risk of standing next to the exhaust of a running car in a parking garage. It was a kind of exposure that didn't particularly worry me.

But sometimes these smells would be so bad that my colleagues and I refused the aircraft, mainly for what we considered comfort reasons. This happened when the smells became unbearable and we would not allow passengers in such densely, though invisibly contaminated air. In general, I was not concerned about any health or safety implications as it seemed such a familiar problem on this fleet and there was a common solution for this. Above a certain threshold of smells, we would call the mechanics to the aircraft. The cause of the smell, either the left or right side of engine air supply, or the APU air supply would be switched off and the aircraft's technical logbook would be stamped. This was usually handled within the time of flight preparations. The mechanic would put a label on the switch stating INOP (the abbreviation of 'inoperative'), which means that this source cannot be used until the next inspection or repair. Flying with one source of air less is not a restriction for operations. Frequently I would take over aircraft from a former flight crew when the sticker and the aircraft's technical logbook were already indicating that the source of air was not intended for use.

I lost my aircrew medical certificate due to health problems in three consecutive years for longer periods of time. When regaining my medical certificate the second time, I found out that a captain, a colleague with whom I never had the chance to fly, had reported a specific incident due to oil fumes 6 years earlier. After this incident, he and his co-pilot filed a safety report.

The captain told me that the smell of oil was noticed on the first leg, but similarly it didn't occur to him, or to his colleagues that this could pose an acute flight safety risk. According to the captain, the technical logbook on that particular flight showed that a previous crew also reported strong smells on this aircraft. When the first signs of smell became apparent on his flight, the cabin attendants didn't notice it in the cabin up to that point. The captain called the company to say that they would fly the aircraft back for one more leg to the maintenance base, but the crew would not accept this aircraft for further flights under this condition. On the subsequent sector back to base, the captain felt throat irritation and strong headaches and he states his co-pilot was suffering from nausea. Because both pilots felt clearly impaired, they put on their oxygen masks. My colleague stated that, when putting on his oxygen mask, he and his co-pilot suddenly realised that their impairment was worse than they thought. The captain says it was as if at that moment, a veil opened before his eyes.

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[1] APU is the abbreviation for Auxiliary Power Unit, a jet engine that provides air conditioning and power from ground operations

An email from the airline, which the captain showed me in an early information exchange about this incident, acknowledged the fact that engine oil leaks were identified and air conditioning packs were contaminated. This led to an engine replacement. I was surprised to learn that this happened within my company and I had never heard about this incident.

Even later I found out that my particular aircraft model, the BAe 146 had been involved in a series of similar incidents around the world. Some of them involved serious impairments and incapacitations. I found out that this BAe146 aircraft even had been the subject of an Australian Senate inquiry. My colleague and I were never informed about these facts by our own airline. We both found out through press articles and internet material that incident reports on the same aircraft model had warned for effects on the flight crews decision-making. Additionally regulators' communications had warned for the fact that crews had regarded these fume events as nuisance rather than a hazard and oxygen masks should be put on as soon as such fume events were noted. My flight training only covered simulations of smoke. It was never part of my training that fumes in the absence of smoke should also prompt pilots to put on oxygen masks. This master thesis has in part been initiated in search of an answer to understand how it is possible that the safety concerns in a number of incident reports, the recommendations from the Australian Senate committee and the aircraft manufacturer had never reached me. Thereby, I am not trying to define the choice of an individual or organisation not to forward information. I find it scientifically more intriguing how a sociotechnical system is able to hide readily available information that was intended to inform pilots about on these very aircraft.

Later, I became active in a one of the European Pilots Associations, working to improve the conditions from workers in relation to contaminated cabin air. I participate in several committees that deal with health and safety standards for cabin air or with technical certification requirements. In these committees I advocate better health and safety conditions for flight crews, but I also strive for a better training and informing of flight crews about the recommendations and flight safety risks formulated by aircraft accident investigation bureaus around the world.

This thesis is written in my personal name in the pursuit of a master thesis, without any support of the organisations for which I participate in the committees mentioned above. I still find it appropriate to disclose my position. In social science this is defined as action research. Action research is social research carried out by an organisation, community or stakeholders seeking to improve the participants' situation (Greenwood & Levin, 2007). Outside the realm of scientific research, I actively participate in the domain of the subject of my research issue. Action research promotes participation in the research process by stakeholders. Sometimes action research is believed to produce research bias. As Greenwood described, the opposite is true: "To the contrary, action researchers, precisely because the results will affect the lives of stakeholders, have a profound interest in the validity of the generated knowledge" (Greenwood & Levin, 2007, p. 4). Being aware of the risk of research bias, I consider that reproducible scientific results and traceable scientific references are the best way to change public debates.

Thesis methodology

The general research strategy was to conduct a qualitative analysis of different sources of data that have created safety concerns in relation to cabin air contamination. These sources are incident reports, regulations, regulator documents, scientific literature and case studies. The chapters to produce 'classic' results/analysis & discussion sections from primary[2] sources are the first and the last chapter, covering incident reports and case studies respectively. In the chapters in between different perspectives that further influence an interpretation of such primary findings are explained. Regulations, scientific literature and document sources are used to analyse the toxicological discourse and the regulator perspective, and the sociotechnical recognition or dismissal of safety signals. The findings of the different chapters were obtained by using different methodologies, these are described below.

Qualitative Coding of Incident reports (Definition of the Problem According to the Incident Reports)

Incident reports are the primary means for flight safety issues to become reported and escalated. These incident reports were therefore subjected to theoretical coding to produce results that can subsequently be analysed for a definition of the problem.

Selection of data and data gathering

I initially started with an arbitrary number of 22 official incident reports from Aircraft Accident Investigation Branch (AAIB) websites by the use generic search terms such as smells, fumes, cabin air contamination, smoke, haze, cabin air quality, etc. I decided I could always add additional incident reports that would be found during the progress of the research and still attach descriptive labels to them in the same way. During the research I was confronted with the difficulties of choosing such a complex issue in combination with the time constraints of a master thesis as new data unfolded. Especially as at one point in time a single source of the secondary literature produced references to a multitude of new official incident reports. I contacted the author of the work 'Health and Flight Safety Implications from Exposure to Contaminated Air in Aircraft' and found that the number of reports doubled when the author responded with an additional collection of official investigations, that do not show when simply looking on the AAIB's websites through search terms. The initial collection of 22 incident reports was subsequently subjected to qualitative coding.

Coding

In general two methods of coding exist: 1) Thematic structuring, where first codes are generated and subsequently data is coded accordingly or 2) Bottom-up coding, where the actual coding can be created at the same time when the coding is done (Mortelmans, n.y.). In this chapter, bottom-up coding was applied, because no similar qualitative coding exists from previous work on the issue and I decided to first analyse the phenomenon by the data contained in the incident reports, independent from their divergent interpretation in the literature. The three steps of bottom-up coding are described as follows:

Open coding

"Open coding is an interpretive process by which data are broken down analytically. Its purpose is to give the analyst new insights by breaking through standard ways of thinking about or interpreting phenomena reflected in the data" (Corbin & Strauss, 1990a, p. 12). In this step categories of themes emerge without looking for their relations. Nvivo software was used for open coding and arranging the labels into main categories. This open coding categorisation facilitated the axial coding process.

Axial coding

[2] Incident reports can be said to be secondary sources but still provide a close relation to the first hand data.

Nvivo Software results of open and early steps of axial coding were transformed in Excel Matrixes as a means of mapping the results and process communication. In the subsequent axial coding, the categories are related to the subcategories that emerged from the concepts, and the relationships of the subcategories (Corbin & Strauss, 1990a; 1990b, p. 13). This was done by subjecting them to the three main qualitative coding framework categories (condition, action/interaction, or consequence) as defined by grounded theory, a methodology of bottom-up coding to further identify patterns and relationships. Requiring that a concept's relevance to an evolving theory (as a condition, action/interaction, or consequence) be demonstrated is one way to guard against researcher bias (Corbin & Strauss, 1990b, p. 7). Every further category will always stand in relationship to the core category (Corbin & Strauss, 1990b, p. 14). "One of the ultimate goals during Axial Coding . . . is to achieve saturation – when no new information seems to emerge during coding, that is, when no new properties, dimensions, conditions, actions/ interactions, or consequences are seen in the data."(Strauss & Corbin, 1998 as cited in: Saldaña, 2013, p. 222).

Selective coding

In the last step of selective coding, all categories might be unified around the core category, which represents the central phenomenon (Corbin & Strauss, 1990b, p. 14). Finally, the core category or categories that are developed must be tested against the data to achieve theoretical sufficiency (Corbin & Strauss, 1990a). Although the theoretical concepts were developed in the originally arbitrary limited number of 22 incident reports they were tested against the more complete dataset that of 55 incident reports, which were obtained while the research developed. The methodology could have been more robust by including the 55 reports in the actual qualitative coding process, but this became a choice in regard to the time constraints of the master thesis and was also related to the fact that I received the reports later in the research process.

Finally Corbin & Strauss have recommended that coding work is better not be done by the researcher alone (Corbin & Strauss, 1990a). Therefore, the intermediate results in the form of Excel coding matrixes were discussed with my supervisor and a meeting with two fellow safety science students was arranged to challenge ideas about further discussion and theory development. More objectivity could have been provided if such external checkers would have been updated for every step in the process until the very end of this thesis, but this turned out to be a too big challenge for the time constraints of a master thesis.

Thick description analysis (The interpretation of signals)

I also discovered during the research process that incident reports provided only limited access to a complete picture of the phenomenon. For example the reports were only produced by a very limited number of national states or described negative forms of information, such as knowledge gaps. I therefore decided that further zooming in on more of the same data by analysing the additional reports in the same way would not reveal a more accurate definition of the actual problem space. I limited my coding work on the initial 22 chosen number of incident report, but still used the totality of 55 reports for a few simple statistical counts.

I therefore chose to add a richer context to the analysis to enable me to insert an important dimension into the analysis in the form of a timeline-based analysis to cover a global perspective to provide positive identification of the phenomena related to interpreting the flight safety issue in relation to cabin air contamination. These choices and difficulties the inexperienced master student experiences eventually will become the same choices the regulator will be confronted with when trying to assess the phenomenon of interpreting the flight safety signals of cabin air contamination.

The middle part of this thesis analyses the understanding of the problem space and covers several chapters. These chapters, that introduce the competing discourses and the regulator perspective, investigate the regulator's understanding of the toxicological assessment and the construction of risk. This is complemented by an analysis of the critiques too toxicological and risk assessments that were made elsewhere in the literature. Data is gathered by scientific literature, regulator documents and illuminated with incident report excerpts. This data is challenged by comparing it with critique from the literature and should prepare the reader to understand the different sides of the debates. It should also further support the analysis of the interaction between how a problem is defined and how it is managed.

The main body of the thick description and analysis is provided by a timeline narrative and covers the interpretation of signals in the form of weak and strong signals. Closely related to that is the discussion about the validity of evidence, in other words the acknowledgement of signals. Such questions answer specific stakeholders' perspectives that add to the thick description of the problem space. Geertz' method of thick description, borrowed from a notion of Rye is described as follows: "the essential task of theory building here is not to codify abstract regularities but to make thick description possible, not to generalize across cases but to generalize within them"(Geertz, 1973, p. 14) and it should enable us to extract from this thick description "transient examples of shaped behavior"(Geertz, 1973, p. 5). Many of these signals by itself will speak better in relation to each other than in isolation. Therefore, analysis of historical accounts and a timeline presentation should help to make a form of social analysis.

Critical case studies (Hidden signals)

In the last stage, two non-published exploratory case studies are presented to the reader. These case studies are used to analyse what the mechanisms are behind the visibility of sociotechnical safety signals. They are presented in the form of a critical scenario. "In general, case studies are the preferred strategy when 'how' and 'why' questions are being posed and when the focus is on a contemporary phenomenon within some real-life contexts from which the boundaries between phenomena and context are not clearly evident" (Yin, 1994, p. 1&13). This definition of the method defends an excellent suitability to complement for the limited understanding by means of the incident reports only.

Critical case studies are when a single case represents an extreme case or unique case where the circumstances may be so rare that any single case is worth documenting and analysing. (Yin, 1994, pp. 40-41) The cases explored in this thesis are rare because they present safety concerns that would otherwise not be visible or known to the public. They cover hidden signals. Case studies can be explanatory, descriptive, or exploratory. (Yin, 1994, p.8) The case study is exploratory, which is when it investigates distinct phenomena characterized by a lack of detailed preliminary research (Streb, 2010, p. 372).

Data gathering (Case studies)

Documentation for one case study was offered by the editorial staff of Zembla, an investigative journalism television program on the Dutch public service television. They provided me with an internal maintenance document related to fume evens, from which they had previously used excerpts in their 2010 documentary on the issue. Maintenance documents are normally not accessible and provide the original information that normally is not accessible to scientists.

A second case study was examined with the help of the Association of Flight Attendants-CWA (AFA). The case study consisted of the description and communication exchange on a series of events between AFA, the Airline where these events happened, The Federal Aviation Administration (FAA) and the National Transport Safety Board (NTSB)

Discussion (Case studies)

The first case study will be compared by earlier defined qualitative labels that were assigned to problems in the NASA space shuttle programme and an analogy is applied in a discussion section. This can be seen as the opposite of the earlier applied bottom-up coding. The qualitative labels are first presented and their significance for the case study under investigation is exposed.

In the second case study two competing views will be contrasted and there differences and underlying assumptions will be uncovered and discussed.

Ethical considerations (Case studies)

The first data source (maintenance document) was already part of the public domain, as it had been used before. I checked with the editorial staff of the television program Zembla for any additional considerations. The editorial staff granted permission without any additional limitations and e-mailed the printable copy of the document.

For the second data source, an agreement with AFA was signed for the permission to use the communication exchange. It was agreed that the names of the flight crew and flight number involved would be de-identified.

CHAPTER 1: DEFINITION OF THE PROBLEM ACCORDING TO THE INCIDENT REPORTS

Qualitative Coding of Incident Reports

The central questions to answer from a meta-analysis of incident reports can be said to be to define 1) what is the commonly defined trigger to start an incident investigation in relation to contaminated cabin air; 2) a conceptual definition of the problem space and; 3) how the system managed the problem. Whereas 1) identified the issue in terms of its input, being the start of an investigation, 2) and 3) define the conclusive definition in terms of its output.

The lack of a clear definition of how cabin air contamination is defined, makes it difficult to establish criteria to objectify the problem. Additionally, there is not a single description label for it. Instead several labels are used: cabin air contamination, oil smell incidents, bleed air contamination and often the term fume events. These can be accompanied by smoke, but fume events can be invisible and are often a non-tangible and transient occurrence. Note that also for fumes an aeronautical definition is lacking (BFU, 2014, p. 18). Definitions of fume provided by dictionaries are as follows:

- Oxford dictionary: "An amount of gas or vapour that smells strongly or is dangerous to inhale"
- Merriam Webster: "a: a smoke, vapor, or gas especially when irritating or offensive <engine exhaust fumes>; b: an often noxious suspension of particles in a gas (as air)"

Due to the lack of consensus-based scientific criteria to describe fume events, I selected incident reports, according a definition taken from a mandatory UK CAA Inspection Service Bulletin, which initiates maintenance to troubleshoot the problem. It states that actions are mandatory, "[w]henever a cabin air quality problem is identified which is suspected of being associated with oil contamination of the air supply from the ECS [Environmental Control System] Packs, whether intermittent or persistent" (BAe Systems, 2001b, p. 4), and I subsequently looked for incident investigation reports that matched this description. In taking this criterion, the phenomenon is described as it is used to initiate maintenance action and establishes a one-on-one qualitative relationship with the real world. With the help of search terms on the AAIB's websites I looked for official investigation reports. Additionally, I wrote down all the references from all the official investigation reports I came across in the literature. I subsequently looked for these official investigation reports on the AAIB's websites by the use of these reference numbers or aircraft registration. Michaelis points out that national databases often do not offer the possibility to enable a quantitative online search of contaminated air events (S. Michaelis, 2010), even not through the use of several search terms. Indeed, I was not able to find some reports from which I knew the reference numbers through scientific publications from other authors beforehand. I had to contact the authors form the literature that earlier referenced these reports to obtain them.

Outside the analysis of this incident report investigation chapter, two further general studies in relation to cabin air contamination exist. One from the German Federal Bureau of Aircraft Accident Investigation (BFU) and another joint study from the Australian Civil Aviation Safety Authority (CASA) & Australian Transport Safety Bureau (ATSB). Both studies have a wider scope than just bleed air contamination events. The BFU study covered a series of other smells that were not typical for bleed air contamination, e.g. burned smell (28,7%), electrical smell (17,7%) and not classified (26,0%) (BFU, 2014, p. 10) and the Australian study showed a similar wider scope by merging typical bleed air problems with other categories. Unfortunately it did not allow a separate statistical analysis. For example air condition problems, the biggest category covered by (Service Difficulty Reports) SDR's did not separate electrical from oily/exhaust smells (ATSB & CASA, 2014, p. 12). Both studies offered a more statistical approach and provided little narrative style descriptions of incidents. The studies depended on the causes transmitted by airlines in the BFU case or Safety (ASIR) and mechanical Service Difficulty Reports (SDR) in the Australian case. Although both studies rather seem to be meta-analyses, the BFU study described that it 'scrutinised' the airline data in the case where an investigation was started (BFU, 2014, p. 27). 40 such investigations were started into serious incidents out of a total 845 reportable and non-reportable events between 2006 and 2013. Whereas a variety of contamination sources was identified, including coffeemakers, 51 were caused by APU or engine contamination. Another 17 were identified to come from chemical fluids such as hydraulic and fuel lines. But in 42 cases a contamination source was not determined to begin with or remained unknown in 386 other cases. Sadly, there is no disclosure in the report on the relation between reported symptoms and the different sources of contamination. The report states that only a minority of cases poses a serious threat to flight safety: "In a very few cases the safety margin was reduced such that a high accident probability - in terms of the legal definition – existed" (BFU, 2014, p. 63). The reports careful choice of words about the 'legal definition' means that aeronautically the accident definition does not entail long-term health impairments. To such symptoms outside the realm of classic official investigations the authors therefore additionally state: "The study shows that fume events with health impairments of aircraft occupants did occur" (BFU, 2014, p. 64).

The German BFU has included a table of the total technical causes transmitted by the airlines, but has not separated these technical findings for the ones which were covered by an investigation and the ones which were not. Furthermore, the studies did not match comparable criteria for a qualitative analysis such as these from the narrative style incident reports. In short, both a health and safety issue are acknowledged, but even more worrying is the lack of available investigation methods in the conclusion: "Verification means and options (e.g. blood tests) are not always available to the BFU and "[t]here are no standardised procedures for reporting and verification (blood tests)" (BFU, 2014, p. 63).

After a brief encounter with the two summary studies in the paragraphs above, the scope of this thesis analysis is therefore restricted to narrative style official investigation reports only. By taking a step back and just making a statistical count of the total geographical distribution of investigation reports, a very simple observation can be made. From the 55 analysed reports, 50% come from the UK only with a total of 27 reports, Australia has seven investigations and Germany has produced six. For Australia and Germany the situation is slightly more complicated, as they both produced studies on cabin air quality with a broader scope than just bleed air. Germany and Australia can thus be said to be a main contributor to the investigations. Switzerland has produced four reports, Ireland investigated three incidents, Sweden two and five countries only issued a single report. When we would limit our focus to just the incident reports as the most important instantiations of the issue, we would have to conclude that this problem exists in specific parts of the EU and in Australia only. However, the fact that entire continents are not represented in the investigations, whereas the literature and mandatory occurrence reports have described the same problems all over the world and in relation to all popular aircraft models (CAA, 2011, 2014; Michaelis, 2010, pp. 531-533; 541; Shehadi et al., 2015) with similar frequency and gravity (Michaelis, 2010; J. Murawski & Supplee, 2008), a first observation can be made. There is no commonly accepted trigger to start an investigation and reactions have strong local variety. A recent paper from Shehadi, with the specific aim to characterise 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 only (Shehadi, Jones, & Hosni, 2015). Until today the US never performed an actual investigation into an incident, although it did produce research in 1984 related to 'a review' from 8 fatal accidents and one non-fatal accident, testing the hypothesis of incapacitation resulting from bleed air contamination (NTSB, 1984). (CF. Chapter Timeline Analysis)

A further analysis of the incident reports shows that, although a wide variety of aircraft types is affected, some types such as the Boeing 757 and the BAe 146 are significantly more affected in the reports. Aircraft models are not specific to certain part of the world, at least not to such an extent that they would provide a valid explanation for the geographical exclusion of whole continents. The BAe 146 and its successor model Avro RJ provide some explanation in the positive sense for the geographical distribution of the production of incident reports, as this single aircraft type was responsible for all reports in Switzerland, Sweden, all but one in Australia, some in Germany and a part of the UK reports.

The limited geographical coverage showed that the investigations are an inadequate source of information to reveal the extent and the history of the problem. This was a research obstacle I had not expected in the beginning and I had to complement with other perspectives in additional chapters.

Even when these important findings are posted in the beginning of this chapter, they are a surprise as they are well documented by states such as the US that seem not to investigate, even when serious health and safety impacts are reported (Murawski, 2011a; Murawski & Michaelis, 2011) and high frequency is well documented via other sources (Shehadi et al., 2015). It therefore emerged as a research obstacle, rather than a concrete result. Nonetheless, the qualitative coding process described below will first focus on what the data from the investigation 'does' tell about the definition of the problem according to the investigation reports. This despite the fact that the incident reports proved to be only a limited source of information to uncover the full extent of the problem. The investigations are unique in that sense that they provide narratives, which make them a rich source of qualitative data.

Open Coding

I started with an open coding from frequently cited incident reports in the literature and in the media. This first step was to just highlight excerpts of text and attach a descriptive label to each excerpt. This produced 2144 excerpts of labelled text and 199 different sorts of labels from 22 incident reports.

As I had to go through an ever-growing multitude of labels during the work, I gradually started to group the labels in different categories that made it possible to identify datasets and subsets more rapidly. In the beginning these datasets were just practicable parent labels that allowed me to speed up the work of dragging text excerpts into the right place. These sets were than restructured several times during the open coding process. Progressively, data sets emerged that resulted in the basis for the axial coding of the incident reports. A framework of labels emerged where child nodes could be structured under parent nodes. Finally all of these nodes were structured into the following nine main datasets: 1) Investigation findings; 2) Symptoms; 3) Toxicology; 4) Regulations; 5) Circumstances /Context / Available information;
6) Recommendations/mitigation; 7) Actions and; 8) Crew actions during incidents.

Datasets

Set	Description
Investigation findings	Investigation aspects that belong to the identification of causal and contributing factors
Symptoms	Reported symptoms
Toxicology	Toxicological information or findings
Regulations	Information related to existing regulations
Circumstances/Context/Available information	Influences on the events/crews e.g. systemic issues - Information available to crews and investigators
Recommendations/mitigation	Mitigations that were implicitly or explicitly expressed as a future recommendation
Actions	Actions generated in response to the events
Crew actions during incident	Crew interventions (oxygen masks, diversion, etc.)

Table 1: Description of datasets

Axial Coding

These sets emerged as the departure point from which I investigated if it would be useful to subject them to the three main qualitative coding framework categories (condition, action/interaction, or consequence) as defined by grounded theory, a methodology of bottom-up coding to further identify patterns and relationships. Every further category will always stand in relationship to the core category (Corbin & Strauss, 1990b, p. 14). These three categories, conditions, action/interactional strategies, or consequences, can be translated into the central phenomenon as a dimension of qualitative coding to which all the data eventually responds, independent from any labels or sets of labels applied by the researcher. When one applies the three bottom-up coding categories to the identified datasets a matrix as shown in table 2 can be produced.

1) Conditions: circumstances in which the investigation process is performed, including previous knowledge
2) Action strategies: all identification processes during the definition of the problem or its constituting factors (core activity of incident investigation)
3) Consequences: the outcome of the investigation itself

	Investigation findings	Symptoms	Toxicology	Regulations	Circumstances/ Context/ Available information	Recommendations/ mitigation	Actions	Crew actions during incident
Condition	-	X	X	X	X	-	-	X
Action Strategies	X	-	-	-		-	X	-
Consequences	-	-	-	-	-	X	X	-

Table 2: Matrix of bottom-up coding categories / Incident report datasets

Often descriptive labels were only used once or twice and these could then be further ignored because they didn't tell anything about a shared view or interest. I further investigated labels that were used remarkably often or those who created oppositions, etc. However, I could not follow simply quantitative reasoning for my findings, because a label that occurred more frequently only says something about the frequency of the description in the report. It does not simply mean that it happened more often. For example, when smoke is described in several chapters of the report such as in its introduction, findings and conclusion, the qualitative coding process might just have repeatedly labelled a single occurrence in different parts of the report. Nevertheless, in many cases the most frequently used labels pointed to interesting areas for further theory development.

Open coding dataset: 'Investigation findings'

Labels that produced the most hits in the first main category 'Investigation findings' were identified as the common effects of cabin air contamination issues being '*fumes, smoke, haze' and 'smells'* on the one hand and causes for such effects, '*oil leaks identified*' identified on the other hand. From a total of 55 reports, 28 reported oil leaks on the engine or APU. An additional 7 reported hydraulic or de-icing fluid leaks that could have pyrolised in the cabin air. This equals 65% of the cases where engine/hydraulic/de-icing fluids were identified, from which 54% were engine/APU oil. In 22 reports (40%) where health symptoms were reported, leaks were identified in the subsequent troubleshooting. There thus seems to be a straightforward link between cause and effect. A typical example of positively identified contaminated sources is described below:

> [t]hese reported events all had a common theme; oil contamination of the air supply from either the APU or the engines. Once the source had been identified and removed, the smell would disappear. Oil leakage on the BAe 146 was generally associated with the carbon face seals of the

No 1 or No 9 bearings in the engines, or the APU cooling fan seal. Failure or defects within these carbon seals allows oil to enter the main gas stream and hence contaminate the bleed-air offtake. (AAIB, 2004b, p. 42)

From the 55 incident reports that were analysed, 36 reports were able to actually identify leaks. The majority were engine or APU oil leaks. Only 3 of them were hydraulic leaks and another 3 identified de-icing fluid. Not every report established the cause of the incident or accident to be the leaks that were found post-incident. Others made clear in their conclusions that they considered residual oil contamination of the air conditioning system or overfilling likely, for example because other defects had been corrected only recently. This cause-effect between the reports and the many identified oil leaks establishes a pattern, but a further statistical analysis remains impossible, because there was no comparable method of investigation. This is not to say that changing the scope of the reports' initial search could not identify alternative sources of contamination. Two already mentioned existing studies, one Australian (ATSB & CASA, 2014) and one German (BFU, 2014), have positively identified other causes such as electrical equipment failure, galley ovens, external sources, etc. alongside contamination from engine and APU. Although bleed air contamination is generally referred to with the description cabin air contamination elsewhere in this thesis and in the literature, it is important to make the distinction between bleed and cabin air. Earlier research has noted that in spite of admissions of cabin air contamination by engines and APU, industry representatives attempt to direct attention toward other sources of odour, and by implication affirm the safety of the jet oil (Vakas, 2007, p. 69).

However, this specific chapter on incident reports aims for a qualitative isolated interpretation of suspected bleed air problems only. Even if alternative sources of contamination other than engine oils and other pyrolised fluids exist, a distinct cause-effect relation is provided for a majority of cases in those reports that began with suspected bleed air problem and escalated into an incident report. Figure 1 depicts the distribution of sources of contaminations

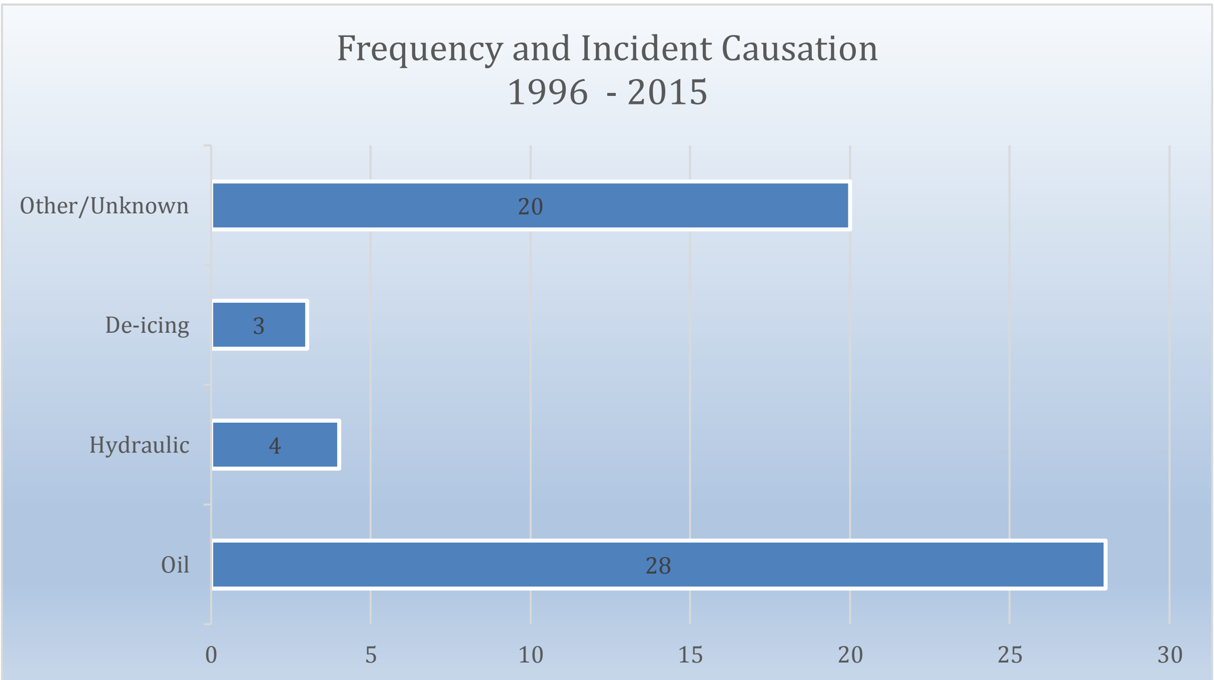

Figure 1: Distribution of technical findings from suspected bleed air contamination from incident reports

The majority of the remaining reports in the category other/unknown could not identify a cause for reported smells, fumes, smoke and/or symptoms and only few searched for alternative conclusions. Some of them provided non-falsifiable conclusions, such as the possibility of residual oil contamination of the ducts from previous fume events (AAIB, 2006c). Such probable causes were not counted as a positive result in the positive identifications of bleed air contamination. The only positive alternative finding, which was not attributable to pyrolised engine oil, hydraulic fluid or de-icing, was provided by metallic parts from turbine blade fatigue (AAIB, 2010b, p. 28) that created smoke in the cabin. Also in this case bleed air design was responsible for the smoke entering the cabin, but it was still counted as other/unknown in figure 1.

Some reports identified other possible sources, in the absence of hard proof, such as the widespread misuse of a toilet-cleaning agent for floor cleaning (AAIB, 1996) in one investigation, although such misuse could not be identified on this particular flight. One report found the source of contamination to have resulted most likely from a chemical within the forward toilet servicing (AAIB, 2007c, p. 5). These too were examples of non-falsifiable hypotheses.

Two reports have described the possibility of a physical-psychological related reaction in the absence of evidence of bleed air contamination. A 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 (BFU, 2013, p. 68). 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 (BFU, 2013, p. 62). The report did not start until one year after the facts. The pilot report, which was sent per fax on request of the captain to both the BFU and the operator, was never received by the BFU. The reason the fax never arrived could not be determined by the investigation (BFU, 2013). The BFU was reassured by the communication from the operator a day after the incident and did not initiate an investigation. The report mentions that only "one year later the severity of the occurrence came to light because of new information the BFU received" (BFU, 2013, p. 65). A physical examination of the aircraft by the investigation could thus not be performed. The circumstances surrounding this investigation, especially the fact that it was not investigated until one year after the facts, received big media attention and caused political escalation (see for example: van Beveren, 2013).

An earlier AAIB report from 2011 described crew impairment according to another physical-psychological related reaction from two pilots as follows:

> the commander may have suffered a disorientation episode caused by a combination of oculogyric disorientation and an alternobaric episode made more likely by the lingering effects of a cold. The resulting natural instinct to hyperventilation could lead to hypocapnia which may well have contributed to the feeling of light-headedness.
> The onset and clearance of the co-pilot's symptoms within approximately 25 seconds may have been a reflection of the potentially evolving situation of crew incapacitation [allegedly in reaction to the colleague's symptoms] at an early stage in the flight leading to mild hyperventilation . . . .
> The reason for the dizziness experienced by both pilots when they first removed their oxygen masks on the ground could not be positively determined but it is possible that it was caused by the effect of a sudden reduction in inspired oxygen concentration on cerebral oxygenation, blood flow and pressure. (AAIB, 2011, p. 17)

The two examples above also explored hypotheses of crew reactions to other effects as a possibility. In those two examples these initial effects were described as massive smells (BFU, 2013) and disorientation from one crewmember followed by individual reaction to that from another crewmember (AAIB, 2011) in the examples. These remained unconfirmed hypotheses in the conclusions. In short, the only causes that could be verified by the investigation to account for the effects of smell, haze and smoke from the collection of suspected bleed air reports were the presence of engine oil leaks and to a lesser extent the presence of hydraulic or de-icing fluids and one occasion of metal fatigue that released metal particles. The explanation for the remainder of the cases remained unresolved.

But the opposite conclusion is also true, being that some reports with incapacitations identified engine oil leaks found that the bleed air contaminations were only a "possible" cause of the incapacitation or impairment, even in the absence of any other alternative explanation (SHK, 2001; AAIB, 2004).

A further label that scored significantly in the open coding for the dataset 'Investigation Finding' was *'primary troubleshooting did not identify the oil leak'*. A number of investigations reveal that the sources of the contamination were sometimes hard to identify, because "[t]he investigation of cabin fumes incidents…has typically been characterised by a difficulty in precisely locating the original source of the oil leak" (ATSB, 2003b). Its relevance can be best described by narrative examples and defines the difficult conditions (table 2), a category concerning the problem identification or investigation findings. It defines the ambiguity surrounding the earlier label *'oil leaks identified'*.

Primary troubleshooting was unsuccessful <u>example #1</u> - HB-IXS:

> [S]moke developed shortly before landing. An evacuation was performed. After this serious incident on 19 March, a check on all four engines and APU was carried out (Swiss Federal Department of Transport, 2006b, p. 10). Nothing was found and additionally a successful check flight was performed. Five days after the actual incident, "[o]n 24 March an unusual smell was perceived both in the cockpit and in the passenger cabin. The subsequent check found "traces of oil in the area of the APU air inlet…air inlet smelt of oil" (Swiss Federal Department of Transport, 2006b, p. 10). The APU involved caused two further events with smoke and a smell after the serious incident (Swiss Federal Department of Transport, 2006b, p. 21).

Primary troubleshooting was unsuccessful <u>example #2</u> - G-JEDP:

> Having failed to find any fault with the air conditioning system following the first incident, the operator's maintenance personnel inspected the engines after the subsequent event and found cracking of the inter-compressor case struts (AAIB, 2005h).

Primary troubleshooting was unsuccessful <u>example #3</u> - VH-NJA:

> On arrival at their destination, the procedure detailed in BAE Systems Information Service Bulletin (ISB) 21-150 was carried out, with no faults found…A subsequent flight with a different crew experienced a similar event, with the flight crew again donning oxygen masks. A subsequent engineering inspection revealed oil contamination in the engine No 3 bleed-air system, and the source of this was traced to a leaking No 1 bearing seal (as cited in: AAIB, 2004b).

Primary troubleshooting was unsuccessful <u>example #4</u> - VH-NJR:

> The aircraft was inspected in accordance with Service Bulletin ISB 21-150 but this did not reveal any oil contamination. However, following an air test it was found that engine No 4 and the APU were both the source of fumes. These were both replaced (ATSB, 2001a).

Primary troubleshooting was unsuccessful <u>example #5</u> - G-CPEL:

> The aircraft was, reportedly, comprehensively checked after this incident, but no defects were identified and it was therefore returned to service. However, four days later, on the 11 November, a strong oily smell was noticed on the flight deck of the same aircraft . . . Subsequent engineering investigation revealed the presence of an oil leak from the APU (AAIB, 2004b).

This could not only be attributed to failed attempts of troubleshooting that only identified the oil leaks after several days or longer, but also to deferred defects, which were believed to be successfully isolated sources of oil contamination, but still produced effects on subsequent flights. This too provides a form where the actions following initial troubleshooting were not sufficient.

Primary troubleshooting was unsuccessful <u>example #6</u> - deferred defects:
In the VH-NJF incident, oil residue was already found at the number two air conditioning pack inlet, resulting from an oil leak from the number four engine on 10 July 1999. The defect was deferred without any operational restrictions being noted. The actual incident occurred, a week later on 17 July. (BASI, 1999)

Other sources of ambiguity in the troubleshooting arose from the messy details and complexity of maintenance work, in the case of the VH-NJX additionally related to a deferred defect.

Primary troubleshooting was unsuccessful <u>example #7</u> - Messy details of maintenance:
In the VH-NJX event (ATSB, 2003b) maintenance engineers originally found an oil leak in the APU generator drive on 2 Dec after fumes were reported. Reparation was postponed until 13 Dec and the APU was isolated from the system. This permitted further operation of the aircraft in non-standard configurations, according existing regulations. The crew who was affected was replaced, but the subsequent cabin crew also became unwell on their second flight. On the 6 Dec again smells were noted, but maintenance could not find anything, and did not suspect the APU as its air conditioning system was isolated because of the known contamination source that was going to be repaired a week later while flights continued. A further event occurred on 12 December, "when the flight deck crew detected fumes shortly after departure. Subsequent inspection revealed oil wetness in the number-3 engine high-pressure compressor; the result of a worn number-1 [sic] bearing seal" (ATSB, 2003b).
Multiple possible sources of contamination, an operational-based decision, and the fact that maintenance "engineers missed an opportunity to identify engines 2 or 3 as the possible source of the contamination" (ATSB, 2003b), which was understandable because they already found another contamination all combined into a complex failure: "It could not be discounted that the cabin fumes were a result of the intermittent leak of oil in the number-3 engine, that was identified ten days after the original incident, instead of, or as well as, the APU" (ATSB, 2003b). The report noted that the likelihood that the engine leak was present since the initial event was supported by the fact that an initial attempt of the co-pilot to clear the fumes on the 2 Dec event, by closing the APU-fed side of the air conditioning, even when the APU was subsequently thought to be the problem, was unsuccessful (ATSB, 2003b). This means, that probably the problem was unwillingly allowed to exist for 10 days, before it was identified and repaired.

Primary troubleshooting was unsuccessful <u>example #8</u> - Messy details of maintenance:
In the HB-IXN event strong smells were noted the first time on 16 April 2005. Two days later on 18 April 2005 a smoke incident report was filled in:

> …we perceived smell of burned oil and shortly after that the SFO (Copilot) [sic] saw light white fumes…the situation was not dramatic we decided to continue approach and set the priority on a stable approach and safe landing. Therefore no emergency was declared and the oxygen masks were not used…(Swiss Federal Department of Transport, 2006a, p. 4)

After the serious incident with the HB-IXN, which only happened day later on 19 April, the mechanic responsible for the boroscope inspection, which had, despite the smoke reported by the pilot, found no oil leaks at the night before the incident occurred. The mechanic made the following statement about his workload:

> At the same time I was responsible for the "A"-Check on IYZ with 36 planned hours work and 2 open workorders. I was also the only B1 on the aircraft responsible for five other mechanics. IXN was put in a different hangar and I had to work between the two aircraft and ensure there would be no problem for IYZ to go to stand at 6 am LT …(Swiss Federal Department of Transport, 2006a, p. 4)

The HB-IXN report describes that next day the cockpit felt with an acrid smell, which incapacitated the co-pilot. He stated that he felt aware of events but was limited in his capability of acting. The captain had to land the airplane manually, without the redundancy from his co-pilot and while the auto-pilot was simultaneously broken. The subsequent troubleshooting defined high oil contamination in bleed band area. The boroscope of 19 April, a day after the unsuccessful attempt from a day earlier found no 1 bearing leakage.

What these examples in the sections above show was a problem that was not simply identified by troubleshooting after crew reports and once it was troubleshooted either persisted or re-appeared. The way the labels describe the problem shows great ambiguity in the identification of what often became acknowledged to be the cause of the problem at a later point in time.

So far the three main labels of the first dataset have established that oil leaks are a common source for events of suspected bleed air contamination that are escalated through incident reports. From the reports narratives it became clear that the risk often remains in the system for several days before it becomes apparent as the actual source of the problem.

Open coding datasets: ‘symptoms’ and ‘toxicology’

The two dataset *‘symptoms’* and *‘toxicology’* are discussed together. The effects from cabin air contamination can be smoke, fumes, haze and smells, but eventually these effects do not jeopardize aircraft systems. Health symptoms that could affect the control of the airplane, and thus flight safety, were often mentioned to have happened in a multitude of similar cases when the investigators consulted other sources than incident reports (AAIB, 2007b; SHK, 2001). Even if bleed air-generated smoke can generate some form of immediate threat, eventually investigators are interested in the effects on crew performance to make an assessment of possible impairment or incapacitation. Some symptoms are clear signs of irritancy, such as eye irritation and respiration problems in the presence of white smoke (RNF, 2009). Several other symptoms such as feeling unwell can be described, from which the cognitive impairment in the cockpit being the most critical for flight safety. Such symptoms can be light headedness & dizziness (AAIB, 2012a), tunnel vision or loss of balance (AAIB, 2007a). Sometimes sensations such as loss of feeling in the hands and lower arms were described (AAIB, 2007a; BFU, 2013), a crew reported to be on the verge of passing out (ATSB, 2001b), and others reported fuzzy, drunk feeling (AAIB, 2007c). Other included headaches and vomiting (AAIB, 2005h), up to complete incapacitation of short (SHK, 2001) and long duration (AAIB, 2004b). Cognitive symptoms were represented or cited as the most significant for their effects on flight safety. The reason is that they might affect the decision making process itself, a risk repeated in several incident reports. An excerpt from the VH-NJR report described: “Previous incidents have indicated that operating crews were not aware of their impairment and the subsequent effect on their decision making ability" (ATSB, 2001a) or "The incident involving G-JEAK, and other events, indicated that an irritant(s) can cause degradation in decision making and the reasoning ability of flight crews"(AAIB, 2004b, p. 55).

The report described how the first officer after a lavatory visit developed symptoms when he entered the flight deck:

> he began to feel nauseous. He sat in his seat but began to feel progressively worse, although his workload was low. He felt 'light-headed' and had difficulty in concentrating. He was aware of a tingling feeling in his fingertips and his arms started shaking. (AAIB, 2004b, p. 3) . . . . The commander who also felt nauseous took over the handling duties and instructed the first officer to put on his oxygen mask. The senior cabin attendant was called in to check on the first officer. When she arrived, the first officer was on 100% oxygen, his seat was well back from the aircraft controls and his hands were seen to be trembling . . . . the first officer took no part in the conduct of the flight although he was able to nod in response to the commander's question . . . . The commander was feeling progressively worse. He felt light-headed and recalled considering three aspects: landing, declaring an emergency and putting on his oxygen mask. However, he felt able to cope only with one decision and continued with his approach. The commander considered that he was subsequently able to complete all of the necessary checks and maintained normal radio contact with ATC. However, he reported that his heart was 'racing' and his mouth was dry. Additionally, when he became visual with the runway at about 1,000 to 1,500 feet agl, the commander seemed to have 'double vision' and had difficulty in judging height. (AAIB, 2004b, p. 4)

Another report describes the crew's medical symptoms as follows:

> During the approach towards Malmö/Sturup airport when the aircraft was descending through FL 150 the co-pilot suddenly became nauseous and donned his oxygen mask. Then, after an estimated period of ten seconds, the commander also became very nauseous and immediately donned his oxygen mask. After a few seconds of breathing in the oxygen mask the co-pilot felt better and thereafter had no difficulty in performing his duties. However, the captain felt markedly dizzy and groggy for a couple of minutes. He had difficulty with physiological motor response, simultaneity and in focusing. Finally he handed over the controls to the co-pilot. During the approach, when the purser went forward to the pilots to tell them that the cabin was prepared for landing she noted that both of the pilots were using their oxygen masks. In his groggy state the captain even had difficulty in grasping the purser's finger as acknowledgement of her clear signal. (SHK, 2001, p. 9)

Both symptoms and toxicology belong to the *'conditions'* category from the qualitative coding matrix (table 2) . Whereas symptoms are the direct information as reported to the investigator, and define the degree and nature of impairment, the investigator relies on further toxicological assessment to explain them. The incident reports often mentioned the existing toxicological knowledge gap, which prevented conclusive definitions to establish exact causative mechanisms. In short there were many instances were the incident reports acknowledged the effects on pilots labelled as severe on one or both pilots (AAIB, 2007b) or having an effect on flight safety (BASI, 1999; SHK, 2001), but none of them that provided a valid explanation for the exact causative mechanism that was useful for its conclusions or these of future incident reports. Even if interpretation would be agreed upon (Cf. Competing discourses section) only few investigations performed actual toxicological testing. Investigations did either not take blood samples and the few that did, lacked pre-defined human-biomonitoring methods and sometimes delayed it until days after the incident (AAIU, 2010). This led some reports to assess chemicals (TAIC, 2008) on an individual non-comparable basis, did not report which tests were performed (AAIB, 2006e, 2012b), or described the difficulties of currently available tests (SHK, 2013). The BFU summary report confirmed the difficulty that there are no standardised blood tests or verification methods (2014, p.63).

Except for the lack of consistent data gathering of medical data, the more fundamental toxicological knowledge gap is also raised as a problem to objectify the issue: "It is recommended that the CAA initiate high priority research efforts with the intention of determining the substances that can enter the cabin air on the aircraft type BAe 146, should oil leakage arise from the engine" (SHK, 2001). This was later repeated in the G-JEAK report (AAIB, 2004b), which in fact did initiate some CAA toxicity research[3] and stated that all identified substances were within acceptable limits but came with inconclusive answers: "There are over 40 different chemicals contained in oil breakdown products and many have no published toxicity data, so it is not possible to be certain whether any of these products contribute to, or are the sole cause of the recorded incidents" (CAA, UK,, 2004, p. vi). The fact that the toxicity matter was unresolved becomes clear from a recent French incident report, which noted: "corrective actions were defined…[as] the study of risks linked to the toxicity of smells and fumes from lubrication oils" (BEA, 2015). The question how toxicity and its subsequent effects on crews and control of the aircraft is mainly understood by refuting

Open coding dataset: 'Circumstances/ context / available information'

Two important open coding labels *'known issue'* and the *'lack of information',* being the inability to interpret or to assess the toxicological situation produced a double signal and eventually an internal contradiction in the conceptual definition of the issue of cabin air contamination. Before explaining this contradiction, I will explain the extent of the 'known issue' and limit myself to information from the reports only, faithful to the aim of this chapter to define this problem as viewed through the eyes of the incident reports.

In many cases investigation reports referred to the problem being a previously 'known issue' on a specific aircraft model (AAIB, 1996, 2001, 2006e; BFU, 2007a, 2007b; SHK, 2013) or a specific airline: "The airline has a history of problems of oil smells in the cabin and cockpit on its Boeing 757 fleet" (AAIB, 2005i). Some more extensive investigations revealed the 'known issue' in more detail and described a wider history of event, previously undisclosed and from which the numbers sometimes was substantial. In the open coding labels the child note 'wider history of event' resided under the parent node 'known issue' and produced several examples:

Known issue, <u>example #1</u> G-JECE:

> "Information from the engine manufacturer indicated that at July 2005 there had been 12 incidents of oil smell or smoke in the fuselage, of which five had been attributed to ICS cracking" (AAIB, 2007b, p. 27)

The same report continues:

> 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 odour 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

[3] This will be discussed in more detail in the chapter about Competing Discourses

> 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 crewmembers had found it difficult or impossible to establish the source of the contamination. Adverse physiological effects on one or both pilots, in some cases severe, were reported in 40 of the cases. A diversion was made in 31 cases. (AAIB, 2007b, p. 28)

Known issue, <u>example #2</u> SE-DRE:

> 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 (MOR14).
> 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. (SHK, 2001, p. 25)

Note that the several hundred reports mentioned in the different paragraphs above are not disclosed by anything else than references, hidden in the reports. They cannot be traced back to the actual events. Nevertheless they were described as 'impairment', 'flight safety' or cases of physiological effects on one or both pilots, in some cases severe. This can be considered as an important finding, especially because, as is described elsewhere in this thesis, other than one would intuitively expect, such descriptions did not trigger investigations. In other words, already by looking at the internal data from the incident reports, there is no commonly defined trigger to start an incident report. The extent of the cabin air contamination cannot be construed by just looking at the investigations only. This finding is repeated in other chapters.

Known issue, <u>example #3</u> G-JEAK:

Additionally, the G-JEAK report referred to this preceding SE-DRE investigation, but was the first investigation to examine the sources of contamination on several other aircraft types. As the report stated: "This revealed that the issue of contamination of the bleed air supply was not limited to the BAe 146, but was prevalent on at least one other aircraft type, the Boeing 757. However, other events, with similar crew responses, were reported to a lesser extent on Boeing 737 and Fokker 100 aircraft" (AAIB, 2004b, p. 55). From the 24 incidents[4] that were mentioned, including the G-JEAK itself, I counted a positive oil leak identification in 11 out of 24 occurrences (AAIB, 2004b). Three additional, events described in the G-JEAK report didn't establish oil leaks, but troubleshooting identified the left engine to be the source of the trouble. This was the case on the G-BMRH, where both APU and left engine were replaced for this reason, whereas on the G-BIKT, both in 2001 and 2002, the left engine had to be replaced after an incident (2004b, p. 30). Thus, in the G-JEAK report only, for 14 cases an immediate relation with engine or APU defects was

[4] The 24 incidents included 6 earlier investigations. 19 new UK reports were described.

identified and the report established precise root causes for further non-disclosed investigations on two particular aircraft, the Boeing 757 and the BAe 146.

Open coding dataset: 'Regulations'

A third dataset belonging to the 'conditions' category collected open coding labels pertaining to 'regulations'. This last dataset that defined conditions (table 2) for the investigation was clearly the most underrepresented and 'regulations' were hardly referred to. When they did, they only referred to general concepts, such as bleed air purity, continued airworthiness or compliance with maintenance procedures. However, there was no critical level of reflection on the meaning behind these concepts. One of the few to describe the problem of regulations critically is the G-JEAK report: "The regulations JAR 25.831, JAR-APU-210, JAR-E-510 and JAR-E-690 all deal with unacceptable levels of contamination of the bleed air, but do not provide details of toxic contamination that is deemed as unacceptable" (AAIB, 2004b, p. 64).[5] Whereas the lack of science and a toxicological knowledge gap were actively defined, references to regulations remained passively absent in the report's description.

Open coding datasets: 'Actions' versus 'Recommendations'

The two last datasets of open code labels fit the bottom-up coding category 'consequences' of the qualitative coding matrix (table 2), being the results or effects produced by the investigation itself. In other words they are the effects the reports produced, or show how a problem is managed. The most important first level finding is that there are five times more labels that point to 'recommendations', then to 'action'. And even then not all the action produced were forms of positive action. For example it also included descriptions labels such as 'poor response', a negative, although infrequently cited quality by the reporters. This should not lead us to make conclusions at this point about this discrepancy, because it is per definition the aim of investigation reports to make future improvements from actual findings. We may only hope to find more labels that point at future action in a single report, but we still wish to see a positive tendency as the net effect of safety investigations, which inherently entails a wish to improve. The qualitative coding process should only describe discrepancies between produced effects (action) and future orientated effects (recommendations) from within the reports.

Positive action could be for example the changes in procedures to prevent overfilling, which were reported to have led to a "significant reduction in the following months in the rate of reporting of oil smells on the Airline's B757 fleet "(AAIB, 2005i). Even then, it was already cited in earlier investigations and could be said to be a late insight already addressed a year earlier: "Another outcome of the investigation by the team was the recognition that over-servicing of oil for the RB211-535C engines contributes to the flight deck odor issue" (AAIB, 2004b, p. 35).

However, even if it was the report's belief that these were positive 'actions' for this particular airline, it was worth checking the validity of that claim against external sources. I performed a search on a UK MOR collection reports from 2006 until 2011, consistent with the effects of engine oil fumes (CAA, UK, 2011). When focusing on positive findings for overfilling in the UK only, I counted 26 cases in this 5-year period. Even in the case where overfilling might have been reduced in one airline as suggested by the 2005 report, this figure from an external source shows that they are still

[5] The 2014 BFU study had similar critique to the regulations, but is outside the scope of this chapter.

commonplace in the years after. Either they still happened in the following years in the airline specific mentioned in the earlier AAIB report or they have happened in other airlines in the UK, which means that there would be a structural communication barrier for mitigations. In both cases the result is suboptimal.

An important recommendation came from the UK AAIB when it identified the need for crews to identify the sources of contamination by installing sensors. The report directly addressed the European and US regulator in a recommendation of the G-JECE report (2007):

> It is recommended that the EASA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a flight deck warning of smoke or oil mist in the air delivered from each air conditioning unit (AAIB, 2007b, p. 30).

The exact same text, but with the successive number 2007-003 addressed the US regulator FAA (AAIB, 2007b, p. 31). In the absence of a reaction, the same UK AAIB repeated the same safety recommendations 2007-002 and 2007-003 in the G-BYAO report: "To date, the AAIB has not received formal responses to these recommendations" (AAIB, 2009, p. 7). Thus, the regulator does not answer the recommendation that enables crews to objectify the problem. With such sensors flight crews would be supported in their decision-making. Pilots could isolate the source earlier in the process, put on oxygen masks when needed, make diversion if necessary, but would even be able to ignore otherwise very ambiguous signals and avoid diversions that create operational costs.

Whereas the means to objectify the issue for crews were not answered, other recommendations calling for last barrier defences were successfully translated into a BAe 146 Airworthiness Directive (AD 002-03-2001): "In the event of flight deck crew experiencing any unusual physical symptoms or with any detection of fumes, it is recommended that they immediately don oxygen masks" (AAIB, 2004b, p. 32). This was based on the following investigators' observation: "A review of the incidents which have occurred, indicates that not only are operating crews abilities likely to be impaired, to varying degrees, but that they may not be able to judge this for themselves and hence take appropriate remedial action" (AAIB, 2004b, p. 50).

In response to this recommendation the UK CAA has issued various FODCOM [Flight Operations Department Communication] 14/01, emphasising the use of 100% oxygen and asking for amendments to the operations manual procedures and re-iterated in 21/2002 (AAIB, 2004b, p. 61). The report states that these calls were successfully implemented: "[m]ost operations manuals now contain information on the donning of oxygen masks when contamination is suspected" (p. 61).

The particular investigation emphasized the use of oxygen masks, because it observed normalization effects: "in general, crews had regarded these events as a nuisance rather than a hazard, although their reactions and reported symptoms had been somewhat varied" (AAIB, 2004b, p. 10). The language suggests that often such occurrences were not identified as a safety issue. A certain frequency, but also a varying effect is acknowledged. This variation introduces an element of surprise. Whereas recommendations for sensors to objectify fumes for crews are not answered, oxygen masks are promoted as the means to fight the uncertainty and possible surprising character of this risk.

Unfortunately, later 'normalisation effects' were still described after the 2001 FODCOM and other reports continued to normalisation effects. The risks of such effects become immediately clear:

Normalisation effects <u>example #1</u>:

> The PIC [Pilot In Command] stated that the aircraft type had a history of fumes related problems and not donning his oxygen mask was a normal practice for himself and, he believed other aircrew employed by the operator. He said `most smells and odours were considered the normal environment of the day to day operation of the BAe 146' and he would have discontinued his . . . diagnostic action if he perceived a flight hazard issue and would have reverted to the emergency checklist action. (ATSB, 2003a)

Normalisation effects <u>example #2</u>:

> The copilot noted that, shortly after she selected the APU bleed air on, she was aware of an unusual smell. She described this as "not being one of the normal smells that you get used to flying the 146" [original emphasis]. . . . When the crew selected the engine air bleeds on in the climb, there was a smell of "sweaty socks". This smell was described as "normal when the aircraft has been standing for a while" (AAIB, 2007c)
>
> "The aircraft type has been the subject of recurring fume incidents throughout its operating life as commented on by the PIC. It has been subject to intense investigations by both operators and the manufacturer. . . . Because of this history, the fume events may have become `routine' in the thinking of some operating crew and awareness of the possible risks may have diminished as a result. This familiarity was a concern to the manufacturer as evidenced by the wording in the AOM to the operator. Familiarity may have led the PIC to delay the donning of his oxygen mask" (ATSB, 2003a).

The results showed that the effects of normalisation were not simply solved by a call from the regulator. Other recommendations in relation to early recognition where not answered, whereas the regulator and aviation industry readily accepted the use for oxygen masks as a successful and satisfactory mitigation strategy. In this case the mitigation strategies include appropriate recognition of the hazard. It is important to understand that in the absence of sensors to assist crews in early recognition accompanying fumes or developing chemical smells remain a very ambiguous signal to recognise the hazard. When these fumes become routine signals, they additionally risk to produce normalisation effects.

Open Coding dataset: 'Crew actions'

This dataset named crew actions, should be seen as pertaining to the first category of bottom-up coding, the 'conditions' (table 2) created to assess the risk. Crew actions could have dampened or intensified the effects of the incidents from suspected cabin air contamination. Even if they are interactional strategies from the crew perspective, they are preconditions in the investigation's assessment. The most used labels included *'the use of oxygen masks'*, and thereafter cases where an emergency or request for priority (PAN) was declared as a last line of defence safety measure. Less frequent than the *'use of oxygen masks'*, but still significantly relevant were examples of the contrary, being open coding labels of cases where *'no oxygen masks'* were being used.

The fact that both labels are identified point to the fact that sometimes defences were applied and sometimes not, but they also point to the problem of a lack of understanding of the possible hazard:

No oxygen masks <u>example #1</u>:

> The commander then took sensible actions in calling the SCA to the flight deck and ensuring that the first officer went on to 100% oxygen. However, at this stage, particularly with the previous reports of unusual smells, it would have been prudent for the commander to also don his oxygen mask to minimise the possibility that he might also become affected. Shortly after, the commander considered that he was being affected and began to feel progressively worse. . . . He subsequently recalled that he was only able to concentrate on one decision and therefore actions were overlooked. Firstly, he did not put on his oxygen mask, secondly, he did not declare an emergency and, finally, the commander of the positioning crew who was qualified on type and who was in the cabin, was not informed of the situation. (AAIB, 2004b, p. 40)

Another such example can be found in such a Swiss investigation where one co-pilot was seriously incapacitated (Swiss Federal Department of Transport, 2006a, p. 8), and the captain continued flight, but did not don his oxygen mask. The same incident was already described earlier in this thesis in relation to the ambiguity involved in maintenance troubleshooting[6]. The Swiss investigators describe that neither the crew of the same aircraft the day before had used oxygen masks during a similar event:

> It is striking that the crew, which reported the incident on 18 April 2005 likewise did not don their oxygen masks. As an explanation the crew stated in their report: ". . . . and the situation was not dramatic we decided to continue the approach and set the priority on a stable approach and safe landing. Therefore, no emergency was declared and the oxygen masks were not used. When one considers the effects of smell and fumes/smoke in a cockpit, this behaviour is incomprehensible in both cases, not least because the airline's corresponding procedures in the OM A do not allow of any discretion. They state that the crew must expect the worst case scenario and consequently must don their oxygen masks in all cases. (Swiss Federal Department of Transport, 2006a, p. 9)

The captain also reported that this specific aircraft "had a history on this" (p. 6). Before flight the crew was told that there had been problems with air-conditioning pack No. 1. In the end the investigators established single instances of breached rules and procedures, but two crews in a row and a mechanic that failed to react to the same set of signals, could alternatively be questioned to be signs of gradually accepted risk, which might be rooted in how these routine signals were handled elsewhere in the system. A preceding report recommended that training for incapacitation procedures with "case based studies are discussed at joint flight deck/cabin crews safety training" (AAIB, 2004b, p. 36). Such case based studies could indeed help front-end operators such as flight crews and maintenance involved at this Swiss incident to break with signs of normalisation.

We could ask ourselves how well the earlier warnings of normalisation effects travelled through the system and if the risk can be defined as a hampered information culture. Despite the fact that crews had not used oxygen masks in this and other cases, the source of oil contamination was identified to be a known problem. The no1 bearing on the BAe146 was a common root cause, a that despite many modifications continued to happen for decades (S. Michaelis, 2010).

No oxygen masks <u>example #2</u>:

Another uncertainty described is when fumes are not detected in all parts of the aircraft: "The first item on the checklist related to the use of oxygen masks and smoke goggles; these were not used initially, as no fumes could be detected on the flight deck at this time" (AAIB, 2009, p. 51). The

[6] Primary troubleshooting was unsuccessful #8 - Messy details of maintenance

haze that was only apparent in the cabin initially escalated into a diversion and an emergency evacuation. Oil from a fractured bearing leaking into the bleed air was identified (AAIB, 2009, p. 50) in the subsequent troubleshooting. However, such subtle risk development as described above could be difficult to recognise. Oxygen masks were only used when the fumes became apparent on the flight deck.

And even when oxygen masks were used, they sometimes introduced additional practical problems as described on several occasions by the next examples:

> According to the commander's statement, he had major difficulties with verbal communication with the mask donned. (Swiss Federal Department of Transport, 2005, p. 16)

A 2008 incident with the UK G-FBEH showed a different problem of similar concern:

> Communication whilst wearing the oxygen masks proved very difficult due to technical problems with the masks. The co-pilot had to repeat calls to ATC to make himself understood and communications between the two pilots were rendered so poor that they had to resort to shouting…. The pilots attempted to communicate with ATC and the attendant fire services by radio, but this proved difficult because of the continuing technical problems with their oxygen masks. They eventually removed the masks and opened the window to speak to the fire services directly. (AAIB, 2010b, pp. 24-25)

In a German investigation involving an Embraer 145, oxygen masks where used after smoke development due to strong oil leakage of the left engine. The plastic lenses of the masks showed to be worn with age and were clouded, and seriously impaired the view of the pilots. "The aircraft overran the end of the runway by about 120 m and came to a rest about 100 m right of the centreline" (BFU, 2006a, p. 3)

In those cases where oxygen masks were used, they presented practical problems on many occasions. This was altered by situations where crews did not use the oxygen masks in critical situations. This might be a side effect that the events became routine signals, as was indicated in some reports, but this was not further investigated by the reports. The fact that the reports do not explain the reason, but narratives confirm that the last barrier risk mitigation is often problematic (also confirmed by Michaelis, 2010) should deserve further investigation in future research

From Axial to Selective Coding and Theory

The next step is the further elaboration of the axial coding. My first step was described by a distribution of datasets that were matched with one of the three categories of bottom up coding, being: 1) conditions; 2) action strategies: and 3) consequences. So far the datasets just provided a logical organisation. Further axial coding subsequently adds a level of critical analysis to the purely descriptive labels and datasets. In a further step I have captured each dataset by a single, or as few as possible axial coding labels. These are described in table 3:

Dataset Collection of Open Coding Labels	Axial Coding
Investigation findings	‘confirmation of contamination’ & ‘problem of objectification’
Symptoms	‘problem of objectification’
Toxicology	‘problem of objectification’
Regulations	‘problem of objectification’
Circumstances/Context/Available information	‘problem of objectification’
Recommendations/mitigation	‘prevent harmful sources of contamination’, ‘overcome problem of objectification’ & prevent effects from contamination’
Actions	‘technical modifications’ & ‘procedural modifications’
Crew actions during incident	‘last barrier defences’ & ‘problem of objectification’

Table 3: Axial Coding of Open Coding Labels

‘Confirmation of contamination’ according the reports description was defined by what was earlier defined as: 1) the effects on the aircraft systems such as ‘*fumes, smoke, haze’ and ‘smells’;* 2) the sources of their contaminations ‘*oil leaks identified’;* 3) the many references to ‘*known issue’,* often referring to a specific technical previous problem on the same aircraft type; and 4) identification of ‘*a known issue’* or ‘*a wider history of events’*, sometimes referring to hundreds of other similar cases in a single report. My statistical count, which revealed that in 65% of the cases engine/hydraulic/de-icing fluids (from which 54% engine/APU oil) were actually identified provided the most positive acknowledgement for the axial label ‘Confirmation of Contamination’[7]. Some of the reports that did identify the bleed air contaminations were reluctant to come to this causative conclusion and provided prudent or open-end conclusions. Such examples originate from the open coding *‘problem of* objectification’-labels such as knowledge gaps. The SE-DRE report for example stated: “Knowledge is lacking concerning modern lubrication oils’ characteristics at very high pressure and temperatures and their effect on human health” (SHK, 1999, p.36), and the G-JEAK report recapped: “It became apparent during the investigation that there was a definite lack of information available on the potential contaminants from lubricating oil, and their associated physiological effects” (AAIB, 2004, p.57). Both these reports therefore came with probable, non-decisive conclusions, despite the fact that they both identified oil leaks in their central investigation and further references. Therefore note the emphasised words in the quotes below:

> SE-DRE:
> The leakage was preliminary localized to a carbon-steel sealing on bearing #2 and as oil leakage from this area, from experience, can cause oil fumes in the cabin, it was assumed that this was the complete explanation for the feelings of sickness (SHK, 2001, p. 15)…The incident was caused by the pilots becoming temporarily affected by *probably* [emphasis added] polluted cabin air (SHK, 2001, p. 35).

[7] This does not provide a quantitative analysis, as the method of collection was not mean to provide quantititve rigidity.

G-JEAK:
The oil leakage on G-JEAK was associated with a seal failure on the APU cooling fan mounting plate and this oil found its way into the air inlet plenum chamber, and hence into the bleed-air system (AAIB, 2004b, p. 63). . . . There is *circumstantial evidence* [emphasis added] to suggest that the flight crew on G– JEAK were affected by contamination of the air supply, as a result of oil leakage from the APU generator cooling fan seal into the APU air stream, and into the ECS system ducting. This contamination allowed fumes to develop, a proportion of which entered the cabin and cockpit air supply (AAIB, 2004b, p. 66).

Paradoxically these reports did not provide a conclusive explanation for a phenomenon, from which their investigation positively identified the contamination by the presence of engine oil and in addition revealed a pattern of similar, but previously undisclosed cases. We have already described the SE-DRE paragraph in an earlier section stating a total of 461 other occurrences, many of them leading to 'impairments' and to have 'negatively affected flight safety', as reported by BAe Systems (SHK, 2001, p. 25).

The report from the second mentioned conclusion, the G-JEAK report referred to this preceding SE-DRE investigation, but it was the first investigation to examine sources of contamination on several other aircraft types. As the report stated: "This revealed that the issue of contamination of the bleed air supply was not limited to the BAe 146, but was prevalent on at least one other aircraft type, the Boeing 757. However, other events, with similar crew responses, were reported to a lesser extent on Boeing 737 and Fokker 100 aircraft" (AAIB, 2004b, p. 55). From the 24 incidents[8] that were mentioned, including the G-JEAK itself, an oil leak was identified in 11 out of 24 occurrences (AAIB, 2004b). Three additional, events described in the G-JEAK report didn't establish oil leaks, but troubleshooting identified the left engine to be the source of the trouble. This was the case on the G-BMRH, where both APU and left engine were replaced for this reason, whereas on the G-BIKT, both in 2001 and 2002, the left engine had to be replaced after an incident (2004b, p. 30). Thus, in the G-JEAK report only, for 14 cases an immediate relation with engine or APU defects was identified and stated: "[t]hese reported events all had a common theme; oil contamination of the air supply from either the APU or the engines. Once the source had been identified and removed, the smell would disappear" (AAIB, 2004b). These were the two reports that best revealed the indecisive conceptual definition of the problem space that will appear as a common theme throughout this further thesis.

Two other extensive reports revealed smoke oil leak contamination, but as there were no symptoms reported, there was no need to express a definition in other than technical terms. Besides many very short few-page reports, an earlier mentioned 2013 BFU investigation report deserves our attention for providing the opposite, an alternative hypothesis without a technical examination. It was unable to make technical findings, as it did not investigate the facts until one year after the event. The BFU had to depend on the operator's maintenance organisation at the time of the event. Maintenance did not identify any contamination. Nevertheless the 72 page report provided multiple explanations to explain the symptoms from the pilots which they assessed as being "significantly impaired in their capacity to perform" (BFU, 2013). Whereas no positive scenario could be concluded, the report points to the possibility of the pilots having reacted to the smells as the reason for the impairment:

The BFU is of the opinion that the psychological effects were even more important. The stress situation already present during the approach was intensified by the strong, unpleasant and

[8] The 24 incidents included 4 earlier described Australian reports and the Swedish report. 19 new UK reports were described.

> annoying smell. Maybe the smell was considered to be a sign of danger which may have triggered massive anxiety and fear. Due to the known discussion about possibly contaminated cabin air in airplanes in combination with TCP and the possible consequences of neurological deficiencies, the sign of danger might even have been intensified.
> . . . .
> Contributing factors could have been. Physiological and psychological effects of the smell on both crew members.
> . . . .
> The health impairments of both pilots combined with a significant limitation of the capability to perform which had occurred during the approach were very likely caused by: Massive development of smell in the cockpit area whose origin and spread could not be determined. (BFU, 2013)

However, the origin of what the report described as a 'massive smell' could not be explained. In the preliminary report it was described that the smell persisted, as confirmed by the mechanics, (BFU, 2012b) until 15 minutes after entering the aircraft on ground. Although the final BFU report had emphasised a possible reason for simultaneous impairment in the reaction of the pilots, I considered that the label 'problem of objectification', although for other reasons also fits this case. The investigators spent 72 pages for several scenarios all marked by some degree of objectification difficulties. Another case in the UK, mentioned earlier in this section, attributed a double impairment to be the physical-psychological related reaction from both pilots as follows:

While banking the aircraft for a turn, "the commander may have suffered a disorientation episode caused by a combination of oculogyric disorientation and made more likely by the lingering effects of a cold", followed by what was described to be a possible reaction to the impairment of the captain with a form of mild hyperventilation from the co-pilot (AAIB, 2011).

These two reports suggested the problem could be related to the crews' individual reactions. But it could also be argued that even at crew level there was no means to objectify the situation at hand. Sensors, a recommendation earlier made by UK AAIB, would have provided a simple remedy to the ambiguity of interpreting contaminated cabin air. Also in the case of psychologically triggered reactions from flight crew, the 'problem of objectification' persists and sensors could prove the 'absence' of contamination. Neither were there any parameters to assist the investigations to objectify their hypotheses.

The axial label 'problem of objectification' eventually becomes the central theme in 6 out of 8 datasets as shown in table 3. In investigation findings, primary troubleshooting was often unsuccessful and the whole process of identification was ambiguous. Human biomonitoring methods are not standardized to address the origin of symptoms or the presence of chemicals and their levels. There is no consistent gathering of medical data and toxicity data is missing on many chemicals. The concepts behind regulations like bleed air purity, continued airworthiness or maintenance compliance are not further objectified. On crew level the narratives show that front-end operators are confronted with ambiguous signals that were often identified erroneous or too late. The 'problem of objectification' appears as a central theme in all of the conditions categories applied by bottom up coding form table 2 and finally gives way to unresolved ambiguity in the output of the incident reports. This uncertainty is continued in the further theory development.

Discussion & Theory Development

Internal Contradiction of the Conceptual Definition

Various reports have recognised that the crews' decision-making themselves can become affected (AAIB, 2004b; ATSB, 2003a). Recommendations therefore urge crews to put on oxygen masks as the first action in response to suspected cabin air contamination. Some of the signals might be easier to interpret in hindsight than in the heat of action. The recommendations from the aircraft manufacturers in reaction to incidents describe actions in response to signals that acknowledge the uncertain conditions of recognition:

> In the event of flight deck crew experiencing *any unusual physical symptoms* [emphasis added] or with any detection of fumes, it is recommended that they immediately don oxygen masks with regulators set to 100%. (AAIB, 2004, p.32)
>
> If at any time the crew is *unsure as to the air quality* [emphasis added] they should don oxygen masks. If at any time *one crew member appears to be unwell* [emphasis added] and uses oxygen, it is recommended that all crewmembers use oxygen as a precaution against any unidentified contaminant. (p.33)

Other reports have described this as the need to accept 'worse case scenarios' (Swiss Federal Department of Transport, 2006a, p. 9). These were in response to the earlier described normalisation effects. Investigations therefore urge crews to consider fume events as a hazard, rather than a nuisance (AAIB, 2004, p.20). Regulators have accepted these safety recommendations and adapted the need for oxygen masks as the first action into regulators' communications (CAA, UK, 2002). This advice has been successfully implemented in operation manuals (AAIB, 2004, 2004, p.61).

To objectively make decisions on the basis of just 'one crewmember feeling unwell or any unusual physical symptom as a precaution against any unidentified contaminants puts a lot of weight on the shoulders of crew members. This is especially true when the condition of the decision maker influences the decision outcome. Therefore, some reports addressed the possibility to objectify the problem in the form of sensors and a flight deck warning that should alert for smoke or oil mist delivered from the air conditioning unit (AAIB, 2007, P.30). But the UK AAIB described that the recommendations for sensors, which should help to recognise the problem more upstream in the system are not answered by the regulators (AAIB, 2009). The German BFU addressed the same problem and issued safety recommendation No 05/2014 to enable crews to distinguish the harmless smells from the harmful events (BFU, 2014, p.81).

Whereas the recommendation for the use of oxygen masks was readily accepted, recommendations for early recognition, upstream of the final effects, were refuted. The engineering committee ASHRAE has written a letter to ICAO, FAA and EASA to request bleed air contaminant monitoring (ASHRAE, 2007), but until today the technology is not installed. This internal contradiction of the problem space can be understood as the regulator's expression of acceptable risk, but is therefore not necessarily shared at the level of the investigating agencies that called for the means of objectification. Sources external to the reports have indeed confirmed the regulators construction of acceptable risk by the use of last barrier defences. The European regulator EASA states that "the potential safety risk can be mitigated by existing procedures and equipments [sic] (including the use of oxygen masks)" (EASA, 2011, p. 4). The Australian regulator CASA report similarly stated that "[i]n the higher risk occurrences, precautionary defences (most commonly diversions) [sic] were found to be effective in avoiding escalation of the event" (ATSB & CASA, 2014, p. i) or further, "the most effective PPE for fumes/smoke events are oxygen masks" (p.44).

Therefore, the focus on assessing flight safety in relation to effects is located downstream of the system in close proximity to the actual incidents. Moreover, retrospective classification of impairments and counting on last barrier defence strategies such as oxygen masks and diversions can only be applied after the effects have already manifested themselves. When depending on such manifestations it would be reasonable to have a full understanding of the toxicity involved especially in the light of the possible effect of "degradation in the decision making and reasoning ability of flight crew" (AAIB, 2004b, p. 55). Similarly an Australian report stated that "previous incidents have indicated that operating crews were not aware of their impairment and the subsequent effect on their decision making ability" (ATSB, 2001a)

However, reports describe the still existing toxicological knowledge gap, but also address the lack of a definition of toxicity or acceptable levels of contamination of the bleed air (AAIB, 2004, P.64). Regulators must specify necessary design and procedures to prevent failure with the hazard level as determined by a system safety analysis in accordance with CS 25.1309 (EASA, 2010). The statistical conditions for prevention of failure are very precise. Incapacitation of crews and passengers should not occur more than once every 10^{-7} engine, whereas crew degradation should not occur more than once every 10^{-5} engine hours. But the regulations' definition of the qualitative hazard is less straight forward, being "concentrations of toxic products sufficient to incapacitate crew or passengers" (EASA, 2011, p.4), without further defining toxicity. Furthermore, investigation bureaus do not have the means to objectify the toxicity of the cabin air. The BFU mentioned in its 2014 study: "A verification of cabin air contamination with toxic substances (e.g. TCP/TOCP) [a chemical of high concern] was not possible with the fume events the BFU investigated" (BFU, 2014, p. 80). In addition to the difficulties to assess the cabin air, the reports showed no systematic collection of biomonitoring data from affected crews; there has been some anecdotal evidence of attempts to do so. This was despite the fact that crew medical tests were cited to be part of a plan of action of BAe Systems in reaction to the 1999 Malmö incident (SHK, 2001) and cited in a 2004 report (AAIB, 2004b).

The problem space that emerges from the recommendations and their reactions or absence thereof by the regulator is one with a strong focus on dampening the effects after they have already manifested themselves. There is little focus on early or systematic recognition of the contamination sources. The aircraft accident investigation authorities describe a problem, form which the exact causative mechanism is not fully understood by the official reports but which is acknowledged to take place and pose a hazard (BASI 199, AAIB, 2004; BFU, 2014). At the same time some reports describe a wider history of events (SHK, 2001, AAIB, 2004; 2005). The regulator, on the other hand seems to accept a factor of risk without further objectification of the problem. The issue and the internal contradiction of the problem space, created by its inputs (investigation recommendations) and its outputs (actions from the regulator) is depicted in figure 2 below. This figure answers both the second and third part of our opening question to search for a conceptual definition of the problem space (2) and answers how the system managed the problem (3).

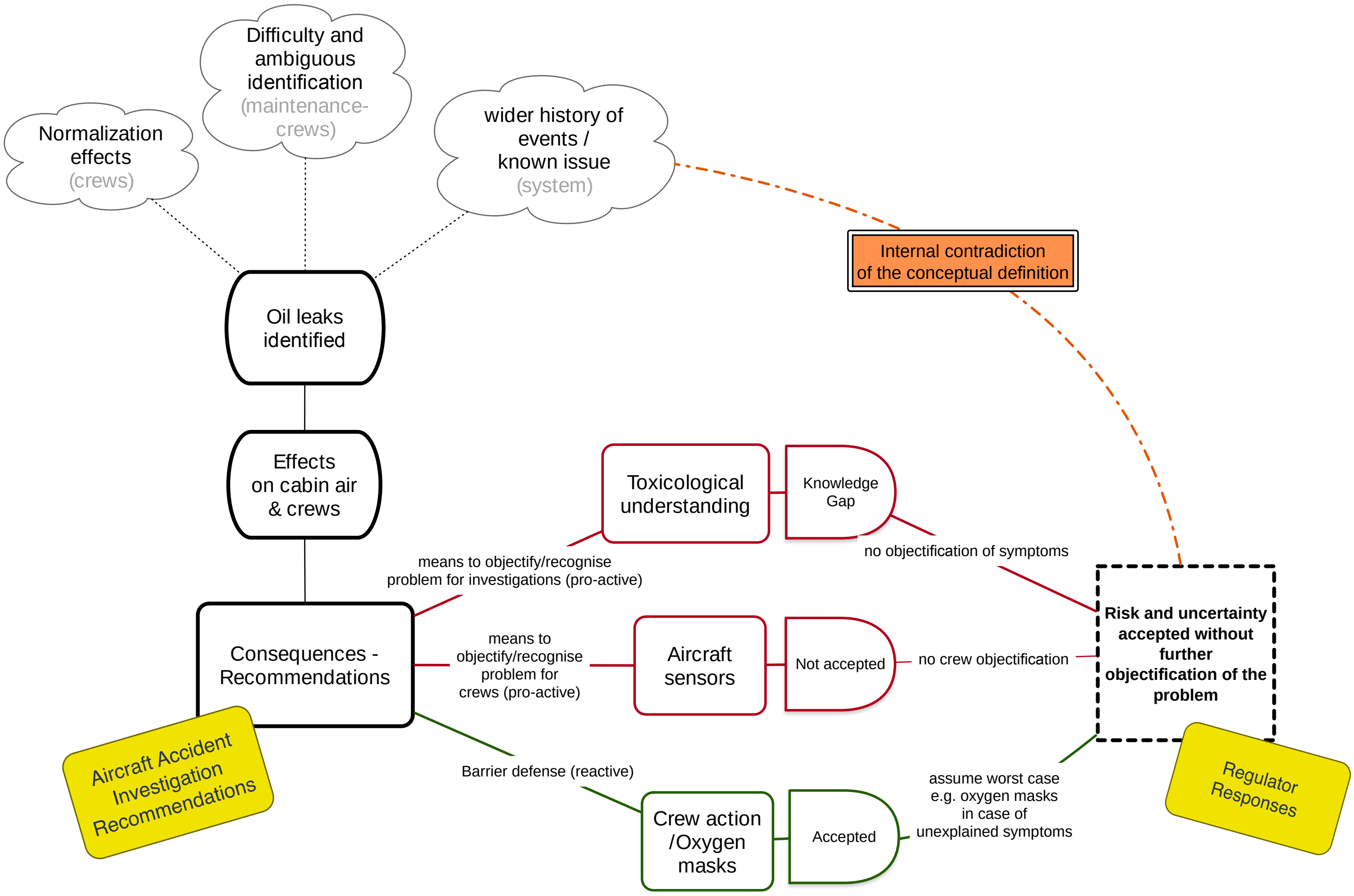

Figure 2: Internal contradiction of the conceptual definition

The many references to a 'known issue' in many smaller subsequent reports and the more thorough investigations that established a pattern of contamination on a multitude of aircraft, sometimes accompanied by particular aircraft type vulnerabilities, showed a more radical definition of the problem. Such a definition revealed a technical preventable error due to a certain technical design or due to erratic maintenance procedures (AAIB, 2004b, 2005i, 2007b). Even if recommendations to completely avoid contaminations at root cause level put more weight on a definition of preventable technical errors, they are not more than a re-iteration trying to solve the problem at the level it was created:

> It is recommended that the Civil Aviation Authority . . . takes early action . . . to require that operators of this type should ensure that the standards of maintenance and modification of the aircraft's air conditioning system, engines and APU are such that air supply contamination by oil from the engines and/or APU, or by any other potentially hazardous substance, is avoided (AAIB, 2004b, p. 54).

Sources such as Mandatory Occurrence Reports (CAA, UK, 2011) showed that the problem of positively identified bleed air contamination is persistent. Research by Michaelis (2007) showed that technical modifications continued for decades but did not alleviate the problem on the targeted aircraft. Between 1985 and 2005 British Aerospace produced nearly 200 Service Bulletin and

Related Actions regarding contaminated air problems on their BAe146 only without solving the technical problem (Michaelis, 2007). This is also supported by the many incident report findings elsewhere in this thesis that showed that root causes are often re-occurring problems such as oil leakage from the Rolls Royce RB211-535C on the Boeing 757 or the #1 and #9 seals of the BAe aircraft engines (AAIB, 2004b). a #1 bearing failure was for example also identified in a 2001 Australian incident (ATSB, 2002), 2002 Australian incident (ATSB, 2003b), and in the 2005 Swiss HB-IXN incident (Swiss Federal Department of Transport, 2006c). This is an example where the definition of the risk as a preventable error could have received more weight. This specific bearing failure was already documented in a 1992 incident (Dust Diseases Tribunal of New South Wales, 2010).

Specific technical aircraft type mitigations and recommendations often remained local lessons as information is not often shared across airlines and fleets, because there was no investigation. The earliest identification of the #1 bearing on the BAE 146 was identified in 1992, but was never disclosed by the authorities as there was no incident investigation. It took another 18 years to be described in a worker's compensation case.

Another example is the recommendation for APU overfilling discovered to be the cause of smoke in a 2005 investigation. These could be a valuable lesson to procedures for all aircraft models but in the reports recommendations stayed restricted to the Boeing 757 only (AAIB, 2005i). It could have provided a likely explanation for events on other aircraft that reported fume events especially in those cases where no contamination was found after the incident.

Michaelis critiqued that "[s]everal ADs [Airworthiness Directives] have been issued with regard to leaking oil on the BAe 146, indicating an unsafe condition exists, however no other ADs have been issued for any other aircraft types leaking oil into the air supply" (Michaelis, 2010, p.619). In this way fragmentation of information obstructs a widespread warning of the issue on all aircraft, because the problem is common for all aircraft models (Shehadi et al., 2015).

Solutions stay local due to organizational structures, the slow pace of litigation processes and prevents organisational learning. Another form of fragmentation is produced by distribution of decision-making. There seems to be no effective integration from the investigation's recommendation into the regulating system. Important regulations are not answered and remain dead-ends in the reports. The internal contradiction of the conceptual definition is shaped by different views at different levels of the decision-making process.

Uncertainty as an Outcome

A further effect can be described as uncertainty/ambiguity. On a socio-technical level there was uncertainty and ambiguity in identifying the problem for maintenance, flight crews and investigators, as a result of the several unresolved identification problems.

Uncertainty as an outcome for maintenance troubleshooting: Only the G-CPER investigation identified unsatisfactory working practices, ineffective maintenance supervision & planning, non-procedural approaches and further organisational aspects such as a culture of 'blind-stamping' as causal factors in the investigation (AAIB, 2005i, pp. 67-68). Although this was the only analysis that specifically identified socio-technical aspects as causal factors, the uncertainty produced in maintenance was not so much created by procedural breaches, but mainly created by the messy details of normal work. The ambiguous nature of operational work itself within complex safety systems has played a role in numerous reports. As Dekker describes: "Operational expertise is indispensable for getting a sense of, the messy details of what it means to get the job done under pressure, goal conflicts and resorts limitations (2014b, p. 153). To design effective regulations, one should also understand everyday complexity and the reality of normal work.

Uncertainty was also created because aircraft, on which signs of contaminations had already been reported, continued to fly for several days or even longer before the problem could be identified. In other cases, the problem reappears, when it was believed to be successfully isolated or rectified and was allowably deferred for later repair.

Uncertainty as an outcome for crews: To always expect worst-case scenarios when critical signs have been preceded by less critical signs poses a risk of their own. In hindsight the more serious effects have sometimes been judged to be treated as nuisance, but such normalisation effects can become a normal by-product of previous routine signals. Normalisation effects had been described by an Australian (ATSB, 2003a), British (AAIB, 2004) and a Swiss report (Swiss Federal Department of Transport, 2006a), but also became apparent from report narratives how crews reacted. Additionally, some reports describe how some crews where not trained to respond to the effects (SHK, 2001, p. 29) from earlier reports.

Without the bigger picture narratives, crews get judged by some reports for not putting on oxygen masks when it was most needed. But just as important as understanding the messy details on the maintenance level it is important to understand the role of what are called second stories, being "overly simplified accounts of the apparent 'cause' of the undesired outcome" (Woods & Cook, 2002, p. 1). Normalisation effects play an important role to explain the reasons for not putting on oxygen masks. Both crews and maintenance can get accustomed to organisational routines if signals are frequent and previously had no critical outcome. Vaughan describes routine signals as follows: " The more frequent the similar events, the more routine the individual case. Seriousness itself becomes routine, a taken-for-granted characteristic of the case, reducing the experience of seriousness for the worker" (Vaughan, 1996, p. 246).

Uncertainty as an outcome for the investigator: In addition to the uncertainty for crews and maintenance I have defined the difficulty for the investigators to find conclusive answers. 'Circumstantial evidence' and 'probably' polluted cabin air were the conclusions from two reports that positively identified oil leaks in the aircraft involved in their main investigations and both found references to hundreds of other such events (AAIB, 2004b, p. 46; SHK, 2001, p. 25), some associated with flight crew incapacitation or impaired flight safety. The reports warn flight crews to treat such events as a hazard and simultaneously identified a wider history of non-disclosed events with similar effects. But the cautioned choice of words is inherent to the purely descriptive nature of incident reports for investigations that are confronted with several objectification problems.

Uncertainty as an outcome for regulator: Concerning the frequent 'known issue'-descriptions it should be noted that without some of these investigations, the wider history would show itself as mere numbers in a database. Relation will only reveal itself when additionally challenging the database with qualitative explanations. The investigation's narratives for example mainly provided difficulties to assess the problem on all levels of the socio-technical system. The main challenge for the regulator is therefore how to have a complete picture of the issue. Some of the frequency and severity of the wider history of events can be guessed from several incident reports' descriptions, but apart from the G-JEAK that established a pattern of root causes, it is often provided as non-specific information such as descriptions of 'a known problem' on this fleet or that airline. Only a few single paragraphs provided information with a short, but dramatic description of sometimes hundreds events, several labelled with flight safety implications.

How representative are the incident reports for the problem?

The incident reports provided a unique and valuable narratives to describe uncertainty, ambiguity, objectification problems, messy details and other qualitative details, but in answer to part 1 of our 3 initial questions at the beginning of this chapter to define 1) what is the commonly defined trigger to start an incident investigation they are an inadequate source of information. They do not reveal the extent and the history of the problem. As said earlier, Shehadi et al. approximate 2 to 3 contaminated bleed air events per day in the US only. Harrison et al. state that current figures from the UK CAA show that between 2010 and 2015 more than 1300 reports of smoke or fumes on one British airline were received and there were 251 incidents of fumes or smoke in the cabin reported between April 2014 and May 2015 (V. Harrison & Mackenzie Ross, 2015). Even if this says something about the current concern and awareness in some countries, there is little accessibility to this data. We need further external sources to identify possible sources of bleed air contaminations or have the reporter's narratives. I therefore compared the number of incident reports with a collection of UK mandatory occurrence reports (MOR) from 2006 until 2011. This was one of the rare sources, external to the investigation reports, with short descriptions of a large collection of events. A compilation with the search term smoke/fumes showed me a total of 277 events that repeatedly displayed the same problems as the incident reports, but did not become the subject of an investigation report. Effects of suspected cabin air contamination were reported in the form of smoke or fumes, but did not include positive findings identified alternative sources of contamination, such as electrical components, etc. In many cases engine oil leaks or engine overfilling were found in the subsequent troubleshooting. The UK MOR collection of events over this 5-year period produced 37 identified cases of engine oil leaks and an additional 26 APU or engine oil overfillings. This creates a higher number of such technical findings than the entire findings of the worldwide incident reports. Even if my collection of 55 reports could have missed some smaller reports that are hard to find through search terms, the contrast between figures of a five-year period in one country remain in sharp contrast with the global figures that started at end of the last millennium. In the UK MOR 57 of these reports, symptoms from a varying degree were reported. One case is provided below as a condensed example containing several of the label identified earlier. A double impairment leading to subsequent identification of an oil leak, which was earlier identified as a known issue, but from which the rectification was deferred:

> 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. 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. (CAA, UK, 2011)

Such occurrences, including this one were not covered by an investigation and never disclosed in anything else but a database. This provides but one example that triggers are variable. This answers part one of our three-fold question, being 1) what is the commonly defined trigger to start an incident investigation. The reports did not define a commonly agreed definition in terms of an input, the start of an investigation.

To conclude, the reports have established that the majority resulted in the positive identification of bleed air contamination and which was often triggered by crew reports not knowing that these contaminations would be the result of the subsequent troubleshooting. This cause-effect correlation establishes enough reason for concern, but is not intended as a quantitative analysis, for the methodological rigidity cannot be established from these sources. There was confirmation of a problem, but not of the exhaustive definition of the causative mechanism of the effects on crews. So in terms of an output of the reports there is no conclusive definition. Still the reports state to react to early signs as if they were hazards, and not dismiss them as a nuisance. An internal contradiction arises from the fact that the system warns from a hazard, which it fails to conclusively define in many cases. Investigators are not responsible for solving the exact causative mechanism and understandably remain cautious in their interpretation. What at first is just a conceptual internal contradiction becomes further amplified by the system's interaction with the definition, for example the regulator's selective use of answerability to the recommendations. This points to a level of non-integration of these agencies in response to their recommendations to protect public safety. The regulator's absence of a definition of toxicity and the lack of sensors repeatedly point to the problem of objectification. This objectification problem identified in this chapter will also play an important role in the subsequent chapters.

CHAPTER 2: INTERPRETATION OF THE SIGNALS - COMPETING DISCOURSES

Competing Discourses on what is acceptable exposure

It is known that organophosphates and hydrocarbons are present in jet engine lubricating oil and neurotoxic effects of some of the ingredients are well described (Winder, 2002). Furthermore, some oil is pyrolised in the engine, and the complex mixture of pyrolysis products may also be present in the bleed air under normal operations (Ramsden, 2011). Continuous low-level exposure occurs at minimal rates because seals per definition allow some leakage under normal operating conditions (Michaelis, 2016). The previous chapter additionally described instances where greater leakage can occur during abnormal operations due to damaged seals or poor maintenance practices. Although hydraulic fluids are theoretically contained in closed circuits some levels of their main ingredients such as TPP and TBP are consistently measured in the aircraft cabin air by different studies (Cranfield University, 2011; Solbu et al., 2011). At the same time these hydraulic oil compounds are significantly raised in flight crews' urine samples (Schindler, 2013). Even if TCP form the engine oil has so far gained the most attention in the literature, recent studies have identified alternative chemicals with similar toxicity when examining fresh and used jet engine oils (Megson et al., 2016). From this the authors conclude that these chemicals should be further considered for their neurotoxic properties. TCP is thus certainly not the only chemical involved, but it has been established to be a very potent neurotoxin and provides a unique chemical signature to the engine oil. This one single chemical raises enough concern to provoke symptoms (Ramsden, 2011). The synergetic effects can add to the toxic effects (Winder, 2002), but their toxicity has not been studied to the same extent and are more difficult to identify. Pyrolysis products are however identified in the aircraft ducts of aircraft with a known history of fume events (CAA, 2004). Problems with lowered oxygen concentrations at typical aircraft pressurization altitudes include changes in sensitivity to toxic exposures and increased altitude may lead to higher respiratory rates and therefore increased exposure (Winder & Balouet, 2002, p. 157).

This brings up a central question: "how much exposure is acceptable?" and 'how is acceptable exposure assessed?' Two competing paradigms provide opposite answers, from which one side concludes a serious concern and another dismisses evidence for a strict causality. Although both paradigms start their assessment from the same available data, it can be said that they give different weights to the various knowledge and data gaps.

To explain the differences, it is worth looking at the sources of information used to defend the view that current exposures are acceptable. Harrison states: "Two specific studies are often interpreted as showing that the chemicals detected in cabin air cannot be responsible for the ill health reported by aircrew (V. Harrison & Mackenzie Ross, 2015).

1) In 2007 the UK Department for Transport commissioned Cranfield University to sample the air quality on board 100 flights, with the aim of identifying the levels of various chemical compounds that were present in cabin air during various stages of flight. Several volatile and semi-volatile organic compounds were detected during routine flight, including carbon monoxide, toluene and TCP.
2) A more recent study, conducted in partnership with KLM airlines, measured levels of TCP isomers in the cockpit of over 20 flights, and found non-ortho isomers (but not ToCP)

> were present in low concentrations on 10 out of 20 flights, but the authors concluded such low levels were unlikely to be responsible for alleged Aerotoxic Syndrome (V. Harrison & Mackenzie Ross, 2015).

Harrison also concludes that "several considerations that should be taken into account before accepting this conclusion": 1) No fume events were observed on any of the flights that were monitored in these studies; 2) These papers have only explored the presence of limited chemicals in the cabin; 3) The authors have not given sufficient consideration to the fact that cumulative low level exposure over time (as opposed to a one off fume event) may be harmful to health and; 4) None of these studies investigated the relationship between air quality measures and symptom reporting. (2015)

Ramsden comes to a similar conclusion as Harrison about the Cranfield report's results. In addition, he critiqued the methodology and the fact that the Cranfield study ignored the peer reviews report about the suitability of the measurement equipment (2011). Ramsden was surprised that even under this conditions the study did identify TCP, not during fume events, but during regular flights. This did not refrain the reporters from concluding: "there was no evidence for target pollutants occurring in the cabin air at levels exceeding available health and safety standards" (as cited in: 2011, p. 156). On the reports conclusion Ramsden states:

> for a relatively involatile, lipophilic substance such as tricresyl phosphate, especially in view of its even more toxic metabolic breakdown products, there may effectively be no threshold exposure limit below which it can be deemed to be safe. (p.157)

Several authors do not support the Cranfield University's conclusion and came to the conclusion that levels of TCP identified in 23% of the samples were a serious concern (S Michaelis & Murawski, 2011; Ramsden, 2011). Michaelis and Murawski concluded that the measured presence of airborne neurotoxins during these flights were found to be acceptable, raises some troubling questions about industry norms (S Michaelis & Murawski, 2011). Ramsden points out that the Cranfield study has since been widely quoted by politicians, aerospace manufacturers and airlines to prove that cabin air is deemed safe. He further refers to a third often-cited source, used by the industry and UK government to show that the chemicals detected are within limits. It was carried out by the Safety Regulation Group of the CAA UK (hereafter: CAA UK report) to assess the flight safety aspects after a series of incidents (Cf. G-JEAK report). Ramsden describes that the experimental part was a careful, high quality study, the main conclusions being that the ducts carrying bleed air from the engines to the cabin were contaminated with substances consistent with the pyrolysis products of engine oil (CAA, UK,, 2004). Mixed isomers of TCP were also found (2011, p. 156). However, Ramsden continues that the part with toxicological review of the literature was seriously inadequate because ToCP was considered to be the most toxic isomer of TCP, whereas it had already been discovered more than 40 years earlier by Henschler that other isomers of TCP (such as MoCP and DoCP) are much more potent neurotoxins (2011). Other limitations, he continues, were that the symptoms of intoxication considered were narrowly defined. Furthermore the alleged safe limits, which were quoted from the UK Health and Safety Executive are irrelevant, because they are only intended for one single isomer of TCP (ToCP) and do not apply above 5000ft (Ramsden, 2011).

Another author, Chaturvedi, comes to a similar conclusion as Ramsden, being that the experimental part of the CAA UK study from 2004 is more thorough than the toxicological review:

> Although the toxicity of the substances in the black carbonaceous particulate material found in the ducts is described and discussed with sufficient relevant scientific references in the CAA

UK study (CAA 2004) [sic], the toxicity of this solid carbonaceous material, as a whole entity, is not given in detail. The chemicals comprising the carbonaceous material may not necessarily be individually toxic at the concentrations found, but if they are mixed together at those concentrations, the mixture may be highly toxic (Eaton and Klaassen 1996, as cited in Chaturvedi, 2011). Because of the difficulty of dealing with complex chemical mixtures, including pyrolysis products, the best approach to resolve this toxicological and aviation safety issue would be to minimize risks by preventing oil leaks into bleed air, and monitoring, cleaning, and/or replacing air ducts on a regular schedule. In addition, a more thorough evaluation of the toxic nature of the oil additives used in aircraft engines would be useful (Nicholson et al. 2003, as cited in Chaturvedi, 2011). (Chaturvedi, 2011)

Whereas Chaturvedi advocates a prudent approach because of the many unknowns involved and the toxicity of the whole entity is not given, Murawski (2011), just as Ramsden (2011), states that assuring safety by applying exposure standards is misleading. Occupational exposure standards "were not developed for workers performing complex tasks like pilots. They are also not intended to apply to complex chemical mixtures that may contain unknown pyrolysis products in a reduced pressure, enclosed space with limited (if any) egress, and workers who may be assigned to work longer than 14 hours. Further, few of the chemicals identified in oil-contaminated cabin air have occupational exposure limits against which in-flight air samples can be compared" (Murawski, 2011b, p. 24). Toxicity from multiple substances and/or multiple sources have indeed been identified by the European Commission as an emerging concern that should be accounted for (2012).

Two different paradigms in the toxicological evaluation can be recognised in the literature. One tries to identify the most toxic component to test the hypothesis of a possible neurotoxicity and comes to the conclusion that what is believed to be the most critical chemical cannot cause the symptoms of impairment and incapacitation as reported by crews. The first paradigm mainly focuses on refuting a possible causality. The second paradigm mainly focuses on the synergetic effects of the mixture as the most critical link. Furthermore, it disagrees on some of the most critical chemicals and states that certain chemicals involved in the engine and hydraulic oils have the potential to cause the symptoms reported and that there is no alternative causative mechanism described. The second paradigm's focus is mainly to provide a valid causal explanation for the reported symptoms. It is interesting to note that scientific publications can be found at both extremes, but most airframe manufacturers completely deny any causal possibility (Airbus, 2014; Boeing, 2016). At the same time regulators accept the problem exists, but state that occurrences are rare and when they occur are under control by crew defence strategies (EASA, 2011, ATSB, 2014).

Both competing discourses thus come to different conclusions based on the same measuring data. But they have different perspectives in interpreting them. Another problem remains, in that on line with Harrison's earlier arguments (2015,) none of the three studies mentioned above captured actual conditions in and of a fume event. Only in the Cranfield study some odours were reported, but there were no major fume events (COT committee, 2013). The risk of interpreting such a small set of conditions was recognised by the UK Committee, which was installed to answer concerns from the several incident reports and crew unions. The COT committee therefore recommended to monitor up to 10,000-15,000 sectors to assess exposures relating to engineering-confirmed oil/hydraulic fluid smoke/fume incidents under varying conditions to establish (2007, p. 20). Eventually it was this recommendation that led to the Cranfield report a few years later. The Cranfield report however did not reflect the original COT committee's recommendation and performed measurements on a mere 100 flights on 5 aircraft registrations only.

A study form Shehadi (2015) with the aim to study potential large-scale, on-board sampling study of bleed air contamination incidents similarly states that in order to characterize incidents one would need tens until hundreds of thousands of flights to ensure the capture of a meaningful number of incidents and to characterize these incidents. This is virtually impossible as acknowledged by Shehadi. Therefore, the problem of objectification persists. Theoretically the question could neither be verified nor falsified because absurd amounts of statistical data would have to be provided first when one wants to capture a variety of normal and abnormal operating conditions.

The KLM partnered study (de Ree et al., 2014) earlier cited as an often-interpreted study (Harrison, 2015) to show that the chemicals detected in cabin air cannot be responsible for ill health reported by aircrew, takes an even narrower set of measurements. Twenty flights under normal operating conditions on nine Boeing 737 were analysed for TCP only as the single chemical of concern. The literal translation of the original Dutch full study titled: "Study of presence and levels of TCP in the levels of KLM Boeing 737 under normal operating conditions [own translation]" (Houtzager, Havermans, & Bos, 2013). This title reveals the very narrow scope of the study and takes a limited set of measurements under non-critical conditions. It resulted in a paper with a very different English title and a wider scope, but was based on the same results: "Health risk assessment of exposure to TriCresyl Phosphates (TCPs) in aircraft: A commentary" (de Ree et al., 2014).

The paper bases a risk model on a single chemical TCP, which indeed is defined as a chemical of concern, but from which it is never claimed that this single chemical would be the sole responsible for the reported health problems by others. The KLM-partnered study continues its risk assessment, by subsequently defining T(o)CP as the most toxic isomer of TCP, despite earlier acknowledgement of the contrary (Henschler, 1958; Winder, 2002). Than it defines that this chemical cannot be responsible for the reported health problems. So far, the conclusion within the self-defined risk model is correct, when one understands the limited scope of the claim of accepting this arbitrary risk assessment:

> Using a risk assessment model with detection limit values of ToCP as input and the available toxicological evidence from earlier studies leads to the conclusion that it is highly unlikely that symptoms of the Aerotoxic syndrome can be explained along the lines of ToCP intoxication. (de Ree et al., 2014)

This is the danger of 'data accumulated within an epistemology legitimated by a paradigm'. The study is aware of some limitations and cites that alternative explanations should be the subject for further study (de Ree, 2014, p.6). Thereafter it disregards this and devoted an entire paper to look for and assess ToCP only.

This study has first produced an arbitrary construction of toxicity, which is subsequently used to deny toxicity as arbitrarily defined. The risk model is extremely poor and misleading to make general claims about health effects and overall toxicity. Furthermore, the KLM-partnered paper does not mention that additionally ToCP isomers have been gradually banned from the engine oils and are nearly non-present. In this light the focus on ToCP in the toxicity section makes even less sense. Winder described a decade earlier that the concentration of ToCP in the oils is 0,005 ppm compared to for example 3070 ppm for MoCP. As MoCP is also 10 times more toxic as described by Henschler and Winder (1958; 2002) and the relative toxicity of MoCP in today's oils is therefore 30700 times greater (2002). When this is multiplied with the difference in concentrations there is a relative difference of a factor of +-600 0000. For this reason it would have been important to state Winders' findings and introduce the other isomers into the risk assessment. Whereas Winder (2002) and Ramsden referred to the effects for the crew on cognitive tasks and flight safety, the KLM partnered study does not make any reference to flight safety and only refers to an occupational risk.

The KLM-partnered study looks at a non-verifiable attribution of toxicity to TCP, subsequently looks for this chemical on a limited set of aircraft under non-critical normal operating conditions and then identifies the toxicity of TCP by the one isomer that has been reduced to virtually zero in the engine oils. Last but not least it disregards or seems not to be aware about the science about more toxic isomers. All together this is an extremely poor safety assurance case.

The paper however is better remembered for its conclusion that "with the currently available scientific evidence, the symptoms of the Aerotoxic syndrome do not constitute an occupational disease in the Netherlands". Actually, there is nothing in the study to support that claim, but it is cited by the aviation industry for its reassuring results (KLM, 2013).

Two different paradigms with competing discourses can be identified. The first paradigm focuses on the most critical component from the toxicological mix and subsequently subjects this to applying safe exposure limits. In the case where different critical toxins apply, the process is simply repeated. However, this method is only as rigid as what it has identified as the most critical part. It is exactly this argument that is critiqued by the second paradigm. In this critique the argument of TCP was just one but important example, where the alleged most critical path of toxicity from the Cranfield and CAA UK study was already proven to be false (Henschler, 1958) decades before the analysis. This danger is inherent to paradigms:

> Data are accumulated within an epistemology legitimated by a paradigm. Some of the possible flaws in a measurement method cannot be identified from within that paradigm's epistemology, for example . . . whether the choice of what to measure and how to measure it is appropriate (Lintern, 2010, p. 74)

The second paradigm believes that the most critical part is the mixture, not a single chemical. Furthermore, it disagrees with ToCP being the most critical component and warns that citing exposure limits is irrelevant within the scope of aviation. It warns that such exposure limits do not provide safety. Per definition it advises that the mixture is more critical than any of its elements because of the possible potentiative and synergetic effects between single chemicals, but also because of interactions with the many identified unknowns such as a reduced pressure environment, low dose effects that behave different from acute poisoning, etc. As toxicity of the mixture has never been quantified, proponents of the second paradigm believe that the risk should be minimized or excluded as a precaution.

Whereas the first discourse denies any causality in line with the outcome of its own paradigm, the second paradigm recognises the patterns of crews as important signals that are consistent with neurological exposure.

Causality and Burden of Proof

Murawski states that "although neurological symptoms are consistent with exposure to neurotoxic substances in pyrolysed oil, a causal association between exposure to oil fumes and chronic neurological symptoms has not been definitively proven" (2011, p.25), but the author adds a rationale to question the burden of proof:

> The hundreds of cases, many of which are documented with abnormal MRIs, SPECT scans, or neuropsychological testing, are often dismissed as "anecdotal". In the absence of other causal

explanations, and especially when it can be demonstrated that: (1) aircraft mechanical records confirm oil in the air supply; (2) multiple members of a crew are similarly affected; and (3) crew members did not either report or seek treatment for such symptoms prior to the documented fume event, then exposure to neurotoxic chemicals is the most reasonable explanation. Formal assessment of the validity of this claim would require a study exposing test animals to pyrolysed oil fumes under reduced pressure conditions and conducting a post-mortem brain analyses of structures or regions involved in cognition or emotion[9].

In the absence of such inhalation studies for the complete mixture under reduced pressure environment, or in the absence of a blood test for a unique marker of neurotoxicity such as TCP and with an additional lack of robust measurements of abnormal operation conditions, we are once more confronted with the problem of objectification from an earlier chapter.

The fact that neurological symptoms are consistent with exposure (Murawski, 2011, p.23) in relation with the fact that many crews had reported such issues was already established two decades ago (Balouet, Hoffman, & Winder, 1999; Winder & Balouet, 2000). Crews in different parts of the world began to report short and long term health effects after fume events in the 90s (Winder, Fonteyn, & Balouet, 2002). Winder and Balouet proposed the "term aerotoxic syndrome in 1999 to describe the association of symptoms observed among flight crew and cabin crew who have been exposed to hydraulic fluid or engine oil vapours or mists. A descriptive epidemiological study was conducted to investigate the health effects of aircrew . . . after exposure to engine oil or hydraulic fluid leak, which caused odours and/ or visible contamination in the cabin" (Winder et al., 2002). Furthermore, some of the short-term effects were described by Winder and his colleagues as a direct flight safety threat (p.7).

In 2002, the same researchers Winder and Balouet complemented their research by investigating the toxicity of commercial jet oils (2002). At the same time the toxicity of hydraulic oils and the pyrolysis products of jet engine oils was further investigated by Van Netten (1999; 2001). Winder and his colleagues defined TCP to be among the hazardous substances and concluded that publicly available information such as labels and Material Safety Data Sheets (MSDS) understate the hazards of such ingredients (Winder & Balouet, 2002). In his pyrolysis studies Van Netten (2000) showed that engine oils when exposed to elevated temperatures are sources of CO, and also create large number of volatiles. The author stated that these and other pyrolysis products could pose a potential hazard to the flight crews.

Both teams of researchers did discriminate between long-term health effects and flight safety, but in the end the overlapping principle is causality, which once established explains varying effects on both health (long term effects) and safety (acute health effects).

Despite the evidence from Winder (2002) and Van Netten (2000) on a wide variety of concerns, TCP just being one of them, the discussion about the exact causative mechanism is debated across scientific publications. The debate inherently puts a claim on the admissibility of signals. The KLM-partnered study comes to the conclusion that the 'a-typical' symptomatology reported by crews is a reason to dismiss a strict causality in relation to TCP (2014). However, the sole focus on TCP/ToCP is the self-chosen scope of the KLM partnered study, and can therefore not be an

[9] Recently a single post-mortem study on a deceased 43 year old airline pilot has been performed and concluded that nervous system injury is consistent with organophosphate-induced neurotoxicity (Abou Donia, 2014)

implication to the symptomatology of crews. Even then, Ramsden objects that "that any agent that damages the nervous system is prima facie expected to have a very broad spectrum of effects, given the pervasive nature of the nervous system in the control of any large multicellular organism" (2011, p. 1). But it was the initial research looking into the patterns of 'aerotoxic syndrom' that gave a definition that is closer to the terms at play in the social construction of causality. Winder et al. defined "common themes in symptom clusters in these studies" and critiqued earlier attempts to dismiss the description of 'a-typical' symptomatology:

> For example, different studies may describe the same symptom as dizziness, loss of balance, light-headedness, feeling faint, feeling intoxicated, or disorientation. It would be incorrect to regard such symptoms as being entirely different from each other — they point to a basic neuropsychological dysfunction affecting balance. But, rather than dismissing such symptoms as being multitudinous and variable, it may be more appropriate to re-categorise symptoms with clearer definitions, so that the artificial distinctions between symptom reporting can be clarified, and a shorter list developed. (Winder et al., 2002, p. 322)

The competing discourses not only have different underlying assumptions, but also start at different ends of the burden of proof. One discourse dismisses that crew symptoms can be explained by the toxicological properties of the assumed levels of single (critical) chemicals from normal operating conditions. The second discourse starts by looking which chemicals could explain the symptoms it describes as recognisable patterns.

The 2004 CAA UK study, one of the often-cited reassuring studies, established that the carbonaceous particulate material found in the ducts were "containing chemicals entirely consistent with the pyrolysis products of aircraft engine oil". It also identified the knowledge gaps from earlier research:

> There are over 40 different chemicals contained in oil breakdown products and many have no published toxicity data, so it is not possible to be certain whether any of these products contribute to, or are the sole cause of the recorded incidents. (CAA, UK,, 2004, p. vi). . . .
> Recommendations . . . [f]urther review and investigation of the toxicity of the meta and para isomers of tricresyl phosphate should be conducted to eliminate the potential neurotoxic effects (CAA, UK,, 2004: chapter 1, p.5). . . .
> The effect of hypoxic conditions on the toxicity of oil pyrolysis products should be investigated [reduced pressure environment] (CAA, UK,, 2004: chapter 1, p.5)

The much-cited conclusion from the CAA UK study was again based on the toxicological interpretation based on the ToCP isomer only. It disregarded the greater toxicity from the MoCP and DoCP isomers, just as the Cranfield and KLM-partnered study. Its conclusion did not identify 'conceivable concentrations' to definitely cause the symptoms reported in cabin air quality incidents'. The rationale was rather absurd and this puts its definition of 'conceivable concentrations' in perspective when it stated: "An average man would therefore be able to ingest 7 metric tonnes of pyrolysed oil per day for 74 days without effect" (CAA, UK,, 2004: chapter 2, page 1).

The G-JEAK reports a flight safety issue in relation to an incapacitation and an identified oil leak. The report found similar oil leaks on other aircraft: "Following such reports, maintenance action had often, but not consistently, identified the presence of oil in the bleed air/air conditioning ducting both from the engines and the APU" (AAIB, 2004b, p. 10). The associated hazard was identified as serious: "The incident involving G-JEAK, and other events, indicated that an irritant(s) can cause degradation in decision making and the reasoning ability of flight crews" (AAIB, 2004). This message produced a strong signal.

Such initial strong signal form a sequence of similar incidents in Australia, Sweden and the UK was enough concern to issue a series of regulator communications that recommend that airlines educate flight deck and cabin crew about the fact that one or both pilots can be incapacitated by exposure to smoke/fumes, and train flight deck crew to don oxygen masks immediately (CAA, UK, 2000). The first reactions were in line with the search for a causal explanation that fits the description of the second paradigm. The symptoms and the identification of oil leaks were enough to investigate the causal relation between reported symptoms on the one hand and identified engine oil leaks on the other hand. The incidents also created enough concern to initiate research on air conditioning ducts from similar aircraft and resulted in the 2004 CAA UK study, which as Ramsden explains had a strong experimental part, but a weak toxicological review. One could say that this is the momentum where the science on this seminal case slipped from the second (seek a causal explanation) into the first paradigm (refute causality). Thereby, the strong signal from the evidence of former oil leaks and the signature of pyrolysis products in the air ducts, in combination with the reported symptoms on these very aircraft became mixed with the weakness of the correlational evidence. The combination of a strong and a weak signal resulted in a mixed and therefore much weaker signal. The significance of such signals on political decision-making is further explained in the next chapter.

The report also stated that there was no evidence for a neurotoxic explanation for the symptoms. It concluded that irritants, which could however not be quantified, were likely responsible for the symptoms experienced by flight crew from the series of incapacitations in relation to previously identified bleed air contaminations (Cf. G-JEAK report). It thereby created a similar internal contradiction of the definition as in the previous incident report chapter. It acknowledged the risk involved with the impairments and incapacitations, but by defining the causative mechanism as irritant, rather than neurotoxic, it changed the status of the causative mechanism. The effect was acknowledged as having an effect on decision-making, but the cause was not brought on neuropsychological dysfunction as defined by Winder et al.

The conclusion that "no single component or set of components can be identified which at conceivable concentrations would definitely cause the symptoms reported in cabin air quality incidents" was the first and main conclusion from the report, and interpreted by many as reassuring. Some knowledge gaps from the opposing discourse, although reflected in the paper, were not accounted for in detail by its conclusion.

The initial discovery of risk, identified by the oil leaks in relation to health effects, was transformed into an acceptable risk by the absence of evidence for an exact causative mechanism. However, this absence of risk is not necessarily the absence of risk in the system, but the absence of risk within the limited scientific scopes of the studies. When we look at how a problem is defined, we can see that the way the problem was identified at this point is a mixed definition. This brings up the question: 'Which is the regulator's perspective and is it enough of a problem?'

CHAPTER 3: INTERPRETATION OF THE SIGNALS- REGULATOR PERSPECTIVE

Construction of risk and interpretation of signals

I will not discuss all the different regulator's perspectives in this chapter, because that would be beyond the scope of this master thesis. I will take the EU regulator as one example, because so far the EU created the majority of incident reports and it could be said that therefore it has been even more challenged to produce a public answer to these reports. It is also a good explorative example because this regulator's construction of risk can be analysed from a publicly available rulemaking decision on this topic, recently issued in the year 2012.

In the preceding chapter I have described competing discourses accompanied by a form of scientific debate. Eventually such scientific information is transformed into reports or communications to support politicians and regulators to whom much of this actual scientific knowledge is not directly available. Vaughan has described specialisation as "a source of systematic censorship" (Vaughan, 1996, p. 260). In her book 'The Challenger Launch Decision" she describes that decision makers do not assess the full information but make judgements under conditions of uncertainty:

> When unable to discriminate, top decision makers tend to rely on signals. Relying on signals is a shortcut, a way of isolating bits of "telling" information from what is available. Decision makers cannot know each individual case thoroughly because confirming or disconfirming each and every fact takes time and energy, often prohibitively costly. Instead, to assess a situation they rely on familiar cues and signals— readily observable characteristics— so that they can turn their energies to other matters (Vaughan, 1996, p. 251).

Vaughan categorises different signals, and their effect on decision-making. The easiest one are strong signals. These are opposed to weak signals, but there are also mixed and routine signals often at interplay with the social construction of risk. Simply said, the absence of signals is more difficult to assess than the identification of strong signals. A weak signal can typically be created when decision makers do not have the fully documented, verifiable set of data that constitutes appropriate evidence. Vaughan describes a strong signal as follows: "One way to overturn an entrenched scientific paradigm is with contradictory information that is an attention-getting signal, too strong to explain away, refute, or deny" (Vaughan, 1996, p. 264).

With this overview on signals in mind, I will analyse the regulator's construction of risk. In 2009, EASA assessed that events wherein "the proportion for which there was an impact on flight safety (e.g. flight crew performance degradation) [sic] is very low" (EASA, 2009, p. 3), but nevertheless starts a consultation because of "an on-going debate among stakeholders about the reporting of these events" (p. 3) and because of the fact that it is not possible to determine a reliable rate of occurrence as reports vary greatly among countries (p. 3). EASA therefore started an Advance Notice of Proposed Amendment (A-NPA). Such A-NPA are a means to pre-announce an intention to issue new or revised regulations, including mandatory tasks, which allows for industry consultation before changes are made (Skybrary, 2016). In this case not only industry, but interested parties on the matters, which are the subject of this Decision, were invited to contribute by answering questionnaires and providing comments (EASA, 2012, p. 2). At this point it is also necessary to define my previously disclosed position as an action researcher. Although I did not provide comments to EASA via the comment response document, organisations in which I am involved filled in the questionnaires. To avoid researcher bias as much as possible, I specifically analyse this decision from a construction of risk perspective, rather than advocating a specific stakeholder view.

EASA's final conclusion is reproduced below:

Article 1

> The Agency concludes that, based on currently available reports and evidences, there is no safety case that would justify an immediate and general rulemaking action.

Article 2

> According to the existing literature and study reports, the Agency understands that a causal relationship between the health symptoms reported by some stakeholders (some pilots, cabin crews or passengers) and oil/hydraulic fluid contamination has not been established. As there is no conclusive scientific evidence available, the Agency is not able to justify a rulemaking task to change the existing designs or Certification Specifications.

Article 3

> The rulemaking task 25.035 'Cabin air quality on board Large Aeroplanes' is hereby terminated without amending EASA regulations.

Article 4

> Although the Agency has not found a justification to launch a regulatory change activity, this topic will be continuously monitored, and some recommendations are provided in the document CRD to A-NPA 2009-10 to further improve the knowledge on exposure health issues and on technologies for bleed air filtering and monitoring. If in the future new elements become available and show that the occurrences of engine or auxiliary power unit contamination of bleed air are a serious threat to safety or health, then the Agency will take appropriate corrective actions including considering regulatory changes options (EASA, 2012, p. 4).

Article 2 shows the importance of explaining earlier competing discourses in interpreting causality. EASA describes that 'a causal relationship between the health symptoms reported and oil/hydraulic fluid contamination has not been established according to the existing literature and study reports'. This is directly related to the formulation of Article 1 that 'there is no safety case'. This claim is EASA's way of stating the absence of a strong signal to prove the contrary, previously described by Vaughan as 'one way to overturn an entrenched scientific paradigm with contradictory information'.

The agency's final decision itself gives us little additional information to find out more about its construction of risk, or what would be a safety case or strong signal. However, more detail can be found in the documents leading to this decision such as the publicly available Comment Response Document (CRD) and the invitation to stakeholders to launch this A-NPA in 2009. The CRD mentions that it is based on "the review of existing and on-going research studies conclusions and the analysis of the information collected by this ANPA" (EASA, 2011, p. 2). This remained a general claim and no literature review or list of references was included. EASA fails to specify any other study than the Cranfield study and the CAA UK study from 2004. Thereby EASA chose to follow two studies that stated that no evidence for causality can be concluded from the available information. The previous chapter identified how these studies were initiated by strong signals, but the absence of evidence of a neurotoxic causality eventually created a mixed signal. Eventually, EASA transmitted the outcome of the studies in its conclusion as a single token, deprived from its chronicles. There is no possibility to identify possible scientific shortcomings or complexities. This is the mechanism Vaughan described when she stated that signals are a shortcut for decision makers, a way of isolating bits of "telling" information from what is available. Information runs a risk to get lost. For example, specific propositions were refuted by earlier science, an exemplary fact being that ToCP was not the most toxic component (Henschler, 1958; Winder & Balouet, 2002) or the Cranfield study was designed to draw conclusions from 5 individual aircraft only (Cf. Cranfield study) and did not reflect the actual conditions of a fume event (COT committee, 2013).

Specialisation remains an obstacle to interpretation. Vaughan described specialisation to be "a source of systematic censorship" (1996) as she described that those decision levels that do not have the full sets of data and science available are often not in 'the seat of understanding' (1996) when making these decisions. To make some abstraction and to simplify things, it could be said that the regulator is not the primary responsible for re-evaluating the scientific evidence that it was offered by intermediary specialism. This is different when it comes to EASA's second key argument from Article 1, the absence of a safety case, which is about interpreting the signals from incident reports or crew reports. It can be said that safety reporting belongs to EASA's core business and contrarily to interpreting the scientific evidence this time the regulator should be sitting in 'the seat of understanding'.

No literature review or references from mandatory occurrence reports were included in the A-NPA conclusion of 2012. Only in the initial explanatory note, which accompanied the call for comments some years earlier. In this explanatory note EASA states that it has searched European databases, but eventually only gave evidence to have searched the CAA UK database and the ICAO worldwide database. EASA says the latter reflected the UK figures with a peak in 2001-2002 with respectively 27 and 29 events and then decreasing to 0 events in 2008 and 2009 and continues that "no official CAA UK events figures are available to EASA for 2007 and 2008, but according to them the tendency is a decrease in the number of reports" (EASA, 2009, pp. 5-6). This worldwide figure of 'no reported events' in the global database contrasts sharply with the literature (Shehadi et al., 2015) and my own findings from the CAA UK, a source I have already used in earlier chapters and which was the same source EASA consulted. The mandatory occurrence reporting describes 104 events on UK aircraft only (CAA, UK, 2011) for the same two years 2007-2008. From this collection the worst description was a captain impaired during flight and who was on oxygen because of fumes. He collapsed in the galley after landing. "The root cause was found to be lower modification state seals, which allowed some engine oil into the ECS [environment control system]" (CAA, UK, 2011, occurence number: 200906317) Furthermore, several incident reports were produced in relation to incidents that happened in these specific years 2007-2008 (AAIB, 2007a, 2010b; AAIU, 2010; BFU, 2007a, 2007b; TAIC, 2008). Several of these reports described oil leaks and impairments.

Both in frequency and severity, EASA's representation of reality by referring to a reduction of zero reports seems to differ dramatically from the available existing information. The 104 existing reports in the UK database were simply not communicated to or traced by EASA. Similarly, ICAO's global database, which was mentioned by EASA did not even seem to reflect any of the 104 UK reports. Therefore, the reports were virtually non-existing for the regulator. Although for safety reporting EASA was supposed to sit in the 'seat if understanding' it failed to do so, and it could subsequently not match its decision to an actual representation of reality. Finally, in EASA's construction of risk rationale, it should also be noted that the agency therefore pictures this as a 'corrected' issue. According to the regulator, the reports were said to have a peak in 2001-2002 and reduced to zero in 2008 (EASA, 2009). Even if this representation is not correct as today's sources still reveal a myriad of occurrences (Shehadi et al., 2015), it is important to acknowledge that this is the picture the regulator describes. By doing so, it described a problem that was under control. Subsequently the regulator did not take any specific measures or change its regulations (EASA, 2012). It could think that the self-regulating risk mitigating measures of airlines and manufacturers after the concerns described in the reports and committees at the beginning of this millennium were responsible for this alleged improvement. But this would also subscribe the level of control to be situated at the level of the regulated, not the regulator. I will describe further below how the aviation industry was asked to share data on this issue during this A-NPA and how the regulator uncritically accepted the industry's refusal to do so (Cf. discussion further below).

To continue this analysis of the regulator's construction of risk, we should also understand how EASA defines a strong signal. Even when it would have identified the apparently missed 104 UK reports and/or the many others outside the UK, we should understand how EASA discriminates what it calls 'a safety case'. In its CRD explanation EASA sheds more light on its definition of safety:

> EASA safety assessment
> The Agency is not aware of any accident (involving injuries or loss of life or substantial aircraft damage) for which cabin air contamination by engine or APU has been identified as the root cause. The known reported serious incidents (involving impairment or incapacitation of crews) are rare and the safety analysis objective for such hazardous event is not put into question. We believe these events are not underreported . . . In such cases, the potential safety risk can be mitigated by existing procedures and equipments [sic] (including the use of oxygen masks). (EASA, 2011, p. 4)

EASA's definition of safety primarily relies on the absence of an actual accident. It accepts serious incidents when their frequency is low. There is some contradiction here because the 'safety analysis objective for such hazardous event is not put into question'. Suddenly, the definition of an earlier absence of causality becomes one of an acceptable risk by means of a low frequency of occurrence, as EASA recaps: "Concerning the serious events involving a degree of crew or passengers' impairment or incapacitation, we believe they are reported and their number remains very limited" (EASA, 2011, p.46). The sudden change from the 'article 2' claim that causal relationship between the health symptoms and oil/hydraulic fluid contamination has not been established to one of acceptable risk raises an internal contradiction of the construction of safety. This even raises serious concerns on the fact that the regulator bases its construction on the absence of causality when in other places serious events from which it follows that the causality cannot be explained are admitted in the comments.

In the case when such serious events do occur, EASA counts on procedures and personal protective equipment to provide an additional layer of defence. In this construction of risk, occurrences are rare and the risk can be controlled. This contrasts with the ambiguity of identifying and controlling the risk in this earlier thesis' chapter about the incident reports. Michaelis concluded that oxygen masks are only used in 12% of the cases by both pilots and an additional 4% by one pilot (Michaelis, 2010, p.182). There is little or no margin for ambiguity in EASA's construction of safety. Another similar an example is the dismissal of underreporting by the European regulator. Several other sources acknowledge underreporting (Michaelis, 2010), including the US regulator FAA stating that "it appears as though there are numerous air carriers/operators, who may not have reported these events as required by regulations" (FAA, 2006, p. 1).

Health has a special status of in the construction of risk. Whether they take the form of acute (safety) or long-term effects (health), in both cases we are dealing with health problems. EASA describes that "[h]ealth issues are not within the primary scope of the Agency's mandate. However, the Agency would take action whenever a health case is evidenced by competent health authorities, which would require a change in the design of aircraft" (EASA, 2011, p. 4). A German BFU study from 2014 received the answer from EASA "that chronic health impairments are not addressed in the CS-25 and are not considered during type certification. These considerations should be carried out by medical health organisations and EASA would then incorporate their results." (2014, p.74).

So first of all, health impairments are not within the mandate of EASA and are also outside the scope of EASA's failure analysis CS 25.1309, described below. EASA hereby indicates that their interpretation depends on competent health authorities and defers responsibility to medical health organisations, which it then fails to appoint. Both long-term or acute health effects are outside the regulator's realm of expertise. The question for the construction of risk is when and how they become translated into safety signals in a failure analysis? Whatever the interpretation would be, they would have to pass the earlier defined systematic censorship of specialism, but also what Vaughan defines as a second form of censorship closely related to that:

> One's role-related specialized knowledge and experience can interfere with understanding matters outside one's own job description. Of the information received, some is absorbed, but not all, leaving a residue of uncertainty. Uncertainty results in . . . systematic censorship. (Vaughan, 1996, p. 251)

Still the regulator promises in its conclusion that it would take action if a health case is evidenced. So once more, we are looking for the expression of strong signal to overcome an existing dominant paradigm. And once more we will need to understand how such a signal looks like for the regulator's construction of risk. The BFU accurately summarises:

> The aim of the engine and APU certification specifications is that crew and passengers do not become incapable to act (Incapacitation). A failure analysis which only takes into consideration health impairments (not incapacitation) is not required. This requirement does not eliminate the hazard of occupants sustaining health impairments through cabin air. (BFU, 2014, p.73)

Health effects are not covered by certification specifications and are in principle not covered by the public protection from the regulator, unless they also turn into an acute safety concern. Health effects are only described as statistical probabilities when they translate into impairments and incapacitations. They are not necessarily expected to 'never' happen, but have numerical accepted margins as described below.

'Hazardous' engine effects are described as concentrations of toxic products in the engine bleed air for the cabin sufficient to incapacitate crew or passengers, for which the probability of occurrence must be lower than 'extremely remote', meaning it should not exceed 10^{-7} engine flight hours. In the major and hazardous engine effects sections, it is stated that toxic products could result from the degradation of oil leaking into the compressor airflow. (EASA, 2007)

'Major' engine effects are described as concentrations of toxic products in the engine bleed air sufficient to degrade crew performance. The probability of such 'major' engine effects should not exceed 10-5 engine flight hours. "Concentrations may be interpreted as the generation and delivery of toxic products as a result of abnormal engine operation that would incapacitate the crew or passengers, except that the products are slow-enough acting and/or are readily detectable so as to be stopped by crew action prior to incapacitation" (EASA, 2007). Under major effects, EASA classifies the impairment of the capability to act, without incapacitation. "This also means, however, that these events, with a certain frequency of occurrence, are accepted ("Major" equals a probability of < 10-5 per flight hour)" (BFU, 2014, p.72)

In this way, the regulations do provide a level of protection, being the statistical control of the detrimental effects they produce. However, even if one is willing to debate if these thresholds for 'Major' and Hazardous' engine effects are exceeded, such certification specifications only show how often events may or may not occur to obtain initial certification. If subsequently root causes for re-occurring problems are identified in reaction to several incident reports such as some reports established clear root causes in the from of oil leakage from the Rolls Royce RB211-535C (AAIB, 2004) or the #1 and #9 seals of the BAe aircraft engines (AAIB, 2004), then they were certainly not designed into the system as a controlled or accepted margin of error. This is an important mechanism to recognise, because as soon as the exceptional protective safety margins for designing aircraft are used to statistically allow for unforeseen design errors, definitions of safety become a socially constructed acceptance of risk. On such safety assurance Leveson argues that,

> care should be used when using quantitative probabilities, i.e. numerical probabilities such as 10-6 equation 'Remote'. Such figures and their associated nomenclature give the illusion and the comfort of accuracy and a well-honed scientific approach. Outside the world of structures, numbers are far from exact (Leveson, 2011, p. 7)

To avoid confirmation bias and compliance-only exercises, assurance cases should focus not on showing that the system is safe, but in attempting to show that it is unsafe with the opposite mindset of the developers (Leveson, 2011, p. 7) "Otherwise, safety assurance becomes simply a paper exercise that repeats what the engineers most likely to have already considered" (Leveson, P.5)

How does the regulator manage the problem?

The phrase "readily detectable so as to be stopped" from EASA's definition of 'major' engine effects involves another part of the regulations about warning indications. Regulation CS & FAR 25, subpart CS25.1309(c) (EU) and FAR 25.1309 (US) say that information concerning unsafe system operating conditions must be provided to the "crew to enable them to take appropriate corrective action. A warning indication must be provided if immediate corrective action is required. Systems and controls, including indications and annunciations must be designed to minimise crew errors, which could create additional hazards." (EASA, 2007, pp. 1-3; FAA, n.d.-a) "EASA stated that the consideration of cabin air contamination is part of the compliance demonstration of the ECS (CS 25.1309)." (BFU, 2014, p. 51) Hence, the regulations exist, but they are not enforced to inform pilots of bleed air contaminants. In 2002 the FAA confirmed the lack of regulative effect of its own rule by saying that "no present airplane design fulfils the intent of 25.831 (cf. ventilation specifications) because no airplane design incorporates an air contaminant monitoring system to ensure that the air provided to the occupants is free of hazardous contaminants." (FAA, as cited in; S. Michaelis, 2010, p. 43).

In short, even strong signals of impairments are acceptable signals in the failure analysis when they are not frequent. Additionally, I have described that their causality is under debate, which would make any statistical classification even more ambiguous. One of the reasons that a failure analysis in aviation can allow statistical failures of some parts or subsystems is because systems must be fail-safe and must be made redundant (See compliance with CS 25.1309(b): EASA, 2007) by other parts of the system, in this case the other pilot. However, if cabin air contamination can affect decision-making as warned for in several reports and regulator communications (AAIB, 2004b), it would be highly questionable to still apply this originally redundancy-based failure analysis. The rationale behind the failure analysis described by the regulator in CS.1309 can however explain why even strong signals would be hard to observe, as they are not per se banned, but accepted as rare. Even when they would appear they would be debatable by means of their classification.

This repeats the narrow definition of safety, which does not account for long-term health effects as described by the BFU in its 2014 critique to EASA's regulations: "A failure analysis which only takes into consideration health impairments (not incapacitation) is not required. This requirement does not eliminate the hazard of occupants sustaining health impairments through cabin air " (BFU, 2014, p.73). The BFU was therefore surprised that certification does not account for long term health effects and "is of the opinion that a product which has received a type certificate by EASA should be designed in a way that neither crew nor passengers are harmed or become chronically ill" (BFU, 2014) and further critiques:

> Engine certification specifications require air purity. This is a general requirement and does not describe which aim shall be achieved in regard to cabin air. The term "purity" does not include whether the requirement is to eliminate smells, harmful concentrations of substances or the hazard of impairing crew capability to act. (BFU, 2014, p.73)

CS-25 certifies airframes, CS-E deals with engines and CS-APU covers APU's. Ventilation regulations are addressed as a subpart of airframes in CS 25.831 (EU) and CFR §25.831 (US). They state that manufacturers must ensure that the crew compartment contains a sufficient amount of uncontaminated air to enable crews to perform their duties without undue discomfort or fatigue, and crew compartment air is free from harmful or hazardous concentrations of gases or vapours (EASA, 2007; FAA, n.d.-d). But EASA in the EU (and the FAA in the US) remains completely silent on the means by which these rules must be complied with, neither do they provide a definition of hazardous concentrations of gases or vapours except for CO, CO2 and Ozone (O3) (CS 25.831 (1)-(2) & CS 25.832). From these chemicals only the first two relate to possible bleed air contaminants. The many toxins of concern formed by engine oil, hydraulic or other pyrolised fluids are not covered, nor required, by the regulations.

There is an additional non-binding industry Standard SAE ARP 4418, which covers an additional seven marker compounds on top of the CO and CO2 levels, which the aviation industry uses internally to certify engines. EASA regulations do not refer to ARP 4418, although the industry standard refers backwards to the EASA regulations as the basis for proving the CO and CO2 levels from CS-25.831. The standard 'assumes' that if representative marker compounds for potential engine-generated contaminants are within specifications, the levels of all other potential engine-generated contaminants will also be within acceptable levels. Furthermore, the testing is only required under factory steady-state conditions (SAE Aerospace, 2008, p. 10). However, transient engine conditions (changes in power settings) are more critical conditions to produce contaminants, which is acknowledged by the same engineering association (SAE Aerospace, 2005, p. 24) and aircraft manuals (BAe Systems, 2007). It is important to note that even if EASA takes part in the making of ARP4418, it can currently not enforce any tests besides the regulatory CO and CO2 limits. In reality supplemental tests by manufacturers may be performed, but they are proprietary information. They are not disclosed to the public, amongst others to protect corporate competition (Personal communication, Airbus; Rolls Royce).

In short, when looking at the accountability of the regulator, it fails to protect for anything else than CO and CO2 at certification level. The UK Aircraft Accident Investigation Branch states: "The regulations JAR 25.831, JAR-APU-210, JAR-E-510 and JAR-E-690 [JAR regulations have meanwhile been changed in CS with the same numbers] all deal with unacceptable levels of contamination of the bleed air, but do not provide details of toxic contamination that is deemed as unacceptable" (AAIB, 2004b, p. 64). The BFU concluded that in addition to the "limited number of substances considered, [it] does not understand how the extensive requirements of CS-25.831 and CS-25.1309 could be met if the certification authority did not conduct a consideration of all substances used" (BFU, 2014, p. 74). For example EASA answered to the BFU "that hydraulic fluids as sources for contaminations are not considered" (p.74).

This has not only repercussions on the way the regulator 'manages the problem' at the level of certification, but also on the way the lack of regulations tacitly create a non-issue. What the regulations lack, is not the absence of a problem, but the absence of a definition of a problem that triggers the regulation to act. In this case meeting the regulations does not provide much actual protection for health and safety. Neither is it defined on the subsequent level of its manifestation as "the term 'fume event' is not defined in any aeronautical regulation" (BFU, 2014, p. 74). And last but not least, it cannot be objectified because the regulations fail to meet their own requirement for a warning indication. It is the interplay of this lack of definitions and objectification possibilities, all within the responsibility of the regulator, that tacitly permit the regulator to construct a non-issue. The regulations ironically provide only very poor objectification of the problem space.

Collection of signals

When reverting to the identification of signals and by analysing what would "justify an immediate and general rulemaking action" (EASA, 2012) as rejected in EASA's article 1, this could either be an accident, or a higher frequency of serious incidents. Even if such a narrow and retrospective definition of safety, is not uncommon for aeronautical and inherently cost-benefit thinking, the only way EASA could gain benefit from consulting stakeholders would be when crews, airlines or manufacturers would come with strong signals. This could be contradictory information either about frequency, severity or causality. EASA therefore asked different stakeholders to fill in a questionnaire to create a better understanding of the issue.

Concerning airline stakeholders, EASA received responses from 7 companies only : CAI First (Italy), KLM (Netherlands), Flybe (UK), Ryanair (Ireland), TAP (Portugal), TUIfly (Sweden), and Air Southwest (UK) (EASA, 2011, p. 22). This is only a marginal section of the European operators. Only 3 of them replied to the online questionnaire:

> From the on-line questionnaire 3 Operators (out of the 7 who replied) have statistical data on air contamination by engine or APU. However, only 1 Operator answered that it would share these data with the Agency, but no data has been received by the Agency. (EASA, 2011, p. 22)

The same can be said about the manufacturers. Only 2 small airframe manufacturers responded to the on-line questionnaire: Dassault Aviation and Fokker Services. The latter declared having statistical data on air contamination by engine or APU but cannot share it with the Agency. The reason Fokker gave in the comments is that these data are not considered reliable because their reporting depends on the Operators willingness and procedures of event reporting. (EASA, 2011, p. 31)

Thus, once more even existing signals such as the ones in the CAA UK database were not even communicated to the regulator. EASA's conclusion of safety led by a retrospective statistical analysis as described above seems doomed to fail with literally no willingness to provide any statistical data to better assess the situation. Neither airlines, nor manufacturers were sources of any signals at all. The AEA (Association of European Airlines), British Airways, KLM, SWISS (Swiss International Airlines) expressed their concern about the Agency "unscientific" approach by opening an on-line questionnaire where flight crews and cabin crews can provide their own "reports of anecdotal events" and "promote their personal views". (EASA, 2011, p. 22)

Similar views were expressed by the manufacturers. Airbus explained that they are not convinced that the EASA questionnaire is an appropriate scientific approach to acquire additional knowledge on frequency and severity of respective occurrences. (EASA, 2011, p. 31). Especially BAe systems could have provided a proven a valuable statistical analysis of impaired health and safety, but their comments did not produce more than three maintenance measures (EASA, 2011, p. 33). In the year 2000 BAe developed a Service Information Leaflet for all their operators as the consequence of three consecutive international incidents with incapacitations. This included a questionnaire for crews and airlines after fume events. The actions, contained in the BAe Service Information Leaflet were meant to inform their operators' crews, maintenance and management about the problems with the BAe 146. It was even updated and re-issued in 2008, the year before the EASA NPA consultation, and again promisingly stated: "This information will be used for analytical / statistical purposes and may be *freely shared by and between interested parties*" (BAe Systems, 2008). But BAe systems didn't take this A-NPA opportunity *to share* the information with the European regulator. In BAe System's own words, the regulator is clearly an *interested party*, which specifically asks for the information with the purpose of assessing possible amendments to its rulemaking. When the manufacturers were asked in the EASA A-NPA, Boeing was the only one that provided some statistical analysis. The others remained silent.

What this EASA inquiry proved most is the regulator's reliance on airlines' and manufacturers' information and how subsequently the aviation industry was completely unwilling to provide this data. EASA constructs its rational for safety on a retrospective safety analysis for which the data that could be provided by the industry itself, remains unavailable. The regulator thus completely depends on the information provided by the subject it wants to regulate. The regulator becomes dependant of the regulated, which disturbs the normal regulator-regulated relationship. EASA thereby granted the regulated subject control to define the relative seriousness of the problem.

This brings up a question discussed in the subsequent chapter. Which signals but also which other forms of information could the regulator have consulted, to get a more complete picture of the situation?

CHAPTER 4: INTERPRETATION OF THE SIGNALS – A THICK DESCRIPTION OF ADDITIONAL SIGNALS

The reliance on signals is closely related to the admissibility of these signals under influence from the competing discourses from the previous chapter. As we are working our way backwards, more or less chronologically through the history of cabin air contamination, each time the issue is transmitted into another part of the world or another decade, context is lost and a signal is just the remaining token of a larger history. These tokens are deprived from the narratives and the reasons that gave rise to the signals. Especially bi-lateral arguments from competing discourses are translated into unilateral conclusions and results. The Australian Senate was a powerful example of a moment in time where the committee members realised that the most important signal was that, whatever the nature of the issue was, it was already present for a decade within their airlines before it became visible through the first official channels. In a first section, I will therefore provide a thick description from the competing discourses in relation to the admissibility of the signals from the Australian Senate committee in 1999. Keep in mind that both discourses are opposed in their conclusion. One paradigm tries to explain the causal explanation between symptoms and contamination by being precautious about all chemicals and their synergetic effects in the mixture, whereas the other paradigm refutes the possibility of such a causal relation by assessing the toxic potential of what it believes to be the most critical chemical within the mixture.

The Australian committee thought it was looking at a concern that started in the 90s (Parliament of the Commonwealth of Australia, 2000, p. xii) on the BAe 146 aircraft only. In reality the issue dated back to the 50s. I will summarise such earlier accounts of discounted signals in a second section of this chapter and provide a timeline of the history of the issue until today. This timeline mainly constructs a problem of organisational memory. Early acknowledgment and descriptions of the issue, scientific studies and even forgotten pieces of regulations show a thicker description of an issue, which has raised many unsolved concerns. Many of them remain unaddressed in today's regulations.

A thick description of the history of the BAe 146 problems

Late recognition of previous discounted signals

In the late 80's concerns about impaired health from crewmembers flying the BAe 146 aircraft started to arise in Australia (S. Michaelis, 2010, p. 282). In 1991, the Australian airline Ansett eventually started an investigation into the rising number of complaints and created an 'odour committee' with union representatives and experts to address repeated health concerns (S. Michaelis, 2010, p. 282). In 1997, this operator suffered its first of a series of incidents, which was also covered by an official investigation. The report stated it was "particularly concerned about the potential for further BAe146 flight and cabin crew to become incapacitated during flight due to exposure to odours being introduced into the aircraft cabin environment" (BASI, 1999). This cabin air contamination event became known as the Kolver incident, named after the captain in charge on that particular flight. The investigation described that "two of the three flight crew members on board the aircraft suffered from symptoms that prevented them from properly carrying out their assigned duties" (BASI, 1999). The report also stated an oil leak and oil residue resulting from an engine #4 failure had been identified several weeks prior to the incident. "The aircraft had been cleared for further flight without any operational restrictions being noted, and the defect was listed for rectification at company convenience" (BASI, 1999). Two years later, in 1999, the Australian Senate Rural & Regional Affairs & Transport References Committee received a large proportion of submissions from crews directed at air safety issues in relation to cabin air quality on the BAe 146 and therefore started an inquiry (Parliament of the Commonwealth of Australia, 2000, p. xi). The Senate Committee recognised that "the cabin air on the aircraft [BAE 146] has been an identified as a persistent problem since the early 1990's" (Parliament of the Commonwealth of Australia, 2000, p. xii). Ansett Australia, the airline who suffered the incident acknowledged the history of events at that time in its Notice to Pilots (NOTOP) 37/97 publication stating that "it was not a new phenomenon" (BASI, 1999) and later confirmed before the Australian Senate that "the odours were traced back to Mobil jet oil 2 leaking in the air conditioning system" (Commonwealth of Australia, 1999, p. 6). It took 2 years until the final report from the 1997 Kolver incident was finished, when also the aircraft manufacturer BAE Systems began notifying the operators of the BAe 146 about problems with contaminated air, and the possibility of crew incapacitation with All Operating Messages (AOM). In a reaction to a similar incident in Sweden AOM 99/024V was distributed by BAe Systems with the recommendation: "In the event of flight deck crew experiencing any unusual physical symptoms or with any detection of fumes, it is recommended that they immediately don oxygen masks with regulators set to 100%" (AAIB, 2004b, p. 32).

Especially the Kolver incident "became an important catalyst for the Senate Inquiry" (Vakas, 2007, p. 122). Captain Kolver had made a written submission to the Australian Senate Committee. Together with other pilots and cabin attendants, he also testified before the committee. Between this 1997 incident and the Senate committee report, three more Australian incidents were subjected to an official investigation. In all four reports, oil leaks were identified (ATSB, 2001a, 2001b, 2002; BASI, 1999). The first of a total of eight recommendation referred directly to the Kolver incident and was critical for the Australian aviation regulator stating that "CASA should reassess matters recommended for further action by the BASI/ATSB incident report (No. 199702276) concerning the incident on 10 July 1997 involving Captain Kolver" (Parliament of the Commonwealth of Australia, 2000, p. xv). Besides the failed regulator follow-up on the incident the committee also criticises airlines and manufacturers:

> The Committee notes that CASA, British Aerospace [BAe Systems] and Australian airlines operating the BAe 146 did not implement the recommendations of the BASI/ATSB report. It is clear to the Committee that the decision not to implement the recommendations was not justified (Parliament of the Commonwealth of Australia, 2000, p. 99).

The committee voiced crew concerns that provided information from outside the routine reporting channels:

> The Committee also received evidence concerning crew reluctance to report fumes incidents. The reported reasons for this reluctance ranged from a fear for future employment, fear for the continued operation of the aircraft and an apparent lack of awareness as to the source of the problem and possible impact on health. (Parliament of the Commonwealth of Australia, 2000, p. 14)

The full list of Australian Senate Committee recommendations is several pages long, but includes better requirements for monitoring the operations and cabin and cockpit air quality, re-assessment of hazards of pyrolised oil, the need for an appropriate and accurate cabin air quality tests, seal requirements; "where necessary, introduce regulations that would cover engine seals, appropriate maintenance and operational procedures that BAe 146 aircraft would be withdrawn from operation and properly serviced and repaired with leaks were identified" (Parliament of the Commonwealth of Australia, 2000, p. xv); a "research program on the effect of exposure to aircraft cabin air on air crew and passengers" (2000, p. xvi) and assess the possibility for high grade filtration options (2000,

p. xvii). It is important to note that although the Australian Senate Inquiry acknowledged short and medium term health effects (2000, p. 97), it was not able to establish a causal link with long term health effects with the provided evidence. Five years after the committee's work was closed, the chairman of the Senate Committee wrote a paper about the fact that the aviation industry had knowingly not revealed all of the available information during the hearings that were available at that time (Woodley, 2005).

The Senate Committee recommended that the regulator CASA should reassess matters for further action by the BASI/ATSB report on the Kolver incident (Parliament of the Commonwealth of Australia, 2000, p. xv), it did not explicitly mention a conclusive causative link between flight safety and the effects of crew incapacitation It rather lacked the necessary monitoring and compulsory reporting requirements (2000, p. xv) and urged the company to pay attention to repair any operating faults resulting in oil leaks and to ensure aircraft are withdrawn from operational flying (2000, p. xv).

Also systemic socio-technical recommendations were made. One example addressed the difficulties crews had with obtaining recognition for their health concerns. To describe the varying long-term symptomatology, the committee recommended the frequently used label 'aerotoxic syndrome' as something which can be properly referenced for future Workers Compensation and other insurance cases (Parliament of the Commonwealth of Australia, 2000, p. xvi). Another recommendation was "to appoint an experienced, retired judicial officer or eminent person who is appropriately qualified to conduct a review of unsuccessful or inordinately delayed employees' compensation cases". An additional Senate Committee recommendation was for this person to assess "whether those cases were dealt with according to requirements and appropriate standards of procedural fairness"(Parliament of the Commonwealth of Australia, 2000, pp. xvi-xvii). It also stated "that incident reports should now be specifically designed so as to reflect the history of the cabin air problem that has been encountered on the BAe146" (Parliament of the Commonwealth of Australia, 2000, p. xv).

The recommendations from the paragraph above address systemic shortcomings. Judicial impartiality and a way of assessing earlier procedural fairness are antidotes for forms of latent coercive power. The fact that the committee decided that the 'history of the cabin air' problem should be reflected is a direct consequence from the fact that the committee revealed submissions, which did not reach the authorities through the official information channels. It was the reason for this committee to come into existence in the first place (Parliament of the Commonwealth of Australia, 2000, p. 6). The committee noted that "[t]he issue has only been further investigated because the crews affected have suffered such extreme hardship as well as in flight safety hazards, that they have sought further recognition" (Parliament of the Commonwealth of Australia, 2000, p. 89).

> Written submissions to this inquiry considered by the Committee, both public and confidential, provide evidence of more than 700 recorded incidents in the last 15 years where fumes have been reported to have entered the cabin and contaminating the cabin air on BAe 146 aircraft operating in Australian airspace. This evidence was provided by aircraft operators and by various unions and associations representing flight crew. (2000, p. 3)

A summary of fume reports provided by the airline Ansett Australia and the Flight Attendants Association of Australia provided by the airlines was a conservative estimate. Even more than mere transparency, the recommendation 'to reflect the history of the cabin air problem points to the fact that claims that crew concerns were seen as isolated and anecdotal evidence by the airlines and manufacturer BAe Systems were successful in concealing the numbers and some critical findings before the Senate committee (Vakas, 2007). In terms of signals, they could be said to have created weak signals only. The face of 'non-decisions' is a form of power that accounts for situations where power struggle does not result in overt conflict (Antonsen, 2009, p. 186), the history of cabin air quality did not directly result in overt conflict, but the fact that it only became 'visible' in hindsight to the committee can be construed in this way because it was only the first incident report that gave the problem some public visibility. Nevertheless, the crew unions were able to produce a 30 page long list of earlier reported events, which nearly all included health symptoms. These were included in Appendix 3 of the committee report. (Parliament of the Commonwealth of Australia, 2000, pp. 121-150).

> Bachrach and Baratz' (1970) concept of 'non-decisions', in which other interests are prevented from engaging in decision making or undermined via agenda setting, is important. This can take a range of forms from overt action to prevent demands reaching a political forum to a perceived threat of sanctions that limit alternative views and processes. (as cited in: Vakas, 2007, p. 37)

Although actions existed they were handled internally, another reason why they were not publicly visible:

> In particular, the Committee highlights remedial programs, largely in the hands of aircrew, …and how these programs have resulted in detailed recording of events of poor cabin air quality on the aircraft (Parliament of the Commonwealth of Australia, 2000, p. xiii).

The recommendations from the Senate inquiry provide further information, because in the absence of a consensus what was to be accepted as valid evidence between crews and industry at both sides of the debate, these recommendations are also a reflection of the socio-technical conditions that are the means to assess whether the signals presented are a proper representation of reality, in other word their 'visibility'. A great level of indeterminacy was introduced during the committee's attempts to objectively assess the diverging claims from crews and industry, as Vakas noted in his PhD thesis analysing the senate committee proceedings and outcome:

> BA [BAe Systems] argued that three scientific studies, which it included in its first submission to the Australian Senate Inquiry into BAe 146, 'have found no health or toxicity issues are identified with the air supply on board BAe-146' (Australian Senate 1999i, p.127) [sic]. . . . *No evidence* of toxicity or risk in the air supply, is not the same as claiming that there is *no toxicity* **or** *risk* or that *no safety or health effects* [original emphasis] have arisen from cabin fume exposure. Nonetheless, this is the implication BA intended to convey. (Vakas, 2007, p. 42)….An examination of the studies cited by BA is instructive in the interpretation of scientific assessments and the construction of non-issues. Studies become tools to support arguments and actions in meeting the objectives of particular interests, through selection and omission of 'factual' information. (Vakas, 2007, p. 52)

Vakas described how on some occasions the cited studies went from scientific indeterminacy of the assessment of cabin fumes to a selective 'certainty' of 'no evidence' (Australian Senate 1999i, p.127, as cited in: Vakas, 2007, p. 42). The claims deduced by the airframe manufacturer from the three studies not imposed to but chosen by the manufacturer were not only ill-cited by BAe systems' use of overly narrow health and safety definitions, the use of selective evidence and using a self-claimed privilege of expertise (Vakas, 2007, p.42 ff.), but they were also in contrast with the submissions from crews, which the industry dismissed as anecdotal evidence. "The Committee received approximately 20 individual submissions describing symptoms experienced by crew members and attributed to oil fumes leaking into the aircraft cabin" and from ". . . . 31 public submissions made to the inquiry, a significant number argued that contamination of cabin air on

BAe 146 aircraft was a continuing problem warranting further action and investigation" (Parliament of the Commonwealth of Australia, 2000, p. 21).

Some of these concerns were discouraged, such as was the case with captain Kolver who raised concerns even before the incident: "He had also submitted a Safety Occurrence Report on 12 June to the company and verbally told the Group Manager of Air Safety of his concerns who assured him that there was no problem"(Parliament of the Commonwealth of Australia, 2000, p. 21). "Aircrew have also noted company attempts to discourage union surveys of fume incidents" (Vakas, 2007, p. 226), which Vakas described with several examples: "[a]n internal memorandum from NJS to all senior pilots, engineers and flight attendants documents attempts to discourage fume incident reporting to the FAA (Australia Senate 2000g, pp. 230-231, as cited in: Vakas, 2007, p.226). And in another example "Ronald Devine, a Training Captain for NJS . . . stated that union survey forms were removed from crew pigeon holes by a 'Company representative' to prevent the survey (Devine, 2000, as cited in: Vakas, 2007, p.226). Discouraging people to report is in conflict with what the senate inquiries called the need to uncover the history of cabin air quality and opposes the learning culture a reporting system tries to achieve. Aviation strongly depends on its reporting systems to build an 'as accurate as possible representation' of reality. This representation of reality was troublesome as some people feared to report. Before and during the committee some reporters wanted to stay anonymous and an employee of the ATSB, the former Bureau of Air Safety Investigation (BASI) told the inquiry the following:

> I asked around on the Internet and through airline and union connections if anybody who had any concerns about the fumes, oil mist and fog, as it was determined that it was in aircraft, could please contact me. I was quite overwhelmed by the number of people who did. I was also overwhelmed by the number who wished to remain totally anonymous and did not want their names and phone numbers put on any files. There definitely seemed to be a reluctance to formally report these incidents. (Parliament of the Commonwealth of Australia, 2000, p. 40)

"Ansett Australia advised the committee that . . . in 1992 their [own] engineering log reports showed an odour was reported once in every 66 flights"(Parliament of the Commonwealth of Australia, 2000, p. 19) and in the first half of the year 2000, Ansett Australia stated that this reduced to "odour occurrence in every 160 flights. Or, if we count only those events that cabin crew judged worth reporting, that figure is one report in every 460 flights" (Parliament of the Commonwealth of Australia, 2000, p. 19). The threshold that made the crews to submit a report in only one out of eight odours will remain unclear and per definition subjective, but the same can be said for the lack of an objective threshold when an odour occurrence becomes a health or safety concern. An accurate explanation of the issue under consideration cannot be built on this level of indeterminacy and this becomes a concern in itself. In its 1999 report of the Kolver incident,

> the Bureau of Air Safety Investigation was unable to determine if details of all reported odour occurrences were entered into aircraft maintenance logs. Other reports were made directly to medical personnel, some to employee representatives, and some were made verbally to the Bureau. Some reporters advised that they would not report to their employers because they feared reprisals (BASI, 1999).

Further to the reports of short-term symptoms and flight safety concerns, crews also claimed before the Committee to have suffered such long-term health problems and some reported they have been forced to resign from work due to ongoing health problems (Baker 1998, in Vakas, p.38). Sometimes several crewmembers from a single flight in relation to a specific fume event had to resign due to health problems, such as in a particular fume incident on 14 November 1994 in which "all flight attendants had to put on portable oxygen. Passengers were 'projectile vomiting' and very distressed. The question is why none of these incidents created signals in the years before the committee was installed. One of the cabin crewmembers testified before the committee, reporting symptoms such as "burning eyes, nausea, headaches, sore throat and numbness down the right side of my body. Two other flight attendants on this flight have also resigned due to illness" (Australian Senate, 1999h, as cited in: Vakas, p.219). Also captain Kolver developed health problems, later involved in another incident. (Parliament of the Commonwealth of Australia, 2000, p. 51). A number of worker's compensation claims were filed and two crewmembers have taken legal action against their airline. (Parliament of the Commonwealth of Australia, 2000, p. 20)

The Committee described the lack of means to assess such long-term health problems:

> The monitoring of the BAe 146, as far as air safety considerations are concerned, does not currently extend to systematic observation, collation and reporting of long-term occupational health and safety matters. Monitoring is carried out on an operator by operator basis, and little or no central assessment or record collection of individual airline monitoring and recording results is currently made (Parliament of the Commonwealth of Australia, 2000, p. 98).

Whereas short-term and medium-term health symptoms were acknowledged (Parliament of the Commonwealth of Australia, 2000, p. 97), the Senate committee is more prudent on the long-term effects and echoes the dichotomy between the two sides of the debate. "The Committee notes that opinion on the hazardous nature of exposure to oil fumes is divided almost exactly between affected flight crew and their medical advisers on the one hand, and the airline industry and CASA on the other" (Parliament of the Commonwealth of Australia, 2000, p. 101).

While committee was prudent in its conclusion and also rejects the claims from the regulator CASA and the airline industry that there is no basis of concern:

> While the weight of evidence to the inquiry suggests that a number of flight crew have suffered from toxicity, the committee cannot readily accept assurances that there is no hazard associated with exposure to oil fumes in aircraft cabin air. . . . The Committee is convinced that aircraft operators recognise that there exists a possibility that individual aircrew can and do reach a 'saturation' level of cumulative exposure to chemicals. Such a possibility should be recognised and further investigated. (Parliament of the Commonwealth of Australia, 2000, p. 101)

The delay to a conclusive answer per definition has effects on the ongoing concerns. As Vakas comments on the assessment of health effects:

> The absence of a substantive response has placed an increased burden on affected aircraft crew to justify and 'prove' their claims. To this end a number of surveys have been undertaken by union bodies and researchers to document incidents and record symptoms but there are numerous difficulties. First, many of the acute and chronic symptoms are not accepted by key stakeholders and simply classed as anecdotal (Vakas, 2007, p. 175).

There is always the danger that others cite the report without providing its context, simply by stating that it was not able to find a causal link on long-term health effects or conclusive causal evidence for incapacitations. In this case it would just repeat the same mistake of turning scientific indeterminacy into an assessment of 'certainty' of 'no evidence'; a position for which Vakas criticised the airline industry earlier (Vakas, 2007, p. 44).

The conclusion from the Senate Inquiry committee unmistakeably also has an opinion on flight safety, as one chapter is titled air safety, from which an excerpt is displayed below:

> In relation to statutory requirements, the Committee consider CASA should ascertain whether current reporting requirements in respect of the operation of the BAe 146 and other aircraft, specifically related to the effect of cabin and cockpit air quality, are adequate. There is sufficient evidence from operators, the British Aerospace, CASA and BASI to conclude that CASA should re-assess and enhance its current scrutiny of the Australian BAe 146 fleet. The Committee believes such a monitoring program, which can be established under existing civil aviation regulations must re-assess and monitor the following matters:

The report then further addresses the need for a specific national standard for checking and monitoring the engine seals; maintenance procedures, including specific maintenance procedures for ageing aircraft; appropriate maintenance and operational procedures for the BAe 146 that should ensure that faults resulting in oil leaks, fumes or smoke are repaired; incident reports should now be specifically designed so as to reflect the history of the cabin air problem; the need for sources of contamination in the cabin and cockpit environment in the BAe 146 to be identified and further evaluated; the need for companies operating the BAe 146 and other aircraft in Australia to provide CASA with specific reports on the results of monitoring in order that CASA can assess the operations of the aircraft. (Parliament of the Commonwealth of Australia, 2000, pp. 102-103)

When one reads this conclusion it is clear that the Australian Senate inquiry implies that before safety can be assessed, the proper conditions for this assessment need to be established first. This raises an important issue for this thesis, being what would install and safeguard the proper conditions for proper assessments of the situation in the absence of such Senate Inquiries? The logic answer is regulations and this is what is repeatedly addressed in the recommendations above. But I have identified in the previous chapter that the regulations themselves create a problem of a definition as a consequence of problems of objectification and identification. This became a circular problem of the failing conditions to define a problem as a problem, being the trigger to create signals.

It is also interesting to observe another definitional problem, the demarcation between flight safety on the one hand and both short-term and long-term health problems on the other hand, then followed by different safety rationales. The evaluation that health symptoms reported by BAe 146 crews do not affect safety, came from the airline industry, the regulator CASA and the investigation Branch ATSB, the latter being sometimes in favour and sometimes opposed to this argument (Vakas, 2007, p.130). Vakas argues:

> If crew are not 'incapacitated', but are working on aircraft with long term health problems that include feelings of intoxication, dizziness and balance problems this is clearly a safety issue. While these symptoms are not recognised as a safety issue by ATSB for cabin fumes exposure they would be recognised if they were self-inflicted, for example if aircraft crew consumed alcohol or drugs that resulted in such effects. (2007, p. 130)

This is an interesting line of reasoning, because indeed the effects of the symptoms seem to be assessed in relation to what caused them. And this causality thinking seems to be a strong driver for the recognition of signals. The 30-page long list of 700 recorded incidents that was provided to the Australian committee, many of them including health symptoms previously did not create a signal. It is remarkable to see that in the absence of an agreed causal mechanism, crew impairments by themselves were not enough to escalate a problem. They created no circumstances to systematically collect data on an emerging concern. The Report notes the lack of proper assessment methods: "Monitoring is carried out on an operator by operator basis, and little or no central assessment or record collection of individual airline monitoring and recording results is currently made. . . . for a considerable period no operator has carried out clinical testing on flight crew exposed to cabin air fumes immediately following the exposure to fumes (Parliament of the Commonwealth of Australia, 2000, p. 98). In its recommendations the committee calls for central collection of epidemiologic data and air quality monitoring. But the chairman reports that years after the committee closed many of such recommendations were not met (Woodley, 2005).

The Australian Federation of Air Pilots argued before the Committee that "[t]he nature of health symptoms encountered and in many cases documented, all have the ability and in many cases do degrade the level of safety required by the Civil Aviation Act and Regulations" (Parliament of the Commonwealth of Australia, 2000, p. 83). Additionally, the Committee states that it "is aware that several flight crew lost employment due to ill health they attribute to fume exposure" (Parliament of the Commonwealth of Australia, 2000, p. 106). In the case that health was not to affect flight safety, this implies that flight personnel and/or their medical checkers would make a decision to stop flying before health problems would start to affect flight safety. Although maybe correct in some cases, this is a somewhat naïve line of reasoning, as the Committee also notes that it is aware that "employers have opposed and may have unnecessarily delayed the settlement of employees' compensation and insurance claims"(Parliament of the Commonwealth of Australia, 2000, p. 106). Expecting that flight crews would end their often passionate careers and financial life lines with surgical accuracy is a denial of systemic understanding of safety. This is especially true when one is aware of the reluctance or fear to report (Parliament of the Commonwealth of Australia, 2000, p. 22), as it was described earlier in this thesis.

So far, this history of the Australian concerns resulting in the Senate committee was restricted to the actors within a single debate arguing about two key questions. 'What is reliable and therefore admissible scientific evidence?' Closely related to this 'what is a reliable and admissible signal of concern?' As discussed in the section above there was evidence of 700 recorded incidents. A 30-page long list of earlier reported events, which nearly all included health symptoms was provided to the Australian committee. These signals were created despite earlier described obstacles such as fear of reporting, but did not provide strong signals. One side of the debate used science as a key argument to challenge the admissibility of the signals. Even if the Australian Senate committee as a whole could be regarded as an important signal, the individual signals were mixed and weakened, as their causal correlation was put into question. As mentioned, Vakas described that a specific interpretation of scientific assessments and the omission of factual information led to the construction of non-issues. Therefore, little of these incidents created strong signals.

The Kolver incident was one exception. As the committee also decided that it had been a missed signal by the Australian aviation regulator that "CASA should reassess matters recommended for further action by the BASI/ATSB incident . . . involving Captain Kolver" (Parliament of the Commonwealth of Australia, 2000, p. xv). The Committee critiqued that in addition to the regulator, the manufacturer and Australian airlines operating the BAe 146 did not implement the recommendations of the BASI/ATSB report and considered this unjustified (Parliament of the Commonwealth of Australia, 2000, p. 99).

John Woodley, the Australian committee's chairman, described in a paper five years after the committee had produced its conclusion that the airline industry had not disclosed all the information it had to the committee's panel (Woodley, 2005). This only became clear to the chairman after the facts. The former chairman of the senate inquiry wrote a paper about how the committee was being misled and concluded that it was "more about politics, power and money in the Australian aviation industry than it is about medical evidence, medical treatment or medical science" (Woodley, 2005, p. 6). He is also pessimistic about the follow-up: "while there was some agreement on exposures and health effects, the failure of the aviation industry worldwide and its regulators to deal adequately with aircraft air contamination - in spite of the advances in medical science and the research that has been conducted on this issue over the last five years was a critical failing" (Woodley, 2005, p. 1) .

How structural secrecy obstructs the production of signals

The Australian committee came at an interesting time, in the year 2000. Not only had the Kolver event happened in the year 1997, but the Swedish SE-DRE incident involving the same aircraft type took place in 1999 and was still under investigation. The so-called Malmö Incident with the SE-DRE aircraft, as mentioned above, became cited in the Australian senate committee during its investigation. BAe systems' submission before the Australian inquiry is interesting because this manufacturer did cross-reference the 1999 Swedish incident. However, at that time the final Swedish report had not yet appeared. Therefore, BAe Systems was in a unique position to be in control of the information it provided. Besides the obvious possibility for 'individual secrecy' form a manufacturer whose corporates interests are at stake, the more subtle 'structural secrecy' can be defined as the way information cannot travel freely through the system because of organisational structures. It is a rather unintended form of secrecy and described by Vaughan as "the way that patterns of information, organizational structure, processes, and transactions, and the structure of regulatory relations systematically undermine the attempt to know and interpret situations in all organizations" (Vaughan, 1996, p. 238). In this example 'structural secrecy' was created by the information barriers from regulators and investigation agencies in different parts of the world while individual secrecy resulted from BAe System's control of information as described below:

In its Australian submission from the year 2000 BAe systems stated about the Swedish incident that "following full engine testing and dismantling of the engine revealed nothing significant with the engines 'that made BAE Systems or the investigator think it necessary to take further action at this time" (Vakas, 2007, p. 60). However, as Vakas noted "[t]his diverged with final report of the Swedish Board of Accident Investigation (SHK) in which problems were found with engine carbon seals on bearings 1, 2, 4, 5 and 9 indicating that leaks occurred on all of these except bearing two which had minor cracks" (Vakas, 2007, p. 60). The final report was only issued in 2001, one year after the Australian Senate Committee. At the same time the Swedish crew was not trained to recognise such risks (SHK, 2001, p. 29) that already emerged in the Australian reports years before. Neither were the symptoms of the flight attendants on the first two sectors recognised as a possible precursor for occurring engine oil leaks and subsequent cabin air contamination. In the press the captain expressed: "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" (Captain Golmer, as cited in: Hansen, 2006). The incident report used a more technical language to describe the same facts: "He [the captain] had difficulty with physiological motor response" (SHK, 2001, p. 6). In addition the captain later lost his medical certificate to fly (S. Michaelis, 2010, p. 455).

> The chairman of the Swedish Board of Accident Investigation said the incident was 'extremely serious' and 'The crew was affected by something in the air, but we don't know what. When the plane landed some of the passengers were like zombies and could not be woken. Fortunately the plane was at 2,500 m. Had it been much lower we would have a major disaster on our hands' (Barnett, as cited in: Vakas, 2007, p. 150-151)

Eventually, when the report from the Swedish Board of Accident Investigation appeared it contained a chapter titled *Measures taken by the aircraft manufacturer* and included the following information provided by BAe Systems. This important paragraph was cited earlier in this thesis, but is repeated here:

> 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 (MOR14) [sic]. 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. (SHK, 2001, p. 25)

The information provided by the airframe manufacturer BAe Systems is followed by (MOR14). The number 14 refers to footnote 14 in the document. At the bottom of the page the footnote only explains that MOR is the abbreviation for mandatory occurrence report. However, it doesn't mention which national state's MOR is meant, neither is there a list of references included at the end of the report. The fact that 36 operators of the BAe 146 aircraft type under consideration are mentioned, gives enough indication that BAe collected information not restricted to Australia only. What is interesting is the subsequent contradiction with this statistical analysis and BAe's own testimony before the Australian Senate committee, during the ongoing Swedish investigation. Mr Black, Senior Vice President, Engineering Customer Support and Quality at BAe Systems (UK) stated,

> between 1991 and 1 November 1999, when the Bureau [Australian BASI] gave evidence, 93 occurrences of fumes in aircraft had been reported….Again, if I refer to the BASI statistics, only 12 out of their 93 were 146 related [146 refers to BAe system's aircraft type]….We are comfortable on the one hand that there is no flight safety risk (Parliament of the Commonwealth of Australia, 2000, p. 35).[10]

So, whereas before the Australian Senate Committee, BAe Systems only acknowledges 12 events in Australia, it was able to offer a broad analysis of nearly 500 reported events to the Swedish investigators as can be learned from the report. These events included 52 impairments, in which 7 cases flight safety was deemed affected. Before the Australian Senate, BAe systems stated nearly simultaneously that there was no flight risk, which is in contrast with the information it provided to the Swedish report. None of these events are traceable by disclosed sources and references.

The Swedish incident happened in 1999, while at the time the Australian Senate Committee took place. In that same year, testifying before the Senate inquire, BAe Systems dismissed the health concerns of the Australian captain Kolver incident as panic attacks, even when oil leaks were identified and several crewmembers suffered symptoms simultaneously. As BAe Systems stated:

> where a person is exposed to a smell and believes that that smell might be toxic or dangerous, they can become acutely anxious, hyperventilate and then lose control of their faculties. The

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[10] In the same paragraph the manufacturer states: "With the weight of human evidence and suffering, which is quite clear, there must be something there. . . . We know there is a health issue and we will continue to work with ASHRAE and with ASTM in order to determine what that is"..

> symptoms that were described in that particular case suggest to me that the pilot panicked. (Dr. Loblay arguing for BAe Systems, as cited in: Parliament of the Commonwealth of Australia, 2000, p. 86)

Under title 'cause of the incident' the Swedish final report states: "The incident was caused by the pilots becoming temporarily affected by probably polluted cabin air" (SHK, 2001, p. 33). Even if oil leaks were identified on engine #2 and subsequently on five of its bearings (SHK, 2001, pp. 18-19), the presence of coking on carbon seals was found, which is evidence for the former presence of oil and the finding that the location of the customer bleed port for the air-conditioning system is not optimal on the engine type (SHK, 2001, p. 33), the investigation only stated polluted cabin air cause was the 'probable' cause, although the contamination was unquestioned. An alternative explanation was not found. The investigation referred to the scientific knowledge gap to fully assess the problem: "Knowledge is lacking concerning modern lubrication oils' characteristics at very high pressure and temperatures and their effect on human health" (SHK, 2001, p. 33). The indeterminacy was openly discussed in the report:

> The measurement techniques that have been applied and the knowledge that exists within this area have perhaps not been sufficient to reveal the facts. An equally possible alternative is that the contamination that caused the symptoms only appears during very special conditions that did not exist during the engine test cell run or during the aircraft test flight. In spite of this, everything points to the fact that the quality of the cabin air was of crucial significance for the incident in question and for other similar incidents that have occurred in other airlines. (SHK, 2001, p. 30)

The investigators addressed the known difficulties for their own toxicological assessments, but also for the pilots: "Instructions are lacking concerning how crews shall act during flight when suspicion arises about contaminated cabin air " (SHK, 2001, p. 33).

The problem of identification appears at multiple levels, including difficult crew identification, limitations of measurement techniques, the problem of not capturing the critical conditions and the scientific evaluation. This was described in the incident report chapter and is no surprise, as the SE-DRE was among the incident reports. However, as this points out we can see that some strong signals from the Malmö-incidents, such as the fact that once more oil leaks were identified after a crew became incapacitated, these were not communicated to the Australian Senate committee during the investigation. The fact that such events take place in different parts of the world on a specific aircraft type, whereas crews were not even aware of the risk, brings up the question of the burden of proof. The 'absence of evidence' of toxicity does not satisfy 'the absence of risk' question that was brought up by incapacitations in relation to identified engine oil seal leaks.

The transmission of and access to information here is obstructed by corporate boundaries of airlines and national boundaries of regulators and investigation agencies. The only party that seemed to have central access to a collection of mandatory occurrence reports was in this case the airframe manufacturer. The same effects of position power and structural secrecy became repeated in a further serious incident, the third in a row with a BAe 146, described in the following section.

A strong signal despite the absence of causal evidence

It was not until a year later, when another similar incident in the UK with a double pilot impairment on a BAe 146 occurred, that even sustained scientific indeterminacy translated into safety recommendations in the form of an All Operator Message (AOM) 00/30V:

> Incidents have been reported involving impaired performance of the flight crew. Investigations have been conducted to determine whether the events could have been caused by inhalation of an agent(s) resulting from oil and/or oil breakdown products leaking from the engine(s) or APU and contaminating the environmental control system. At this time, there is no substantiated evidence indicating that oil breakdown products can impair crew….If at any time one crew member appears to be unwell and uses oxygen, it is recommended that all crewmembers use oxygen as a precaution against any unidentified contaminant (BAe systems, 2001a).

The 'absence of evidence' of toxicity could this time not completely be ignored and precautionary measures were identified in several Safety communications from the regulator as *Flight Operations Department Communication* (FODCOM) and the manufacturer's *All Operator Messages* (AOM):

In FODCOM 17/2000 UK aviation regulator notes that one or both pilots can be incapacitated by exposure to oil fumes and recommends that airlines educate flight deck and cabin crew about the fact that one or both pilots can be incapacitated by exposure to smoke/fumes, and train flight deck crew to don oxygen masks immediately (as cited in: CAA, UK, 2001), followed by FODCOM 14/2001 (CAA, UK, 2001) recommendations that in case of serious incidents oxygen masks should be selected to 100% .

The British double pilot impairment resulted in a final report four years later. The report described:

> he [first officer] began to feel nauseous. He sat in his seat but began to feel progressively worse, although his workload was low. He felt 'light-headed' and had difficulty in concentrating. He was aware of a tingling feeling in his fingertips and his arms started shaking. (AAIB, 2004b, p. 3)
> The commander who also felt nauseous took over the handling duties and instructed the first officer to put on his oxygen mask . . . the first officer was on 100% oxygen, his seat was well back from the aircraft controls and his hands were seen to be trembling . . . the first officer took no part in the conduct of the flight although he was able to nod in response to the commander's questions . . . . The commander was feeling progressively worse. He felt light-headed and recalled considering three aspects: landing, declaring an emergency and putting on his oxygen mask. However, he felt able to cope only with one decision and continued with his approach. The commander considered that he was subsequently able to complete all of the necessary checks and maintained normal radio contact with ATC. However, he reported that his heart was 'racing' and his mouth was dry. Additionally, when he became visual with the runway at about 1,000 to 1,500 feet agl, the commander seemed to have 'double vision' and had difficulty in judging height. (AAIB, 2004b, p. 4)

The 2004 report was a thorough investigation into the issue, which took four years to complete. This also means that it took all these years for the information covered in the report to be part of the public domain. The Swedish investigation, which was ongoing at that time, also discussed this UK incident in its 2001 report. It quoted an airworthiness directive and five safety recommendations, which the CAA UK had issued in reaction to this incident. They addressed crew instructions for recognizing and handling such incidents, developing required maintenance and modification standards. Additionally there was a recommendation that the CAA should undertake high priority research efforts (SHK, 2001, pp. 26-27). Also, the Swedish report preliminary revealed about the UK incident that oil by-products from the aircraft's engines, together with other contaminants in the air probably had accumulated in the aircraft's air-conditioning system. But about the cause of this UK incident with the G-JEAK aircraft, the Swedish investigation finally stated, three years before the actual UK final report appeared: "No technical fault on the aircraft that could explain the occurrence has been found" (SHK, 2001, p. 26). The findings of the 2004 final report three years later was in sharp contrast with the alleged claim that no technical fault could explain the occurrence:

> 2. Fumes were evident in both the cabin and on the flight deck of G–JEAK, indicating contamination of at least the No 1 ECS pack, prior to and after the event, until the replacement of the APU on 14 Nov 2002 [sic: *although the report states 14 Nov 2002, it probably means 14 Nov 2000. Elsewhere in the report it is stated that the engine was removed on 14 November 2000, 6 days after the event*].
> 3. The APU on G-JEAK supplied air contaminated with oil to the ECS packs.
> 4. The oil leakage on G-JEAK was associated with a seal failure on the APU cooling fan mounting plate and this oil found its way into the air inlet plenum chamber, and hence into the bleed-air system.
> 5. Both ECS pack condenser heat exchangers on G-JEAK were contaminated with black semi-hard deposits and wet oil.
> 6. The black deposits were analysed and determined to have derived from Exxon 2380 oil, used in both the engines and APU of G-JEAK. (AAIB, 2004b, p. 53)

An ongoing investigation once more was ill informed about recent incident findings, filtered by structural secrecy as a result from fragmentation of different investigations in different countries. Just as the Swedish incidents technical findings on oil leak identification were withheld from the Australian Senate inquiry, the Swedish incident investigation did not receive the unbiased technical findings of identified oil leaks in the UK incident investigation, which can be triangulated from the chronologic inconsistencies in the manufacturer's statements in three separate investigations in the paragraphs above. From these paragraphs in three incidents in different parts of the world with a single aircraft model, it can also be derived that the manufacturer was consulted as a central source, but did not share the full information on technical findings and incident reports.

The UK AAIB in cooperation with the CAA did not wait for the final report to address safety and recommendations. The goal of risk mitigation respond is to respond decisively, regardless of the fact that a certain level of scientific indeterminacy exists. This scientific knowledge gaps were accurately described in the UK G-JEAK final report:

> It became apparent during the investigation that there was a definite lack of information available on the potential contaminants from lubricating oil, and their associated physiological effects, and this was determined to be wholly or in part due to the following:
> i) No comprehensive airborne analytical test programme had thus far been conducted on a particular aircraft which suffered from such an oil 'fumes' incident, where the aircraft remained in the same state as it was when the incident occurred. For example, with the subject (defective seal) engine still installed and with the same type of oil as was being used at the time of the incident.
> ii) No airborne tests of the above type appeared to have been conducted thus far with a standard of analytical sampling equipment capable of identifying all of the potential contaminant compounds which may enter the cabin air from the engines.
> iii) No test data appeared to have been made available from the oil manufacturing companies, which lists all of the compounds which may be released from engine lubricant oils as a result of leakage into air conditioning bleed air from a defective engine or APU oil seal. This includes conditions where such oils and/or their products undergo thermal degradation.
> iv) Many of the potentially harmful compounds which may be produced by such oils apparently have no available or reliable inhalation dose/effects data available (AAIB, 2004b, pp. 47-48).

The G-JEAK report showed a history of cabin air quality events in the UK around the millennium change. The AAIB report found several similar incidents:

> Prior to this event this aircraft, in common with several others in the same fleet, had been subjected to engineering checks on several occasions due to reports of unusual smells, variously described by flight and cabin crews, of a hot oil, petrol, burning or of an acidic nature. In general, crews had regarded these events as a nuisance rather than a hazard, although their reactions and reported symptoms had been somewhat varied. Following such reports, maintenance action had often, but not consistently, identified the presence of oil in the bleed air/air conditioning ducting both from the engines and the APU. (AAIB, 2004b, p. 10)

What this report described was an ongoing history of oil leaks on the G-JEAK aircraft, but also on other aircraft in the fleet. It was not until one incident produced a strong signal that other earlier and following incidents attracted attention:

> The source of the fumes was subsequently traced to the No 3 engine, which was replaced on the following day, the 24 November. 22 [G-JEAM] (2004, p.22) . . . . The number three engine vibration and smoke was subsequently traced to a failed No 8 bearing. 22 [second incident on G- JEAK] (2004, p.27)

The G-JEAK incident had incapacitated the first officer, whereas other incidents often only led to impairments. Additionally, the UK investigation reports also revealed that other operators had reported the issue on different aircraft types and that in many cases oil leaks were identified,

> The BAe 146 was not the only aircraft type affected with fumes in the cabin and flight deck. The Boeing 757, Boeing 737 and Fokker 100 all were reported to have had experienced similar events, but with lesser effects on the flight crew (AAIB, 2004b, p. 54).

A further description in the report also identified oil leaks on other aircraft types such as on the following Boeing 757's:

> After an uneventful landing, a technical investigation revealed an oil leak in the APU compressor gearbox. In addition, the compressor back shroud attachment bolts were loose and this had allowed oil to leak past the shroud into the diffuser and subsequently into the air supply. [G-BPED] (2004, p.27) . . . . Subsequent engineering investigation revealed the presence of an oil leak from the APU [G-CPEL] (2004, p.28)

There seems no way of predictive control over the outcome in these cases, as neither in the engines or hydraulic lines, nor in the subsequent engine-fed air conditioning system, there are sensors or alarms installed to detect leaks. The only somewhat ambiguous way to predict such leaks, are by previous reports of fumes or unusual smells. Ironically the more smells occur without causing serious impairments or incapacitations, the less likely they are to be treated as a safety warning. This mechanism is earlier described in other socio-technical safety investigations as "the reliance on past success as a substitute for sound engineering practices" (NASA, 2003). In the case of bleed air contamination, the success is only operational, despite a technical failure. Dekker defines such mechanisms as the possibility to initiate organisational drift: "Such past success is taken as guarantee of future safety. Each operational success achieved at incremental distances from the formal, original rules or procedures or design requirements can establish a new norm" (2011, p. 108). The G-JEAK's final report stated that in the preceding absence of a more serious impairment, the events were usually treated by the crews as a nuisance rather than a hazard (AAIB, 2004b, p. 10). And each nuisance offers the crews a chance to get accustomed to these occurrences. But, regardless of the outcome, oil leaks that contaminate bleed air ducts are a deviation from the design requirement.

I have already established in an earlier chapter that multiple hundreds of incidents[11,12,13] went unnoticed and were only reported in the margin of other investigations. The most important finding is that they did not create signals at the time when they happened and therefore were not assessed as to belong to an issue that needed central collection of data and monitoring. Eventually, some key reports and especially the Australian Senate committee established a wide history of events. The patterns of earlier events were initiated by the SE-DRE report and further unravelled by the G-JEAK report. However we have seen that one of the earliest accounts to seriously investigate the existing safety concerns was not provided by an incident report, but by the Australian Senate committee. The recommendations it produced were clear, but unsuccessful in timely reaching the crews in other countries and according to the chairman the recommendations made were in vain and have not been adapted (Woodley, 2005). The narratives from some of the 700-recorded events were reduced to a single conclusion, being one of scientific indeterminacy. The recommendations to solve this scientific indeterminacy have been forgotten.

Timeline analysis

At this point it is time I pick up the earlier question which signals could have been used by the regulator to have a better understanding of the issue. Vaughan defines the reliance on signals as isolating 'bits of telling information' to support decision makers. The thick description of the BAe history provides a history of cabin air and an account that many reports were treated in isolation on an operator-to-operator basis, without a central assessment of data and without blood testing for crews. Realising that, despite incidents no concern had evolved from isolated information for a period of a decade, and by observing that crews on the same aircraft type outside of Australia were not familiar with the risks, the Australian Senate Committee made one of the most underestimated recommendations: "incident reports should now be specifically designed so as to reflect the history of the cabin air problem" (Parliament of the Commonwealth of Australia, 2000).

It wasn't until several years after the Australian Senate committee made its conclusions that researchers, affected crews and their union representatives started to identify that the problems with bleed air contamination pre-dated the Australian concerns by several decades. The problem had appeared ever since bleed air technology was introduced in the 1950s and not in the 1990s as the Australian committee itself believed (Parliament of the Commonwealth of Australia, 2000, p. xii). Papers on the issue, including description of events started in the 1950s and continued in the decades thereafter. A 1977 paper for example titled: *"Human intoxication following inhalation exposure to synthetic jet lubricating oil"* (Montgomery) or Boeing produced studies called *'Decontamination Program'* after fume events on the B-52, dating back to 1953. In this early study mitigation measures such as reverting to the bleedfree systems before the 1950s were already suggested, even though at the time of the report toxic effect of the contamination were described to be still unknown. The toxic effects were researched and described a year later in 1954 by a USAF study (Treon et al., 1954).

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11 Australian Senate Committee (2000): 700 incidents, from which only a few were disclosed before the committe investigation started

12 SE-DRE report (2001) Reports nearly 500 reports with a single aircraft model and crew impairment issues (SHK)

13 G-JECE (2007): "153 cases of fumes, with 119 probably resulted from conditioned air contamination" (AAIB)

Not long after these first accounts and concerns from fume events, a second set of signals appeared. After the manifestations of fume events and the concerns from mainly the Aeromedical Association, studies as soon as 1959 (Carpenter, Jenden, Shulman, Tureman, & Bethesda, 1959) began to provide answers to the toxicological concerns. For example, these publications began to describe other more critical toxic components than ToCP. Other studies such as from the US Navy (Siegel, Rudolph, Getzkin, & Jones) repeated and further explore such concerns in 1965. Such toxicological concerns that became scientifically acknowledged in mainly military aviation studies in the late 1950s have been forgotten in todays' studies from the last 10 years cited by the regulator, as shown by the UK CAA Report (2004) and the Cranfield Report (2011). Only a few years after bleed air was introduced on civil aircraft in 1955 the whole range of concerns had already been described in studies. These consisted of documented fume events (Boeing, 1953), inhalation studies (Treon et al., 1955) that established toxicity, concerns about the toxicity other than from ToCP and mitigation such as filtration or reverting back to bleed-free designs (Boeing, 1953).

Finally, a third set of signals emerged decades later. Independent from the early studies described above it also came to the conclusion that bleed air contamination is problematic and should be mitigated without further discussion. Many agencies, committees and studies recognise the effects and associated risks. Different mitigation measures are called for, mainly sensors (AAIB, 2007; 2009; ASHRAE, 2009, 2016; BFU, 2014; Cox, 2006; NRC, 2002) .

What these three sets of signals create in the examples below is a problem of organisational memory and an issue repeatedly not solved throughout history. However, the many instances of scientific progress already identified in the early days of bleed air use are not remembered by today's regulatory perspective. Regardless of the competing discourses, this can be defined as a problem of its own. Figure 3 provides a graphical overview. Thereafter a chronological summary explains the different data from figure 3 in more detail.

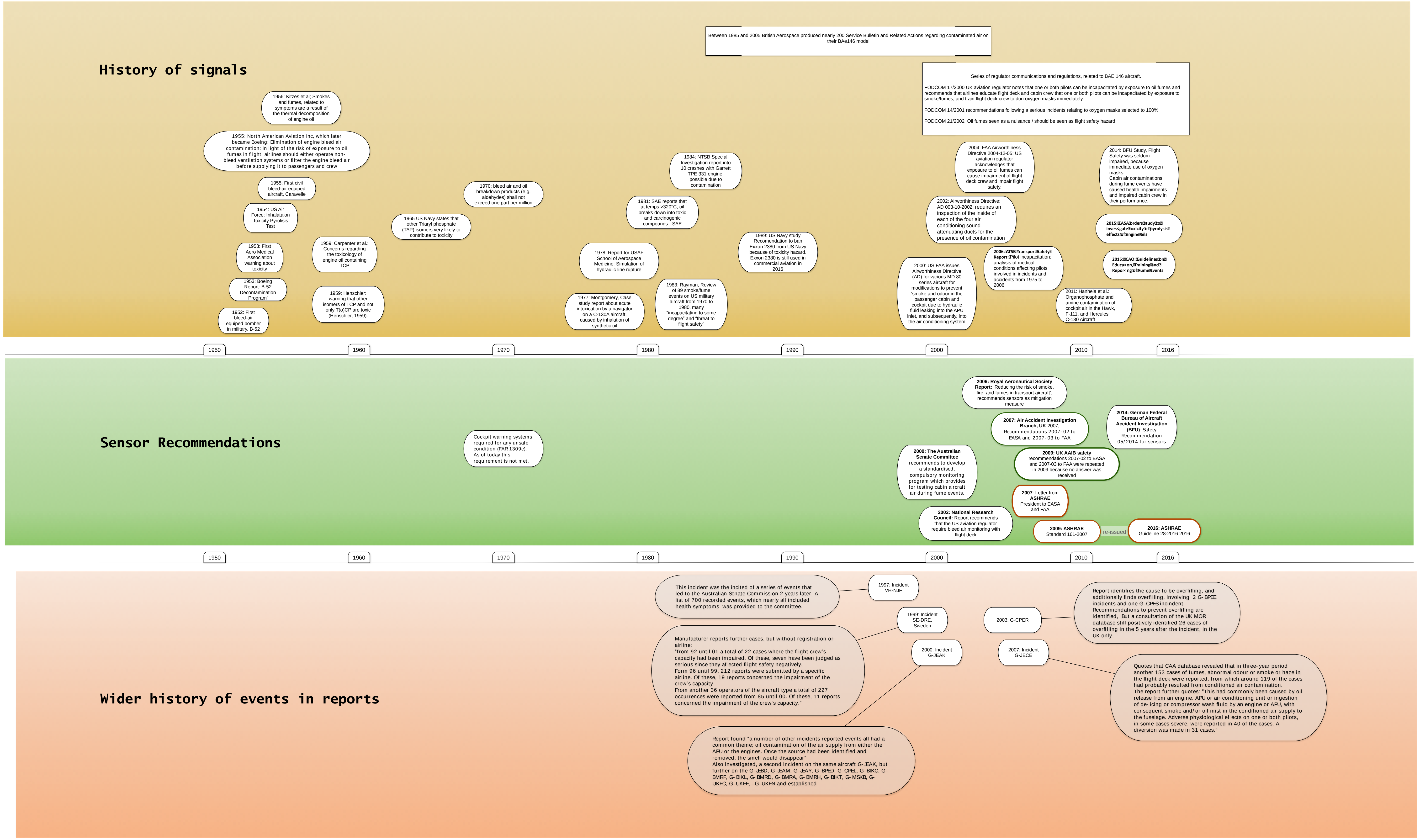

Figure 3: Timeline

Before 1950: In the early ages of aviation, air for crew and passengers in the aircraft cabin was delivered via external air inlets. Due to the low amount of oxygen in ambient air at altitude, it had to be compressed via external compressors. This design was first changed in military jet aircraft in the late 1940s (S. Michaelis, 2016), killing two birds with one stone by bleeding off air from the engine's compressor and providing it to the cabin. This technical modification offered a practical and economical advantage. In the early fifties the military started to use this bleed air on fighters and bombers such as the Boeing B-52.

1953: The earliest description of the problem can be found in a 1953 Boeing document with the title 'Decontamination Program' for its B-52 model. It contains a chapter 'The air contamination problem', which states "observations of the flight crews constitute the first evidence of the existence of the problem. They [flight crews] have repeatedly reported presence of smoke and odor in the occupied compartments of the airplane" (Boeing, 1953, p. 2). The document discusses how "[o]bvious increases in the contamination level were noted during changes in engine power conditions" and describes that "crews used 100% oxygen throughout all flights", because "toxic effect of the contamination is still unknown." The document also discusses different options for bleed air filters (Boeing, 1953).

1953: In the same year as the Boeing B-52 decontamination program, the Aeromedical Association expressed its concerns, stating that "pyrolised oil can contain irritant and toxic aldehydes and other dangerously toxic products of incomplete combustion . . . Even a small degree of bodily impairment from toxic gases would lead to increased pilot error and so be hazardous in aviation." (as cited in: S. Michaelis, 2010, p. 169)

1954: A USAF study exposed animals to engine oils via ingestion, dermal exposure, inhaling unheated mist, and inhaling heated fumes. The fumes were notably more toxic than the other exposure types, and the toxicity of the fumes increased with temperature. The authors concluded that the oil fogs produced pneumonitis and degenerative changes of the brain, liver, and kidneys (Treon et al., 1955). In 2016 there are no updated inhalation studies for the complex mixture of engine oils. The only available toxicity studies for some limited set of chemicals are based on the oral uptake (ingestion). The relevance of oral toxicity studies to explain inhalation uptake toxicity was among others challenged by the US Air Force in 2003 (see below).

1955: The first bleed air-equipped passenger aircraft, the French manufactured SudSE 210 Caravelle, came into service in 1955 (S. Michaelis, 2016).

1955: An engineer with North American Aviation Inc. (which later became Boeing) recommended in a document called "Elimination of engine bleed air contamination" that, in light of the risk of exposure to oil fumes in flight, airlines should either operate non-bleed ventilation systems or filter the engine bleed air before supplying it to passengers and crew. (Reddall, 1955) The paper cites that "compressor bleed air used for aircraft air conditioning is increasingly subject to unacceptable contamination . . . It is believed that the compressor bearing seals are the main source of oil leakage, although there are other possible sources of internal leakage ", (1955, p.1), thereafter described as "hydraulic oil leakage into the engine inlet air stream". This was an early precautionary warning for the problem, a signal that came from the manufacturer itself. The problem with this design came to light just after the technology was introduced and was described to be identical to the problems from today's incident reports. The engineer suggested to revert to the solution as it was on all aircraft just a few years before, "a separate cabin compressor that compresses free stream ram air"

(1955, p.1). It took Boeing another 55 years until 2009 to re-introduce the first non-bleed aircraft with their Boeing 787.

1956: Kitzes (1956) published some of the findings from the last years in *Aviation Medicine* and presented them at the 26th annual meeting of the Aero Medical Association. He warns of the risks, which came to light in the previous years. He stated that both the military aviation services and the aircraft industry have recently become aware of similar if not the same problems in newly developed high speed aircraft. In the Air Force test pilots complained of obnoxious odors, eye and nasal irritations, and headache associated with the presence of smoke in the aircraft cabin during flight operations. Preliminary investigations revealed that the smoke, including fumes and gases, were a result of the thermal decomposition of engine oil, which had leaked into the compressor of the gas turbine engine.

1959: Carpenter (1959) raises concerns regarding the toxicology of engine oil containing TCP and in the same year Henschler describes that all isomers of TCP and not only ToCP are toxic (Henschler, 1959). This knowledge was reinstated by for example Winder (Winder & Balouet, 2002) and thereafter by others (Marsillach et al., 2011; Ramsden, 2011). Although the focus on TCP is probably too narrow to understand the full causality, the TCP argument can be used as exemplary for the fact that specialisation remains an obstacle to interpretation as an important systematic mechanism. The papers that serve for the regulator's assessment such as the 2004 CAA UK study and the Cranfield Report (2011) seem not to be aware of Henschler's finding. This is what Vaughan (1996) defined as 'specialism censorship', were such critical details are lost in the interpretation of the full set of initial data.

1965: Research from US Navy (Siegel et al., 1965) states that other Triaryl phosphate (TAP) isomers very likely to contribute to toxicity. Notes that "TCP" is a term used "rather loosely" to describe complex mixtures of triaryl phosphates which vary in toxicity, and there are components of equal or greater toxicity than T(o)CP. This basically repeats the 1959 findings of Henschler and Carpenter, but this time as researched concern acknowledged by the US Navy. In addition to the concerns about technical root causes known to the manufacturers such as Boeing, this shows that end users such as the US Navy clearly had early awareness concerning the toxicity of chemicals contained in the oil. Identifying the most critical components was in line with Henschler (1959) and Winder (2002). The knowledge was more accurate in this 1965 paper than in the much later produced 2004 CAA UK Report, the Cranfield Report (2011) and the KLM-partnered study (De Ree, 2013) that were often cited for their reassuring results.

1970: Cockpit warning systems to alert flight crew for any unsafe condition (FAR 1309c) are required by the regulator. As of today this requirement is not met.

1973: MIL-E-5007-D, certification standard states that oil leakage within the engine shall not cause contamination. It states that bleed air and oil breakdown products (e.g. aldehydes) shall not exceed one part per million. (Department of Defence, 1973). These particular requirements have been lost in today's current bleed air certification specification such as ARP 4418 (SAE Aerospace, 2008). This shows that those that designed certification standards were aware of the concerns in the 1970s, but such stringent requirements have been discounted in later years.

1977: Case study of acute intoxication by a navigator on a C-130A aircraft due to exposure to engine oil fumes inflight states:

> A recent case has dramatically demonstrated acute intoxication following inhalation of aerosolized or vaporized synthetic lubricating oil. The patient, a 34-year-old Caucasian male in

> good health, was flying as navigator in a military C-130A aircraft when he noticed the gradual onset of headache, followed by slight dizziness, nausea, vomiting, incoordination, and diaphoresis. By the time the plane could be landed he had difficulty standing. . .Investigation of the involved aircraft revealed a maintenance history compatible with the aerosolization of the synthetic lubricating oil into the air ventilating system. (Montgomery, Thomas Wier, Zieve, & Anders, 1977)

1978: Report for USAF School of Aerospace Medicine with the title 'Fluid contamination of aircraft cabin air and breathing oxygen' (Paciorek et al., 1978). Researchers measured "significant quantities of toxic compounds" when a line rupture was simulated onto a hot surface heated to 450 degrees C. This resulted in "the presence of excessive fluid degradation. In all instances, significant quantities of hydrocarbons, carbonyls, and alcohols were produced" (Paciorek et al., 1978).

1981: SAE reports that Engine compressor bearings upstream of the bleed ports are the most likely sources of lubrication oil entry in the engine air system and hence into the bleed system contaminating the cabin/cockpit air conditioning systems and additionally states that at temperatures greater than 320°C, oil breaks down into toxic and carcinogenic compounds (SAE, 1981).

1983: Review of 89 smoke/fume events on US military aircraft from 1970 to 1980, many of which were described as "incapacitating to some degree." The article concludes that "smoke/fumes in the cockpit is not a rare event and is a clear threat to flight safety." (Rayman & McNaughton, 1983)

1984: NTSB Special Investigation (1984) started a review of eight fatal and one non-fatal crashes, all on turboprops equipped with the same engine type (Garrett TPE 331) to determine whether or not these accidents could have been caused by incapacitation of the pilots by toxic by-products of turbine engine oil. Therefore, oil was injected while an engine was running with a broken seal. A deliberate incident with bleed air contamination was simulated under laboratory conditions.

In all but one trial, a glass wool liquid/vapour separation filter were installed in the sampling line and only measured the gaseous contaminants (NTSB, 1984). The study concluded "no evidence was developed to support the hypothesis of pilot incapacitation due to bleed air contamination" (NTSB, 1984). However, the accompanying inhalation study by Crane et al. (1983) on animals to complement the technical bleed air simulation made some additional considerations. The presence of a number of identifiable gases were reported to be present in low concentrations and added:

> However, the presence of an unidentified substance of exceptional toxicity (e.g. more toxic than CO) emanating from the engine could not be ruled out. Furthermore, these NTSB – sponsored tests showed that when oil was injected directly into the engine air intake it appeared as a mist in the bleed airline, but this mist was removed by glass wool filters ahead of the sampling/analytical devices. It was possible, therefore, that with an unfiltered line a significant toxicity could be associated with breathing the oil mist. . . . even though several potentially toxic species are measured, it is at present almost impossible to predict the combined toxic expression of such a mixture. (Crane, Sanders, & Endecott, 1983)

The design of the study after the first measurements concluded that CO would be the most toxic substance to cause incapacitation and therefore the accompanying animal testing study focused on CO only. However, later studies have identified a range of other possible contaminants that are suitable candidates for incapacitations. Therefore, the accompanying Crane report (1983) on animal testing was right in his prudence about the technical measurements when this researcher pointed to the limitations of the study, one of them being the fact that the combined toxic expression of the mixture could not be predicted.

This 1984 NTSB study is special, because it was not forgotten and even became cited for its reassuring conclusion in the 2004 G-JEAK report. However, its conclusion was based on the distinct hypothesis that CO must be the most toxic compound. This was cited in the G-JEAK incident report without any critical reflection. The fact that the measurement equipment altered the conditions by glass wool filters was not mentioned. The concerns that a significant toxicity could be associated with breathing the oil mist were not included in the cited paragraphs. Once more scientific uncertainty and specialism are obstacles to a correct interpretation of the full data.

A further incident with the exact same engines as involved in the series of incidents from the NTSB report involved a double pilot impairment. The pilots suffered light-headedness and vision impairment and one pilot thought he may faint or pass out (TAIC, 2008, p.9). "The crew undoubtedly suffered some form of incapacitation" and the report concluded that there was likely to have been some form of contamination of the air inside the aircraft" (TAIC, 2008, p.15). The report cited that "transport safety and investigation organisations identified no other similar cases of crew incapacitation or toxic cockpit environment on a Dornier 228 aircraft" (TAIC, 2008, p.14). The report seemed completely unaware of the series of the NTSB reported incidents with the same Garett TPE331engines installed on other aircraft types and the NTSB follow-up research. This is a typical example of fragmentation of information.

1989: "Twenty-six different oils, hydraulic fluids and lubricants in the U.S. Navy inventory were screened for yield of the neurotoxin Trimethylolpropane phosphate (TMPP) in order to obtain an estimate of safety hazard potential . . . TMP-P was formed very rapidly (within 5 minutes) with formation beginning in a temperature range of 350 to 400 C" (Callahan, Tappan, & Mooney, 1989, p. 1). Due to the formation of TMPP, in the report described as a potent neurotoxin, the US Navy recommended to ban Exxon 2380 because of toxicity hazard. Exxon 2380 is still a widely used in many commercial airlines in 2016. What the military deems a serious hazard is not critical for the civil regulator.

1991: Ansett Australia Airlines started an investigation into the rising number of complaints related to contaminated air and created an 'odour committee' in 1991 to address concerns being raised by employees (Michaelis, 2010). It took until the year 2000 before this internal concern gained public visibility in Australian Senate Committee. (Cf. Chapter: A thick description of the history of the BAe 146 problems)

1992: An incident with the VH-EWS occurred and resulted in long-term lung injuries to a flight attendant. Even if the APU led to a serious injury in the Turner case, the No 1 or No 9 bearings from the main engines were mentioned in 1992 as a known source of contamination. They also failed in the 1999 Swedish SE-DRE incident, and it was found as a common theme in the 2004 G-JEAK recommendations. A No 1 bearing failure was also identified in a 2001 Australian incident (ATSB, 2002), 2002 Australian incident (ATSB, 2003b), and in the 2005 Swiss HB-IXN incident (Swiss Federal Department of Transport, 2006c).

But the 1992 VH-EWS description of this known root causes was never part of an official investigation and only became public when Turner won her workers compensation claim, 18 years later. This incident on an Australian aircraft was not even mentioned in the Australian Senate Committee. A requirement for the court to judge in favour of Turner in this workers compensation claim was to determine that the damage was foreseeable. The court found it foreseeable that smoke from leaking APU oil would enter the cabin of the aircraft and additionally judged that the crack in the seal or failure of the seal was foreseeable (Dust Diseases Tribunal of New South Wales, 2009, [97]), but also cited several other reasons to establish the principle of foreseeability:

> There was a history of complaints relating to health in relation to VH-EWS before 4 March 1992…That history included several complaints relating to breathing difficulties in January and February 1992. (Dust Diseases Tribunal of New South Wales, 2009, [126])
>
> Once the defendant knew of the problem of the oil smell in the cabin, it was appropriate for it to take remedial action to try to fix it. The question arises as to whether the action it took failed to meet a proper standard of care. (Dust Diseases Tribunal of New South Wales, 2009, [124])

This notion of foreseeability provides an alternative possibility to define the construction of safety in comparison to the regulators' views. EASA for example concluded that "a causal relationship between the health symptoms reported by some stakeholders (some pilots, cabin crews or passengers) and oil/hydraulic fluid contamination has not been established" (EASA, 2011, p. 4). An Australian court judged differently in the case of Joanne Turner.

2000: The US FAA issued an Airworthiness Directive (AD) (FAA, 2000) for various MD 80 series aircraft for modifications to prevent 'smoke and odour in the passenger cabin and cockpit due to hydraulic fluid leaking into the APU inlet, and subsequently, into the air conditioning system.' This AD was the result from complaints from hundreds of flight attendants that claimed to have suffered unexplained sickness aboard Alaska flights during the past 10 years on the MD-80 (Acohido, 1999). From 1974 until 2001, eight U.S. carriers documented 1,051 incidents of fumes, smoke, haze, mist or odours entering the cabin air supply system of DC-9s and MD-80s (Acohido, 2002). The flight attendants' claims of neurological illness due to fume events were disputed by the airframe and engine manufacturer. The concerns, which started in the early 90s were eventually settled out of court in 2001, by a Lawsuit that was initiated by 26 flight attendants in 1998 (Acohido, 2002). Contrary to the Australian committee they did not gain much public attention, although the concerns were very similar.

2000: As a result of the ongoing complaints of fumes on the BAe 146, a study of thermal degradation properties of the oil was conducted by Van Netten et al. The thermal breakdown products of jet engine lubrication oils, two commercially available oils were investigated under laboratory conditions at 525 degrees C. Carbon monoxide (CO), a chemical that can produce incapacitation, was produced under simulated oil leak conditions, at levels in excess of 100 ppm (1).

2002: 'Toxicity of commercial jet oils': Examination of the ingredients of the oil indicates that at least two ingredients are hazardous: N-phenyl-1-naphthylamine (a skin sensitizer) and tricresyl phosphate (a neurotoxic agent, if ortho-cresyl isomers are present). Publicly available information such as labels and MSDS understates the hazards of such ingredients and in the case of ortho-cresyl phosphates by several orders of magnitude.

2002: NRC (2002) report recommends that the US aviation regulator require bleed air monitoring with flight deck indication and investigate/report on the need for and feasibility of installing air cleaning equipment to address bleed air contamination during ground operation, normal flight, and air-quality incidents.

2003: US Air Force investigation (Bobb & Still, 2003) into potential explanations for long-term neurological symptoms reported by flight crews after inhalation exposure to oil fumes; concludes that exposure to CO and TCPs may be responsible. The authors note that the route of exposure (in this case, inhalation) and exposure duration can influence the dose required for an adverse effects, and explicitly notes that no inhalation toxicity studies for oil fumes are available. US military researchers refer to chronic neurological effects associated with exposure to carbon monoxide and TCP oil additives, even at doses below the recognized threshold for acute exposure, and challenge the relevance of oral toxicity studies of engine oils." no completed studies on inhalation of jet engine oils or tricresyl phosphate were available" (Bobb & Still, 2003).

2004: A review paper (Singh, 2004) reports the frequency of smoke/fume events in the Australian Defence Force as 0.5 per 1000 hours. The Author caution about chronic exposure to low-level contaminants and the error in applying occupational standards to the aircraft environment. This is a good example of the competing discourses. In the same year where the CAA UK Report produces reassuring conclusions amongst other things based on occupational standards, Singh (2004) cautions for applying such thresholds to assure safety.

2006: Royal Aeronautical Society (Cox, 2006) report with the title 'Reducing the risk of smoke, fire, and fumes in transport aircraft: Past history, current risk, and recommended mitigations' raises concerns regarding increased stress and work load of pilots during smoke/fume events, and notes the difficulties that pilots face when trying to locate the source and nature of smoke/fire/fumes inflight. The authors recommend sensors to enable pilots to quickly and objectively identify source and location of smoke/fire/fumes.

2007: COT Committee (COT committee, 2007): Report notes that UK pilots (three airlines) report fume events on 1% of flights, but maintenance only investigates one in twenty of the pilot reports. The committee did not definitively attribute ill health/impairment to oil fumes, but recommended that 10,000 - 15,000 flight segments be sampled in order to characterize exposure during fume events.

2007: An internal Boeing email (Bates, 2007) with the title: 'Toxicty???' reveals a conversation amongst colleagues who discuss the question whether the toxicity is addressed when they sign for the relevant regulation 25.831{b). The answer from one colleague expresses with clear concern: "No, I have not been signing for toxicity other than to make sure my parts have MI numbers. Hydraulic Mist is another toxic product I refuse to get involved with". The respondent of the internal mail also answers that he does not understand that the regulator has not properly regulated the issue so far:

> Given the number of COSP events for the 757 I RB211-535C & -535E engines resulting from failed Fan and Forward IPC Bearing Oil Seals allowing, oil by-products in the bleed ducts, I would have thought the FAA would have forced the issue. With all diversions (about l every 2 weeks) and Return to Base events due to in the Cabin, I would have thought the FAA [regulator] would have made the Engine Manufacturers address this by now. Some of the 757 events have been pretty significant in that the crew reported blue smoke with defined waves in the smoke. The visibility was limited so that the attendants in the aft galley could not see to the mid cabin over-wing exits. This is more than a light haze that we debate endlessly about for smoke evacuation. Who knows what the by-products are in hot synthetic Turbine Oil. The Material Data Sheet has warnings about skin contact and breathing the fumes of the oil, let alone the complication of partial combustion products {Bates, 2007 #991}.

This mail is from 2007, one of the years where EASA assumed zero global incidents as discussed in the earlier regulator perspective. Such reports with diversions and blue smoke have not created any signals, even when the manufacturer was readily aware of them. This is a strong example that the absence of signals has little meaning for the actual representation of the issue.

2009: ASHRAE Standard 161-2007 the standard requires the installation of "one or more sensors intended to identify a substance or substances indicative of air supply system contamination with partly or fully pyrolised engine oil or hydraulic fluid" with flight deck indication when such fumes are present to enable the pilot(s) to respond appropriately and rapidly. This was repeated in the 2013 update of the standard (ASHRAE, 2009). A year earlier the ASHRAE president sent a letter to EASA and FAA addressing: "the committee requests that, this year, you investigate and determine the requirements for bleed air contaminant monitoring and solutions to prevent bleed air contamination, including maintenance/operating/design control measures and bleed air cleaning equipment" (ASHRAE, 2007). The requirements were repeated and updated in the 2013 revision of the standard.

ASHRAE produces voluntary standards, so strictly these measures must not be installed. On the other hand the standard is designed an approved by a committee that includes airlines, crewmember unions, passenger representatives, but also includes the main aircraft manufacturers such as Boeing, Airbus, etc. One would expect that the very aircraft manufacturers being the ones that amongst others developed the committee decisions, would subsequently develop the sensors and filtration as called for by this standard. Until today, there is no aircraft equipped with such sensors and only one aircraft is certified to have bleed air filtration as an option. Only one cargo airline in the world has this option installed (Personal communication, Pall Aerospace).

2011: Royal Australian Air Force investigated contamination in Hawk, F-111 and Hercules C-130. Sampling identified TCP oil additives, phenyl-α-naphthylamine and dioctyldiphenylamine (jet engine oil) and trialkylphosphates (hydraulic fluid). Highest level of total TCPs was 22 ug/m3. Levels were described as low but authors recommend that total TCPs should be kept below at 1 ug/m3, which is only 1% of the limit which the regulator deems safe in the absence of an occupational exposure limit. This is similar to what Singh (2004) warns of.

2014: BFU Study looking into cabin air quality events recommends sensors. Describes that fume events do occur and have resulted in contaminated cabin air, but flight safety was seldom impaired, because immediate use of oxygen masks. The authors state that cabin air contaminations during fume events have caused health impairments and impaired cabin crew in their performance.

2014: A post-mortem study on a deceased 43-year old airline pilot was performed. The resulting scientific publication concluded that his nervous system injury is consistent with organophosphate-induced neurotoxicity. 2 years later no scientific reactions have been published in reaction to this peer-reviewed study.

2015: ICAO (2015a) 'Guidelines on Education, Training and Reporting Practices related to Fume Events' acknowledges the problem and describes a guideline for crews, maintenance and management to deal with the problem.

The information provided above shows that the effects and the root causes of fume events have been acknowledged ever since bleed air was introduced. Some more recent sources that simply acknowledge the risk and the effects ask for early detection of the problem, but these recommendations have not been addressed. Similarly, many early scientific discoveries have identified toxicological concerns that are not managed by today's regulations, with their narrow focus on CO, CO2 and O3 (Cf. part of chapter 3: how the regulator manages the problem). What this timeline also reveals is that before the reports from crews in the Australian Senate committee and the concerns from crews on the MD-80 in the US arose in the 90s, no competing discourses existed. The problem was simply acknowledgment without any further debate. There were knowledge gaps, but these were gradually researched and often resulted in concerns that resulted in caution about low-level exposure, the fallacy of applying exposure limits. The publications from that time resulted in new insights that redefined the potential toxicity of the mixture. The first papers from the other paradigm that doubted a causal relation were produced only a decade later.

Three such sources are often cited for their absence of evidence by the aviation industry, being the CAA UK Study, the Cranfield and the KLM-partnered study (Harrison, 2015; Ramsden, 2011). They make virtually no references to the history and the many safety concerns on the timeline presented above. This broad set of signals has been discounted in the safety assessments from the EU regulator, mainly based on the conclusions from the CAA UK (2004) study and the Cranfield (2011) study.

The discounted information has also a critical implication for the regulator's role, not just in the EU, but also for regulators worldwide. The reason is that many of these examples describe a problem that emerged historically as an issue that was addressed, but never fully managed by the regulator. Some early regulation specifications, such as the certification standard (Department of Defence, 1973) that basically expressed that bleed air contamination should simply not been allowed (shall not exceed one part per million) have been discontinued.

The Australian Senate committee and the BAe incident reports at the beginning of the millennium can be viewed as a pivoting point, where the problems could have become public common knowledge for the aviation regulators. But even the signals that were produced after this pivoting point, such as a continued call for sensors by various bodies, have been discounted in the safety assessments. The regulator has not responded to the many expert recommendations for sensors, paradoxically already prescribed by existing EU and US regulations. The Australian Senate committee was a further recognition of safety concern signals. Whereas the committee concludes that measures should be taken and especially that the proper conditions for a correct assessment of future investigations should be created, these health and safety concerns seem to be forgotten, which was confirmed by a publication from the committee's chairman five years after the committee produced its report. He stated his concern that the committee's recommendations were not put into effect (Woodley, 2005). The system seems to have reduced the conclusion from the committee, to a claim of no toxicity or risk. The report was not remembered by the whole of its recommendations or its actual conclusion of scientific indeterminacy, which had yet to be resolved. Despite the claims of the absence of evidence, crews around the world continued to report fume events and expressed their concerns for several decades.

Ironically enough it was an e-mail from Boeing employees that discusses in internal communications why the regulator has not 'forced the issue from oil by-products in the bleed ducts'. Such internal communications are a special set of signals, because they reveal a view from the inside, and surprise us because they suddenly reveal what was hidden before. Such signals can bypass a whole set of previously held beliefs that a system was proven safe. When defining the issue of cabin air contamination on a regulative perspective, it reveals that even highly specialised people inside the system realise that the regulator has not defined the problem. Whereas Boeing's management expresses no concern in its corporate responses (Boeing, 2016), the engineering seems to differ in opinion in their internal communication.

The following chapter reveals more about hidden signals and the mechanisms behind it.

Chapter 5: Case studies: Hidden signals

So far this thesis has only dealt with signals in relation to bleed air contamination that were accessible for decision makers or academic researchers. Research depends on published accounts of information. But the production of signals and information is unavoidably shaped and regulated by the social construction of risk. Information that reaches top decision makers is inherently filtered and is already a reflection of the intermediary frames of reference that shape interpretations of objects and experiences. Therefore, it is also good to look at some case studies that provide fresh unbiased signals from inside the sociotechnical system. I will present two case studies that tell stories about signals that are not accessible to the academic domain and examine if such mechanisms could alter the reflection on the existing signals.

Case Study 1: Normalisation of Bleed Air Contamination

Results of Case Study 1

The editorial staff of the Dutch television Zembla, an investigative journalism on the Dutch public service television provided me with an internal maintenance document, which they received when they investigated a series of occurrences on Fokker 70/100 aircraft in a documentary in the year 2010. The documentary described the following events. In 2009 a Fokker 100 aircraft returned to base due to oil smells. Three weeks later the same aircraft was affected, when it approached Vienna and it was thereafter flown back to base without carrying passengers. The authorities confirmed the events and the Fokker vice-president confirmed that the crew felt dizzy during the first incident, but he claimed that a technical cause could not be determined (Zembla, 2010). When the journalists asked which tests were performed, the Fokker vice-president could however only state two measured parameters, airflow and temperature. Several pilots reported anonymously in this documentary how oil smells and even smoke had affected them on this particular aircraft type (Zembla, 2010). The usual competing signals from concerned crews and the aviation industry were already described by this media coverage, so I will not repeat this description. My analysis is rather meant to describe an internal perspective, being the maintenance perspective. My analysis is reconstructed from a maintenance document that was obtained by the television makers. Such maintenance documents are a source decision-makers and academic researchers rarely have direct access to and therefore provide a unique perspective.

I will also make an analogy to an identified problem in the NASA space shuttle programme; being the normalization of deviance in the Challenger Crash and the normalization of risk as a maintenance problem in the Columbia Crash.

An internal 2009 troubleshooting communication (Personal communication, editorial staff Zembla) from the Fokker maintenance provider shows in detail how the reported smells are mitigated. The document was titled 'Experience Sheet to Troubleshoot Bad- and Wet Sock Smell Complaints for Fokker 70 and 100' and describes some known sources of what the documents calls 'bad- and wet-sock smells':

> APU Oil System
> The APU system is one of the most important sources of contamination. Indeed, oil leakage can penetrate into the APU bleed air system and produce an "oily/burned" smell in the air-conditioning system.

> Air Cycle Machine
> In some cased [sic], small oils has been noticed during troubleshooting. As such, the ACM oil and air–oil mist can penetrate into the ducting downstream of the turbine.
>
> Bleed Air Leakages
> We recognise to potential sources of bleed air contamination . . . . Stub wing bleed air connection leakages (7th & 12th staged check valve corrujoint seals failure).
> (Personal communication, Zembla)

This troubleshooting guide describes further how,

> insulation blankets may become wet as a result of hydraulic system leakages during maintenance… and if not replace in time, will generate a bad smell in proximity of hot leader ducting…. The hydraulic tank pressurization system is also a potential source of contamination if the in-line check valves are failed to the open position. As such, hydraulic or fumes can enter the bleed air system when all systems are turned off…. (Personal communication, Zembla)

The word safety is not used in the maintenance communication, and it does not become clear that maintenance is aware that the mentioned APU and hydraulic oils contain known neurotoxins. The above-mentioned occurrences described in the documentary did not trigger any incident reports. Nevertheless, three of these particular aircraft covered among others in the maintenance document, were cited as earlier incidents in the G-JEAK report and had fume event occurrences nine (2) and thirteen years earlier (1). At that time these very aircraft had British registrations. I only found this out by looking up how their earlier British registrations G-UKFF, G-UKFN, and G-UKFC were changed into the later Dutch registrations PH-OFF, PH-KLE, PH-OFC when the aircraft switched airlines (n.a., 2002-2016). This is just one example of how unintended 'structural secrecy' can obstruct the transfer of information.

But the mechanic's search for sources of 'wet sock smell' also produced ambiguous outcomes and uncertainty. The maintenance communication mentions that, besides APU oil and hydraulic fluid, other less harmful sources were known. These were described as smells from some electric appliances, a single case of new floor covering glue, and a leak in the toilet servicing line, or bacterial growth. This all adds up to the complex reality of normal maintenance uncertainty. This routine variety of possibilities includes what is stated in the communication as the fact "that even if a large number of findings can be attributed in this category, it is also "believed that a fair portion of these events are most likely due to the perception by the crew of bad/burning smell" (Personal communication, Zembla).

The language used suggests nothing else than normal systems variability, certainly not malevolence. It is even remarkable upfront by including factors, normally only overseen by managers' expectations, such as time pressure and suboptimal communication, which sometimes caused that: "[t]he initiated troubleshooting was insufficient due to time constraints or in adequate information supplied by the operating crew" (Personal communication, Zembla). The maintenance guide than shows "an overview of aircraft that are known for their wet socks problem over the past half year:" 6 aircraft registrations have a large history; 7 aircraft registrations have a medium history; and the remaining majority (+30 registrations) have a low history (Personal communication, Zembla). The categories of low, medium and high refer to the frequency of occurrences listed per registration. By categorising all the aircraft in this fleet, the language normalises the problem as pertaining to this aircraft type, even if 'low history' might mean that some aircraft are not or hardly affected. How this was reflected in the airline's internal documentation can be triangulated with a maintenance log from an additional aircraft with registration PH-OFL both referenced in this maintenance document and also referenced in Michaelis PhD (2010, p. 581). Between 2 October 2008 and 15 April 2009 the maintenance log for aircraft PH-OFL showed 16 events with similar descriptions such as 'unacceptable wet sock smell'. During this period, several hydraulic fluids were identified (2010, p. 581). On several occasions such reports were transferred to the deferred defect list until the end of the flying day, indicating that the aircraft could continue flying for the remainder of the day" (2010, p. 581). This is another indication that such leaks are regarded as a maintenance issue without an acute danger. This message is the expression of an acceptable risk. Again this should not so much be assessed as a rule violation, but as a sign that with the given indeterminacy, the causes and effects of leaks were accepted as a maintenance issue, and less as a hazard.

This is not the only example where a safety issue came to be regarded as a maintenance issue. The Swedish 1999 SE-DRE investigation describes:

> The occurrence was *not initially handled as a serious incident but as an engine fault* [emphasis added]. For this reason SHK was not informed of the occurrence until four days later. Therefore the corrective measures that were performed on the aircraft during this period took place without the participation of any representative from the SHK (SHK, 2001, p. 22).

In this case there was no safety report from the airline, not even with impaired pilots and the use their oxygen masks, as the Swedish incident report describes. With the lack of a safety incentive form the safety department, it was initially handled as an engine fault. In the Fokker case the incidents never escalated in such external investigations.

This is why this case study turned out to be a hidden signal for the aviation industry and regulator's safety assessment. Whereas in the publicly available information, there is no single confirmation of jet engine and hydraulic oil contamination for these incidents on Fokker 70/100 aircraft, this maintenance document shows that such leaks were and are a well-known source of contamination. It further discusses contaminated insulation blankets that could reproduce such events after the source is eliminated. And finally crew reports were matched to hydraulic leaks (2010, p. 581), but this didn't generate any signals to the outside world. I described in an earlier chapter how the manufacturer Fokker stated that it had statistical data, but was not willing to share this with the regulator EASA (EASA, 2011, p. 31). This is troublesome for decision makers as this 'Experience Sheet to Troubleshoot Bad- and Wet Sock Smell Complaints' document shows that the manufacturer had very valuable information on a safety issue under the regulator's investigation. This not only a breach of public accountability, but also creates the by-product that for those mechanics working on Fokker aircraft oil and hydraulic jet where defined as a maintenance issue, not a safety issue.

Similarly, data from the airline KLM owning the aircraft of concern could have helped the regulator EASA, and it would have been valuable to know if the reasons the pilots in the documentary were afraid to testify in person were legitimate. One year later the airline amongst other airlines expressed to the regulator in its advanced proposal to rulemaking "their concern about the Agency 'unscientific' approach by opening an on-line questionnaire where flight crews and cabin crews can provide their own 'reports of anecdotal events' and 'promote their personal views" (EASA, 2011, p. 31). The facts from the documentary one year earlier or the triangulation with the maintenance findings were not shared. Contrary to the earlier described forms of structural secrecy these are examples of 'individual secrecy'.

Analogy with identified problems in the NASA Space Shuttle Program

The sections above resemble findings from the investigation of the Columbia Space Shuttle Crash on February 1, 2003, one of the most comprehensively investigated accidents so far. In the case of the Columbia crash, foam-shedding impacts from the Space Shuttles' own thermal insulation led to the Columbia break up. How these foam-shedding impacts "came to be regarded more as a turnaround or maintenance issue, and less as a hazard to the vehicle and crew" was identified as one of the key mechanisms in the conclusions (NASA, 2003, p. 130).

> The physical cause of the loss of *Columbia* and its crew was a breach in the Thermal Protection System on the leading edge of the left wing, caused by a piece of insulating foam which separated from the left bipod ramp section of the External Tank….During re-entry this breach in the Thermal Protection System allowed superheated air to penetrate through the leading edge insulation and progressively melt the aluminium structure of the left wing, resulting in a weakening of the structure until increasing aerodynamic forces caused loss of control, failure of the wing, and break-up of the Orbiter…. there was no possibility for the crew to survive. (NASA, 2003, p. 9)

> Despite original design requirements that the External Tank not shed debris, and the corresponding design requirement that the Orbiter not receive debris hits exceeding a trivial amount of force, debris has impacted the Shuttle on each flight. Over the course of 113 missions, foam-shedding and other debris impacts came to be regarded more as a turn-around or maintenance issue, and less as a hazard to the vehicle and crew. . . . NASA's lack of understanding of foam properties and behaviour must also be questioned. Although tests were conducted to develop and qualify foam for use on the External Tank, it appears there were large gaps in NASA's knowledge about this complex and variable material. (NASA, 2003, p. 130)

NASA had no complete knowledge of the possible consequences, but did certainly not hide the issue. It was just not defined as a safety problem. It gradually accepted the risk, of an anomaly that was against original design requirement expectations, of a vehicle that functioned over the course of 113 earlier missions. Similarly, rectification measures for the maintenance issues in the 2009 maintenance communication on the Fokker 70/100 described oil and hydraulic leaks as mere maintenance issues, despite the fact that early descriptions dated back to investigation reports from the year 1996 and 2000.

> The history of foam-problem decisions shows how NASA first began and then continued flying with foam losses, so that flying with these deviations from design specifications was viewed as normal and acceptable. (NASA, 2003, p. 130)

In the case of the Fokker maintenance document, multiple contamination sources were described and aircraft were categorised by maintenance for their 'wet sock smell' according to their respective low, medium or high history. There is little access from reports by crews to maintenance gained but one single aircraft having 16 such reports in 2 years, including some with positive identification of hydraulic leaks (Michaelis, 2010) has an undeniable frequency. This does not establish a particularly bad outcome for every flight and does not prove malevolence, but establishes the fact that the deviance from the design requirements has established a new norm.

This mechanism, described as the 'normalisation of deviance' was first described in another Space Shuttle disaster, the Challenger crash in 1986, which happened nearly 17 years before the Columbia break-up. The physical cause of the Challenger accident was traced back to the Shuttles' O-rings, designed to seal the gap created by pressure at ignition. The erosion of the O-rings turned out to be a known risk. “Each time, evidence initially interpreted as a deviation from expected performance was reinterpreted as within the bounds of acceptable risk"(Vaughan, 1996, p. 9). For example, “a NASA internal memorandum stated that seal erosion had occurred 12 times during flights” (Vaughan, 1996, p. 9).

> . . . the O-ring problem had a well-documented history at the space agency. Earliest documentation appeared in 1977— nearly four years before the first shuttle flight in 1981. Moreover, the Commission learned of a midnight-hour teleconference on the eve of the Challenger launch between NASA and Morton Thiokol in Utah, the contractor responsible for building the Solid Rocket Boosters. Worried Thiokol engineers argued against launching on the grounds that the O-rings were a threat to flight safety. NASA managers decided to proceed. (Vaughan, 1996, pp. xi-xii)

Diane Vaughan became one of the founders of organisational safety science with her own analysis of the Challenger Launch Decision (1996). Her investigation was aimed at understanding the reasons behind “the string of controversial launch decisions at NASA prior to 1986” (1996, p. 62). Vaughan’s ethnographic re-examination easily overruled the conventional explanation of the earlier findings by the presidential Rogers commission, which stopped its analysis at identifying the faulty designed O-ring as technical cause of failure and NASA’s flawed decision-making process as a contributing factor. The Rogers Commission deepest level of analysis was one of managerial wrongdoing. Instead what Diane Vaughan reconstructed in more than 500 pages, was the local rationality of the decisions that were made at that time by NASA:

> Risk is not a fixed attribute of some object, but constructed by individuals from past experience and present circumstance and conferred upon the object or situation.
> . . . in the years preceding the Challenger launch, engineers and managers together developed a definition of the situation that allowed them to carry on as if nothing was wrong when they continually faced evidence that something was wrong. This is the problem of the normalization of deviance (Vaughan, 1996, p. 62)

Vaughan’s analysis “resulted, not in rule violations and misconduct, but in conformity and mistake: a decision to go forward once again despite signals of potential danger” (Vaughan, 1996, p. 74). Vaughan describes how an earlier drafted title Rule Violations eventually landed in the wastebasket. What she, “as an outsider, thought of as rule violations not only were behaviours [sic] conforming to formalized NASA rules but also appeared to be the norm” (Vaughan, 1996, p. 58)

Just as in the NASA analysis, the maintenance practices on the Fokker 100 should not be judged as violations, but as behaviours of maintenance workers, who were conforming to formalized maintenance practices that appeared to be the norm. Even if some contamination sources were known, solutions also seemed unpredictable:

> For aircraft that have a large history with the wet socks smell…this list proved to be insufficient to solve the problem. Nevertheless, each time this list is performed there are still findings on the air conditioning system. Experience shows that it is not possible to reproduce the smell during an engine ground run and therefore <u>an engine run does not contribute</u> [original emphasis] to the troubleshooting (Personal communication, Zembla).

Whereas the Columbia report stated that foam shedding impacts *“came to be regarded more as a turnaround or maintenance issue, and less as a hazard to the vehicle and crew”*, the G-JEAK report which contained some Fokker incidents: *“In general, crews had regarded these events as a nuisance rather than a hazard”* (AAIB, 2004). It would be interesting to know if the mechanics ever knew that, years earlier the UK AAIB advised against normalisation of deviance at the flight crew level, let alone in relation to these three of their aircraft that had changed country and registration. As defined in an earlier chapter these can be unwilling effects of fragmented information or structural secrecy, the by-product of organizational and physical barriers between operations.

Therefore, the UK AAIB addressed maintenance and manufacturers "that air supply contamination by oil from the engines and/or APU, or by any other potentially hazardous substance, is avoided" for the BAe 146 and the Boeing 757 (AAIB, 2004b, p. 57). Although the final G-JEAK report mentioned three Fokker 100 incidents in its investigation, it did not issue a maintenance or design requirement safety recommendation for this specific aircraft type. This might be another reason why the risk, defined by the report as possible effects on flight crew decision-making, might not have been communicated to the mechanics of their maintenance provider. An issue which is not defined as a safety issue, but as a maintenance issue, driven by the normalisation of deviance are reasons why signals do not emerge in the first place.

Case Study 2: Structural Secrecy / a non-issue

Results of Case Study 2

For Vaughan "structural secrecy is the way patterns of information, organizational structure, processes, and transactions, and the structure of regulatory relations systematically undermine the attempt to know and interpret situations in all organizations."(Vaughan, 1996)

Data collection for case study Flight #123:

The airline, flight number and tailsign used in this case study are de-identified. The mechanisms developed in this thesis analysis could be about any airline, not a specific airline. On the 16th of Jan 16 2010, the crew noticed fumes during ground operations, climb out and then again on descent during flight #123 departing from a Caribbean island and arriving in a US city on the Eastern Seaboard. Twelve ambulances met the aircraft. Inflight, passengers were complaining of an unpleasant odour, headaches, and nausea (AFA, 2010). A CNN electronic news article states that eight passengers receive medical treatment at the airport and seven crew members were taken to the hospital (Chernoff, 2010). The footage of the ambulances meeting the aircraft, including a flight attendant and one of the pilots that were brought on stretchers to the hospital hit the US television news channels the same day. A CNN electronic article cites the Association of Flight Attendants' (AFA) description of the crewmembers' symptoms, which included headaches, confusion, some disorientation, dizziness and nausea. The aircraft mechanical records confirmed that there had been a leak on a seal in the right engine (AFA, personal communication, 2016). The airline's vice president of safety and regulatory compliance stated in the press that: "there was a little bit of oil that seeped into the cabin. It vaporizes and that's what caused the symptoms" (Chernoff, 2010). In a letter to the FAA, a year after the event, the cabin crew and pilots associations described:

> the pilots [names omitted here] have now both lost their licenses to fly as a result of ongoing neurological symptoms since they were exposed to oil fumes on [the incident] flight in January 2010. Four of the five flight attendants on their crew have similar ongoing symptoms and have also not returned to work. That day, the flight attendants did smell the characteristic "dirty sock" odor in the cabin prior to pushback, but had not been trained to recognize that odor as oil. The pilots did not see or smell anything, but developed symptoms as the flight progressed (AFA & USAPA, 2011).

As of May 2016, neither the two pilots nor three of the five cabin crewmembers have been able to return to work, meanwhile one cabin crewmember resumed work, but still reports (and is treated for) ongoing symptoms (AFA, personal communication, 2016).

Further course of events:

One or more crewmembers documented an additional 11 fume events on this same aircraft over a three-month period (Dec. 2009 – Mar. 2011), seven of which airline management had reported to the FAA and all of which were documented in the aircraft maintenance records (AFA, personal communication, 2016). This series of incidents on a single aircraft, including the Jan. 16 incident during which flight safety was clearly compromised, prompted AFA and the US Airline Pilots Associations to contact the National Transport Safety Board (NTSB). A meeting was organised in April 2010, a month after the last in the series of incidents. AFA and US Airline Pilots Associations representatives met with NTSB Chair and an NTSB investigator, in addition to the captain and first officer involved in the 16th of Jan. 2010 incident (AFA, personal communication, 2016). AFA provided the NTSB with a copy of the crewmembers reports and triangulated it with Service Difficulty Reports (SDRs; fume event reports submitted by the airline to the FAA, per 14CFR121.703 and 14CFR121.705) that the airline had submitted to the regulator (where available) and the relevant aircraft maintenance records, which had been obtained via the attorneys retained to represent the affected crews in worker's compensation claims (AFA, Personal communication, 2016). The joint information package contained a list of 11 documented fume events for the incident aircraft from December 2009 until March 2010. AFA also forwarded seven related SDRs.[14] Further attachments were a CNN report from March 10, 2010 and an e-mail from the airline's vice president of inflight services to segments of the cabin crew work group (AFA, personal communication, 2016). In this mail the company acknowledged that hydraulic fluids contaminated the air supply system in an earlier event dating December 2009, and engine oil contaminated the air supply system in January 2010. (Myers, 2010)

The info in the next paragraphs describes the list of documented smoke events from AFA to the NTSB. I have added my personal notes where, according to my own analysis of the data, the factual information from crew reports to the AFA could be supported by the data provided to the NTSB in the form a list of e-mails, a press article and SDRs to separate the parts from the crew reports from the parts that were disclosed by the airline in the reporting system. My primary goal is not so much to verify the accuracy of the data provided by the crew reports, because SDR per definition contain limited information. They are for example not required to document reports of illness from passengers or crew. My aim is rather to reconstruct how the NTSB could have systematically reviewed the concerns form the crew representatives by comparing it to the existing SDR content and examine matches and discrepancies after the SDRs with the request to investigate the issue of cabin air contamination on this specific aircraft registration. This allows to examine hidden signals that would otherwise not be known to the NTSB. In the later discussion of this thesis, the relevance of the hidden signals will be analysed.

Additional documented events to the one from the 16th of January, 2010 on the same aircraft registration start chronologically three weeks before the 16th of January and end two months later. The information is quoted from the information that AFA provided to the NTSB:

- "On Dec 28, 2009, the pilots and flight attendants reported symptoms upon arrival in SJU

[14] SDRs dating Dec. 28, 2009; Dec. 30 2009; Jan. 16 2010; Jan. 21, 2010; Jan. 29, 2010; Mar. 10, 2010, and Mar. 16, 2010.

(PHL-CLTSJU) on B767 aircraft #234. Paramedics met the flight. Mechanics were not able to find the source of the problem. The company sent a crew down to SJU to ferry it back to PHL on oxygen . . . . Reported symptoms included fever, sore throat, coughing, lower back pain, profound fatigue, itchy eyes, severe headaches, and poor quality sleep. The APU had been over-serviced for oil that day and was replaced two days later ” (AFA, 2010).

Thesis author remarks: Strong odour and APU change were confirmed by Service Difficulty Report 28.12.2009 (FAA, 2009a). No crew or passenger symptoms where referenced in the SDR, because it is a maintenance report, not a health report.

- “On Dec 30, 2009, the flight attendants and one of the pilots went to the ER upon arrival in SJU after the flight from CLT on B767 aircraft #234. They had noticed a “stinky socks” odor upon boarding but the plane had been dispatched anyway. The odor returned more strongly during descent. The crew reported nausea, bad headaches, coughing, lethargy, and confusion. Some of them were diagnosed with carbon monoxide poisoning at the ER [Emergency Room]. . . . The company wanted the crew to ferry the aircraft back to CLT, but the captain refused to take the flight attendants without protection. A few days after the exposure, some of the crewmembers described chills, muscle aches, and fatigue. These symptoms are consistent with exposure to TCPs. The APU had been overserviced with oil on Dec 28 and the APU was replaced on Dec 30” (AFA, 2010).

Thesis author remarks: Strong odour and internal leakage found with reservoir pressure contamination, as well as passengers and flight attendants feeling nauseous and faint are described in SDR 30.12.2009 (FAA, 2009b).

- “On Jan 8, 2010, one of the flight attendants developed vertigo, nausea, and dizziness on B767 aircraft #234. One of the pilots also got sick, reporting extreme fatigue and chronic headaches. On Jan 5, hydraulic fluid contamination was identified in the aircraft air supply system. There is no reference to the ducts being cleaned since then, so there may have been residual exposure to hydraulic fluid on this flight” (AFA, 2010).

Thesis author remarks: No SDR was filed by the airline. Mechanical records, obtained through workers compensation claims confirmed hydraulic fluid contamination in the bleed air system three days before this incident. (AFA, 2010)

- “On Jan 9, 2010, both pilots were affected during and after a flight on B767 aircraft #234. Both now have respiratory problems and fatigue. One also has joint pain, and some memory/concentration issues” (AFA, 2010).

Thesis author remarks: No SDR was filed. Hydraulic fluid contamination in the bleed air system was identified four days before this incident (AFA, 2010), and just a day before both pilot and cabin crew developed symptoms.

- “On Jan 14, 2010, one of the pilots had a headache, sore throat, vomiting, diarrhea, fatigue, and delayed flu-like symptoms during and after flying on B767 aircraft #234” (AFA, 2010).

Thesis author remarks: No SDR was filed by the airline. Only a day later pilots reported symptoms again.

- “On Jan 15, 2010, one of the pilots reported tingling in his extremities and fatigue during and after flying on B767 aircraft #234” (AFA, 2010).

Thesis author remarks: No SDR was filed by the airline. But only a day later the aircraft was taken out of service and oil was found in the bleed air system in the major central event as I described in the beginning of this chapter (Flight #123):

- "On Jan 16, 2010, the crew noticed fumes during ground operations, climb out and then again on descent during flight #123 from STT-CLT on B767 aircraft #234. Twelve ambulances met the aircraft and the entire crew and some passengers were taken to the ER [Emergency Room]. Inflight, passengers were complaining of an unpleasant odor, headaches, and nausea. Four of the five flight attendants and both pilots are still off work with serious neurological symptoms [as mentioned on April 15, 2010, 4 months after the incident]. In an email to its flight attendants, the company attributed this event to an engine oil seal leak. On Jan 19, oil contamination was identified in the #1 engine (replaced right and left bearing manifold seals), and on Jan 18, it was reported that [oil] residue was baked on to the engine bleed air face" (AFA, 2010).

Thesis author remarks: The SDR report described that there were fumes reported and also that the aircraft returned to gate and maintenance action were pending in SDR 16.01.2010 (FAA, 2010a). The SDR only suspected overfilling as the cause of the fumes. One of the two hydraulic leaks and one engine oil leak were confirmed in an e-mail from the airline to its flight attendants. Two recent events were discussed and it stated that "a failed valve . . . allowed a small amount of hydraulic fluid (Skydrol) to be introduced back into the cabin air system" and "the second event was caused by a faulty bearing seal on the #1 engine" (Myers, 2010).

- "On Jan 21, 2010, Xyz airlines reported a "scorched odor, like a gym or locker room… in the entire cabin" to the FAA. Again, this was on B767 aircraft #234. On Jan 19, maintenance workers were directed to check for evidence of fluid residue due to repeated complaints about air quality" (AFA, 2010).

Thesis author remarks: Odours, troubleshooting attempts and flight-testing were disclosed in SDR dating 21.01.2010 (FAA, 2010c). The SDR stated that no technical abnormalities were found.

- "On Jan 26, 2010, the flight attendants noticed symptoms on B767 aircraft #234 a half hour before landing on flight 1996 (CLT-PHL). They noticed an unpleasant odor, metallic taste, tingling in their throats, coughing, and nausea. The captain acknowledged the smell but could not identify the source. He notified the mechanics upon arrival in PHL" (AFA, 2010)

Thesis author remarks: No SDR was filed by the airline, even if this incident happened only a week after an incident that ended with paramedics bringing passengers and crew to hospital and an oil leak and old oil residues were identified.

- "On Jan 29. 2010, during flights 1297 and 968 (CLT-SJU-CLT), one of the pilots reported skin rash/welts and joint pain after flying on B767 aircraft #234. He had flown on the same aircraft the day prior" (AFA, 2010).

Thesis author remarks: No SDR was filed by the airline.

- "On Mar 16, 2010 all five flight attendants, both pilots, and six passengers were taken to the ER [Emergency Room] upon arrival after exposure to fumes during taxi out on B767 aircraft #234 in CLT (en route to MBJ). The aircraft returned to the gate immediately. The odor was difficult to describe. One flight attendant was admitted to hospital overnight because she could not stop coughing and was having difficulty breathing. One of the pilots described burning lungs and chest pain. The company initially attributed the event to electrical fumes and then to exhaust fumes that entered through a leaking door seal. However, mechanics did not consider the "broken cosmetic seal" over the aft door seal to be an adequate explanation. The aircraft was taken off line for two weeks (until Apr 2) for a major overhaul. The majority of the aircraft parts were replaced. During that time, an engine oil seal leak and a major hydraulic fluid leak were identified and fixed, and the contaminated ducting was replaced" (AFA, 2010).

Thesis author remarks: SDR dated 16.03.2010 (FAA, 2010b) only disclosed that the aircraft returned to gate due to fumes. No technical findings were noted. SDRs do not document reports of illness from passengers or crew, but additionally a media report confirmed that the crew and six passengers were transported to hospital.

As mentioned at the beginning of this chapter, this information was discussed with the NTSB a month after this series of events for this specific aircraft ended. The fact that the NTSB hosted a meeting with union representatives and the pilots of one of the incidents indicates that the NTSB welcomed the information and took the concern serious at this point. AFA additionally wrote to the NTSB, with a formal collection of the facts later that year on October 6. A few months later, on December 22 the NTSB investigator answered to the AFA:

> "My search of the Board's base did not find any related incidents or accidents, nor did we investigate [the incident flight] on January 16, 2010. In accordance with CFR Part 830.50, the National Transportation Safety Board is charged by the US Congress to investigate transportation accidents, determined their probable cause(s), and make recommendations to improve transportation safety. Because the Safety Board has no regulatory authority over airlines operations, it may be more helpful to discuss your concerns with an FAA representative." (NTSB, 2010)

Hereby, the NTSB declined to investigate the source of the acute and chronic neurological symptoms documented by the seven crewmembers, five of whom never returned to work after flight #123. Instead, the e-mail deferred responsibility to the FAA and announced that an investigation will not be conducted. The AFA followed the NTSB's advice and contacted the FAA on the 5th of August, 2011. It has to be noted that, at that point, the FAA was already familiar with the problem for nearly a year. What happened on flight #123 had been presented at the International Aircraft Fire and Cabin Safety Research Conference, hosted by the FAA on the 28th October 2010. At that conference, a full panel was devoted to the issue, including presentations from scientist members of the FAA- funded 'Airline Cabin Environment and Research' (ACER) consortium, clinical professor and occupational physician Robert Harrison, flight attendants and pilot association's representatives, and the personal testimonials of the captain and first officer of flight #123. The panel's conference proceedings can be found online (R. Harrison, 2010; Kubik, 2010; Lance Haney, Fergus, Overfelt, & Andress, 2010; Loo & Jones, 2010; Murawski, 2010). The pilots' most important message was that they had not been trained to deal with the recognition and handling of cabin air quality contamination. A claim, which was repeated in the AFA and USAPA's letter to the FAA by stating that: "None of the crewmembers recognised the significance of what they were being exposed to until it was too late" (AFA & USAPA, 2011). The conference attendee list notes a global representation of participants of aviation regulators and airframe manufacturers. Sponsoring authorities were aviation authorities from the UK (CAA), Canada (Transport Canada), Brasil (ANAC), Australia (CASA), Singapore (CAAS) and Europe (EASA).

Since the issue had now been deferred to the FAA, the AFA collected further necessary evidence describing airline's failure to consistently comply with SDR (smoke/fume event reporting) regulations (AFA, 2011b) and broadened the matter into an airline's operational issue. This was initiated by the NTSB's refusal to accept the necessary thresholds to start an investigation. Including 9 of the 11 events from the aircraft with tailsign #234, the AFA collected a total 87 incidents in the 2-year period from 1 Jan 2010 until 31 Dec 2011 for one component of this airline's operations. The airline was copied in on AFA's letter to the FAA, requesting: "(1) an investigation into alleged violations of SDR requirements by Xyz airlines; and (2) regulatory measures fleet wide to protects against exposure to all fumes in the aircraft cabin and flight deck (AFA & USAPA, 2011). The letter included:

- "Improved airline reporting of events, and penalties for non-compliance with SDR reporting rules;
- Immediate requirements for requisite crew education/training to recognise and respond to potential oil fume (…);
- Requisite preventive maintenance/inspection practices (…);
- Phase in requirement for bleed air monitoring equipment that operates in real time with flight deck indication, suitable bleed air cleaning equipment, and less toxic oils."

(AFA & USAPA, 2011)

The letter also included a part on how health and safety impairments were a common theme:

> During some of these flights, the safety and security of flight was compromised. For example, one or more flight attendants reported symptoms on at least 68 of the flights. As well, one or more pilots reported symptoms during at least 27 of the flights. As an indication of severity of symptoms, one or more crewmembers had symptoms serious enough to require emergency medical care after 27 flights, follow up medical care after 43 flights, and lost work time after 37 flights.
> Worse, an unusual odor and/or smoke/haze was reported on 44 of the flights before takeoff, but of these, only 20 flights were cancelled or delayed, while the remaining 24 flights continued because crewmembers had not been trained to recognize and respond to fumes. Regarding these 24 flights, one or more flight attendants reported symptoms on 21 of them, one or more pilots reported symptoms on nine of them, one or more crewmembers sought emergency medical care after 12 of them, one or more crewmember sought follow up medical care after 13 of them, and one or more crewmember was ill enough to lose work time after 13 of them…for the 87 documented fume events over a two-year period, aircraft mechanical records confirm that oil contaminated the supply air on 41 of the flights, and maintenance identified either unspecified or hydraulic fluid contamination on another 16 of the flights. After 30 of the flights, no mechanical cause was identified, but oil was suspected based on the event characteristics (AFA, 2011b).

The airline responded to the FAA on the 26th of Aug, 2011 expressing surprise about the allegations and providing explanation. The airline responded that "some of the AFA-tracked events were never reported to Xyz airlines in many other instances, no aircraft anomalies were found. For other events, reported odours were traced to a variety of different sources, to include galley equipment, onboard trash, outside air, electrical equipment, dirty water separators and de-icing fluid." The airline also provided explanation why it did not provide a SDR in 44 out of 87 events and listed reasons why it deemed some events unnecessary to report:

- 12 events were not recorded by the crew in the flight deck maintenance log (FDML);
- 23 events did not implicate any failed components;

- 7 events involved reported odors that were deemed innocuous (and no report of adverts symptoms were recorded in the FDML);
- 9 events did not occur in flights;
- 3 events were caused by external factors not associated with the aircraft." (Xyz Airlines, 2011)

The FAA encouraged AFA to seek and maintain a "responsive dialogue" with the airline and the promise to track this through surveillance routine (FAA, 2011). AFA repeated its original concerns in a letter to the new acting administrator of the FAA and provided a counterpoint to the airline's explanations for what AFA saw as its failure to comply with fume event reporting rules:

> The SDR reporting rules state that an airline must report 'each failure, malfunction, or defect concerning an aircraft component that causes accumulation or circulation of smoke, vapor, or toxic or noxious fumes in the crew compartment or passenger cabin during flight' (14 CFR 121.703(a)(5)). Some of the 57 incidents occurred on the ground, not "in flight." Still, the FAA requires that smoke/fume events occurring during ground operations must also be reported if the airline considers that flight safety either is or may be endangered (14 CFR 121.703(c)). Presumably, the captain cancelling a flight because of smoke/fumes is reason enough to believe that flight safety may have been endangered, had the aircraft been dispatched. Still, [Xyz] airlines failed to report some of those events, too. And the remaining 30 events had characteristics consistent with exposure to oil fumes, including particular odors, reported illness, and some cancelled/delayed flights.
>
> ….
>
> As an example, on November 23, a [Xyz] airlines crew refused A319 aircraft #[345] at the gate in Richmond, VA because of an unusual odor that maintenance said was oil fumes. Although maintenance told the flight attendants to stop boarding passengers, they were on the aircraft for 50 minutes until the company confirmed that they could get off. That day, all three flight attendants went to the ER [Emergency Room], and two were admitted to the hospital for four days, while the third was released from the hospital that day. Any health impact on the passengers is unknown. Maintenance has since confirmed that the APU oil reservoir was overserviced, causing oil to leak into the bleed air supply, resulting in oil fumes that were delivered directly to the cabin.
>
> ….
>
> Also in his August 26 letter, Mr. Isom claims that 'in many instances, no aircraft anomalies were found.' This is true – in 30 of the 87 documented smoke/fume events that we cite, all of which had characteristics strongly suggestive of oil or hydraulic fluid smoke/fumes, maintenance workers did not identify a specific component failure. But the presence of a strong odor or visible smoke that sends crewmembers to the emergency room, for example, is strongly suggestive of a "failure, malfunction, or defect," whether or not maintenance had the time and tools to identify the specific source. Exposure to "onboard trash" does not send people to the ER [Emergency Room] (AFA, 2011a).

AFA also urged the FAA to facilitate a meeting with the airline and the FAA and to enforce a collective review of the incidents. At this point the FAA refused to impose such a meeting and recommends that "the best course of actions is to continue to engage Xyz airlines with your concerns" (FAA, 2012a). AFA eventually filed a Freedom of Information Act request. At least the releasable portion was communicated to AFA, thereby closing the investigation. The main conclusion from the FAA was that in the Xyz airlines response to the investigation,

> the difference in opinion on most SDR events was due to how reporting is handled for events that occur on the ground. (…) Additionally, it is Xyz' Airlines opinion that most of the SDR

events in question, there was no accumulation of circulation of smoke, paper or toxic noxious fumes in the crew compartment passenger cabin during flight. Therefore, no SDR was required for those type events (FAA, 2012c).

After a consultation with Xyz Airlines and after further review by this office, we have determined that Xyz Airlines complies with the FAA CFR's regarding SDR reporting requirements. Therefore, we have concluded our investigation into this matter and have determined this matter does not warrant any enforcement action. This office considers this matter closed (FAA, 2012b).

AFA & Airline's perspective matrix													
	Risk	Safety	General frequency airline	Recognised reporting channels	Alternative explanations	Investigation	Symptoms/ effects	Source of events	Definition of the issue	Regulations	Compliance reporting	View on aim of reporting
AFA	both recognise that it is a potentially serious matter	Broad definition	excessive number of smoke/fume events	Crew reports & SDR	none that can explain the severity of symptoms	Investigation requested by authorities	reports effects in the forms of symptoms	root cause engine oil, hydraulic, overfilling enegine	variety of sources all lead to the same known issue	non effective	non-compliant	assist with tracking, not enough to solve the issue
Airline		Narrow definiiton	infrequent	SDR only	galley equipment, onboard trash, outside air, electrical equipment, dirty water separators	Internal accomplishment of necessary maintenance	does not address symptoms	majority "not attributed to pyrolised oil or hydraulic fluid	single cause cannot be esatblished	complied with regulations	compliant	no view expressed

Table 4: AFA & Airline's perspective Matrix

Discussion of Case Study 2

The views expressed by the airline and the crew union on the possible correlation of fume events are far apart. A schematic overview of the differences is provided in table 4. Whereas the airline sees an infrequent series of unrelated events from which it considers the risk is managed by individual evaluation and maintenance accomplishment, AFA identifies a pattern of frequent manifestations from a single risk. There are only a few findings on which the airline and AFA seem to agree. This is primarily the hazard involved, which both parties recognise as a potentially serious matter (Cf. table 4). Furthermore, the airline acknowledged on several occasions that engine oil and hydraulic fluid have contaminated cabin air on several occasions and thereby caused symptoms. It is only by the effect of these symptoms that AFA has gained knowledge of those events that were not covered by SDRs. Access to such information was only gained by documentation from attorneys retained to represent the affected crews in worker's compensation claims. This poses an issue of position power in relation to the access of information. The airline normally is the only one with central access to the data and therefore critical relational thinking by triangulation of data is nearly impossible for external parties. This is germane to structural secrecy as a system property in which information cannot travel freely through the system because of organisational structures. But more than structural secrecy as just an unintended system property, it also contains position power and creates power differences in actors' access to and control of agendas (Antonsen, 2009, p. 186) "When organisational decisions are made, the decision processes are always preceded by selection processes that singles out which alternatives are worth considering as viable. (Antonsen, 2009). AFA invited to look into an alternative. One that was up to that point not considered a viable explanation by the airline.

AFA's perspective states that "SDR rules do not prevent events, but at least they assist with tracking. The problem is that there is ample evidence of non-compliance" (AFA, 2011b), by which it refers to the fact that in many cases SDR were not filed, even if required by the reporting regulations. Apart from restricted access to technical information, AFA's view about SDRs also implies that compliance is not sufficient to create safety, as it states that "regulations to prevent and quickly identify exposure are wholly inadequate" (AFA, 2011b). It further notes that the "only relevant operating Federal Aviation Regulation (FAR) is a maximum allowable limit for Carbon Monoxide[15] exposure with no means to ensure compliance" (AFA, 2011b). Whereas the actual communication exchange is one about reporting compliance, even the views expressed on the level of protection that is provided by fulfilling the regulations are very different (Table 4).

The regulation to merely monitor Carbon Monoxide (CO) is marginal in the light of the published science about the risk of neurotoxins and asphyxiates from triaryl phosphates and volatile organic compound from both engine and hydraulic oil. CO sensors are neither required nor installed, so the discussion is hypothetical when it comes to real time monitoring. CO is odourless and colourless and will not even be detected when the regulation's exposure level is exceeded.

The airline's view could be regarded as a belief that safety is created by previous prepared rules that are fully able to protect the public. The airline defines safety in a narrow way, as the absence of an accident, whereas AFA applies a broader definition of safety; one which includes the prevention from any harm to people. But AFA's view is also proactive in defining that "safety and security of flight was compromised" (AFA & USAPA, 2011) by crewmembers that could not optimally fulfil their duties because of impairments. The airline's view on the other hand is retrospective as the

[15] Carbon Monoxide is only one of many markers for possible bleed air contamination (ASHRAE, 2013; SAE; 2008)

post-flight analysis produced no accidents. AFA pointed to the fact that some of these symptoms lead people to receive hospital treatment and medical care. It is surprising that the airline does not communicate about the significant number of people that reported symptoms and needed medical care. "One or more crewmembers had symptoms serious enough to require emergency medical care after 27 flights, follow up medical care after 43 flights, and lost work time after 37 flights" (AFA, 2011a). In lay terms, this would be called work accidents, but because of the difference with the aeronautical definition these are not considered. In its defence to AFA's allegations, towards the FAA and NTSB, the airline did not express any views on the fact that all but one crewmember on flight #123 lost the ability to work after the specific incident. This is especially surprising because oil leaks were confirmed and the onset of symptoms occurred during flight and included passengers. The airline thereby defines the absence of an accident purely in aeronautical terms. One should be mindful that public protection of the health of passengers is absent from the whole defence of AFA's allegations in response to the authorities.

AFA's critique in relation to a lack of adequate operating regulations and the lack of a means to quickly identify exposure is in line with earlier findings from the chapter on the regulator's perspective and the problem of objectification. The scope of the regulator in this thesis was previously limited to the EU, but these regulations are literally mirrored by the US regulations from which they are derived. CS 25.831 (EU) ventilation requirements are for example addressed in its counterpart CFR §25.831 (US). This is the reason why they have identical regulation reference numbers. An earlier critique by the German BFU that the engine and APU certification requirements in the EU do not eliminate the hazard of occupants sustaining health impairments through cabin air (2014, p.73) is also true for the US requirements stipulated in FAR §33.75 (FAA, n.d.-c) titled 'Aircraft engines: Safety analysis'. Even if one accepts that the causality for health effects has not yet been established on a number of incidents, including flight #123, it could be even more worrying that it is not so much a proven causality which is missing but an investigation into a possible causality is denied.

Once more the face of 'non-decisions' presented earlier as the ability to keep potential issues out of decision-making processes, prevails from commencing technical investigation and full disclosure of data. The airline for example, decided not to share any information above what is defended as the strict reporting compliance minima. The airline might consider patterns of symptoms as unrelated and deny causality, but still allow further investigation to exclude hypotheses it does not support, for example to restore trust between employees and employer. It is also surprising that the airline did not use the investigation opportunity to find supporting evidence for its beliefs that this and other aircraft of its fleet provide a safe worker's environment, especially when workers complaints are pending.

Non-decisions were not only noted from the side of the airline. They were also produced by NTSB's refusal to start an investigation. Additionally, the deferral of responsibility from the NTSB to the FAA caused a shift from a safety issue into a reporting compliance issue, which resulted from the NTSB's statement that it 'has no regulatory authority over airlines operations'. This is also the simple and unintended consequence of the stringent separation of safety and operational accountability between the NTSB and the FAA. Dekker described such mechanisms as the bureaucratization of safety and the distribution of decision-making. This author also mentions that since the seventies an accelerated bureaucratization of safety and an increase in safety as measurable bureaucratic accountability have brought secondary effects that run counter to its original goals (Dekker & Nyce, 2014). Safety is not automatically created by the measurable accountability of mere reporting compliance.

"Bureaucratic distribution of decision making across different units in an organization . . . can exacerbate it." (Rasmusssen, 1997, as cited in: Dekker, 2014a) This is closely related to the structural secrecy mechanism as the "by-product of physical and psychological separation between operations, safety regulators and bureaucracies", the principle by which "critical information may not cross organizational boundaries, and mechanisms for constructive interplay are lacking" (Vaughan, 1996, as cited in Dekker; 2014). The separation between safety and operations is artificial and does not necessarily represent factual boundaries. When the issue was deferred by the NTSB (safety) to the FAA (operations), AFA just stuck to its previous rationale, which was one of matching patterns for a sign of trouble deeper inside the system. Instead of looking for a pattern of events on a single problematic aircraft, AFA seemed convinced that the safety issue would become even more pronounced when such a pattern could be demonstrated on a broader set of operations. The airline on the other hand stuck to its original perspective of non-related isolated events in which every report was scrutinised on a one-by-one basis for meeting the definition of reporting compliance. Finally, the focus on measurable bureaucratic accountability in terms of reporting compliance, gained more value than a substantive response into a better understanding of the issue. Even when the regulations do not cover health impairments, and the definition of an accident is interpreted purely aeronautical, this collection of events at least raises concerns that were unanswered by an alternative explanation. In contrast to the difference in perspectives, one of the only shared views between the airline and AFA from the findings section was that both recognised the hazard involved as a potentially serious matter.

This case study is also a part of the chapter on hidden signals because without the attorneys' worker's compensation claims documentation, there would be no trace for data triangulation between health complaints and maintenance data. Worker's compensation claims do not belong to the realm of standard information channels. Normally workers and their representatives have little to no access to technical data. In the US, the only route is via SDR, but AFA noted that in many cases SDR were not filed despite the requirements. The position power of accessibility to information also constitutes a form of power. This power is different from coercive power, but is exercised by defining what are "legitimated procedures for the acquisition and (re-)production of knowledge, which often operate largely invisibly and silently in any field of inquiry"(Dekker & Nyce, 2014, p. 48). This was for example noted by the semantic discussion in the difference of opinion on ground operations. The FAA's acknowledges that 'the difference in opinion on most SDR events was due to how reporting is handled for events that occur on the ground', and thereby also accepts its bureaucratic role to answer to a reporting issue, not a safety issue. Therefore, it becomes important to understand how systems with bureaucratized safety systems are allowed to address questions, or how, not only how they answer them. The mechanism of how certain questions cannot be asked is again described by Dekker: "Bureaucratic accountability not only implicitly and explicitly specifies the kind of data that counts as evidence (and may disincentivize the reporting or classification of certain data), it also determines who owns it up to where and from where on" (Dekker, 2014a, p. 352). An investigation into this event could have provided valuable information to solve the debate between the competing discourses. All the ingredients for investigation of a possible causal relationship were present. Oil and hydraulic fluids leaks were confirmed. The aircraft was involved in a series of incidents in which crew members and passengers needed medical care and nearly a whole crew lost the ability to work. Therefore, the absence of an investigation cannot substantially answer AFA's safety concern as no data from an independent investigation was gathered. Although the paradigm that defends the lack of a causal relation seems to tacitly dominate the authorities' decision, no data was gathered to challenge any of the two paradigms.

Safety investigations might be the NTSB's responsibility, but the aviation regulator FAA would be responsible for some aspects of safety, including training issues. This was specifically addressed when the pilots of flight #123 urged the FAA at the Fire and Cabin Safety Conference to take initiatives to train crews to recognise and handle cabin air contamination events. One of the main findings of the crew unions was that none of the crewmembers recognised the significance of what they were being exposed to until it was too late. The cabin crewmembers noticed a smell during push back, but did not communicate that to the pilots as they were not informed about the existing safety recommendations from regulators around the world as discussed in chapters elsewhere in this thesis. It is important to not only produce safety information, but also to make this information travel through the system. The fact that the crewmembers only recognised the significance of what they were being exposed to until it was too late, was already mentioned in another case by the Swedish captain of the SE-DRE a decade earlier: "[we] didn't realise that we were being intoxicated before we were really ill" (Hansen, 2006).

Such earlier reports and their recommendations (see report SHK, 2001) did not seem to have reached this US crew. Critical information has not crossed organisational boundaries, and mechanisms for constructive interplay are lacking" AFA therefore also addressed the need for proper training and identification of the risks as a safety concern to the FAA:

> …an unusual odor and/or smoke/haze was reported on 44 of the flights before takeoff, but of these, only 20 flights were cancelled or delayed, while the remaining 24 flights continued because crewmembers had not been trained to recognize and respond to fumes. Regarding these 24 flights, one or more flight attendants reported symptoms on 21 of them, one or more pilots reported symptoms on nine of them, one or more crewmembers sought emergency medical care after 12 of them, one or more crewmember sought follow up medical care after 13 of them, and one or more crewmember was ill enough to lose work time after 13 of them. As an example, on one of those flights, the flight attendants reported a dirty socks odor during ground operations, but the aircraft was dispatched anyway. Upon arrival, the aircraft was met by ambulances that took the entire crew plus seven passengers to hospital. As of this writing 18 months later, four of the five flight attendants from that flight are still off work with chronic neurological and respiratory symptoms, as are both pilots who have each lost their medical license to fly because of health problem that their doctors attribute to the fumes exposure. (AFA, 2011a)

The labelling incidents and accidents is not merely a semantic discussion. Recognising an incident or accident, and even the decision that a specific event deserves an investigation, has an important signalling function on overall organisational learning. Incident reports account for what is officially recognised as a risk and transmit the will to learn from an earlier course of events. They are also an efficient way to overcome isolated operator experiences as incident reports in aviation are part of the public domain and are often used by airline's training departments or so-called 'share your experience' programs.

In the end, AFA said it did not see SDR reporting as enough to solve issues, it just helps in tracking them. Still, the SDR compliance seemed the only means to escalate its concerns to investigate and better understand the issue. Safety systems depend on critical relational thinking. It was the chance to engage in such relational thinking that was denied to begin with. Neither the pilots' plea for better future training at the 'Fire and Cabin Safety Conference', nor AFA's plea for an investigation created concerns to further airlines and regulators.

One of the consequences of not having an investigation is that there is no information available of this critical case study to foreign aircraft investigators or regulators. Thereby even such critical events remain a non-issue. Concerning flight #123, the airline acknowledged an engine seal leak in the media, crew members and passengers ended up in the emergency room, the pilots' licences were revoked by the FAA on the basis of their symptoms, 4 crew members from a single flight are off work until today and the same aircraft was involved 11 fume events in a 3 month period. EASA, the EU regulator based its 2012 decision on the absence of a safety case, two years after flight #123 There exists a risk when decision makers rely on signals, isolating 'bits of telling information' as shortcuts for the full data. It creates systematic censorship that filters information before it can be assessed and we are unable to know if EASA would identify this specific case as a safety case when it has simply no knowledge of it. Not even the serious efforts form pilots or crew representatives to escalate this incident created a visible signal of concern. Therefore, this case study is not only an example of a hidden signal, but is also labelled critical because it disproves an earlier hypothesis of the EU regulator assessment, being that it is aware of all the events that take place and there is no underreporting (EASA, 2011). This specific case shows that structural secrecy can sometimes be more powerful than courageous personal attempts. In the end, pilots that meet with the FAA and NTSB or speak up at safety conferences to share their experience and advocate for better training and recognition of fume events might not have the same impact than some inadvertent bureaucratic mechanisms, regardless from the fact whether these series of events deserved an investigation. Bureaucratic decisions whether investigation will or will not take place, inadvertently have great influence on which critical information crosses organisational boundaries.

DISCUSSION

The thesis title asks the question how to define a problem considering the competing discourses This was examined by which signals were generated and how these signals were interpreted in relation to flight safety.

The central question was accompanied by a set of sub questions, being which conceptual definition emerges from the incident reports conclusions and recommendations, and being which signals are taken into account to assess the flight safety aspects of the issue. Thereafter, I explored how the regulator defines the problem and consequently manages it.

The different chapters showed that often existing signals were not transmitted further down the system, mainly because they were not defined as a problem to begin with and this created circular problems of definition.

The first chapter about incident reports looked at the definition in terms of input, a trigger to start an investigation and an output, the definition of the problem space from a regulator perspective. I relied on the fact that the phenomenon would reveal some of its essential properties by looking at the data it has produced itself as part of the incident reports. In part, it did by revealing that the problem has only been the subject of investigation in Australia and the EU, but was absent in other parts of the world, even if there was a shared global concern in the literature and frequency of events was distributed across all aircraft models (Shehadi et al., 2015). The US case study shows that in one particular event where an engine and a hydraulic leak were acknowledged, crew's losing their medical certificate and emergency room visits by passengers, did not trigger an official investigation outside the airline. This tells us that whatever the issue is, there are great differences in its investigation. The difference in visibility is related to either a difference in institutional designs or is the effect of Bachrach and Baratz' concept of 'non-decisions' (as cited in: Vakas, 2007, p. 37). In the latter case, other interests are prevented from engaging in decision-making or undermined via agenda setting. The subsequent lack of visibility poses the problem that the regulator does not have a complete picture of the issue. The regulator is not able to assess the full set of data and signals, because interpretation is applied beforehand and subsequently signals are filtered out before reaching the regulator, unaware from processes of acquisition and (re-)production of knowledge from other departments or agencies. The definition of the problem on the one hand, and collection & interpretation of signals on the other hand, are strongly related to each other. Competing discourses and the lack of a unanimous definition behind which airlines and manufacturers can hide, restricts the collection of the full data (see chapter 5, both case studies). Additionally, the regulator has no reliable database information for a central assessment of the frequency of occurrences. Neither will such events completely fit state taxonomies. This was supported by the fact that many existing incident reports, which I had obtained through other channels, could not be found by common search terms in the national databases.

The flight safety issue in relation to fume events can take several forms. Most easy to recognise is the straight forward effect of reduced visibility and immense workload created by observable smoke (AAIB, 2007b). Other effects arise when the proper execution of flight crew duties becomes obstructed by impairments (AAIB, 2007a; ATSB, 2001a) or even incapacitations (AAIB, 2007b; Swiss Federal Department of Transport, 2006a). Note that in most cases fume events are not accompanied by smoke and therefore the biggest threat to flight safety comes from subtle, sometimes multiple crew members' incapacitation; especially when it affects pilots' decision making (AAIB, 2004b; ATSB, 2001a, 2003a). Note that the neurotoxins itself are colourless and odourless and the only method of detection is by smelling the by-products of other non-toxic components of the engine oil or aircraft system fluids (Ramsden, 2011). The ambiguity of subtle incapacitations that additionally affect cognitive functions and decision making and from which the exact causative mechanism is not yet fully understood poses a flight safety threat.

This nourishes the ambiguity surrounding the two paradigms that are indicative for the competing scientific discourses. One paradigm refutes a causal relationship by trying to explain specific reported symptoms by what it believes to be the most critical chemical. The other paradigm bases a precautionary interpretation on known neurotoxic properties from the chemicals involved and a priori expects an atypical symptomatology. In contrast to the first paradigm it identifies the mixture to be more critical than a single critical chemical.

When accepting the paradigm that a causal relationship is unlikely, many existing reports are not assessed as valid manifestations. However, there is a contradiction in refuting the absence of a causal relation as the most important stakeholders do not deny the existence of crew impairment and incapacitation due to fume events. Many authorities have acknowledged that crew impairments in relation to contaminated cabin can occur: technical engineering committees SAE (2005) & ASHRAE (2016); United Nations aviation agency ICAO (2015b), US regulator FAA (FAA, 2004), UK regulator CAA (2002), EU regulator EASA (2011) and Australian's CASA (2014); and last but not least many national aircraft accident investigations branches (AAIB, 2004b; BASI, 1999; BFU, 2014; Swiss Federal Department of Transport, 2006a). On the other hand, the second, precautionary-oriented paradigm focuses on the known neurotoxic properties of numerous identified chemicals and the potential of their synergetic effects. It has not been able to prove the exact causative mechanism in specific incident cases. This absence of proof can be explained by the lack of epidemiological data and the fact that human biomonitoring effects from affected crews are mostly unavailable, both paradigms have something in common; neither side can explain or dismiss the exact causative mechanism.

Stakeholders with corporate or liability interests can deny a causal relation by hiding behind uncertainty and ambiguity created by the two competing discourses and the unresolved matters at the core of the issue. It was critiqued by previous authors elsewhere in this thesis that those studies and scientists that cannot find a causal relation have never assessed the full toxicological set of identified chemicals or synergetic effects (V. Harrison & Mackenzie Ross, 2015; S Michaelis & Murawski, 2011; Ramsden, 2011) and follow-up research after early concerns has never been performed (Michaelis, 2010). A small set of reassuring studies, said to be cited by the industry (Ramsden, 2011), often derived their reassuring conclusions from a relatively small set of non-incident flights. My personal reading of these studies supports the fact that scientists, such as the authors of the Cranfield or the KLM-partnered study, have not disproven a causal relationship all together, but have studied very limited qualitative or quantitative scopes. My personal reading also supports that scientists made conclusions that were outside the scope of their own study in line with Ramsden's critique (2011) (Cf. Chapter 2).

The competing interpretation of causality acts as a structural filtering mechanism to either accept patterns of symptoms as causally related, or dismiss them as unrelated isolated events. Depending on the diverging sides of the burden of proof this interpretation leads to the generation of signals that deserve further investigation or alternatively to the creation of non-issues. This leads to an absence of agreement between official investigations and regulators on which risk mitigation measures should be taken. The problem space that subsequently emerges is not explicitly described, but can be derived from the political inertia that does not respond to existing recommendations. Whereas several investigation bodies have recommended early recognition or mitigation more upstream of the system, the regulator has only answered by last defence barriers. The difference between official investigations' recommendations and the regulators' answers can be better understood if one understands the underlying constructions of risk and competing discourses of causality. But it is also explained by the fact that a poor definition of the problem and the generation of further signals dampen each other out. The irony is that the regulator itself prescribes sensors in its airworthiness regulations (EASA, 2007; FAA, n.d.-d), but seems not to require airlines and manufacturers to comply (EASA, 2011, 2012).

The regulator's causality view is based on a small set of studies only. Inevitably the regulator relies on interpreting signals, rather than assessing the full set of data. This is accompanied by mechanisms of specialisation and uncertainty that act as 'sources of systematic censorship'. More than focusing on the mere toxicological details of the competing discourses introduced in this thesis, this thesis highlights the risks of the ambiguity created by the competition between discourses and by the risk of relying on signals as bits of telling information. This reminds of the analogy with NASA's Columbia crash from which Dekker and Nyce described that flight risks were misunderstood because of "systemic products of overconfidence in quantitative data, a marginalization of non-quantitative data, an insensitivity to uncertainty and loss of organization memory" (Dekker & Nyce, 2014, p. p.45); and also critiqued "the illusion that engineering problems and solutions could be addressed independently from organizational goals" (2014, p.45).

Therefore, this thesis encourages regulators to rely on more than mere statistical information and understand the nature of the issue, including its own role. The regulator relies on the very subject of future regulations as a primary source of data and does not assess the risks of losing the regulator-regulated distance. From the comment response document to EASA's 'advance notice of proposed amendment', some airframe manufacturers acknowledged they had statistical data on air contamination by engine or APU but openly stated that they cannot share it with the Agency (EASA, 2011). The regulator did not challenge the airframe manufacturer about this attitude or the airlines reluctance to provide data (2011).

Regulators should identify further shortcomings in their way to manage the problem, which was identified as the lack of a definition and objectification of the problem. These circular objectification problems are responsible for the fact that the disagreement between the competing discourses has not been resolved for several decades.

This thesis also advocates a fuller investigation of the full data, especially because many concerns and knowledge gaps have been identified (C. Van Netten & Leung, 2000; C. van Netten & Leung, 2001; Winder, 2002; Winder et al., 2002), but not answered (de Boer et al., 2015; V. Harrison & Mackenzie Ross, 2015). Certification and airworthiness could embrace the issue by introducing stricter and more prescriptive regulations for bleed air purity. Today the regulations describe initial certification limits for Carbon monoxide, Carbon dioxide and Ozone only, whereas Swedish and British investigations (CAA, UK,, 2004; SHK, 2001) identified several hundred additional chemicals in the bleed air, often with neurotoxic properties, found in heavily contaminated ducts (CAA, UK,, 2004). Mandatory sensor requirements are not enforced. Regulations are not specific on how bleed air problems should be prevented or maintained (EU, 2003; FAA, n.d.-b) for continued airworthiness during an aircraft's lifespan, typically several decades. Certification specification regulations are inadequate, continued airworthiness regulations are non-existing and sensor regulations exist, but are not enforced. This thesis identifies a need for future research to scrutinize existing regulations.

The regulator also has the fundamental duty to interpret flight safety, directly related to the research question. One should be mindful that the regulator acts only on its own construction of safety, which was deconstructed first. The first part of the research question 'which signals the socio-technical system has generated in relation to cabin air contamination' can be answered by a multitude of examples throughout this thesis. Crew reports, incident investigations, official committees, mandatory occurrence reports and scientific papers together identified several thousand fume events that were communicated as concerns within the boundaries of specific organisations or committees. As Vakas noted, when one would not consider the questions raised about causality and assess the mere medical symptoms that crew reported, this would have created serious safety concerns (Vakas, 2007). Strong signals from the evidence of former oil leaks, the signature of pyrolysis products in the air ducts (CAA, 2004) and reported medical symptoms became mixed with the weakness of the correlational evidence. In this form the signals never crossed the border of one organisation, nation or committee. Nevertheless, the case studies from chapter 5, the statistical positive cause-effect correlation from chapter 1, and the many acknowledgments of the problem and consistent unanswered scientific concerns in the timeline analysis from chapter 4, leave to many open questions from a problem whose manifestation is often invisible and subtle (Ramsden, 2011) and is additionally recognised by official investigations to affect decision making (AAIB, 2004b; ATSB, 2001a, 2003a). The recommendations that have been produced focus on assuming worst-case scenarios by pilots in the form of putting on oxygen masks in the case of unexplained symptoms. Paradoxically this has not forced the regulator or manufacturers to apply the same worst-case scenarios reasoning they expect form pilots in their risk assessment. EASA concluded it sees no safety case that would justify a change in its rulemaking (EASA, 2012). The regulator describes the use of oxygen mask as a successful mitigation strategy. The uncertainty on which this primary risk mitigation measures is based suddenly disappears when the risk is assessed.

It is at the crossroads of regulation circumstances, recognition of signals, and what is accepted as valid evidence, where the conceptual definition from the incident-report-chapter, the construction of risk from the regulator-chapter and the regulators' response (or lack of response) meet. The schematic representation in Figure 2 on page 39 showed that the aircraft investigations called for better means to objectify the problem with a better toxicological understanding and standard biomonitoring requirements, but also to pro-actively support crews' decision-making by installing sensors.

What emerges is a problem space of an issue from which the manifestations are recognised, but from which the exact causative mechanism is not fully understood and from which the regulator believes that a catastrophic outcome can be controlled by last barrier defences. The regulator's problem space assesses flight safety in relation to effects located downstream of the system in close proximity to the actual incidents with a retrospective classification that can only be applied after the effects have already manifested themselves.

From the 55 official incident investigation reports that were analysed in this thesis, 36 reports did identify leaks. Other thesis chapters in which sources, other than official investigations, such as case studies and Mandatory Occurrence Reports, showed identical findings and confirmed that a significant number of leaks and spills occur. A typical example, a UK MOR collection of events over a 5-year period produced 37 identified cases of engine oil leaks and an additional 26 APU or occurrences of engine oil overfilling. Such pure technical findings were complemented by narratives that showed that maintenance saw fume events as a typical maintenance problem. In one case study, causes ranged from engine to hydraulic leaks and subsequently contaminate insulation blankets (Nayak Aircraft Services, 2009). This same maintenance documentation also described that the problem is hard to identify and hard to mitigate, even hard to reproduce on ground (Nayak Aircraft Services, 2009). Existing official incident reports have provided similar narratives on technical troubleshooting difficulties and the 'messy details' of maintenance work.

Therefore, the regulator's problem space in relation to effects located downstream of the system in close proximity to the actual incidents should be corrected for a problem space that should focus on the fact that oil and hydraulic leaks are accepted as an incremental deviance from the design requirements. With the results from this thesis I introduce a new definition of the problem space: **"As a significant number of oil leaks are documented, which create a foreseeable problem, the problem space becomes by which means the regulator protects public health and safety."**

The status of this definition in close proximity to the technical cause of the problem, becomes even more important because of several further findings in this thesis that acted as a filtering mechanism on the creation of strong signal in relation to flight safety:

- systematic forms of censorship on several levels of the socio-technical system,
- systematic forms of structural secrecy,
- normalisation effects,
- primary troubleshooting did not identify the actual leak (often leading to several further flights with crews unaware of the contamination before rectification occurred),
- critical information has not crossed organizational boundaries
- a safety problem that is treated as a maintenance problem,
- a safety concern that is replied by the authorities as a matter of mere compliance,
- bureaucratised distribution of decision making, which can run counter its own original goals
- loss of organisation memory

These mechanisms hide the already accepted incremental deviations from the initial design requirements by contamination of engine oil or hydraulic fluids becomes normalised. Such normalization of deviation effects can occur because the system's problem focus is on its effects and not on technical and social deviations from the norm. The mere fact that contaminations happen have become an acceptable risk and provide one more example how a problem is not defined as a problem.

The risk of the regulator retrospectively assessing a problem in relation to effects located downstream of the system in close proximity to the actual incidents instead of the above suggested origin is best demonstrated by the documentation that was provided by the European regulator itself (See references to EASA CRD, 2011). Its depiction of the events was contrasted with actual information from other sources in the same years that differed substantially in qualitative and quantitative nature. EASA's construction of risk amongst others relied on the fact that EASA thought this issue largely disappeared after an increase of reports around the years 2001 and 2002. This seems not only disproven by the very same databases the regulator used, but also by concerns from the current literature and the presented case studies. The regulator is overly dependent on the aviation industry for the interpretation of frequency and severity of the issue. This is problematic issue for a healthy regulator-regulated relationship.

This thesis identified the mechanisms, reasons and examples that enable a problem not to be defined as such. Exposing such mechanisms in the language of social safety science is an important contribution from this thesis. This adds to the earlier studies from Vakas (2007) who has researched the social construction of health and safety in the Australian Senate committee form a social science perspective and Michaelis (2010) who has in several parts of her PhD provided in-depth descriptions of withheld information and hampered organisational learning. The mechanisms of systematic censorship are supplemented by the vested interests of aviation industry. This industry gave evidence of actively engaging in the non-production of signals when it stated in the regulator inquiry that it was is not willing to share statistical data. Examples were also found in the case study chapter, and were present in the historical description from the Australian Senate. As Vakas noted when writing about the issue of cabin air contamination, studies can become tools to arguments and actions in meeting the objectives of particular interests, through selection and omission of factual information (Vakas, 2007, p.52). Aviation industry was cited to turn scientific indeterminacy into a selective certainty of no evidence as identified by Vakas (2007) or Ramsden (2011). This is part of describing an issue as a non-issue, again by means of its definition, the central theme of the thesis title. The regulator creates the conditions of ambiguity by a lack of regulations and especially by sustaining a problem of identification. Rather than solving the causality question debated in the competing discourses from the thesis title, it creates the conditions that create and maintain the ambiguity to begin with and create mixed instead of strong signals.

Frequent citations by aviation industry of a weak correlation became mixed with earlier strong signals that are subsequently labelled as rare events. This constructs a message of acceptable risk. Possible forms of vested interests, as a form of individual secrecy, can better be understood when one understands how it its facilitated by structural secrecy. Earlier research (Michaelis, 2010; Vakas, 2007) and journalists (Hinrichs & Van Beveren, 2014; Learmount, 2008; van Beveren, 2013) have described vested interests in relation to this issue. Rather than describing such vested interests, this research has put more focus on describing the enabling structural mechanisms that explain how essential information can get lost in the system.

There is little access to information of patterns of events. These events are not defined as more than isolated events, so it is difficult to reconstruct bothered histories pertaining to certain aircraft registrations or specific parts of a fleet. This restriction of access is made possible by fragmented and bureaucratised accountabilities between different responsible agencies. "The proceduralization or bureaucratization of safety assessments may in fact hamper the kind of relational thinking that is necessary to see possible correlations that become relevant or critical in a crisis" (Bieder and Bourrier, 2013, as cited in Dekker, 2014, p.350).

The sub question - how the problem is managed - both follows and precedes these definitional problems. The problem that triggers an investigation is currently defined as "concentrations of toxic products in the engine bleed air for the cabin sufficient to incapacitate (or impair) crew or passengers", which is a circular problem because of the "lack of a definition of toxicity or acceptable levels of contamination of the bleed air" (AAIB, 2004, P.64) Other means to objectify fumes once they have manifested themselves in the form of sensors and biomonitoring are also lacking. Political inertia in relation to managing the problem directly influences the accuracy of the problem's definition.

The absence of an accident is retrospectively assessed, whereas the earlier warnings from regulator communications point to the risk to produce one. Therefore, the difficulty of managing uncertainty and predicting unexpected events often as an effect of bureaucratically organizing safety (Dekker, p.350), clouded by systematic forms of censorship and structural secrecy deserve consideration in an alternative definition of a bigger problem space. The regulator has narrowly defined safety as not having an accident, but has for example not answered the broader definition of safety that includes health problems. If health problems would be accepted in the construction of risk, several people becoming unable to work due to respiratory and neurological symptoms for many years would easily be defined as a serious accident.

The case studies and some incident reports show a critical finding, being that even after all the information which is produced, many pilots were taken by surprise and where not trained to recognise fume events and their risks. They were not trained to recognise and handle fume events. The fragmented information effects that have prevented the pilots from being informed about the lessons learned from earlier committees and incident reports were defined as an important factor in all chapters of this thesis, whereas the Australian Senate committee already recommended in 2000 that "that incident reports should now be specifically designed so as to reflect the history of the cabin air problem" (Parliament of the Commonwealth of Australia, 2000, p. 15).

Systemic issues such as fear of reporting and underreporting are not identified by the regulators to contribute to the problem space of the risk assessment itself. The same can be said about the uncertainties that can emerge from the ambiguity and messy details of maintenance work. The regulator's reliance on what mainly seems a binary view of safety, being that either a condition is safe or unsafe, that can be simply controlled by adding a simple safety barrier, contradicts the uncertain nature of the issue.

CONCLUSION

The interpretation and definition of the risk can best be understood by a bottom-up approach. The answer to the question 'how to define a problem' should be started by pointing to the many gaps in the definition to objectify the problem. Certification specifications currently do not regulate acceptable levels of toxicity. Neither do they describe what is bleed air purity or give a workable definition of a fume event to act as a common trigger to start an incident investigation. The same is true for the means of objectification to assess levels of toxicity once they have manifested themselves. Sensors or requirements for human biomonitoring are not available to flight crews, even when they are prescribed by the regulators' own airworthiness certification specifications. What starts as an objectification problem eventually becomes a lack of adequate means to assure public protection.

The lack of objectification opens an ambiguous, but avoidable debate in all possible directions to interpret the possible effects on crews as described in the incident reports. An internal contradiction of the definition is created as crews are told to accept every event as a possible worst-case, whereas the reaction at the regulators level for further objectification is weak. Many concerns have been identified, but have not been fully researched and uncertainty prevails. In such cases it is difficult to objectify risk:

> When risk is no longer an immediately knowable attribute of the object and the possible harm associated with it depends on other, less knowable factors, we move into the realm of uncertainty and probabilities. Under conditions of uncertainty, the potential for variation in interpretation of risk is even greater. (Vaughan, 1996, p.63)

The way the problem is managed is not an answer to an earlier defined problem, but fundamentally interferes with the possibilities to objectify the problem and therefore also interacts with the definition of the problem space itself. Thereby, the regulator's definition allows an issue, from which we do not understand the exact causative mechanism, but from which the regulator communications warn for its effects, possibly affecting flight crews' decision making. When regulators and airlines rely on last barrier defences such as diversions and the use of oxygen masks to control negative outcomes without gaining further understanding of the issue, structural normalisation effects are created. The discussion between the causality of two competing discourses is created by a problem deeper inside the system, that starts at the regulation level. Safety signals are obscured and therefore the regulator is not able to build a complete picture of the issue. The fact that two paradigms exist in the literature, one of which refutes a causal link, confounds and creates the conditions for structural secrecy and the opportunity to hide behind the bureaucratization of safety.

This thesis defends a deeper examination of the critical cases on the one hand, and pattern-related relational thinking on the other hand. This will lead to a better understanding of the causality involved, but also improve organisational learning from single cases. Both sides of the competing discourses would gain insights from this.

The patterns and relationships that could be identified more upstream of the dominating definition of the problem space, with its strong focus on the effects, paradoxically must wait to establish such relationships until the problem manifested itself. The access to such effects, a wider history of problems is often only provided in hindsight by other incidents or did not even create signals to begin with. The creation of signals is closely linked to the recognition of the status of the scientific knowledge gaps from which all parties essentially accept they exist. To develop a complete picture of the issue, the system should also actively map the scientific knowledge gaps or actively design mechanisms to overcome the aviation industry's refusal to provide data. The history of the issue dates back to the beginning of the use of bleed air, but many of the early concerns have been discounted and discontinued in today's assessments.

One conclusion is that the regulator has too narrowly interpreted the risk. The issue of cabin air contamination deserves to be re-assessed by the full set of data and by thick descriptions. Instead of selective conclusions, the actual scope, limitations and of scientific studies should be understood by decision makers. Patterns should be studied from the raw data that can be triangulated from technical and medical data. Such data should not be governed by position power or filtered out beforehand as anecdotal. Additionally, such data should be systematically collected and investigation agencies should be supported with the proper means to collect such data. Another result of a narrow definition of the problem is that health problems are not covered in aeronautical accident definitions. This does not fulfil an intuitive level of expected public protection. definition of a problem should not be deferred because of the unsolved causal indeterminacy. The bureaucratic and organisational responses were answered as maintenance and compliance issues, but did not provide a substantial explanation for the reported effects in relation to recognised contaminations. The actual problem space that arises from this thesis is concerned with the fact that oil and hydraulic leaks are accepted as an incremental deviance from the design requirements and is concerned by which means the regulator protects public health and safety for a foreseeable problem.

Fragmented information has often prevented earlier or local warning signs to be communicated to the people that depend on this information. Subsequently critical information has not travelled through the system as a safety issue that needs to be more precisely understood and better communicated to crews to be adequately recognised and handled. These are the consequences from a debated problem that lacks conceptual definition, and subsequently treated as a form of isolated events. In this form the definition of the problem itself is too weak to alert crews that were not familiar with the issue in several incidents.

Fragmented information and structural secrecy become a handicap for the system to build a complete picture of the issue. This visibility of problems and events is not only true for earlier events, but even for earlier generated scientific and toxicological discoveries. This is maintained by a position power governed access to information and several mechanisms of structural censorship.

The narratives of normalisation of deviance, ambiguous maintenance signals and eventually contamination sources that seem difficult to master, are not accounted for as an additional risk by airlines and regulators. A safety issue, which can affect the decision-making of crews and lead to incapacitation, but is simultaneously surrounded by great difficulty to be identified by both crews and maintenance, has great potential to cause an accident from a systems thinking perspective.

Paradoxically, if the system would enforce more stringent regulations on the design of aircraft or install the sensors that are already mandated by airworthiness regulations, we might not even have to fully understand the issues that have created so much debate in the events of this thesis and in the literature.

The US critical case study gave a powerful way to understand how the issue should not only be understood by the answers that the system gives us, but also by the questions we can ask of it.

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