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Fume Events in Aircraft Cabins

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Problem Statement

A literature study will be conducted to determine what is known about the phenomenon of fume events in aircraft. The attention on this phenomenon will be clarified among a group of flight crew and a sample of people on Gløshaugen campus.

Main Contents:

1. Perform a literature study; use scientific sources to find out what is known about fume events and following possible health impacts.

2. Describe the technical background of fume events.

3. Give an overview of the severity and frequency of such fume events, given through media coverage and other sources.

4. Conduct a survey among a selected group of flight crew and a sample of people on Gløshaugen campus to clarify if they acknowledge the extent of these events.

5. Discuss the importance of the phenomenon's nature and its extent of attention indicated in the results from the surveys.

Preface

This thesis is the final product of "TIØ4925 - Safety, Health and Environment, Master's Thesis", conducted as a part of our Master's Degree at the Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU). It was formed between January 2015 and June 2015.

First of all we would like to thank our supervisor Kristin Hirsch Svendsen (NTNU) for taking her time, giving us good advice and constructive feedback through the whole process. We would also like to thank our co-supervisor Halvor Erikstein (SAFE) for providing theoretical understanding about the topic, and giving us the opportunity to attend the Global Cabin Air Quality Executive (GCAQE) meeting in London.

Thanks to Pål Haugen Strand (SAS) for arranging contact with Parat Luftfart, and thanks to Parat Luftfart for communicating the survey to pilots and cabin crew in Norway. We would also like to thank Kyrre Svarva at the Faculty of Social Sciences and Technology at NTNU, for helping us with SPSS analysis of survey data.

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Abstract

The inlet for ventilation air to the cabin and cockpit is placed in the aircraft engines. The air supply is known as bleed air, which is used on most commercial aircraft. During leakage due to malfunctions in the engines, such as ineffective or damaged seals, the air may be contaminated with constituents like organophosphates and other hazardous chemicals from jet engine oils or hydraulic fluids. This phenomenon is described as a fume event. Media attention regarding the air-quality in aircraft cabins has the latest years increased. Flight crew and passengers have reported symptoms and negative health effects assumed to be associated with exposure to contaminated bleed air. The aim of the study was to find out what is known about the nature of fume events, and its attention among flight crew and a sample of people on Gløshaugen campus. In addition, it was desirable to clarify the severity and estimate the frequency of such events. A literature study was conducted to examine the technical background and characteristics of a bleed air system, the phenomenon of fume events, and possible health impacts following these events. Surveys were distributed to a selected group of flight crew and a sample of people on Gløshaugen campus, to clarify if they acknowledge the extent of fume events. An overview of possible fume events between January 2007 and December 2014 was compiled by the use of different databases and news articles.

The response rate of the survey among pilots and cabin crew was 21 %. The results from the survey showed that 70.5 % of the 624 respondents were familiar with fume events, while 43.6 % considered air contamination a problem in the aircraft industry. The response rate of the survey among people on Gløshaugen campus was 94.3 %. Of the 100 respondents, 85 % had not heard about such events, while 6 % had noticed an unusual smell or smoke in the cabin. There were found 701 possible fume events, which resulted in an estimated frequency of 0.24 events per day. Researchers have attempted to find whether there exists any connection between reported health effects and fume events. Fume events have not been manifested by measurements or sampling of contaminated air during an event, but it is assumed that aircraft occupants can be exposed to a “chemical cocktail” of contaminants. Some of these chemicals are known to cause symptoms and adverse health effects.

The general knowledge about fume events among flight crew is considered relatively good. Although the number of respondents in the survey among people on Gløshaugen campus is low, the results indicate that academics have less knowledge and attention about fume events than flight crew. Compared to other results from previous studies, the estimated frequency of such events is low. However, oil leakage episodes are known to be underreported due to variations in thresholds by flight crew to report an event, as well as subjective assessment of the air-quality. Further research is necessary to clarify whether the reported negative health effects can be explained by fume events. The air-quality in aircraft needs to be measured by the use of incident samplers. These should be placed in all aircraft to continuously measure the concentrations of contaminants entering the cabin and cockpit during a fume event. If the general population acquire better knowledge about fume events, the aircraft industry may be willing to implement mitigating measures to prevent such events, given that they are proven to cause the reported health impacts.

Sammendrag

Inntaket for ventilasjonsluften til kabin og cockpit er plassert i flymotoren. Lufttilførselen er kjent som “bleed air”, og brukes i de fleste kommersielle fly. Ved lekkasje i motoren, eksempelvis som følge av ineffektive eller ødelagte pakninger, kan luften bli forurenset med organofosfater eller andre farlige kjemikalier som finnes i motorolje og hydraulisk væske. Fenomenet med forurensning av luften i fly kalles fume event, eller forurensningshendelser. Luftkvalitet i fly har de siste årene fått økt oppmerksomhet i media. Flybesetningen og passasjerer har rapportert symptomer og negative helseeffekter som er antatt å ha en forbindelse med eksponering for forurenset bleed air. Målet med oppgaven var å undersøke hva som er kjent om fume events, samt klargjøre grad av oppmerksomhet fenomenet har blant flybesetning og et utvalg personer på Gløshaugen campus. I tillegg var det ønskelig å klargjøre alvorlighetsgraden og beregne hyppigheten av slike hendelser. Det ble utført en litteraturstudie for å undersøke den tekniske bakgrunnen og funksjonen til et bleed air-system, fenomenet fume events, og mulige helseeffekter som følge av slike hendelser. Spørreundersøkelser ble distribuert til et utvalgt piloter og kabinansatte, samt et utvalg personer ved Gløshaugen campus, for å avklare om de er kjent med fenomenet fume events. Ved bruk av ulike databaser og nyhetsartikler ble det utarbeidet en oversikt over mulige fume events fra januar 2007 til 2014.

Svarprosenten i spørreundersøkelsen blant piloter og kabinansatte var 21 %. Resultatene fra undersøkelsen viste at 70,5 % av 624 respondenter var kjent med fume events, mens 43,6 % anså luftforurensning som et problem i flyindustrien. Svarprosenten i undersøkelsen blant personer på Gløshaugen var 94,3 %. 85 % av de 100 som svarte, hadde ikke hørt om slike hendelser, mens 6 % hadde lagt merke til uvanlig lukt eller røyk i kabinen. Det ble funnet 701 mulige fume events, noe som resulterte i en beregnet frekvens på 0,24 hendelser per dag. Forskere har tidligere forsøkt å finne ut om det eksisterer en sammenheng mellom rapporterte helseeffekter og fume events. Forurensningshendelser har ikke blitt bekreftet ved målinger eller prøvetaking av forurenset luft under en slik hendelse, men det er antatt at flybesetning og passasjerer kan bli utsatt for en “kjemisk cocktail” av forurensninger. Noen av disse kjemikaliene er kjent å forårsake symptomer og negative helseeffekter ved eksponering.

Den generelle kunnskapen om fume events blant flybesetningen anses å være relativt god. Selv om antallet respondenter i undersøkelsen blant personer på Gløshaugen campus er lav, tyder resultatene på at oppmerksomheten og kunnskapen om fume events er mindre blant akademikere enn blant flybesetning. Sammenlignet med resultater fra tidligere undersøkelser, er den beregnede frekvensen av slike hendelser lav. Forurensningshendelser er imidlertid antatt å være underrapportert, siden flybesetning har forskjellige grenser for når hendelser må rapporteres, samt at luftkvaliteten blir vurdert subjektivt. Det er nødvendig med ytterligere forskning på området for å avklare hvorvidt de rapporterte negative helseeffekter kan forklares av fume events. Luftkvaliteten i fly bør måles ved bruk av prøvetakere, som bør plasseres i alle fly for kontinuerlig måling av konsentrasjoner av forurensning i kabin og cockpit under fume events. Hvis den generelle befolkningen får økt kunnskap om slike hendelser, samt at den antatte helserisikoen blir påvist, kan det fremtvinge eller gi incentiv for flyindustrien til å iverksette tiltak for å hindre slike hendelser.

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Abbreviations

AAIB	Air Accident Investigation Branch
AAIU	Air Accident Investigation Unit
ACh	Acetylcholine
AChE	Acetylcholinesterase
ADF	Australian Defence Force
AFA	Association of Flight Attendants
APU	Auxiliary Power Unit
ATSB	Australian Transport Safety Bureau
BALPA	British Airline Pilots Association
BHT	Butylated hydroxytoluene
BDP	Butyl diphenyl phosphate
BTP	Butylated triphenyl phosphate
CAA	Civil Aviation Authority (UK)
CAS	Chemical Abstracts Service
CH_3	Methyl cresyl
CNS	Central Nervous System
CO	Carbon monoxide
CO_2	Carbon dioxide
COHb	Carboxyhaemoglobin
COT	Commitee on Toxicity
CS	Certification Specification(s)
DBPP	Dibutyl phenyl phosphate
DOCP	Di-ortho-cresyl phosphate
EASA	European Aviation Safety Agency
ECS	Environmental Control System
ECCAIRS	European Coordination Centre for Accident and Incident Reporting Systems
FAA	Federal Aviation Administration
FARs	Federal Aviation Regulations
GCAQE	Global Cabin Air Quality Executive
GC-MS	Gas Chromatography–Mass Spectrometry
Hb	Haemoglobin
HCN	Hydrogen cyanide
HEPA	High Efficiency Particulate Air
ICAO	International Civil Aviation Organization
IgG	Immunoglobulin
LD_{50}	The amount of a material, given all at once, which causes the death of 50% of a group of test animals (Lethal Dose)
LOD	Limit of Detection
LTLL	Low Time Low-Level
MOCP	Mono-ortho-cresyl phosphate
MSDS	Material Safety Data Sheet

NAA	National Aviation Authorities
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
NO_2	Nitrogen dioxide
NSD	Norsk Samfunnsvitenskapelig Datatjeneste
NTE	Neuropathy Target Esterase
NTNU	Norwegian University of Science and Technology
NTSB	National Transportation Safety Board
O_2	Oxygen
O_3	Ozone
OHRCA	Occupational Health Research Consortium in Aviation
OPICN/COPIND	Organophosphorus Ester-Induced Chronic Neurotoxicity/ Chronic Organophosphate-Induced Neuropsychiatric Disorder
OPIDN/OPIDP	Organophosphorus Ester-Induced Delayed Neurotoxicity/ Organophosphate-Induced Delayed Polyneuropathy
OPs	Organophosphates (also; aryl phosphate esters)
PEL	Persmissible Occupational Exposure Limit
P450	Cytochrome P450
PAN	N-Phenyl-1-napthylamine
PNS	Peripheral Nervous System
PO_x	Phosphorus-Oxygen
PPD	p-Phenylenediamine
SAFE	Sammenslutningen av Fagorganiserte i Energisektoren
SARPs	Standards and Recommended Practices
STAMI	Statens Arbeidmiljøinstitutt
TAIC	Transport Accident Investigation Commission
TAP	Triaryl phosphate
TBP	Tributyl phosphate
TCEP	Tri-(2-chloroethyl) phosphate
TCP	Tricresyl phosphate
TIPP	Isopropylated triphenyl phosphate
TMP	Trimethylolpropane
TMPE	Trimethylolpropane esters
TMPP	Trimethylolpropane phosphate
TOCP	Tri-ortho-cresyl phosphate
TPP	Triphenyl phosphate
TPPT	Triphenylphosphorothionate
TSB	Transport Safety Board of Canada
VOC	Volatile Organic Compounds
WES	Workplace Exposure Standards
WES-STEL	Short-Term Exposure Limits
WES-TWA	Time Weighted Average

1.0 Introduction

Commercial aviation grew rapidly after World War II, and as a result of globalization, the utilization has had a large increase worldwide. Millions of people use them daily as a mode of transport. Reports of episodes where passengers, crew and pilots became ill after or during flights, have led to a growing concern about what may be the cause. Suspicions have been directed towards the breathing air inside the aircraft and possible contamination of chemicals from the oils and fluids used in the engine. As a result of this, increased attention has the latest years been given to the quality of aircraft cabin air, and especially the phenomenon of fume[1] events.

Several non-governmental organizations (NGOs), such as the Global Cabin Air Quality Executive (GCAQE), the Aerotoxic Association, and the Occupational Health Research Consortium in Aviation (OHRCA), have been established to investigate the phenomenon. In 1953, the Aeromedical Association was the first (known) to express their concerns about risks of contamination from hydraulic fluids and lubricants, and the negative health effects associated with these (Rizzolo, 1954, Winder and Balouet, 2001). The first found report of suspected intoxication from contamination of the breathing air in an aircraft was written by Montgomery et al. (1977) (Winder and Balouet, 2001).

According to Michaelis (2010, p 286), sources of air supply contamination are recognised to include hydraulic fluids, jet engine oils, de-icing fluids, fuel, exhaust fumes, ozone, pesticides, solvents and anti-corrosion spray, among others. On most commercial aircraft, the inlet for ventilation air to the cockpit and cabin is placed in the aircraft engines. The air supply is known as bleed air, and during leakage due to malfunctions in the engines, such as ineffective or damaged seals, it may be contaminated with engine oil containing organophosphates and other chemicals (Balouet et al., 1999). Bleed air is neither filtered nor monitored, so if it gets contaminated when it passes through the engines, the air inhaled by aircraft occupants will be contaminated without any alarms going off (Michaelis, 2010, p 47,52, Solbu et al., 2011, GCAQE, 2014). Fume events may be noticed by an unusual smell of engine or oil, wet dog, smelly socks or visual smoke (Michaelis, 2003, Schindler et al., 2012). The terms for this phenomenon are “fume event”, “contaminated air event”, “contamination event”, “oil leakage episode”, and “fume incident”, which are used interchangeably.

If compounds from the oils are inhaled, many different symptoms may occur. Neurological symptoms are mainly thought to be caused by isomers of tricresyl phosphate (TCP), which are organophosphate compounds used in the jet engine lubricants as anti-wear additives (Singh and Sharma, 2000, Abou-Donia, 2003, Winder and Michaelis, 2005). TCP is the most studied chemical from the reviewed literature in this context. A generic term to describe the associated health effects caused by exposure to fume events is “aerotoxic syndrome” (Balouet et al., 1999).

[1] “Fume” can be defined as an aerosol of solid particles, which may be formed by chemical processes or thermal mechanisms.

The pilot profession has long been, and still is dominated by males, while most females work as cabin crew (Pawlowski, 2011, FAA, n.d-a, Goyer, n.d). There are currently about 130 000 airline pilots worldwide and approximately 4 000 of them are females, but these numbers are constantly changing (ISWAP, 2015). The exact number of pilots in Norway is not known, but is estimated to be about 2 500 (DN, 2013). In Norway, the maximum permitted working hours per year are 2 000, and the shifts are irregular dependent on the flight destination (Lovdata, 2005).

Contamination of air in the aircraft cabin and cockpit has been a topic of interest in the media the last few decades, where several aircraft crew and passengers have stood out and described symptoms possibly caused by the contaminants. The Norwegian newspaper Dagbladet has published several articles about the topic, among others one article about an aircraft with 73 passengers flying between Stockholm and Malmö on the 12th of November 1999. The aircraft was about to crash as a result of the pilot and co-pilot feeling dizzy and incapacitated (Hansen, 2003). A case that has been brought up in the media in 2015 is the death of a pilot named Richard Westgate, who suffered serious health problems for years before he died in December 2012. The pilot claimed he had been poisoned by contaminated air in the cockpit. Newspapers wrote that examination of the pilot showed he had been exposed to toxic fumes on board (Hansen, 2015).

Prior to 1962, the ventilation system used bleedless technology, where fresh air was drawn in through inlets at the wing roots rather than through the engines. After 1962, bleed air was used on all commercial flights until 2009, when the Boeing company manufactured Boeing 787 with bleedless ventilation systems (GCAQE, 2014, p 4).

Previous studies have attempted to find an estimate of the frequency of fume events, but due to the lack of an industry standard regulatory system for reporting, and the fact that there are different criteria of reporting such events in different airlines, no well-known frequency exist to date. The great variation in how such events are characterized and followed up between different airlines makes it challenging to assess the severity of the phenomenon. Based on the above, one can first ask whether the current knowledge about fume events is limited among the people that potentially are exposed the associated health risks, such as passengers and flight crew. No previous studies to find out whether they acknowledge such events have been done. It is assumed that the general public have insufficient knowledge about this issue, based on that it is not a topic that is discussed among “everyone”. Secondly, one can ask if the phenomenon and its causes are sufficiently described by available literature. It is believed that increased knowledge about the phenomenon would allow aircraft occupants, especially flight crew, to recognize and report fume events objectively when they occur, in addition to, potentially, demand change by implementation of preventive or mitigating measures. Similarly, if the frequency of fume events was properly quantified, and found to be high, the industry and the regulators may be more inclined to develop such measures.

This assignment is part of the course TIØ4925 - Safety, Health and Environment, Master’s Thesis, incorporated in the Master’s degree of Safety, Health and Environment, at the Norwegian University of Science and Technology (NTNU). A literature study will be conducted to determine what is known about the phenomenon of fume events in aircraft. The attention among flight crew and people on Gløshaugen campus regarding this phenomenon will be clarified by the use of surveys. Additionally, an overview of the frequency and severity of registered fume events will be presented. Information will be collected through scientific sources, media and other sources, all of which are specified, in addition to participation on GCAQE's annual meeting in London in February 2015.

1.1 History

In a handbook published in 1953, the Aeromedical Association expressed their concerns about the toxicity risks of cabin air contamination by hydraulics and lubricants (Rizzolo, 1954). Winder and Balouet (2001) and Ross (2008) reviewed an article by Montgomery et al. (1977) about a 34 year old military navigator, who experienced acute intoxication following inhalation of vaporized synthetic lubricating oil from a contaminated air supply. This was the first paper found regarding ill health followed by exposure to contaminated air. Since then, a number of papers have been published, with descriptions of both acute and chronic symptoms from reported exposure to contaminated air. The appearing neurological symptoms are mainly thought to be caused by isomers of the organophosphate tricresyl phosphate (TCP), which are used as additives in jet engine lubricants (Singh and Sharma, 2000, Abou-Donia, 2003, Winder and Michaelis, 2005).

1.1.1 The History of Tricresyl Phosphate

According to Winder and Balouet (2002b), organophosphorus compounds have, at least since 1899, been known to be toxic to humans. During earlier treatment of tuberculosis with phosphocreosole, there were reports of neurotoxicity. In the 1930s, there was an outbreak called "Ginger Jake Paralysis" which affected between 20 000-50 000 people in the United States (Schopfer et al., 2010, Ehrich and Jortner, 2002, Craig and Barth, 1999, Baron, 1981). The paralysis was caused by tricresyl phosphate which was an adulterant in a medicinal alcohol extract of ginger called "Jamaica Ginger". The extract was a convenient way of consuming alcohol during the Prohibition, as it contained about 70 % alcohol (Parascandola, 1995). Craig and Barth (1999) proposed that approximately 3.3 grams of TCP had been added per fluid ounce of extract (1 fluid ounce=0.02957 l). The subsequent symptoms would typically be numbness in the legs, followed by weakness and ultimately paralysis. In many cases the nervous system suffered damage, where patients got permanent disabilities (Parascandola, 1995). According to Schopfer et al. (2010), TCP has infamously been associated with this particular incident. Later on, there have been a number of reports regarding outbreak of TCP poisoning, with the latest reported in 1995 in China. It has generally been accepted that the ortho-cresyl phosphate isomers are the neurotoxic component of TCP (Winder and Balouet, 2002b). The chemistry of TCP will be described in chapter 1.10.2.

1.1.2 Tricresyl Phosphate in the Aircraft Industry

Winder and Balouet (2002b) claim that most commercial use of TCP has ceased, despite that it is a commercially useful material. Earlier applications, among many, include TCP as a plasticizer, lubricant, hydraulic fluid, paint additive, oil additive and dust suppressant. TCP has flame retardant properties and is still used as an anti-wear additive in jet engine oil to enhance load bearing properties, and to improve tolerance for increasing the speed of rotating and sliding motion. “Torpedo oil” was a TCP product used during World War II, which with its content of about 25-40 % ortho-cresyl isomers (isomers of TCP) was highly toxic. To minimize the potential of neurotoxicity, the manufacturers reduced the content of ortho-cresyl isomers in the oils. By the 1950s, the content of ortho-cresyl isomers was reduced to about 3 % in commercially available TCP, and during the 1980s and 1990s the level was further decreased.

Since 1962 until 2009, the bleed air technology was the only applicable design of aircraft. Bleed air enters the cabin from jet engines. The jet engine operates by compressing outside air, before it enters the combustion chamber. Some of the compressed air is extracted (bled off) and used as ventilation air in the cabin and cockpit. In some earlier aircraft, like Douglas DC-8 and Boeing 707, this technology was not used. Instead, the outside air was drawn into the cabin by the use of turbo compressors or blowers. These were located on the outside of the fuselage, allowing air to enter into the aircraft during flight; the air was called “ram air”. Contamination of ram air was only possible when the outside air was contaminated from external sources, whereas bleed air may also be contaminated by internal sources such as components in the engine oil during leakage. The argument for choosing bleed air rather than ram air was mainly grounded in that a bleed air system was more economical, since the ram air system was heavy and not very fuel-efficient (GCAQE, 2014, van Netten, 2005).

1.1.3 Increased Attention on Oil Containing Organophosphates

A number of events since the 1980s in international aircraft industry led in 2002 to the Norwegian Oil Workers’ Trade Unions’ (OFS, now SAFE) demand of a full review of the occupational health, by a survey of health among people who had been exposed to turbine and hydraulic oils containing organophosphorus compounds (Bjørseth and Paulsen, 2003). In the spring of 2003, the Norwegian newspaper Dagbladet published an extensive series of articles about “Giftoljesaken”. The articles were related to serious incidents and health effects, where organophosphates in hydraulic and turbine oils were suspected to be the cause. This was a result of OFSs earlier suspicions regarding a connection between the previously mentioned substances, and cases that included neurological damage. In the early 90s, there were a number of cases where workers on a Norwegian offshore platform showed symptoms of multiple sclerosis. Since the turbines offshore have many resemblances with jet engines on aircraft, parallels were drawn between the health effects among offshore workers and aircraft occupants and -technicians (STAMI, 2011).

1.2 Regulations and Standards

Different guidelines and legislation exist in the aircraft industry to ensure that the aircraft are operated in a safe and airworthy manner. The only organization with regulatory authority to establish standards for the aircraft cabin environment is the Federal Aviation Administration (FAA) (National Research Council, 2002, Tao et al., 2011). The International Civil Aviation Organization (ICAO) was founded in 1944, and works with various global aviation organizations to develop international Standards and Recommended Practices (SARPs). In 2013, the number of member states was 191, where Norway was among the Council member states (ICAO, n.d). Guidelines based on ICAO and nationally adopted regulations are mainly related to the aircraft function. A key element in the safety of aviation internationally is airworthiness of an aircraft. Standards to describe airworthiness of transport category aircraft are established by ICAO, and are explained in detail in part 25 of the U.S. Federal Aviation Regulations (FARs). The standards define the requirements for an aircraft to be "fit for flight" or "airworthy". The areas covered in the standards are, among others, aircraft design, power plants, aircraft performance and -equipment, and aircraft ventilation requirements (Michaelis, 2010, p 31, U.S. Government, 2015).

ICAO developed several protocols that member countries are obliged to pursue through their own legislation, set down by each national aviation regulator. In Norway this is the Civil Aviation Authority (Luftfartstilsynet). The established set of guidelines is based on FARs or the European Aviation Safety Agency (EASA) Certification Specifications (CS) (Michaelis, 2010, p 31, EASA, 2014). When countries follow established set of guidelines, they avoid spending considerable time making their own.

The first aviation regulation on fumes and carbon monoxide (CO) in cabin or cockpit was founded in 1937 by the FAR, and required that *"a suitable ventilation system shall be provided which will preclude the presence of fuel fumes and dangerous traces of carbon monoxide"* (Murawski, 2009, Michaelis, 2010, p 32). The FAR Ventilation Regulation 25.831 from 1964 stated that *"...the ventilation system must be designed to provide a sufficient amount of uncontaminated air to enable the crewmembers to perform their duties without undue discomfort or fatigue and to provide reasonable passenger comfort"*.

From Certification Specifications for Large Aeroplanes CS-25.831, it is stated that *"crew and passenger compartment air must be free from harmful or hazardous concentrations of gases and vapours"* (EASA, 2007, p 1-D-31). Further, *"there must be provisions made to ensure that the conditions prescribed (...) are met after reasonably probable failures or malfunctioning of the ventilating, heating, pressurisation or other systems and equipment"* (EASA, 2007, p 1-D-32).

By government regulation the cabin pressure cannot be less than the equivalent of outside air pressure at approximately 8 000 ft. (2 400 m) (National Research Council, 2002). The regulations present clear boundaries for contents of carbon monoxide, carbon dioxide (CO_2) and ozone (O_3) in the cabin air, but it has been claimed that they fail to incorporate the levels of other contaminants. This may be due to the intention that there are not supposed to be any other contaminants present (Michaelis, 2010, p 35). The Occupational Safety and Health Administration (OSHA) establishes permissible occupational exposure limits (PELs), which is intended for workplaces populated by healthy, working adults. Hence, they are not applicable in aircraft, where people of all ages and with different medical conditions reside (Tao et al., 2011).

Considerations about health and comfort for the passengers are limited, apart from some health issues like medical first aid provisions, and some regulations for pressure and ventilation (Michaelis, 2010, p 31). There are certification requirements for some of the cabin environmental factors, but the existing standards for the specific environment of the cabin are not addressed in detail. When taking the risk of possible exposure to contaminated air by passengers and crew into account, it has been argued that the regulations have to be improved (Michaelis, 2010, Dechlow and Nurcombe, 2005). The environment in an aircraft is different from the one at sea level, which requires an artificial indoor climate. As a consequence, there should be standards especially for the flight environment. Even though it is over 50 years since the bleed air system was taken into use, few regulations to either prevent or monitor exposure to contaminants in the cabin and cockpit ventilation air exist to date (Dechlow and Nurcombe, 2005, Ministry of Business, 2013, Murawski, 2009). Currently, it does not exist any airworthiness standards about the filtration system to regulate the level of filtration removal efficiency required on board aircraft (Michaelis and Loraine, 2005).

1.2.1 Guidelines to Exposure Standards

Different workplace exposure standards (WES) are applied to measure the quality of cabin air. Examples of some of them are time-weighted average (WES-TWA) and short-term exposure limits (WES-STEL). The first standard represents an 8-hours working day and a 40-hours working week, and the assigned value should not be exceeded throughout the working period. WES-STEL is a 15-minute exposure standard, and hence applies to any 15 min period of the working day (Ministry of Business, 2013). Limit of detection (LOD) is a term used to describe the smallest concentration of a substance that can be reliably measured by an analytical procedure (Lawson, 1994). Countries use different terms for exposure standards.

1.3 Technical Background of Fume Events

1.3.1 Commercial Jet Engines

To move an aircraft through the air, thrust is generated by a propulsion system; the engine. The turbofan engine was first used in 1960, and is still used in most commercial aircraft and military fighters today. This engine has a propeller-like device inside the engine assembly, and is a combination of a propeller-driven aircraft and a pure turbojet. The engines are usually mounted under the wings, the tail or on the sides of the fuselage rear on the aircraft (IEEE, 2013, Smith and Mindell, 2000, p 107). Airbus and Boeing, two well-known aircraft manufacturers, are used in commercial flights worldwide (Boeing, n.d., Airbus, n.d.).

In order of market share, the turbofan engine market is dominated by General Electric Aviation, Rolls Royce plc and Pratt & Whitney, according to the companies' web pages.

1.3.2 Turbofan Engine

Turbofan engines are the most modern variant of the basic gas turbine engine (also called jet turbine engine). As with other gas turbines, it contains a core engine that is surrounded by a fan at the front and a turbine at the rear (Figure 1). The core compressor and core turbine are composed of many blades, which are connected to an additional shaft. The “turbo” in turbofan refers to a gas turbine engine which takes mechanical energy from combustion. The “fan” is a ducted fan that draws air into the engine. The bypass stream is compressed, which lead to 75-80 % of the engines thrust by accelerating air rearwards. Turbofan engines can be divided into two categories; low-bypass turbofans (low ratio), which use more jet thrust relative to fan thrust, and high-bypass turbofans (high ratio), which conversely use more fan thrust than jet thrust (NASA, 2014h, p 107, Rolls Royce, 2015b, Smith and Mindell, 2000).

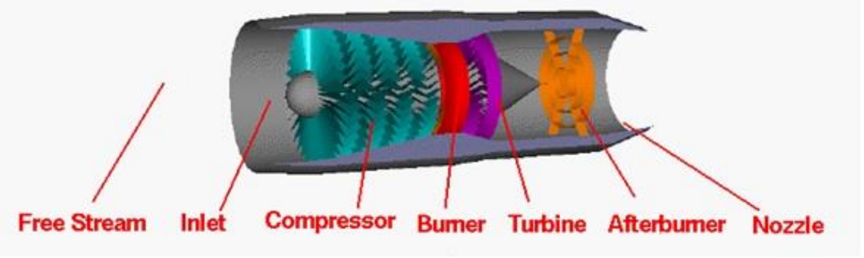

Figure 1: Schematic cross sectional view of a jet engine. Air is compressed by the fan blades as it enters the engine. The air is mixed with fuel before it enters the burner/combustion section. The hot exhaust gases provide forward thrust and turn the turbines that drive the compressor fan blades (NASA, 2014c).

1.3.3 Subsonic Inlet

All turbine engines have an inlet placed upstream of the compressor (Figure 2). The main function of the inlet is to bring a suitable mass flow into the engine and reduce the speed of flow to a level suitable for mechanical compressor operation. This is dependent on different flight speeds and altitudes (Greatrix, 2012, p 163). For aircraft with speed much less than the speed of sound, the aircraft is said to be subsonic. Typical speed for subsonic aircraft is less than 250 mph (NASA, 2014g).

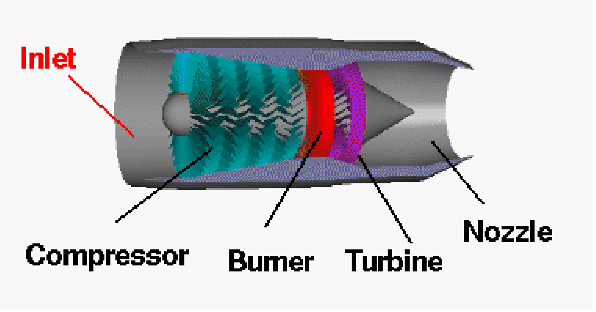

Figure 2: Schematic cross sectional view of an engine inlet. The incoming air enters through the engine inlet (NASA, 2014d).

1.3.4 Compressor

The primary purpose of the compressor is to increase the pressure of the incoming air before it enters the combustor (Figure 3). The total engine performance is highly dependent on the compressor performance. Alternating stages of rotating blades (rotors) and static vanes (stators) make up the compressor. The rotors are connected to the central shaft and rotate at high speed, while stators, on the other hand, are fixed and do not rotate. The compressor is attached to a shaft connected to the power turbine. Modern large turbojet- and turbofan engines usually use multi staged axial compressors due to the high amount of compression such engines require. The multiple stages increase the pressure and temperature of the air step by step as it flows through them. If a lesser amount of combustion is needed, the simpler single stage centrifugal compressor is applied. Air that flows through a centrifugal processor is turned perpendicular to the axis, and as a result of this, a system of multiple centrifugal stages would be inefficient because it would require air to be routed back to the axis at each stage (NASA, 2014b, Rolls Royce, 2015a, Greatrix, 2012, p 181).

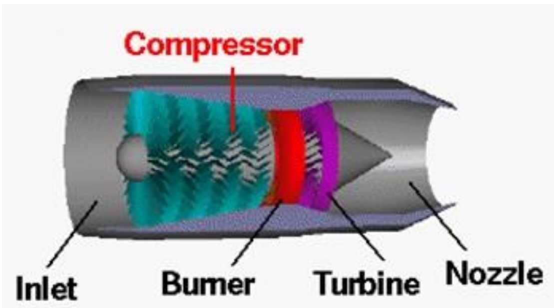

Figure 3: Schematic cross sectional view of the compressor section of a jet engine. The compressor increases the pressure of the incoming air before it enters the combustor (NASA, 2014b).

1.3.5 Burner/Combustion Chamber

Some of the incoming air passes through the fan and continues into the core compressor and further into the burner. The burner in turbofan engines is situated between the compressor and the power turbine, as shown in Figure 4 (NASA, 2014a). The combustion chamber can simplified be described as the place where fuel and air are mixed and burned to convert the chemical energy of the fuel into thermal energy. The term for this chemical process is combustion and it is continuous once the engine has started. The fuel is combusted at temperatures of over 2 000 °C within the combustion chamber, which means that the jet fuel to be used should have good overall combustion properties. Appearance of soot or smoke is evidence of unburnt fuel in the exhaust (Greatrix, 2012, p 190, Rolls Royce, 2015c, Palocz-Andresen, 2013, p 153). When a hydrogen-carbon-based fuel (like gasoline) burns, the exhaust includes hydrogen, oxygen and carbon dioxide. Film cooling is commonly applied for inner liner surface cooling, using bled-off compressor air (NASA, 2014a).

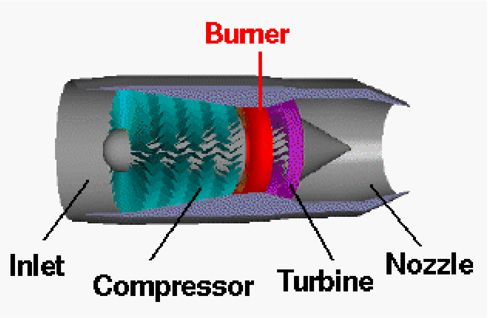

Figure 4: Schematic cross sectional view of where combustion takes place in a jet engine. In the burner, air is heated by the injection, vaporization, and subsequent burning of the jet fuel (NASA, 2014a).

A burner usually has an outer casing, and an inner liner, which generally is perforated to enhance mixing of the fuel and air. There are three main types of combustors, and all of them are found in modern gas turbines, as shown in Figure 5 (NASA, 2014a).

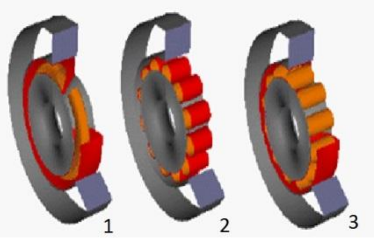

Figure 5: Illustration of the three main types of combustors. 1) Annular combustor with the liner (orange) inside the outer casing (red). Many modern burners have an annular design. 2) Can or tubular design. Each can have both a liner and a casing, and the cans are arranged around the central shaft. 3) Can annular design is a compromise between the two designs described above; the casing is annular and the liner is can-shaped (NASA, 2014a).

The turbine is composed the same way as the compressor, with rows of air foil cascades called rotors and stators (Figure 6). Mechanical energy from hot gasses in the combustion chamber is extracted by the turbine. Since the turbine extracts energy from the flow, the pressure decreases across the turbine (Torenbeek and Wittenberg, 2009, p 220). Turbine blades experience flow temperatures of about 540 °C, and as the combustor walls, they must be made of materials that can tolerate heat or be actively cooled (NASA, 2014f).

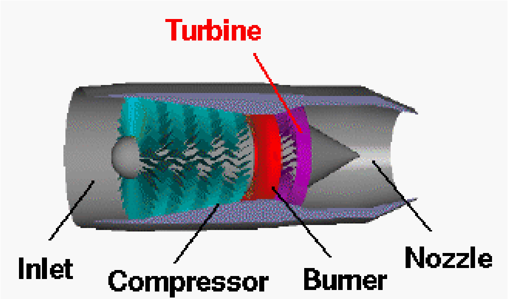

Figure 6: Schematic cross sectional view of a turbine. The turbine extracts energy from the air flow, and in that way the pressure decreases across the turbine. It is composed the same way as the compressor (NASA, 2014f).

1.3.6 Nozzle

A nozzle is a specially shaped tube through which hot gasses from the turbine flow (Figure 7) (NASA, 2014e). After the final stage of the turbine, the remaining hot gas expands at high velocity through the engine exhaust nozzle, providing 20-25 % of the engine thrust (Rolls Royce, n.d).

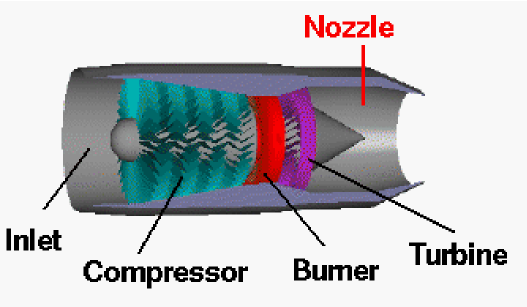

Figure 7: Schematic cross sectional view of a nozzle. The hot gasses flow through a nozzle, which is a specially shaped tube. The nozzles come in different shapes and sizes, depending on the aircraft utilization (NASA, 2014e).

1.4 Fume Events in Aircraft Cabins

Aircraft occupants may be exposed to many different air contaminants in the aircraft cabin, including carbon monoxide (CO) from engine exhaust, O_3 from outside air, and organic compounds of biological origins. The latter are generated by emissions from materials in the cabin and the human body, as infectious agents, irritants and allergens. Incidents that result in the intake of potential contaminants from jet engine oils and hydraulic fluids can be described as fume events. These events occur if unintended release of engine oils, hydraulic fluids, de-icing fluids, and combustion products pass through the environmental control system (ECS) and into the cabin (National Research Council, 2002).

Leakage of jet engine oil, hydraulic oils, and de-icing fluids may lead to exposure of contaminants from the bleed air in the aircraft cabin. The oils are known to contain different neurotoxins, carcinogens, irritants and other toxic agents (WHO, n.d). Contamination by aircraft fluids can be due to smoke from engine fire, leaks of combusted or pyrolyzed materials, or seal failures, among others (Balouet et al., 1999). In case of seal leakage in the compressor stage of the jet engine oil system, the oil enters the bleed air stream, gets aerosolized, compressed, and heated to a high degree, before it enters air condition packs, and finally ends up in the cabin and cockpit (Hocking, 2005, p 200). Contamination may also be due to wear and aging of materials, ground operations at gate or on tarmac (as airport surrounding, de-icing procedures, pack burnout procedures or recirculation), design flaws (as fluids accumulating at the APU-inlet, rear engines ingesting hydraulic leaks, or thrust reverser hydraulic lines), or residual contamination from lack of cleaning after contamination events (Balouet et al., 1999).

Solbu et al. (2011) developed a simple automatic air incident sampler with the purpose to assess concentrations of organophosphates (OPs) from jet engine oils and hydraulic fluids in aircraft when fume events occur. The sampler was supposed to collect samples during sudden and unexpected incidents with potential of exposure to semi-volatile organophosphates and possible volatile decomposition products. Ten incident samplers were placed in ten different aircraft within a one year period, but were never taken into use, since such incidents did not occur during the period. To date, there are no long-term samplers in use to measure aircraft air quality in the aircraft industry.

1.4.1 Organizations That Register Fume Events

The American Federal Aviation Administration (FAA) regulates and monitors all aspects of civil aviation in the United States. The agency falls under United States Department of Transportation (FAA, n.d-a). The National Transportation Safety Board (NTSB) is an independent Federal agency charged by the Congress. It investigates every civil aviation accident in the U.S. and issues accident reports following the investigation. The reports are available online (National Transportation Safety Board, n.d).

The European Coordination Centre for Accident and Incident Reporting Systems (ECCAIRS) is a database that the National and European transport entities use in their work to collect, share and analyse their safety information in order to improve public transport safety. The incidents are, according to the Norwegian newspaper Dagbladet, reported according to four levels of seriousness; aviation accidents, serious incidents, aviation incidents and operational malfunctions (the reporting levels in ECCAIRS could not be confirmed, due to denied access). Some cases of gas or oil smell on board aircraft are probably not looked upon as serious incidents, and may be reported as “operational malfunctions”. These events are to be reported to the Authority, but are not recorded in any databases. Hence, there may be underreporting of these types of incidents.

In Norway, incident reporting is divided into incidents, aviation accidents and serious aviation accidents, according to the current regulations for reporting, BSL A 1-3 (Lovdata, 2007, Ingebrigtsen, 2014). During 2015, a new legislation for the regulation of reporting will take effect, the Regulation (EU) No 376/2014. All new reporting systems should be compatible with the reporting system in ECCAIRS (European Parliament, 2014, Ingebrigtsen, 2014). Several organizations are concerned with fume events in aircraft cabins, the ones mentioned in this thesis is shown in Table 1.

Table 1: List of organizations with concerns about fume events in aircraft. The information in the table is found in the organizations respective web pages.

Name of the organization	**What they do**
Aerotoxic Association	Incidents including fume events are continuously updated. The organization concentrates on aerotoxic syndrome.
European Aviation Safety Agency (EASA)	The centrepiece of the European Union's aviation safety system comprises of the Agency, the European Commission and the National Aviation Authorities (NAAs).
Federal Aviation Administration (FAA)	The American Federal Aviation Administration (FAA) regulates and monitors all aspects of civil aviation in the United States.
Global Cabin Air Quality Executive (GCAQE)	An international organization with primary purpose of affecting necessary changes in the aircraft industry to prevent exposure to oil and hydraulic fluid. Represents air crew (pilots, cabin crew and engineers), offshore workers and consumers.
International Civil Aviation Organization (ICAO)	Works with the Convention on International Civil Aviation Member States and global aviation organizations to develop international Standards and Recommended Practices (SARPs) that the States refer to when developing their legally-enforceable national civil aviation regulations.
Norwegian Civil Aviation Authority (Luftfartstilsynet)	Independent administrative body with regulatory responsibilities for the Norwegian Civil Aviation.
Occupational Health Research Consortium in Aviation (OHRCA)	The Occupational Health Research Consortium in Aviation (OHRCA) received some of the funds from FAA to carry out research on air quality incidents and health effects on airline crew members.

1.4.2 Frequency of Fume Events

Murawski (2011) states that neither the individual airlines nor the general aircraft industry have a well described frequency, cause and characteristic of fume events. Some researchers have attempted to find an estimate of the frequency of such incidents. Air contamination events, or fume events, are assumed to be underreported (Murawski, 2011, Murawski and Supplee, 2008, Michaelis, 2010, van Netten, 2005). There are only a few studies regarding frequency of fume events that exist to date, some of which follow below.

van Netten (2005) identified air contamination events to occur in 1-3.8 per 1 000 flights, and found that the frequency depends on the type of aircraft and its maintenance. It is claimed that underreporting occurs, and that the cause appears to be, among others, subjective assessment of the air quality within the aircraft. The flight crew may consider the temporary smell when engines start as "normal", and since they are somewhat used to it, they do in some cases not find it necessary to report. It is also claimed that there is an intimidating factor due to underreporting, in which pilots are afraid to lose their job if they report symptoms after noticing smell or smoke in the cockpit, since they are dependent on their medical certificate to continue their career. Hence, a pilot do not want to complain about his health following exposure to the co-pilot, because it would target his health status if the co-pilot does not notice any symptoms (Murawski, 2011, van Netten, 2005).

Murawski and Supplee (2008) did a study where data about fume events was collected in the U.S. between January 2006 and June 2007. The reports that were used included the specific words “fume”, “haze”, “mist”, “odour”, “smell”, or “smoke”. 350 out of 470 incidents were reported by the airlines to the Federal Aviation Authorization and put into their database, while others were reported by flight attendants to the Association of Flight Attendants (AFA). Some of the incidents were also found in media articles. Most of the incidents, 319 (68 %), occurred while in-flight, of which the majority was specified to climb (42 %) or cruise (26 %). 57 % of incidents that occurred while en route returned or diverted to the nearest airport, whereas the incidents that occurred when the aircraft was on ground rejected take-off and were either delayed or cancelled. Several of the reports did not include any cause of the incidents. This was assumed to be due to the time required to find a plausible cause, and that the airlines do not want to provide information about the cause of an event with absence of exposure data. It was furthermore assumed to be because there are no monitors to assist in identifying fume events, and that sense of smell by the flight crew is unreliable. They may sense the smell as electric, even though the cause is oil leakage. The results of the study indicated an average of 0.86 events per day in the U.S., by the noted time period.

Murawski (2011) conducted a case study in 2009-2010, where a total of 87 fume events of one major U.S. airline were identified. The results showed that the crew reported unusual smell on 83 of the 87 flights. The smell was noticed prior to take-off on 44 (50.6 %) of the flights, and 20 (45.5 %) of these were either delayed or cancelled. 34 of the events (39.1 %) occurred while the aircraft was airborne. Oil was confirmed to contaminate the air supply on 41 of the 87 flights, and one or more crewmember reported symptoms in all of the 87 fume events. In 35 (40.2 %) out of the 87 flights the smell was characterized as “dirty socks or smelly feet”. The smell was mainly present prior to take-off in 44 flights (50.6 %), which shows different results than the study conducted by Murawski and Supplee (2008). It was recommended that airlines should train pilots and cabin crew to recognize when they may be exposed to fumes (Murawski, 2011).

Michaelis (2010) conducted a review of reported fume events in the UK to determine the frequency of such events. The databases used included the Civil Aviation Authority of the United Kingdom (CAA), the Air Accident Investigation Branch (AAIB), and the Australian Transport Safety Bureau (ATSB). A total of 1 050 events were found between 1985 and mid-2006. It was claimed that less than 4 % of all fume events are assumed to be reported, and that reasons for this are, among other factors, that regularly smell is seen as normal, flight crew assume that their symptoms can be explained due to something else than exposure to fumes. In addition, fumes are only seen as health and comfort issues.

The UK Committee on Toxicity (COT) reported that events occur in 1 % of flights. This value is based on information from 3 airlines in the UK. Based on engineers’ verification of smoke, it occurs in 0.05 % of flights in the UK, noting that the frequency may vary by engine type, maintenance practices and the type of aircraft where incidents occur (COT., 2007).

The U.S. Federal Aviation Administration (FAA) reported in 2010 more than 900 smoke or fume events of all kinds, including but not limited to, hydraulic fluid and oil in the air (FAA., 2011, Furlong, 2011).

Shehadi et al. (2015) conducted a case study where the frequency of fume events was estimated by examining incident databases from the FAA, NASA and other sources from 2007 to 2012 for flights that either originated or terminated in the U.S. Incidents where smoke, oil smell, fumes or any symptoms that could relate to fume events had been noticed, was included. The results showed an average incident rate of 0.2 per 1 000 flights in the U.S. Occurrence of incidents were found to be spread widely across all major aircraft manufacturers and models.

1.4.3 Fume Events Reported in the Media

Following are some accidents assumed to have a connection with contaminated air in aircraft. The events are only a small part of all registered incidents, but are mentioned here due to their severity, and media attention.

"Pilots Knocked Out by Nerve Gas" (1999)

Dagbladet began to take an interest on the topic of toxic fumes on board aircrafts and published in 2003 an article regarding this. The incident happened on the last of three flights between Stockholm and Malmö in 1999. The aircraft was from the BAe 146 series. Both the pilot and co-pilot were struck by severe dizziness and nausea, and even though they put on oxygen masks, the captain continued to have symptoms. The cabin crew had on the two earlier flights noticed that something was wrong with the cabin air (Hansen, 2003).

The Swedish Accident Investigation Board compiled a report about the same incident. It emerged that some of the cabin crew had experienced the feeling of fainting, pressure in the head, nasal itching and ear pain on the first and second flight, while the pilots did not notice anything abnormal. Subsequent to the incident on the third flight, the airline performed a trouble-shooting of the aircraft. This revealed an external leak in one of the engines, which led technicians to test the bleed air- and air-condition system. These revealed no indication to which chemical substances could have caused the symptoms, and no technical fault could explain the incident. The board concluded that the pilots probably were affected by polluted cabin air (Lundström and Elinder, 2001).

"Norwegian Airline Captain Permanently Injured" (2000)

In 2000 there was an incident on a flight from Gardermoen, Oslo, to Charles DeGaulle, Paris. The aircraft was from the Boeing 737 series. The co-pilot noticed an acrid smell in the cockpit after about five minutes at cruising level, and both pilots started to feel unwell. The smell was recurrent, and the captain decided to return to Gardermoen, but finally made an emergency landing at Torp airport. The pilot experienced symptoms such as confusion and dizziness (Hansen, 2006).

According to a report by the Norwegian Accident Investigation Board from this event, the cargo compartment was inspected, but the source of the smell was not detected, neither at the moment of the happening or after further investigation. Subsequent to the incident, the pilot had reduced general state and was granted sick leave. After a period, he was declared incapable as pilot for medical reasons and was given “loss of license” (HSL., 2002).

“Dead BA Pilots Victims of Toxic Cabin Fumes” (2013)

There were suspicions about the relationship between exposure to toxic oil fumes on aircraft and the death of a 43 year old pilot, Richard Westgate. Prior to his death in 2012 he suffered persistent headache, chronic fatigue, mood swings and loss of confidence. The same article also mentions Karen Lysakowska, a 43 years old female pilot who died only days before Westgate. As with Westgate, she believed that she had been exposed to toxic fumes (Jeory, 2013). Ante-mortem in vivo blood had been collected prior to Westgate’s death, due to his suspicions about toxic fumes being the cause of his ill health. There was also conducted tests post-mortem. Scientific researchers concluded that injury to the nervous system was consistent with organophosphate-induced neurotoxicity (Abou-Donia et al., 2014).

“Passengers and Crew May Have Been Exposed to Toxic Fumes” (2014)

In a more recent case, from 2014, the passengers in a Boeing 737-800 heading to Brüssel from Oslo were evacuated on the runway, after the crew noticed smoke in the cabin. A spokesman from STAMI claimed it was a typical “smoke-in-cabin incident”, while a spokesman from SAFE claimed that it “looked like a fume incident”. The airlines head of information claimed that the smell was similar to the one used during training, and that it is not toxic or harmful. Increased concentrations of organophosphates were found in the cabin following the incident (Hansen, 2014). No investigation report of the incident is published.

“Plane Carrying 185 Passengers Forced to Make Emergency Landing After Nine Crew Fall Ill due to Noxious Fumes” (2014)

It was declared emergency on an A330 Airbus flying from Venice to Philadelphia, when cabin crew started to feel nauseous and dizzy two hours into the flight. According to the Irish Aviation Authority, the aircraft turned around and diverted, and the aircraft was evacuated on the airport. None of the pilots or passengers reported feeling ill, whereas nine cabin crew members were taken to a hospital for examination. The incident was investigated by both the U.S. National Transportation Safety Board (NTSB) and the Irish Air Accident Investigation Unit (AAIU) (Boyle, 2014). There is no investigation report published of the incident.

1.5 Environmental Control System

Aircraft are equipped with an environmental control system (ECS) to deal with the extreme conditions at cruising altitude. The main functions of the ECS are to provide pressurized air and thermal comfort for the passengers and cabin crew, and air supply without harmful contaminants. Passengers and crew are able to breathe due to the pressurized environment in cabin in flight (Dechlow and Nurcombe, 2005, Michaelis, 2010, p 47).

The ECS has some primary functions regarding air conditioning. These include heat exchangers, compressor, water extraction and turbine, and the air distribution, -recirculation and -pressurization, including associated fans, valves and ducts. The bleed air system delivers hot air from the engines, Auxiliary Power Unit (APU) or external sources to the ECS, and a trim system let off some of this hot air before it passes through the air conditioning unit. The air is led to a distribution duct for temperature control reasons. One of the challenges with the ventilation system is that requirements of both crew and passengers must be fulfilled within the same cabin conditions (Dechlow and Nurcombe, 2005).

1.5.1 How Air Enters the Cabin

The airflow from outside enters into the engine and either goes around the core of the engine (“fan air”), or to the core where it is compressed. The compressed air enters the combustion section of the engine, where jet fuel is added. The majority of the air entering the core of the engine passes on to the combustion section, but some of the compressed air, typically 2-8 %, is bleed air. This can be taken from specific stages of the compressor section in the engine, depending on the design by the engine manufacturer. The location of the bleed air ports on the engine is dependent on the pressure or temperature required for a particular task or stage of flight (Michaelis, 2010, p 47, Smith, 1991).

Usually, engines are designed with a low and a high stage pressure bleed air take-off point in the compression section. At high power settings, the bleed air will normally be taken from the lower pressure take-off point. When the pressure at low pressure point decreases beneath a predetermined level, the bleed air returns back to the high pressure take-off point. The bleed air is taken from the compressor section, before the compressed air enters the combustion section (Hunt et al., 1995).

The bleed air from the compression section keeps high temperatures, from 350-600 °C, at high compression stage, and between 100-300 °C in the low stage compressor. Thus, when air containing various substances passes through the engine, such as when leakage of oil within an engine occurs, there is always a risk of combustion which may cause by-products to end up in the cabin air (Spittle, 2003). The air that enters through the engines is not distributed evenly throughout the aircraft.

The cockpit receives outside air continuously, which means that the air is 100 % new outside air. In the cabin, however, the air is 60/40 % recycled air, which means that the cabin receives about 10-fold less bleed air. At this ratio, the air from outside will refill the air space in the cabin every three to five minutes. As a consequence, pilots situated in the cockpit would be exposed to components from oils and hydraulic fluids to a higher degree during fume events, than people in the cabin (van Netten, 2005, de Boer et al., 2014, Michaelis, 2010, p 55). The air drawn in from the engines passes through air-conditioning packs, which is an air cycle refrigeration system that cools the hot air before it enters different locations of the cabin or cockpit (SKYbrary, n.d.). By the use of heat exchangers, a combined turbine and compressor machine (an air cycle machine), valves for temperature and flow control. The unfiltered outside air enters a mixing chamber (called the "mix manifold") after being cooled by the air-conditioning packs, and is mixed with an equal amount of recirculated air before it enters the cabin from the overhead outlets (Figure 8) (Michaelis and Loraine, 2005). The recirculation system is equipped with High Efficiency Particulate Air filters (HEPA), which removes dust and other small particles like viruses and bacteria from the recirculated air. HEPA filters do not remove gases and vapours due to their small molecular sizes (Hunt et al., 1995, Bull and Roux, 2010). New filtering system is being developed, and a new system based on nano-photocatalytic oxidation has been introduced. By the use of this type of filter, it was claimed that bacteria and viruses would be killed, in addition to clear the VOCs in the cabin (Tao et al., 2011).

The bleed air can also flow through an APU, but this is mostly used on the ground or in some cases during take-off and landing. The APU is used to provide air to the air conditioning packs, and to start the engine or electrical power from a relatively small self-contained engine. It is located at the rear on most commercial aircraft. The on-board APU, a small gas turbine (turboshaft) engine, can be valved to deliver high-pressure air to an engine's starter turbine (Greatrix, 2012, p 194, Michaelis, 2010, p 52).

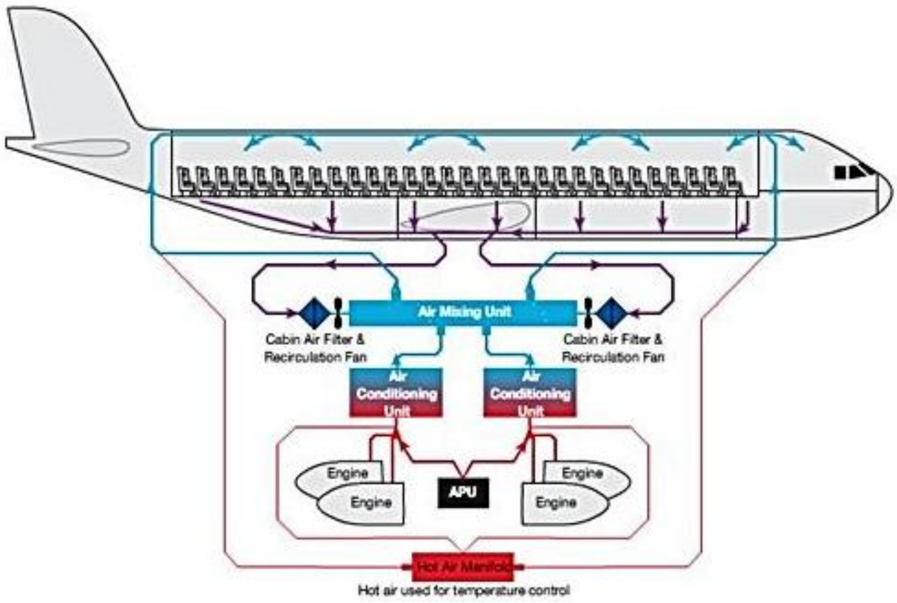

Figure 8: Schematic overview of the ventilation system on an aircraft. Outside air passes through the engine and is heated as a result of pressure changes. The air continues to the air conditioning unit to get a suitable temperature. From the air condition unit it enters the air mixing unit. Here, the bleed air is mixed with filtered and recirculated air from the cabin. The mixed air finally enters the cabin and then either passes back to the air mixing unit, or is discharged to the atmosphere (Pall, 2014, Michaelis and Loraine, 2005).

1.5.2 Emergency Oxygen Masks

The emergency oxygen system is designed to store or generate a supply of oxygen. It regulates, dilutes and distributes oxygen to aircraft occupants. Depending on type and role of the aircraft, the oxygen system may be used during normal operations, to provide supplemental oxygen for specific situations or to provide emergency oxygen in case of events with smoke, fire, fumes or loss of pressure. National regulations for provision and use of supplemental or emergency oxygen systems are based on the guidance provided in Annex 6 of the ICAO Standards and Recommended Practices (SARPs) (SKYbrary, 2014). SARPs' Annex 6, part II reference 2.2.3.8, states that the pilot in command have to ensure that breathing oxygen is available to crew members and passengers in sufficient quantities. This is valid for all flights at altitudes where lack of oxygen may change the crew members' abilities to work or harmfully affect the passengers. Reference 2.4.6.1 states that aeroplanes intended to be operated at high altitudes shall be equipped with oxygen storage and suppliers capable of storing and dispensing the oxygen supplies required in reference 2.2.3.8 (ICAO, 2010).

The drop-down oxygen masks on an aircraft provide recirculated cabin air, which may contain oil contaminants in case of leakage. Pilots and flight attendants have access to 100 % pure oxygen from portable bottles. When the pressure in the cabin becomes too low, pilots and cabin crew have access to about 15 minutes of pure air from their oxygen bottles. This is the estimated time needed to lower the altitude and increase the pressure inside the aircraft (Nassauer, 2009). The oxygen masks used by the passengers can be used in at least 10 minutes in case of low pressure. This air is not 100 % pure oxygen as it is mixed with the air in the cabin (Loraine, 2008).

1.6 Environmental Factors

Some environmental factors have to be taken into account when considering the airworthiness of an aircraft, and specifically the aircraft indoor quality. Reported negative health effects may be explained by other factors than fume events, such as a pressurised environment, temperature, humidity and biological factors, or a combination of these factors and fume events.

1.6.1 Pressure at Cruising Altitude

The lowered pressure outside an aircraft is hostile to human life at cruise levels of modern aircraft. 11 000-12 200 m above sea level is the typical cruising altitude, and in the cabin, this height is equivalent to the outside air pressure at 1 800-2 400 m above sea level (called the cabin altitude). Oxygen (O_2) levels remain constant at 20.9 % at increasing altitude, which means that the proportion of oxygen in air remains unchanged. To keep both cabin crew and passengers healthy, a certain amount oxygen saturation of the blood is required, depending on the oxygen partial pressure of the cabin air (Dechlow and Nurcombe, 2005). Since the atmospheric pressure decreases at increasing altitude above sea level, the partial pressure of oxygen decreases (Figure 9).

Healthy passengers usually tolerate the effects of reduced cabin air pressure, but those with certain medical conditions, such as heart- and lung diseases, and blood disorders, may not tolerate an environment of reduced pressure (Winder and Balouet, 2002a, WHO, n.d).

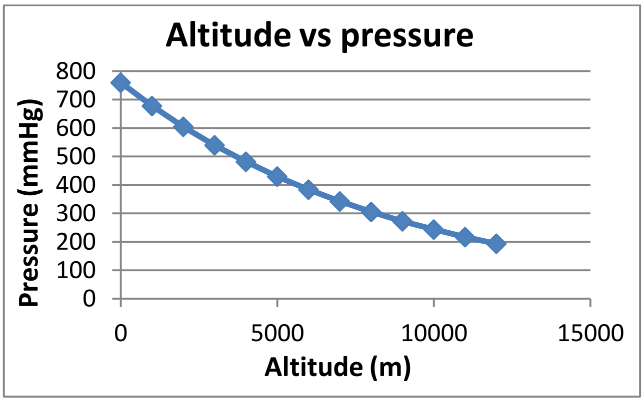

Figure 9: Change in atmospheric pressure with altitude.

1.6.2 Effects of Low Pressure

The sensitivity to toxic contaminants is changed with lowered oxygen concentrations. Hypoxia is a condition with low absorption rate of oxygen from the lung alveoli into the bloodstream. When cruising at high altitude, people have higher respiratory rates and increased inhalation due to the hypoxic environment (reduced oxygen environment) at cruising level (Ross et al., 2006). Reduced air pressure may cause crew members and passengers to not obtain enough oxygen for their physiological requirements. As a consequence, increased respiratory rates may cause a higher susceptibility in case of exposure to toxicants (Winder and Balouet, 2002a).

Since the aircraft is pressurized to the equivalent between 6 000 and 8 000 ft., symptoms of hypoxia that may act adversely with exposure to chemical exposures, may occur. An example of a compound leading to hypoxia is the odourless and colourless gas carbon monoxide (CO), which has 50 % higher toxicity at 8 000 ft. (2 438 m above sea level) than at sea level (Winder and Balouet, 2002b). When contaminants entering the bleed air supply system are thermally decomposed, CO may be generated. It may also be produced as a by-product of incomplete combustion. The concentration of CO depends on the air flow, the quantity of the contaminant, the temperature of the bleed air, as well as surfaces in contact with the contaminant (Michaelis, 2010, p 111). When CO is inhaled, it combines with haemoglobins (Hb) in blood to form carboxyhaemoglobin (COHb). COHb have a much higher affinity to Hb than oxygen, which causes a lack of oxygen for the cells in the body (Boyle, 2006).

Hyperventilation is claimed to be a common condition in the pressurized aircraft environment, especially when flight attendants are confronted with an unusual event or emergency in the aircraft. The symptoms after being exposed to fumes in the cabin are reported to be the same as those seen during hyperventilation. Hence, it is concluded that some cases of fume events can be explained by hyperventilation (Bagshaw, 2014).

1.6.3 Temperature and Humidity in Aircraft Cabin

Thermal comfort can be defined as a combination of air, temperature, air velocity, rate of velocity fluctuation and humidity, including the ratio of these parameters. To ensure that the ventilation air supply is correctly distributed throughout the cabin, it is important to consider the air flow pattern. Large commercial aircraft often use a circular flow pattern, where ventilation air enters at the top of the cabin and circulates as two counter-rotating advection rolls, before being exhausted at floor level (Dechlow and Nurcombe, 2005). For every 1 000 ft. (305 m) of increase in altitude in the troposphere[2], temperature reduces with a constant of about -2 °C to -3.5 °C. The aircraft uses the environmental control system to keep the temperature at a constant when temperature outside decreases (FAA, n.d-b, p 22).

For human comfort and aircraft safety, the humidity is controlled. High humidity in the cabin air may lead to passenger discomfort, especially in addition to high temperature. In addition, it may lead to condensation, dripping, and freezing of moisture on the inside of the aircraft shell, and eventually corrosion. Biological growth can also be a result of condensation. As the humidity at cruising altitudes is usually very low, respiration and evaporation from the skin of occupants are the main sources of humidity in the cabin air (National Research Council, 2002, p 52).

1.6.4 Biological Factors

Other factors likely to cause negative health effects in people are biological agents. Agents from plants, microorganisms and animals have been found on aircraft. Biological airborne particles are termed bioaerosols, and can be found in the outdoor air near the ground, or in the outside air of the aircraft. Biological material, especially fungal spores and pollen grains are contained in outdoor air up to an altitude of about 4920 ft. (1 500 m). The amount and mixture of different bioaerosols depend on the location of the aircraft, as well as the ambient conditions. These enter through open doors and the ventilation system. The primary source of airborne bacteria is humans. The cabin passengers and the furnishing have been concluded to cause the presence of airborne microorganisms such as cultivable bacteria and fungi. Most of these microorganisms are found on the human skin, and rarely cause any infections (National Research Council, 2002, WHO, 1998).

[2] The lowest layer of the atmosphere, where most civilian aviation cruise.

1.7 Jet Engine Oil System

The regulations for international aviation demand that each engine is equipped with an independent oil system that under all conditions should be capable of providing continuous oil flow to the engine (Exxon Mobil, 2014b).

1.7.1 Engine Seals

Seals are installed in the jet engines to prevent oil leakage from the engine bearing chambers. The seals control the cooling airflow and prevent entrance of the mainstream gas into the turbine disc cavities. Various type of seals have been designed to only allow air and not engine oil through the compressor stage of the engines (Michaelis, 2010, p 52).

The jet engine oil system stores, carries, cools, and distributes oil that is needed for lubricating and cooling of components in the engines. Oil sumps are a part of the oil circuit, and to prevent oil leakage and pollution of the bleed air, the oil must remain inside the oil circuit at all times (Figure 10). A front sump is located in the compressor section, a mid sump is placed after the burner, before the turbine, while an aft sump is located in the turbine section (Exxon Mobil, 2014b).

The sumps are sealed by labyrinth or carbon seals, and the bearings and gears enclosed inside the sumps require lubrication. The pressure inside the sumps must be lower than outside to prevent oil leaking into and contaminating the cabin air. From the core engine compressors, the pressurizing air is bled off and injected between two labyrinth seals into the dry cavity in the bearing sump before it flows across the oil seals. An oil mist is created when air mixes with part of the oil inside the sump cavity. The ventilation air that carries droplets has to be discharged overboard through a rotating air/oil separator (Exxon Mobil, 2014c).

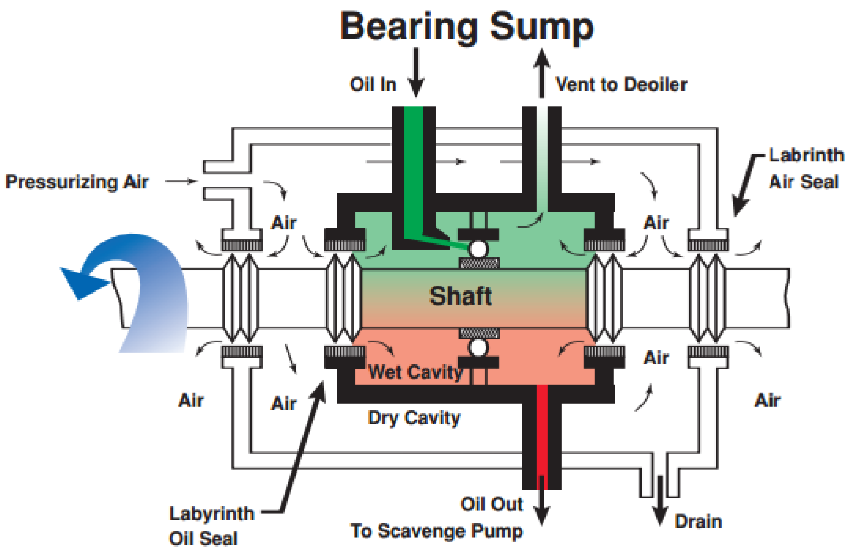

Figure 10: Schematic view of a jet engine oil system. The oil sumps are located along the main shaft line and surrounded by a dry cavity. The core engine compressors bleed off pressurized air, and the air is injected between two labyrinth seals into the dry cavity before it flows across the oil seals (Exxon Mobil, 2014c).

1.8 Jet Engine Oils, Hydraulic Fluids and De-Icing Fluids

Jet engine oils and hydraulic fluids are used in jet aircraft operations, where the former are developed specifically for aviation gas turbine engines. Their main functions are to lubricate and cool engine bearings. The jet engine oils used in the aircraft industry are needed to operate over huge temperature differences, from -40 °C for cold starting, and up to more than 250 °C. During many different aircraft operations, lubricants in the jet engine oils will undergo extreme heat (Exxon Mobil, 2014g).

Hydraulic fluids are the medium by which energy is transferred in hydraulic machinery. The fluids transmit energy in fluid-filled, pressurized systems, from the generating sector (the hydraulic pumps) to the motor sector (the hydraulic motors, actuating cylinders, or turbines). Valves control the quantity, pressure and direction of flow of the fluid. There exist two types of hydraulic principles; hydrokinetic and hydrostatic drives, where the latter are being used in aviation. The pressure in a fluid is distributed evenly in all directions in the hydrostatic drives. A certain volume of hydraulic fluid is displaced by the pump per stroke against the pressure in the system (Ramesh et al., 2013, Möller and Young, 2000).

Hydraulic fluids also have other functions than energy transfer; to lower friction between moving sliding parts and reduce wear (lubrication), to effectively remove heat in the system, to protect the steel or metal surfaces from corrosion, and to keep the system clean from oil insoluble products, such as dust or oxidation products. Hydraulic systems intended for aviation have to fulfil various functions, like moving flight control surfaces that help steer-, take-off- and land the aircraft, engage aircraft brakes and deploy- or retract landing gear. Hydraulic fluids used in aircraft have particular requirements, such as extremely low wear in pumps and valves, very good low-temperature behaviour, and very low tendency to fire propagation (Möller and Young, 2000, Exxon Mobil, 2014g).

Jet engine oils and hydraulic fluids contain base stocks, which is the main ingredient of the oils and fluids. The main functions of the base stock are to ensure the correct viscosity properties, due to the low temperature fluidity requirement for cold starting, and the need to have a sufficient oil film even at the highest bearing temperatures (Exxon Mobil, 2014g). The base stocks may be very different with respect to both the performance characteristics and the chemical composition. In addition, different types and quantity of additives are added to the base stocks (STAMI, 2003).

Additives are used in all fluids and oils to improve the lubricant performance of base stocks. They may be used to avoid rapid wear of engine components (anti-wear), or to improve the oxidative stability of ester lubricants (antioxidants) (Rudnick, 2006). These are comprised in less than 3 % of the formulation. The additives are commercially useful products, but have been recognized to cause negative neurotoxic health effects in humans after exposure. The commonly used anti-wear additives are triaryl phosphates (TAP), especially tricresyl phosphate (TCP) (Phillips et al., 2013, Winder and Balouet, 2002a).

1.8.1 Synthetic Jet Engine Oils

Synthetic lubricating oils used in gas turbine engines of aircraft are made up of a base stock, additives and antioxidants (Bernabei et al., 2000). The reasons why synthetic oils, also called *"*designer fluids*"*, are used in the aircraft industry are the molecules ability to stay together, the resistance to oxidation at high temperatures, the ability to keep the metal surfaces clean, and to maintain the required lubricant film. Synthetic oils are nearly wax free and therefore have the possibility to flow at low temperatures, in addition to fulfil a variety of viscosity requirements (Michaelis, 2010, p 59).

The base stocks in the synthetic oils are mostly based on a synthetic polyol, such as derivatives of erythritol, like pentaerythritol, which comprise around 95 % of the oils. Sometimes the oils may be based on trimethylolpropane esters (TMPE), and if tricresyl phosphate (TCP) and TMPE react together, it may be formed trimethylolpropane phosphate (TMPP), a potent neurotoxin (Wright, 1996, STAMI, 2003, Centers, 1992). This is described further in chapter 1.11.

N-Phenyl-1-naphthylamine (PAN) is a liphophilic solid often used as an antioxidant in jet engine oils. It acts as a radical scavenger in the auto oxidation of lubricants (Michaelis, 2010, p 68). These aromatic amines are used in concentrations of 0.25-5 % in the synthetic oil. The substituted diphenylamine is also an antioxidant used in concentrations not greater than 1 % (Winder and Michaelis, 2005).

The most common oils used in the commercial aircraft industry, shown in Table 2, are Mobil Jet engine oil II (Exxon Mobil, 2014f), Mobil Jet engine oil 254 (Exxon Mobil, 2014d), Mobil Jet engine oil 387 (Exxon Mobil, 2014e), BP Turbo Oil 2380 (BP, 2015), BP Turbo Oil 2197 (BP, 2014a), BP Turbo Oil 2389 (BP, 2014b), Aeroshell Turbine Oil 560 (Shell, 2013) and Turbo Nycoil 600 (Petro-Canada, 2015). Mobil Jet engine oil II commands almost half (49 %) the synthetic jet engine oils market share (Winder and Balouet, 2002a).

In the MSDS of the oils it is stated among others that *"The product is not expected to produce adverse health effects under normal conditions of use"*, "*Avoid breathing of vapours, mists or spray",* and *"Not considered to be an inhalation hazard under normal conditions of use"* (BP, 2015, Shell, 2013, Exxon Mobil, 2014f). What "normal conditions of use" means, is not further described in the MSDS.

The additives in the oils, listed as hazardous, include the chemicals found in the MSDS, product data sheets, on oil packaging material and in other oil company data. The base stocks that comprise 95 % of the jet engine oils are only described as "synthetic esters", with no further details about which base stocks that can be found in the different oils.

Table 2: List of jet engine oils and their respective constituents. These are found in the Material Safety Data Sheets by the manufacturers.

Manufacturer	Name of oil	Chemical name of constituent	CAS No.	Concentrations
Exxon Mobil	Mobil Jet engine oil II	Alkylated diphenylamines	68921-45-9	1- <5 %
		Tricresyl phosphate	1330-78-5	1- <3 %
		N-phenyl-1-naphthylamine	90-30-2	1 %
		Phenol, dimethyl-, phosphate (3:1)	25155-23-1	0.025- <0.1 %
	Mobil Jet engine oil 254	Tricresyl phosphate	1330-78-5	1-3 %
		Phenol, dimethyl-, phosphate (3:1)	25155-23-1	0.1-1 %
	Mobil jet engine oil 387	Tricresyl phosphate	1330-78-5	1-2.5 %
BP	BP Turbo Oil 2380	Tricresyl phosphate	1330-78-5	≥1- <3 %
		N-Phenyl-1-naphthylamine (PAN)	90-30-2	≥1- <3 %
	BP Turbo Oil 2197	Tricresyl phosphate	1330-78-5	≥1- <2.5 %
	BP Turbo Oil 2389	Tricresyl phosphate	1330-78-5	≥1- 2.5 %
Shell	Aeroshell Turbine Oil 560	Benzenamine, N-phenyl-, reaction products with 2,4,4-trimethylpentene	68411-46-1	1-3 %
		Tricresyl phosphate	1330-78-5	1-2 %
Petro-Canada	TurboNycoil 600	Phenol, isopropylated, phosphate(3:1)[Triphenyl phosphate > 5%] (Triisopropylated phenyl phosphate)	68937-41-7	1-5 %

TurboNycoil 600 oil is developed by a French company named NYCO. It is now used by the U.S. Navy and by many military agencies worldwide. Additionally, it is used in many commercial engines and APUs. The oil does not contain TCP at any measurable quantity, unlike the previously mentioned oils. The TCP is replaced with isopropylated triphenyl phosphate (TIPP). In the Material Safety Data Sheets (MSDS) of the oils it is stated: *"Contains material that may cause adverse reproductive effects"* (Piveteau, 2009). Thus, there still exists toxicity risk of using the jet engine oil (Petro-Canada, 2015).

1.8.2 Hydraulic Fluids

The four main groups of hydraulic fluids are mineral oils, poly-α-olefin oils (synthetic hydrocarbons), alkyl or aryl phosphate ester oils, and polyol esters (Möller and Young, 2000, STAMI, 2003).

The mineral oils are complex mixtures of aliphatic and aromatic hydrocarbons, which are made up from refined petroleum oil (Solbu, 2011). Since the 1940s, a mineral based hydraulic fluid named MIL-H-5606 has been one of the most widely used fluids. The fluid did provide excellent operational properties, but had a high degree of flammability. This was increased by the high pressure required for hydraulic system operation (2.07 x 10^7 Pascals). As a result, hydraulic systems based on phosphate-ester-based hydraulic fluids were developed, which now are used by all big civil transport aircraft. When an aircraft is certified, the hydraulic fluids for each application point are specified on the “Type Certificate” (Shell, 2012, p 181-182).

The hydraulic fluids in the aircraft industry often contain phosphate esters, due to their fire resistant properties (Solbu, 2011). Tributyl phosphate (TBP), which is a phosphate ester, is often the base stock (main ingredient) in hydraulic fluids. It is a colourless and odourless trialkyl phosphate ester, often mixed with dibutyl phenyl phosphate (DBPP), triaryl triphenyl phosphate (TPP) and butyl diphenyl phosphate. About 40-60 % of all TBP utilized in the U.S. is used as base stock in hydraulic fluids (WHO, 1991). All of the common hydraulic fluids, among others, Hyjet V, Hyjet IV-A Plus, Skydrol LD4 and Skydrol 500B-4, contain TBP.

Neopentyl polyol esters, abbreviated “polyols”, are made by a reaction between multifunctional alcohol and monofunctional fatty acids. Variations in these raw materials can have a major influence on the final physical properties of the esters. The polyol ester component of the base stock is made up of polyhydric alcohols, like pentaerythritol and sometimes trimethylolpropane (TMP/TMPE), and may be varied to change physical properties of the lubricants, such as the viscosity (Rudnick, 2006).

The MSDS contains further information about the ingredients in hydraulic fluids (Exxon Mobil, 2013, Exxon Mobil, 2014a, Eastman, 2013a, Eastman, 2013b) . The most used hydraulic fluids in the aircraft industry are listed in Table 3.

Table 3: List of hydraulic fluids and their respective constituents. These are found in the Material Safety Data Sheets by the manufacturers.

Manufacturer	Name of hydraulic fluid	Chemical name of constituent	CAS No.	Concentration
Eastman/ Solutia	Skydrol 500B-4	Dibutyl phenyl phosphate (base stock)	2528-36-1	40-70 %
		Tributyl phosphate (base stock)	126-73-8	19-20 %
		Butyl diphenyl phosphate (base stock)	27752-95-6	10-30 %
		2-ethylhexyl 7-oxabicyclo[4.1.0] heptane-3-carboxylate (aliphatic epoxide)	62256-00-2	<10 %
		2,6-Di-tert-butyl-p-cresol (additive)	128-37-0	0.1- 1 %
	Skydrol LD4	Tributyl phosphate (base stock)	126-73-8	55- 65 %
		Dibutyl phenyl phosphate (base stock)	2528-36-1	20-30 %
		2-ethylhexyl 7-oxabicyclo[4.1.0] heptane-3-carboxylate (aliphatic epoxide)	62256-00-2	<10 %
		Butyl diphenyl phosphate (base stock)	2752-95-6	5- 10 %
		2,6-Di-tert-butyl-p-cresol (additive)	128-37-0	1- 5 %
Exxon-Mobil	Hyjet V	Tributyl phosphate (base stock)	126-73-8	70- <80 %
		Phenol, isopropylated, phosphate(3:1)[Triphenyl phosphate > 5%] (Triisopropylated phenyl phosphate)	68937-41-7	10- <20 %
		Aliphatic epoxide	62256-00-2	5-7 %
		2,6-di-tert-butyl-p-cresol(additive)	128-37-0	0.1- <1 %
	Hyjet IV-A Plus	Tributyl phosphate (base stock)	126-73-8	70- <80 %
		Phenol, isopropylated, phosphate [Triphenyl phosphate > 5%]	68937-41-7	10- <20 %
		Aliphatic epoxide	62256−00−2	5- <10 %
		Calcium sulphonate	57855-77-3	0.1- <1 %
		2,6-di-tert-butyl-p-cresol (additive)	128-37-0	0.1- <1 %

1.8.3 De-Icing Fluids

The use of de-icing fluids is the most common technique to remove frozen precipitation from the critical surfaces of aircraft. In addition it protects the aircraft against re-freezing, and thus, re-contamination. The main ingredient in de-icing fluids is ethylene glycol or propylene glycol. Ingredients also include thickening agents, wetting agents, corrosion inhibitors and coloured UV-sensitive dye (Michaelis, 2010, p 69).

1.9 Potential Toxicity Following Exposure to Jet Engine Oils and Hydraulic Fluids

Toxicity can be defined as the degree to which a chemical substance (or physical agent) causes an adverse effect on the biological system of an organism exposed to the substance over a designated time period. Toxicity can be divided into two groups; acute and chronic toxicity. The cause of acute toxicity is a single dose or exposure, while the chronic toxicity is the result of long-term or numerous brief exposures (US National Library of Medicine, 2014).

Changes in product formulations of synthetic oils, hydraulic fluids and de-icing fluids have been made, but still there exists concern about the potential toxicity an exposure to these materials may cause (Daughtrey et al., 1996, Abou-Donia, 2015). Even small amounts of toxic fumes, like some of the organophosphate ingredients in oils and hydraulic fluids, may cause serious ill health effects in humans. There exist a large number of reported health effects followed by exposure to contaminated cabin air (Solbu et al., 2011). The earliest case found in the literature was reported in 1977, where a pilot had a sudden indisposing during flight, with neurologic impairment and gastrointestinal distress. After one day, his clinical status returned to normal. The cause of his symptoms was believed to be inhalation of aerosolized or vaporized synthetic lubricating oil coming from the jet engine of the aircraft (Montgomery et al., 1977, Winder and Balouet, 2002a).

There is missing information about the retention, absorption, metabolism or distribution of inhaled mist containing organophosphates. In general, the rate of absorption of an inhaled substance via the lung depends on the molecular size and solubility of the substance. Oil mist droplets larger than 5 μm tend to be trapped in upper airways and later swallowed or expectorated, while the smaller droplets may be carried down and detained in the lungs (Craig and Barth, 1999, p 291).

According to information from a presentation by Abou-Donia (2015) during a Global Cabin Air Quality Executive meeting in London (2015), the chemical-induced adverse health effect of chemical exposure in cabin and cockpit is dependent on two factors; the long-term, repeated exposure and the cocktail of combined chemicals. The so-called “chemical cocktail” is described as a blend of components from the engine oils, hydraulic fluids, flame retardants, by-products after combustion, insecticides sprayed inside the aircraft, and other chemicals.

1.10 Components in Jet Engine Oils and Hydraulic Fluids

1.10.1 Amines

N-Phenyl-1-naphthylamine (PAN)

Synonyms: phenyl-α-naphtylamine, 1-Naphthalenamine, N-Phenyl-, 1-Anilinonaphthalene, antioxidant PAN, N-(1-Naphthyl)aniline (Figure 11)
CAS No. 90-30-2

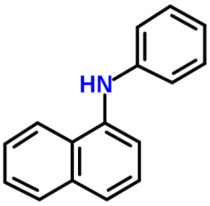

Figure 11: Chemical structure of N-Phenyl-1-naphthylamine (Royal Society of Chemistry, 2014).

N-Phenyl-1-naphthylamine is a liphophilic solid often used as an antioxidant in lubrication oils (TOXNET, 2005a). The commercial product of PAN is comprised at concentrations of about 1 % in lubricating oils, and has a typical purity of about 99 %. From different studies it is found that the antioxidant may have a carcinogenic effect, but there are made no conclusions regarding this. Mammalian systems readily absorb PAN, and convert it rapidly to metabolites (WHO, 1998). By single dosing it does not seem as particularly toxic, with LD_{50} above 1 g/kg. The chemical has a mechanism of toxicity similar to that of many aromatic amines with meta haemoglobin production (Winder and Michaelis, 2005, Winder and Balouet, 2002b).

In some studies, the chemical shows no irritation effect to skin and eyes, while in other studies it is shown to be a strong skin sensitizer (Boman et al., 1980, Kalimo et al., 1989, Winder and Balouet, 2002b). There are reports of little genotoxicity potential, while various forms of cancer were found among workers exposed to antirust oil containing 0.5 % PAN. Some studies indicate a mild carcinogenic effect, while others have reported no carcinogenic potential (Winder and Balouet, 2002b, Wang et al., 1984).

Alkylated diphenylamine

Synonyms: N-Phenylaniline, anilinobenzene, N-Phenylbenzenamine, benzenamine, N-phenyl-, N,
N-Diphenylamine (Figure 12)
CAS No. 122-39-4

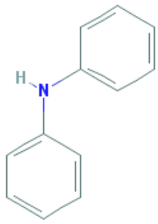

Figure 12: Chemical structure of alkylated diphenylamine (National Center for Biotechnology Information, n.d).

Alkylated diphenylamine antioxidants have been used for many years to suppress the oxidation of industrial- and engine oils. Improved oxidation resistance of base stocks has led to the development of longer life turbines, which often have required the use of higher levels of antioxidants. There have been small changes in the types of antioxidants available due to the cost associated with development and commercialization of new antioxidant components. Alkylation of diphenylamines can occur both ortho- or para to the nitrogen atom, in addition to possible occurrence of mono-, di-, or tri-alkylation (Gatto et al., 2007).

The substance may be irritating to mucous membranes, eyes and skin. Incidents of occupational human poisoning have been reported with bladder symptoms, tachycardia[3], hypertension, and eczema. Sensitization is unlikely, and has been observed only as a consequence of cross sensitization to p-Phenylenediamine (PPD) (National Center for Biotechnology Information, n.d).

1.10.2 Organophosphates

Butyl diphenyl phosphate (BDP)

Synonyms: phosphoric acid, butyl diphenyl ester (Figure 13)
CAS No. 2752-95-6

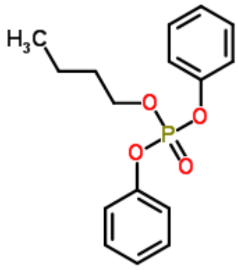

Figure 13: Chemical structure of butyl diphenyl phosphate (Royal Society of Chemistry, 2014).

Organophosphates are often highly toxic pesticides (Lewis, 2008, p 1114). Studies on BDP are not available.

Dibutyl phenyl phosphate (DBPP)

Synonyms: phosphoric acid, dibutyl phenyl ester, dibutyl phenylphosphate, Di(n-butyl) phenyl phosphate, CCRIS 4604 (Figure 14)
CAS No. 2528-36-1

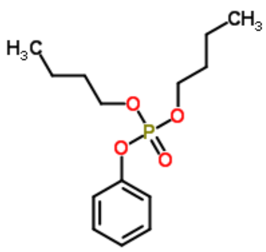

Figure 14: Chemical structure of dibutyl phenol phosphate (Royal Society of Chemistry, 2014).

[3] A heart rate that exceeds the normal resting rate (also called tachyarrhythmia).

Formulations of dibutyl phenyl phosphate have been reported to lead to marked pain in the eyes, following contact. However, no reports where such contact caused actual damage to the eyes have been found. Irritation in the form of drying and cracking of exposed skin has been caused by repeated or prolonged skin contact (National Center for Biotechnology Information, n.d, TOXNET, 2015).

Exposure to aerosolized dibutyl phenyl phosphate formulations or to vapours at high temperatures has been reported to produce nose and throat irritation, accompanied by coughing and wheezing. Dibutyl phenyl phosphate is not considered to be a primary irritant or a sensitizing agent based on patch testing of 50 human volunteers. The recommended maximum permissible concentration of DBPP in the working zone is suggested to be 0.1 mg/m^3 (National Center for Biotechnology Information, n.d, TOXNET, 2015).

Isopropylated triphenyl phosphate (TIPP)

Synonyms: Phenol, isopropylated, phosphate (3:1), tris(4-propan-2-ylphenyl) phosphate, tris[4-(propan-2-yl)phenyl] phosphate (Figure 15)
CAS No. 68937-41-7

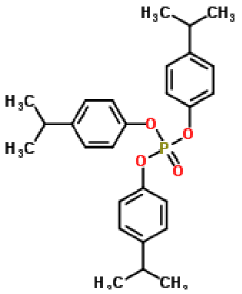

Figure 15: Chemical structure of isopropylated triphenyl phosphate (Royal Society of Chemistry, 2014).

The substance is poisonous by subcutaneous route, and moderately toxic by ingestion. It is absorbed slowly, especially by skin contact. It is not a potent inhibitor of human cholinesterase. When the substance is exposed to heat it is combustible, and when heated to decomposition, it emits toxic fumes of phosphorus-oxygen (PO_x) (Lewis, 2008, p 1396).

Phenol, dimethyl-, phosphate (3:1)

Synonyms: Tris(3,5-xylyl) phosphate, Phenol, 3,5-dimethyl-, phosphate (3:1), HSDB 3912, Trixylenyl phosphate mixed isomers, 3,5-Xylenol, phosphate (3:1), tris(3,5-dimethylphenyl) phosphate (Figure 16)
CAS No. 25155-23-1

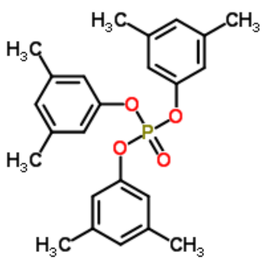

Figure 16: Chemical structure of Phenol, dimethyl-, phosphate (3:1) (Royal Society of Chemistry, 2014).

Phenol, dimethyl-, phosphate (3:1) is produced through the reaction between phosphorus oxytrochloride and xylenols. Breathing or swallowing large quantities may cause ataxia[4]. It may be irritating to the skin, respiratory tract, mucous membrane and eyes (CAMEO, n.d). The chemical may contain impurities of tri-ortho-cresyl phosphate and other ortho-cresyl-components (National Center for Biotechnology Information, n.d).

Hens exposed to hydraulic fluid containing phenol, dimethyl-, phosphate showed delayed neurotoxicity (TOXNET, 2013). From studies on roosters, there were not found any neuroparalytic effects when they were given phenol, dimethyl-, phosphate (3:1) orally. When orally given 1 g/kg/day for 40 days, the results showed low toxic effect (National Center for Biotechnology Information, n.d).

OMTI, a fireproof aerosol lubricant for turbines based on phenol, dimethyl-, phosphate (3:1), were in another study inhaled by mice, rats and guinea pigs. The dose was 1-10 mg/m^3, 4 hours daily for 16 weeks, and the results showed relatively low toxicity to the lung, skin and peripheral nerves (National Center for Biotechnology Information, n.d).

Tributyl phosphate (TBP)

Synonyms: Tri-n-butyl phosphate, Butyl phosphate, Phosphoric acid tributyl ester, Tributylphosphate (Figure 17)
CAS No. 126-73-8

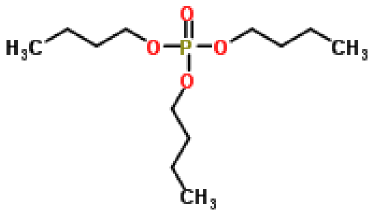

Figure 17: Chemical structure of tributyl phosphate (Royal Society of Chemistry, 2014).

Tributyl phosphate can be absorbed into the body by inhalation of its vapour, through the skin or by ingestion. Hence, the target organs are eyes, skin and respiratory system. Symptoms of exposure may include irritation to the above mentioned, in addition to headache and nausea. Severe irritation was produced in the skin (inducing erythema and oedema) of all rabbits given a single dermal dose of 500 mg TBP (Sjögren et al., 2010, p 38). It can be combusted under hot conditions. The phosphate is shown to have a slightly inhibitory effect on the activity of human plasma cholinesterase, from an in vitro protocol (National Center for Biotechnology Information, n.d).

[4] Lack of muscle control.

Tricresyl phosphate (TCP)

Synonyms: Tri-p-cresyl phosphate, Tri-p-tolyl phosphate, Tritolyl phosphate, Tris(4-methylphenyl) phosphate, Phosphoric acid, tris(4-methylphenyl) ester (Figure 18)
CAS No. 1330-78-5

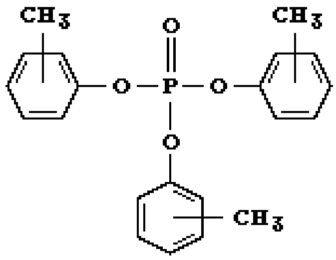

Figure 18: Chemical structure of tricresyl phosphate, TCP (WHO, 1990).

Tricersyl phosphate is used as a flame-retardant additive for extreme pressure lubricants and non-flammable fluid in hydraulic systems (Michaelis, 2010, p 60, Mackerer et al., 1999). It is colourless to bright yellow, with a slightly aromatic odour. It is a viscous organophosphate with low water solubility. TCP essentially consists of a mixture of ten isomers of varying toxicity. The isomers are divided into three main groups: meta-cresyl, para-cresyl and ortho-cresyl. These are difficult to separate due to their approximately equal boiling point, respectively 202, 201.8 and 191-192 °C (De Nola et al., 2011). Isomers have the same molecular formula but different structural formulas, which result in different toxic properties. Persmissible Occupational Exposure Limit (PEL) is 100 µg/m^3 (=0.1 mg/m^3) as an 8 hour time-weighted average (TWA) (OSHA, n.d). The structural formula of TCP is $C_{21}H_{21}O_4P$, as can be seen in Figure 18 (WHO, 1990).

Toxicity of Different TCP-isomers

Most synthetic jet engine oils contain TCP as an additive. The commonly used oils (Table 2) contain between 1-5 % TCP. The ten isomers of the organophosphate have different level of toxicity depending on the ortho-, meta-, or para- location of the methyl cresyl (CH_3) groups in the cresyl ring (Figure 19). The tri-ortho isomer has been the most studied of the ten TCP isomers, which is the only isomer with an exposure limit of 0.1 mg/m^3 (PEL) (Craig and Barth, 1999).

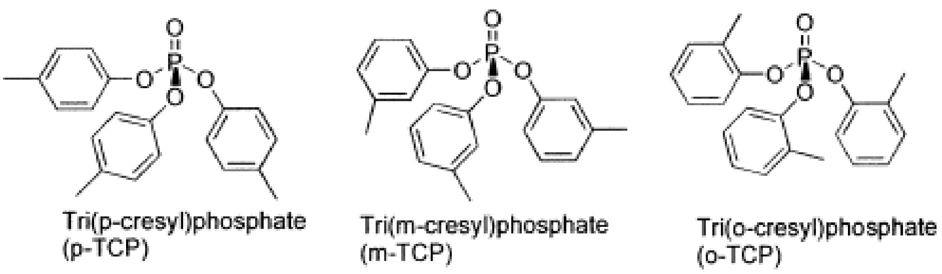

Figure 19: Chemical structure of the para-, meta-, and ortho-location of -CH_3 on TCP (Johnson et al., 2002).

The synthesis and composition of commercial TCP have changed over time. Formerly, TCP contained high levels of all the isomers, but now commercial TCP is manufactured by the reaction between phosphorous oxylchloride, and a mixture of alkyl phenols derived from coal, tar or petroleum, in which the majority is m-cresol (3-methylphenol) and p-cresol (4-methylphenol). TCP only containing m- and p-cresyl isomers are considered relatively non-toxic (Craig and Barth, 1999).

Already in 1931, the neurotoxic potential of the ortho-cresyl isomers was recognized, with focus on tri-ortho-cresyl phosphate (TOCP). This is the isomeric form suspected to be the primary responsible component for organophosphate-induced delayed neuropathy (OPIDN). OPIDN are explained in chapter 1.14.2 (Craig and Barth, 1999, De Nola et al., 2008, de Boer et al., 2014).

The connection between neurotoxic effects of TCP and alkyl substitution in the ortho-position of the aromatic ring has been known since the 1950s (De Nola et al., 2008, Henschler, 1958). TOCP was formerly presumed to be the only reason for TCP-toxicity. In a study carried out by Henschler (1958), it was suggested that TCP containing 25-30 % mono-ortho-cresyl phosphate residues are more toxic than pure TOCP (Craig and Barth, 1999). His studies ascertained that the mono-ortho-cresyl phosphate (MOCP) and di-ortho-cresyl phosphate (DOCP) isomers were most toxic, respectively ten and five times more than TOCP (Figure 20) (Henschler, 1958, De Nola et al., 2011, De Nola et al., 2008). Although Henschler's findings showed that MOCP was the most toxic isomer, the manufacturers have concentrated on reducing the content of TOCP in the oils. The isomer now only occurs as a smaller constituent in commercial mixtures, and is regulated to not exceed 0.2 % (Winder and Balouet, 2002a, Abou-Donia, 2015).

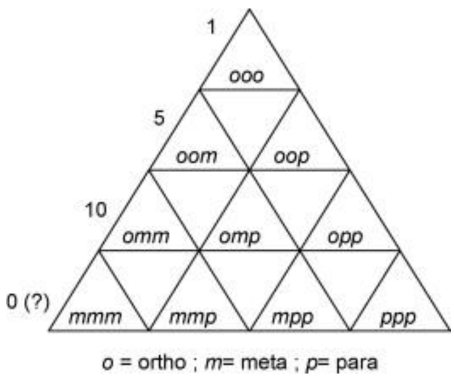

Figure 20: Triangular view of the ten different TCP isomers. MOCP is considered to be ten times more toxic than TOCP, while DOCP is presumed to be five times more toxic than TOCP (De Nola et al., 2008).

The level of TCP in jet engine oils is normally 3 %, and only about 0.003-0.03 % (30-300 ppm) of this is ortho-cresyl phosphate (Winder and Balouet, 2002b). The human exposure limit of TCP is based on the toxicity of the TOCP isomer, even though it is considered to be present as a minor impurity (De Nola et al., 2008). Thus, several of the previously reported poisonings may be the result from consumption of TCP with high content of asymmetric mono-ortho and di-ortho isomers (Craig and Barth, 1999). The total toxicity of a particular composition depends on the content of each ingredient, and interactions between the various chemicals. On this basis, it was claimed that the presence of all ortho-cresyl-containing molecules should be considered in the overall toxicity of TCP (Winder and Balouet, 2002b)

1.10.3 Other Compounds

Calcium sulphonate

Synonyms: calcium 2,3-dinonylnaphthalene-1-sulfonate, Naphthalenesulfonic acid, dinonyl-, calcium salt, 86329-66-0, calcium bis(2,3-dinonylnaphthalene-1-sulfonate), Naphthalenesulfonic acid, dinonyl-, calcium salt (2:1), AGN-PC-02K3CO (Figure 21)
CAS No. 57855-77-3

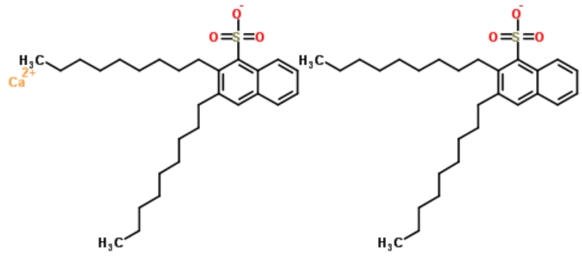

Figure 21: Chemical structure of calcium sulphonate (ChemSpider, n.d.) .

Calcium sulphonate has been shown to induce sensitization in guinea pigs. It has been noted to be irritating to rabbits' eyes, and acute toxicity is low for the dermal route in rabbits and the oral route in rats. In human volunteers no sensitization was observed in a repeated insult patch sensitization test (EPA, 2012).

2,6-Di-tert-butyl-p-cresol

Synonyms: 2,6-Di-tert-butyl-4-methylphenol, Butylated hydroxytoluene (BHT), Butylhydroxytoluene, 2,6-Di-tert-butyl-p-cresol, Dibunol (Figure 22)
CAS No. 128-37-0

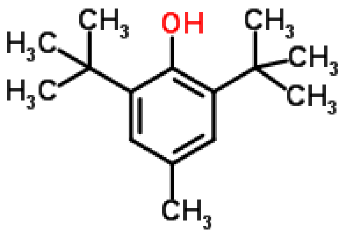

Figure 22: Chemical structure of 2,6-Di-tert-butyl-p-cresol (Royal Society of Chemistry, 2014).

2,6-Di-tert-butyl-p-cresol is used as a readily absorbed antioxidant used in fats and oils, and packaging material for fat-containing foods. Results from studies on rats showed that there was some deposition in adipose tissue following a high dosis of (3)H-BHT ip for 35 days. Liver tissue and body fat showed elevated concentrations, which varied among female and male rats. Rats fed high doses of BHT showed increases in serum cholesterol in both sexes (National Center for Biotechnology Information, n.d, TOXNET, 2005b).

The substance is toxic by intraperitoneal and intravenous routes, and moderately toxic by ingestion. It is a skin and eye irritant, and questionable a carcinogen. The substance is combustible when exposed to heat, and may under such circumstances emit acrid smoke and fumes. It can react with oxidizing materials (Lewis, 2008, p 170).

2-Ethylhexyl 7-oxabicyclo (4.1.0) heptane-3-carboxylate

Synonyms: 7-Oxabicyclo[4.1.0]heptane-3-carboxylic acid, 2-ethylhexyl ester, 7-Oxabicyclo(4.1.0)heptane-3-carboxylic acid, 2-ethylhexyl ester (Figure 23)
CAS No. 62256-00-2

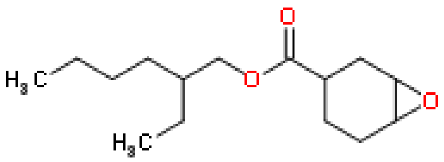

Figure 23: Chemical structure of 2-Ethylhexyl 7 oxabicyclo (4.1.0) heptane-3-carboxylate (Royal Society of Chemistry, 2014).

Aliphatic epoxides are suspected to be carcinogens, with experimental tumours of the skin, lung, and blood-forming tissues (Lewis, 2008, p 35).

1.11 Products of Combustion and Pyrolysis

The bleed air may sometimes be contaminated with combusted or pyrolyzed engine oil and hydraulic fluid, as mentioned earlier (Harrison et al., 2009). Maintenance, operation, and design failures or deficiencies give the potential of heated engine oil and hydraulic fluid to contaminate the cabin and cockpit air, and may thus lead to negative health effects in the cabin crew and passengers (Murawski, 2005). Pyrolysis of the chemicals may occur at high temperatures, and chemicals from heated engine oils not included in the original ingredients, may be created in this process (van Netten and Leung, 2001). Currently, the knowledge about which chemicals and combustion products that enters the ventilation systems of aircraft from the engines or APU is insufficient.

In an effort to find agents that may be responsible for the symptoms experienced by pilots, flight crew and passengers, a number of researchers have attempted to describe the constituents of the oils and fluids used in aircraft engines, and their pyrolytic degradation products (Daughtrey et al., 1996, van Netten, 1999, van Netten, 1998). Carbon dioxide (CO_2), carbon monoxide (CO) and fumes from oil leaks, hydraulic leaks, and water leaks are potential contaminants. The substances known to be emitted due to pyrolysis of commercial jet engine oils and hydraulic fluids are: cresyl- and the more volatile butyl-phosphate esters, potentially irritant acid, aldehyde and ketone volatile organic compounds (VOC) (Expert Panel on Aircraft Air Quality, 2009).

There have been, and still are, concerns about the potential reaction of ingredients in some base stocks, such as the reaction between trimethylol phosphate (TMP) polyols and TCP during elevated temperatures, which may produce the potent neurotoxin trimethylolpropane phosphate (TMPP) (Centers, 1992, STAMI, 2003). Synthetic oils are, as mentioned, sometimes based on trimethylolpropane esters (TMPE), and can be mixed with triaryl phosphates, like TCP, as anti-wear additives. Under extreme temperatures (350-700 °C), model experiments have shown that a potent neurotoxin, trimethyl propane phosphate (TMPP) can be formed by a reaction between TCP and trimethylolpropane esters (TMPE) (STAMI, 2003, Wyman et al., 1987, Kalman et al., 1985, van Netten and Leung, 2000). TMPP is known to cause epileptiform seizures potentially followed by death (Wyman et al., 1993, Keefer et al., 2001).

In a study conducted by Kalman et al. (1985), there was found production of TMPP during pyrolysis of synthetic aircraft engine oil. Once decomposition temperatures were reached, the formation of products was rapid, and some TMPP production occurred within 2 minutes.

Wyman et al. (1987) investigated the formation of TMPP during pyrolysis of synthetic jet engine oils. The oils were primarily composed of a trimethylol propane (TMP) ester base stock. To quantify the production of the neurotoxin, rodent bioassay and GC-MS analysis were performed. The temperature that gave the maximum production of TMPP for sealed tube and open air methods of pyrolysis was respectively 500 °C and 650 °C.

Centers (1992) did an experiment to determine the potential of TMPP formation in thermally degraded synthetic ester turbine lubricants. It was concluded that the neurotoxin only could be formed at high temperatures. In studies on mice, the neurotoxin caused convulsion followed by death. The LD_{50} was 1.0 mg/kg body weight when injected intraperitoneal[5], and 50-100 mg/kg when applied dermally. For some formulations, 7-10 mg or more of TMPP per millilitre of lubricant were found to be produced by open-to-air pyrolysis at very high temperatures (350-700 ºC).

van Netten and Leung (2000) compared two commercial available jet engine lubricating oils and their volatile pyrolytic degradation products in a study regarding the aircraft BAe-146. Castrol 5000 and Exxon 2380 were the two jet engine oils compared. They were investigated under lab conditions at 525 °C to measure the release of CO, CO_2, nitrogen dioxide (NO_2), and hydrogencyanide (HCN), as well as volatiles, to find out if TCP and TMPP would be present or formed. The article does not state whether or not the TMPE are contents in the two oils compared initially, but it was stated that TCP and TMPE are both common constituents in jet engine oils. TMPP was not found in any of the experiments. Some CO_2 was generated along with CO, which reached levels in excess of 100 ppm. HCN and NO_2 were not detected. TCP was confirmed in the bulk oils and in the volatiles, but not in the cabin air. CO and volatilized components, as well as pyrolysis products, could pose a potential hazard to flight crews if engine oil seals fail in an aircraft. It was expected that localized condensation in the ventilation ducts and filters in the air condition packs was likely to be the reason why TCP was not found in the air (van Netten and Leung, 2000).

[5] Injection of a substance into the peritoneum (body cavity).

1.12 Short-and Long Term Symptoms of Exposure to Contaminated Air

When it comes to route of exposure of contaminants in aircraft, it is stated that inhalation is an important route. A second, less significant route is exposure of uncovered skin, such as exposure to oil mists or vapours. A third route is ingestion, which is considered unlikely in this case (Winder and Michaelis, 2005).

The acute effects of exposure to contaminated air in aircraft show a close temporal relationship with exposure and usually ends after the exposure ceases (Ross et al., 2006). Chronic health effects have been reported to last for months or years after exposure. From a survey sustained by Winder and Balouet (2001), the symptoms of exposure were divided by short- and long-term low-level symptoms or residual symptoms. These are further organized in subcategories, shown in Table 4. Repeated exposure over an extensive period of time may be a problem for frequent fliers, predisposed individuals, and when severe oil leaks enter the air cabin environment.

Table 4: Overview of symptoms of exposure to contaminated air on aircraft. The table is compiled out of information in an article by Winder and Balouet (2001).

Subcategory	**Single or short-term symptoms**	**Long term low-level or residual symptoms**
Airways	Irritation of eyes, nose and upper airways	Irritation of eyes, nose and upper airways
Cardiovascular symptoms	Increased heart rate and palpitations[a)]	Chest pain Increased heart rate and palpitations
Gastro-intestinal symptoms	Nausea Vomiting	Salivation Nausea Vomiting Diarrhoea
General		Weakness and fatigue (leading to chronic fatigue) Exhaustion Hot flashes Joint pain Muscle weakness and pain
Neuropsychological symptoms	Memory impairment Headache Light-headedness Dizziness Confusion Feeling intoxicated	Memory impairment Forgetfulness Lack of co-ordination Severe headaches Dizziness Sleep disorder
Neurotoxic symptoms	Blurred tunnel vision Nystagmus Disorientation Shaking and tremors Loss of balance and vertigo Seizures Loss of consciousness Parasthesia[b)]	Numbness in fingers, lips, limbs Parasthesia

Respiratory symptoms	Cough Breathing difficulties (shortness of breath) Tightness in chest Respiratory failure requiring oxygen	Breathing difficulties (shortness of breath) Tightness in chest Respiratory failure Susceptibility to upper respiratory tract infections
Sensitivity		Signs of immunosuppression Chemical sensitivity leading to acquired or multiple chemical sensitivity
Skin symptoms		Skin itching and rashes Skin blisters (on uncovered skin) Hair loss

a) Perceived abnormality of the heartbeat.
b) Sensation of tingling, tickling, pricking, or burning in the skin with no apparent long-term physical effect.

1.13 Aerotoxic Syndrome

In 1999, scientists from the US, France and Australia, Professor Chris Winder, Jean Christophe Balouet and Dr Harry Hoffman, respectively, proposed the term "aerotoxic syndrome" to explain the association of symptoms observed among aircrew exposed to contaminated air. The Australian Senate Inquiry endorsed the term one year later (Ross et al., 2006). According to Winder and Balouet (2000), the characteristics of this syndrome are related to flight crew and passengers exposed to toxic atmospheric contaminants from jet engine oils and hydraulic fluids during flights. Oils and hydraulic fluids can exist in unchanged form, be combusted or pyrolized when exposure occurs. Symptoms following aerotoxic syndrome have been described as chronologically development of irritancy, sensitivity and neurotoxicity, as headache, confusion, loss of balance, muscle weakness, numbness and neurobehavioral problems (de Ree et al., 2014, Abou-Donia, 2003, van Netten, 1998). The syndrome may be reversible following brief exposures, but after a significant or long term exposure, a chronic syndrome may occur. Many systems in the body are affected, as a cause of the broad range of symptoms reported (Winder and Balouet, 2000).

The accuracy of the term aerotoxic syndrome has been debated by, among others, Bagshaw (2014) and Liyasova et al. (2011). The reason for this is that the association between illness (areotoxic syndrome) and exposure to fumes from jet engine oil is not clearly proven and therefore it is disputed among experts in the field. As mentioned earlier, it was stated that the symptoms are identical to the symptoms resulting from hyperventilation. It was furthermore claimed that based on current knowledge it can be concluded that the amount of organophosphates which aircraft crew may be exposed to, even over long-term exposure, is not sufficient to cause neurotoxicity (Bagshaw, 2014).

1.14 Organophosphates and Health Effects Following Exposure

Researchers have mainly focused on organophosphates (OPs) when studying the relationship between reported health effects and fume events. Esters, amides and thiols are derivatives of orthophosphoric- and thiophosphonic acid, and constitute the collective term organophosphates (Reichl and Ritter, 2011, p 200). The general structure of organophosphates is presented in Figure 24. R_1 and R_2 are most commonly alkoxy groups. Oxygen or sulphur is attached to the phosphorus with a double bond, and X is the so-called leaving group. The latter are most sensitive to hydrolysis, and are displaced when the OP phosphorylates acetylcholinesterase (AChE) (Klaasen and Watkins, 2010, p 312, Costa, 2006). Among other utilization areas, OP isomers have been, and still are, used as industrial chemicals, in light oils, as agricultural pesticides, in pharmaceuticals, as nerve agents, as fuel additives and as flame retardants (Abou-Donia, 2003, Baron, 1981).

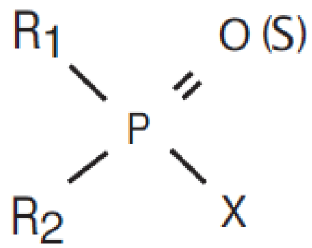

Figure 24: Chemical structure of organophosphate. Oxygen or sulphur is attached to the phosphorus with a double bond. The R-groups are most commonly alkoxy groups, and X is the leaving group (Klaasen and Watkins, 2010, p 312, Costa, 2006).

Organophosphates are not stored externally or internally by organisms because of their biodegradability. After uptake by ingestion, inhalation or through the skin, organophosphates are well absorbed, and rapidly distributed to all organs and tissues. Degradation occurs primarily by oxidation of cytochrome P450-dependent monooxygenases of the liver, and by hydrolytic cleavage of ester bonds (esterase) (Reichl and Ritter, 2011, p 200). Organophosphates possess a high acute toxicity, and are neurotoxic to insects and warm-blooded animals. The compounds inhibit acethylcholine esterase (AChE) in the nervous system. Inhibition of AChE by OPs leads to accumulation of acetylcholine at cholinergic synapses, followed by overstimulation of muscarinic and nicotinic cholinergic receptors (Figure 25). “Aging” of the enzyme-inhibitor complex occurs when there is loss of one of the two alkyl (R) groups. The aging leads to a very stable complex, considered to be irreversibly inhibited. Synthesis of a new enzyme is required to restore activity, but this process may take days (Reichl and Ritter, 2011, p 200, Klaasen and Watkins, 2010, p 312). The mentioned receptors (muscarinic and nicotinic) are localized in most organs of the body, which means that many body parts may be affected (Abou-Donia, 2005, Baron, 1981).

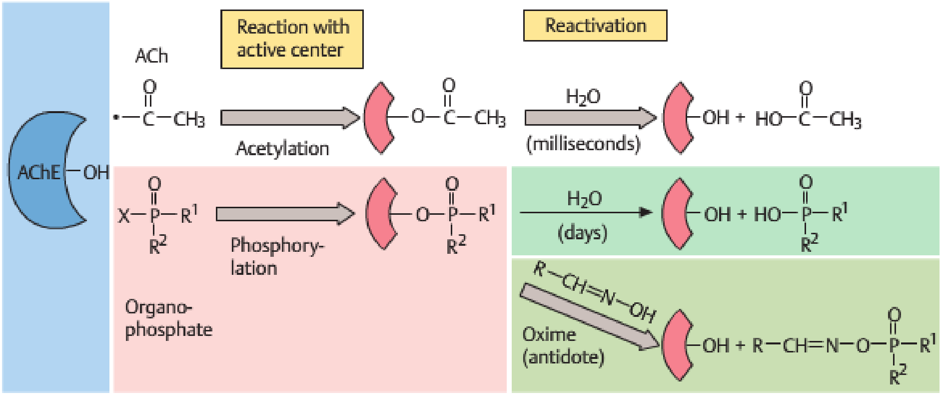

Figure 25: Mechanism of action of organophosphates (Reichl and Ritter, 2011, p 201).

Exposure to organophosphorus compounds in single or short-term exposures, single large toxic dose, or long-term low level repeated exposure, may lead to the development of neurotoxicity (Winder and Michaelis, 2005). According to Abou-Donia (2003), there are three distinct neurotoxic actions associated with organophosphorus compounds: cholinergic neurotoxicity of organophosphorus compounds, organophosphorus ester-induced delayed neurotoxicity (OPIDN) and organophosphorus ester-induced chronic neurotoxicity (OPICN). Neurotoxic effects in humans have also been divided into four categories; cholinergic syndrome, intermediate syndrome, organophosphate-induced delayed polyneuropathy (OPIDP/OPIDN) and chronic organophosphate-induced neuropsychiatric disorder (COPIND/OPICN) (Jokanović and Kosanović, 2010). Here, the classification by Abou-Donia (2003) will be looked further into. Figure 26 shows an overview of different influences from organophosphate poisoning in humans.

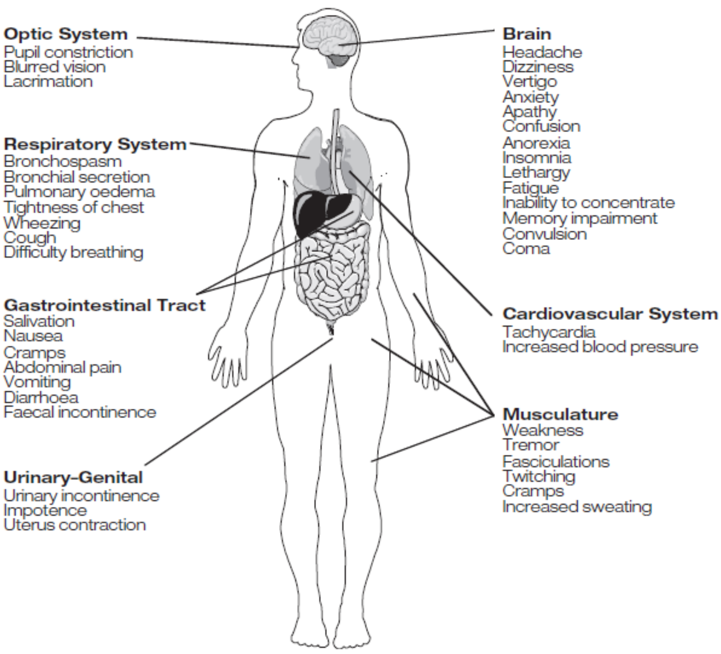

Figure 26: Overview of possible reactions in the body from organophosphate poisoning. Signs of intoxication by organophosphates may include headache, concentration difficulty, confusion, tremors, diarrhoea, vertigo, increased sweating, muscular twitching and various central nervous system effects (Klaasen and Watkins, 2010, p 312, Winder and Michaelis, 2005, Abou-Donia, 2005).

1.14.1 Cholinergic Neurotoxicity of Organophosphorus Compounds

Cholinergic neurotoxicity may be caused by exposure to organophosphorus compounds. This occurs when the cholinergic system that includes AChE and its neurotransmitter acetylcholine is disrupted. The mechanism involves inhibition of AChE by organophosphorus esters when the serine hydroxyl group at the catalytic triad site is phosphorylated. This nerve stimulation (inhibition) results in a release and accumulation of acetylcholine and further overstimulation at some receptors in the central nervous system (CNS) and the peripheral nervous system (PNS), muscarinic and nicotinic receptors. The result of this is muscle contraction and gland secretions. Hydrolysis of AChE terminates the reaction. The acid ester (phosphoric or phosphonic), formed with the enzyme is very stable and gets slowly hydrolysed. Organophosphorus compounds undergo detoxification by binding to other enzymes that contain the amino acid serine. Cholinergic symptoms are dependent on dose size, frequency of exposure, duration of exposure, and route of exposure, as well as other factors (Abou-Donia, 2003, Jokanović and Kosanović, 2010).

Erytrocyte AchE and the activity of these enzymes are regarded as biomarker of toxicity of OP compounds. This is because clinical diagnosis of acute poisoning is relatively simple, and confirmation of diagnosis can be made by measurement of erythrocyte AChE or plasma cholinesterase (Jokanović and Kosanović, 2010).

1.14.2 Organophosphorus Ester-Induced Delayed Neurotoxicity

OPIDN can occur as a result of single or multiple exposures to organophosphorus esters. This neurodegenerative disorder is characterized by a delayed onset of prolonged ataxia and upper motor neuron spasticity. The earliest known incident of OPIDN was due to the use of tri-o-cresyl phosphate-containing creosote oil, with the intention of treatment to pulmonary tuberculosis in France in 1899 (Abou-Donia, 2003). It was identified as the chemical responsible for the Ginger Jake paralysis in the 1930s, where 20 000-50 000 people suffered from OPIDN, as mentioned in chapter 1.1.1 (Ehrich and Jortner, 2002, Baron, 1981, Schopfer et al., 2010, Craig and Barth, 1999).

Within hours of exposure to OP compounds, inhibition of a carboxylesterase called neuropathy target esterase (NTE) occurs in the nervous system. If the OP compound does not induce OPIDN, the NTE enzyme is not inhibited. To develop neuropathy, there are some conditions that must be present; the OP compound must inhibit NTE, the inhibition must be significant ($\geq$70 % after acute administration and approximately 50 % after multiple exposures), and the interaction between the OP compound and NTE must be strong enough to reverse the inhibition. The precise relationship between NTE and OPIDN has not been defined, and the mechanisms that lead to OPIDN are still unknown (Ehrich and Jortner, 2002, Baron, 1981).

There is a latent period between exposure and appearance of effects, typically a delay of 6 to 14 days or more (Baron, 1981). The symptoms start as sensory loss in hands and feet, followed by motional difficulties and abnormal reflexes (Ehrich and Jortner, 2002, Craig and Barth, 1999). OPIDN has been divided into three classes, where all of them are produced by organophosphorus compounds and characterized by central-peripheral distal axonopathy (Abou-Donia, 2003).

Daughtrey et al. (1996) did an experiment to determine the neurotoxicity of synthetic polyol-based lubricating oils. The oils contained either 3 % of TCP (tricresyl phosphate), triphenylphosphorothionate (TPPT) or butylated triphenyl phosphate (BTP). They used clinical, biochemical and neuropathiological endpoints in groups of 17-20 adult hens. The oils were administered orally at a “limit dose” of 1 g/kg, 5 days a week for 13 weeks. A group of positive control hens also received 7.5 mg/kg TOCP (tri-ortho-cresyl phosphate), given some days before the end of the experiment to observe clear organophosphorus-induced delayed neuropathy (OPIDN). A negative control group received saline. Six weeks after treatment, the neuropathy target esterase (NTE) activity in brain and spinal cord of hens dosed with the lubricating oils was not significantly different from the saline control. After 13 weeks, NTE was inhibited 23-34 % in the brains of lubricant-treated hens. Clinical assessment of walking ability did not show any significant differences between the negative control group and the hens treated with lubricant oils. There were no alterations in the neuropathology which could indicate OPIDN in the groups that did not receive TOCP. Significant inhibition of NTE was observed in the positive controls at both 6 and 13 weeks of dosing, in addition to clinical impairment and pathological lesions indicative of OPIDN. Although inhibition of NTE was observed in the hens treated with lubricating oils, the values were well below the threshold for effect and did not occur with the indication of OPIDN. The results indicated that synthetic polyol-based lubricating oils containing up to 3 % TCP, TPPT, or BTP had low neurotoxic potential, and it was claimed that they should not pose a hazard under realistic conditions of exposure.

1.14.3 Organophosphorus Ester-Induced Chronic Neurotoxicity

OPICN describes a nervous system disorder induced by organophosphorus compounds, which involves neuronal degeneration and subsequent neurological, neurobehavioral, and neuropsychological consequences (Rea and Patel, 2010). The neurotoxicity is distinct from both cholinergic and OPIDN effects. Clinical signs consist of neurological and neurobehavioral abnormalities and damage is present in both the peripheral- and central nervous system (PNS and CNS). The symptoms are primarily related to CNS injury with resultant neurological and neurobehavioral abnormalities. Within the brain, neuropathological lesions are seen in various regions, which are characterized by neuronal cell death resulting from early necrosis or delayed apoptosis. Because CNS injury predominates, improvement is slow and complete recovery is unlikely. The neurotoxicity may continue for a prolonged time, ranging from weeks to years after exposure. OPICN may be caused by an acute exposure that results in cholinergic toxicity, or by exposure to subclinical doses that does not produce acute poisoning (Abou-Donia, 2003).

Studies have shown that chronic neurological and neurobehavioral illness include diffuse symptoms as headache, drowsiness, dizziness, mental fatigue and -confusion, depression, anxiety and irritability. Other symptoms described are reduced concentration, tremors, insomnia, impaired vigilance, generalized weakness, memory deficit, linguistic disturbances and reduced information processing. In cases of chronic toxicity, respiratory, circulatory, and skin problems may be present as well. It should be noted that not every patient experience all of the symptoms (Singh and Sharma, 2000, Abou-Donia, 2003, Winder and Michaelis, 2005). The occurrence and severity of OPICN is influenced by factors such as environmental exposure to other chemicals, stress, or individual genetic differences. Stress, which also causes oxidative stress, may result in increased OPICN due to a decreased threshold level required to produce neuronal damage (Abou-Donia, 2003, Winder and Michaelis, 2005). According to Abou-Donia (2003), the long-term neurologic deficits reported by flight crew and passengers can be explained by OPICN induced by low-level inhalation of organophosphates present in jet engine oils and hydraulic fluids.

1.15 Exposure and Health Effects Reported in Literature

Michaelis (2003) conducted a survey where 600 questionnaires were sent out to pilot members of the British Airline Pilots Association (BALPA). 106 responded the questionnaire, and 93 (87.7 %) of them reported that during their flying career, they had been involved in at least one leak event of jet engine oil or hydraulic fluids into the aircraft. Following the indicated exposure, a wide range of symptoms in many body systems was reported. Symptoms that were most frequently reported was among others, confusion, memory impairment, diarrhoea and nausea. Michaelis suggested by her findings that the problem of oil leakage into bleed air is serious, and hence it must not be treated as insignificant. She states that more medical and scientific research is needed to understand the short- and long-term health effects of exposure to contaminated air.

Hanhela et al. (2005) did a survey of cockpit air contamination by organophosphates and amines in a Hawk, F-111 and Hercules C-130. The purpose of the study was to determine concentrations of TCP in the aircraft cockpit cabin air and determine the potential health risk to aircraft occupants- and engineers from exposure to the contaminated air. Concentrations of amine additives were also measured in the Hercules C-130. Concentrations of TCP were below 4 µg/m^3, with two exceptions; where oil leakage had occurred the concentrations were 21.7 µg/m^3 and 49 µg/m^3. This value is lower than the maximum permissible concentration of 100 µg /m^3 at the time-weighted 8-hour mean (TWA), which is based on TOCP. N-Phenyl-1-naphthylamine and dioctyldiphenylamine concentrations were also very low (<0.06 µg/m^3) in the Hercules C-130. Trialkyl phosphates were found in the F-111 and Hercules C-130 aircraft at concentrations of <6µg/m^3. Thus, the concentrations were considered unlikely to cause negative health effects.

De Nola et al. (2011) conducted a study on three types of military aircraft. The aircraft have a previous history of pilot complaints about cockpit air contamination. It was developed a procedure to measure TCP in aircraft cabins and cockpits. It was also examined concentrations of airborne TCP to assess the potential health risk to the flight crew. The results showed that TCP is mainly present as aerosol instead of vapour, and only four out of ten isomers was detected; mmm, mmp, mpp, and ppp. However, the ortho isomers were all under limit of detection (LOD). The total ortho isomer content of TCP have previously been shown to be around 0.004 % (40 mg/kg) in modern turbine oils used in the Australian

Defence Force (ADF) aircraft. The results in three planes generally showed low levels of TCP <5 µg/m^3, and thus the expected concentration of ortho isomers is approximately 0.0002 µg/m^3. Whether the results are representative for commercial aircraft or not, is not known.

Liyasova et al. (2011) did an experiment by looking at the changes of butyrylcholinesterase in plasma of aircraft passengers, to examine if they had been exposed to tri-ortho-cresyl phosphate (TOCP). The passengers did not notice any fume, smell or odours during the flights. It was conducted laboratory samples of the TOCP isomer, where 12 passengers were tested by blood tests after their flight. The results for half of them were positive (proven TOCP), although the levels were low, and none had toxic symptoms. Only 0.05 to 3 % of butyrylcholinesterase in plasma, which is one of the target enzymes of organophosphates, was changed. When testing of the passengers after some months, all samples were negative for the isomer. This was the first report where TOCP was detected in aircraft occupants.

Schindler et al. (2012) conducted a study to examine if amounts of three metabolites of TCP isomers (oo-, mm-, pp-dicresyl phosphate), as well as dialkyl and diaryl phosphate metabolites, was found in urine of pilots and cabin crew after the occurrence of smoke or odour during flight. 332 urine samples were taken, and none of the samples contained TOCP above the limit of detection (LOD 0.5 µg/l). There were found higher metabolite levels of TBP, tri-(2-chloroethyl) phosphate (TCEP) and triphenyl phosphate (TPP) in cabin crews than in unexposed persons from the general population. The elevated metabolite levels could be due to traces of hydraulic fluid in cabin air, or release of flame retardants. It was stated that the results indicated that health problems reported by passengers and crew after air contamination during flight could not be due to TOCP (Schindler et al., 2012). The MOCP isomer was not measured in this experiment, although the isomer is proposed to be the most toxic one (Henschler, 1958).

Abou-Donia et al. (2013) conducted an assay on 12 healthy control persons, and a group of 34 flight crews who had experienced adverse health effects after possible exposure to air contaminants in the aircraft. The purpose was to examine whether there were changes in the level of autoantibodies. Findings showed significant elevations in levels of immunogloblulin G (IgG) class autoantibodies. IgG is generally considered to be an indication of the immune status to particular pathogens in an individual. The results suggest a possible development of neuronal injury and gliosis[6] due to presumed exposure to cabin air contaminant containing organophosphates.

de Ree et al. (2014) measured TCP on nine Boeing 737s. The background of the study was to increase the insight of a possible association between exposure to TCPs, via contaminated cabin air, and aerotoxic syndrome. The results showed that the samples of TOCP- isomers and other ortho isomers were below the LOD between 0.3-0.75 ng/m^3 depending on the length of the flight. It was established a toxicological risk model to find a “hazard quotient” of TOCP. The results indicated meta- and para-isomers in low concentrations, while TOCP and other ortho isomers were not detected. It was concluded that the concentrations of TOCP were not high enough to explain aerotoxic syndrome.

[6] Change of glial cells in response to damage to the central nervous system.

To examine the relationship between previous measured results from different studies of TCP, de Boer et al. (2014) performed a literature study. They found that concentrations of total TCP in cabin air are at maximum 50-100 ng/m^3, and thus not exceeding toxic thresholds (stated to be 14 mg d^{-1} in the article). These thresholds contain uncertainty and need further confirmation. They summarize that TCP concentrations reported in the literature are insufficient to explain the health effects reported by pilots. Given that analytical standards for MOCP are not available, the exact concentrations could not be determined. It was concluded that the levels may be higher than measured.

2.0 Methods

To do research involves selecting methods that can provide means to answer the research questions, knowing what and how to gather data needed, and to analyse the results and their quality. Methods and their application encompass different sources of error, and ethical aspects. These have to be considered closely to carry out the best research practice possible. The choice of method is a central part of the research process, because it acts as framework for what results are within the scope of work, and hence influences the quality of the research.

2.1 Choice of Methods

To gather background information and get an understanding of existing knowledge about the topic, a literature study was conducted. The work to find literature is time consuming and requires research skills, since the literature relevant for the topic is selectively chosen. It makes an important part of the thesis, as it gives a summary of the research that previously has been done. Incidents are found in databases or media articles, and these sources were used to estimate a frequency of possible fume events within a given period.

To answer the research questions about how well the issue of oil leaking into the cabin air is known a quantitative approach was chosen, in the form of two surveys. A quantitative method can provide a large number of respondents, and with a high response rate the results may be generalized. Hence, conclusions of the results can be drawn to a larger group than the sample. The reason for choosing surveys to answer some of the research questions is that the data collection and analysis can be completed in a short period of time. Closed-ended self-administered questions were applied, where people answered a specific set of questions. Qualitative research methods could have been used in addition, to get more detailed answers from the people who were surveyed. Since the purpose is to get an overview of how many people who know about fume events, the most advantageous method was found to be quantitative research.

2.2 Literature Study

To find relevant literature, several scientific search engines and books, various public web pages and internal presentations from participating a meeting with GCAQE in London, were used. Additionally, first-hand information from the supervisor and an assigned contact person was received.

Search Engines

Scientific articles were found by use of various databases in the web pages of NTNU. The search engines used to find articles were SCOPUS, PubMed, Web of Science, SpringerLink and BIBSYS. Following, some of the keywords used in different databases are described. In the research process, several keywords were usually added after the first search result to narrow down the findings.

Given that the prior knowledge about the topic was limited, no filter, or the original filter in the current database was used during the searches. It is important to notice that the same keywords have been used in more than one search engine, and in multiple combinations with each other. Some examples of searches carried out are described below.

In SCOPUS, the first keywords were “hydraulic fluid”. To narrow down the number of documents, the words “jet engine oil” was used. The result was then 84 articles, where all of the summaries were skimmed through. By another search in SCOPUS, the first keywords were “aerotoxic syndrome”, which resulted in only 21 articles. Some of the articles were not in English, and were therefore excluded. To find out about the history of tricresyl phosphate, the keyword “jamaica ginger” was used. This gave 27 results in SCOPUS, which were skimmed to consider if they had any relevance.

In PubMed, the first keywords were “organophosphates and aircraft”, which gave 62 results. These were quickly skimmed. To narrow down for articles of even more relevance, the word “exposure” was used, which resulted in 16 documents. By another search in PubMed, the first keywords used were “aerotoxic syndrome”. This resulted in 14 articles, which were read through.

In Web of Science, the first keyword was “aircraft”. Since this gave too many results, the words “bleed air” were added, which led to 81 results. After reading the titles and some of the summaries, the word “incident” was used, which resulted in four documents (Figure 27).

Figure 27: Example of a search made in the search engine Web of Science.The search was narrowed down from over 59 000, to only four hits. The keywords used were “aircraft, bleed air and incident”.

The database SpringerLink was mostly used to find technical literature. The filter was set to “with all of the words”, and the search words were “turbofan engine”. Since this search resulted in 796 documents, the filter was set to “with at least one of the words”, and “where the title contains”, where “aircraft engine” and “turbofan” was inserted, respectively. This gave 24 results, where the abstracts were read.

BIBSYS was used to find relevant books in addition to two books received from the supervisor. Here, the keywords “tricresyl phosphate”, and “aircraft and incidents” were used in two different searches.

Throughout the entire process, relevant articles were discovered, both through search with specific words, and through the reference list of articles already used. Due to limited access from NTNU's web pages, Google Scholar was used when articles found in other literature could not be found in full text.

Material Safety Datasheet (MSDS)

MSDS' of the relevant hydraulic fluids and engine oils were downloaded from web pages of different manufacturers. The manufacturers included are Exxon Mobil, British Petroleum, Shell, Solutia Inc. and Petro-Canada.

Web Pages and Media

Several web pages from the media, international organizations authorised by the government and NGOs, were applied to find popular scientific-, and other public information of relevance. The sites used are listed alphabetically in Table 5. Information from these pages has been reviewed with a critical eye, but has been included to get an understanding and a holistic view. In addition, web pages of various manufacturers of aircraft and aircraft engines, as well as airline companies, have been used for supplementary reasons. These are among others Boeing, General Electric Aviation, Rolls Royce and SAS.

Table 5: List of web pages and media sites that have been used.

Name of the organ	**Internet access**
Aerotoxic Association	http://aerotoxic.org/about-aerotoxic-syndrome/
Dagbladet	http://www.dagbladet.no/
European Aviation Safety Agency (EASA)	https://www.easa.europa.eu/
Federal Aviation Administration (FAA)	http://www.faa.gov/
Global Cabin Air Quality Executive (GCAQE)	www.gcaqe.org
International Civil Aviation Organization (ICAO)	http://www.icao.int/Pages/default.aspx
Norwegian Civil Aviation Authority (Luftfartstilsynet)	http://www.luftfartstilsynet.no/
Occupational Health Research Consortium in Aviation (OHRCA)	http://www.ohrca.org/

Global Cabin Air Quality Executive (GCAQE) conference

Through participating on a two-day conference with GCAQE in London, literature and new research results were gathered. Some of the researchers who attended the conference had done recent research, which provided access to unpublished literature. Cabin crew and researchers were willing to help and provide information if needed, and their contact information were received.

2.3 Survey Among Pilots and Cabin Crew

The purpose of the survey was to find out if pilots and cabin crew in Norway are aware that the cabin air may be contaminated, which may be caused by leakage of engine oil. In addition, it was desirable to determine how extensive this phenomenon is, by considering how many pilots and cabin crew who claim to have experienced incidents of contaminated air in the aircraft cabin. The sample of the survey was based on this, and was hence limited to include pilots and cabin crew.

Since the Norwegian trade union, Parat Luftfart, agreed to send out an electronic questionnaire, it was chosen to collect data from pilots and cabin crew who are members of the union. In this way it was assumed that the response rate would be higher than in the practice of interview. At the same time this would not provide any opportunity for verbal communication, and detailed answers would thus be excluded. Because the collection of data by using electronic questionnaire is subject to notification, registration was sent to Norsk Samfunnsvitenskapelig Datatjeneste (NSD). It was made in SelectSurvey, which is the Faculty of Social Sciences and Technology Management's system for online surveys at NTNU. After acceptance to start the collection of data, the questionnaire was made. After the survey was prepared, it was sent to Kyrre Svarva, a SPSS expert at NTNU, for a quality check. This could avoid people to misunderstand the questions, and at the same time it would be better to change anything in the survey based on professional feedback. It was essential to design a simple questionnaire, so that it would not be time-consuming for the participants, and to limit the work of analysing the answers. There was no opportunity to answer questions from the participants directly, since the questionnaire only was submitted by e-mail. Hence, the questions had to be understandable and carefully planned.

In the questionnaire shown in Table 6, the respondent could only choose one answer for every question, except question 3, where the number of years was typed in by the respondent. Question No 1, 2, 3, 4, 6, 8 and 9 was not optional, while question No 5 and 7 were follow-up questions for question No 4 and 6, respectively. The participant could not move forward in the questionnaire before answering all questions on the page.

To gather as many answers as possible, and at the same time maintain the anonymity of the participants, the questionnaire to the pilots and cabin crew was sent out by e-mail by Parat Luftfart. The survey was sent out to a total of 2 952 persons (pilots and cabin crew) on the 25th of March, with deadline for responding set to the 17th of April. Parat Luftfart did also send a reminder of the survey to the participants on the 7th of April on request. In addition to the link to open the questionnaire, the e-mail contained information about the survey and this thesis, see Appendix C. The survey and information were sent to the respondents in Norwegian language, but have been translated for use in this thesis.

Table 6: Questionnaire that was sent out to 2952 pilots and cabin crew in Norway. Since the survey was distributed in Norwegian, the term "fume events" was replaced with a description of how the event may be noticed.

Information at the beginning of the questionnaire:
We are two students working on our Master's degree in Health, Safety and Environment at NTNU, and are now writing our master's thesis. The topic of the thesis is contamination of jet engine oil which may enter the air in the aircraft cabin and cockpit, commonly known as fume events. We want to examine whether cabin crew and pilots in Norway are aware that such contamination may occur. In addition, we want to find out how extensive this matter is, considering how many believes they have noticed/experienced incidents of contaminated air in the aircraft cabin/cockpit.

The answers from the questionnaire will be treated confidentially, and it is voluntary to participate in the survey. All data will be anonymized.

Responsible for the survey:
Tonje Trulssen Hildre (student)
June Krutå Jensen (student)
Professor Kristin Svendsen (supervisor)

No	Question	Answer options			
1.	**Age**	20-30	31-40	41-50	>50
2.	**Gender**	Male		Female	
3.	**For how long have you been working as a pilot/cabin crew?**	0-9 years	10-19 years	20-29 years	>29 years
4.	**Are you familiar with events where oil leakage has led to contamination in the cabin air and/or cockpit? Contamination in this case means unusual smell of engine/oil, wet dog, smelly socks or visual smoke.**	Yes		No	
5.	**Where have you heard or read about these events?**	Media (news-paper, television, internet)	Co-workers	Airline	Others
6.	**Have you ever noticed a strange smell/smoke in the cabin?**	Yes	No	Uncertain	
7.	**How often have you noticed contamination as smell/smoke in the cabin/cockpit (number of times)?**	1	2-5	6-10	>10
8.	**Have you ever registered if someone else noticed a strange smell/smoke in the cabin/cockpit?**	Yes		No	
9.	**Do you consider such air contamination a problem in the aircraft industry?**	Yes	No	I don't know	
	Thank you for participating in the survey!				

The participants got 23 days to answer the questionnaire. This time limit was chosen because of pilots and cabin crew's unusual working hours, and because it was Easter holiday during the response period. After the time limit of 23 days, the data was collected and analysed by the use of IBM SPSS (Stastistical Package for the Social Sciences). The software was recommended by the Faculty of Social Sciences and Technology Management. The variables were coded automatically, and data was presented by tables to get an understandable overview. Different questions in the survey were cross tabulated to assess whether there was any connection between them.

2.4 Survey Among People on Gløshaugen Campus

The purpose of the survey was to find out whether people on Gløshaugen campus at NTNU are aware that the aircraft cabin may be contaminated by engine oil. In addition, it was desirable to find out how extensive this subject is, by considering how many who claim they have experienced incidents of contaminated air in aircraft cabin. This was due to the fact that the largest proportion of these people probably are academics, and that this is a group of people who keep themselves updated on the news and hence could have heard about the phenomena of fume events. In advance of handing out the survey, it was assumed that 100 respondents could give an indication of knowledge about the phenomenon among academics, and also how many who claimed they had experienced incidents of contaminated air in an aircraft cabin.

The data was collected by the use of a self-made questionnaire in Microsoft Word (Table 7). The questionnaire was written in Norwegian language, but has been translated for the use in this thesis. The questionnaire was printed and handed out to random participants on Gløshaugen campus. It was chosen not to conduct an online survey, to save time. By using printed questionnaires, it was not necessary to inform and get permission from NSD, as it was not collected any information electronically. By handing out the survey personally, it was possible to inform about the thesis and the survey directly to the respondent, in addition to written information on the sheet handed out. This could give the respondents an opportunity to ask questions if something was unclear. At the same time, the participants answering a paper version of a questionnaire had to allocate time at the exact moment to answer, whereas at an online survey he/she could have chosen to respond at a time better suited. Since the two questionnaires were given to two different groups in the population, pilots/cabin crew and people on campus, the questions were asked differently in the surveys.

For every question, the respondent could only choose one answer, except question No 5, where it was possible to answer more than one of the alternatives. Question No 1, 2, 3, 5 and 7 was not optional, while question No 4 and 6 were follow-up questions for question No 3 and 5, respectively. The results from the questionnaire was immediately collected and coded in IBM SPSS. The variables were analysed, and data were presented by tables to get an understandable overview. Afterwards, the results were interpreted and discussed.

Table 7: Questionnaire handed out to 100 participants on Gløshaugen campus. Since the survey was distributed in Norwegian, the term “fume events” was replaced with a description of how the event may be noticed.

<table>
<tr><td colspan="9">Information at the beginning of the questionnaire:
We are two students taking a Master’s degree in Health, Safety and Environment at NTNU, and are now writing our master’s thesis. The topic is contamination of air in aircraft cabin. Contamination may occur if there is a leak that allows oil from the engine to enter the cabin with the ventilation air, commonly known as fume events. We want to find out if people on campus are aware that such contamination may occur.

The air that enters the cabin and cockpit is initially clean air from the environment outside the aircraft. This air passes through the engine before it is used as ventilation air and gets inhaled by people inside the aircraft. Leakage may occur in the engine, which may cause the jet engine oils to be mixed with the ventilation air that enters the cabin. The oils used in aircraft engines contain chemical substances, so-called organophosphates, which under high temperature may develop into toxic compounds. Exposure to these compounds has been shown to have negative health effects. Air contaminated by oil can be detected for example by an odour of engine/oil, wet dog or smelly socks, or it may be visible as smoke.

Please make a circle around your answers.</td></tr>
<tr><td>1. Age</td><td colspan="2">18-25</td><td colspan="2">26-33</td><td colspan="2">34-41</td><td colspan="2">>41</td></tr>
<tr><td>2. Gender</td><td colspan="4">Male</td><td colspan="4">Female</td></tr>
<tr><td>3. Do you travel by aircraft?</td><td colspan="4">Yes

If yes; please continue to question 4</td><td colspan="4">No

If no; please continue to question 5</td></tr>
<tr><td>4. How often do you travel by aircraft? (Roundtrip equals one time)</td><td colspan="2">1-5 times per year</td><td colspan="2">6-10 times per year</td><td colspan="2">11-15 times per year</td><td colspan="2">>16 times per year</td></tr>
<tr><td>5. Sometimes oil leakage may occur, which may lead to smoke or a strange smell in the cabin. Have you ever heard or read about oil leakage episodes?</td><td colspan="4">Yes

If yes; please continue to question 6</td><td colspan="4">No

If no; please continue to question 7</td></tr>
<tr><td>6. Where have you heard/read about such contamination? (Oil leakage episodes)</td><td>News-papers</td><td colspan="2">Tele-vision</td><td>Internet</td><td>Others</td><td colspan="2">Tele-vision and internet</td><td>News-papers and internet</td></tr>
<tr><td>7. Have you ever noticed a strange smell or smoke in the cabin?</td><td colspan="4">Yes</td><td colspan="4">No</td></tr>
<tr><td colspan="9">Thank you for participating in the survey!</td></tr>
</table>

The way the surveys are designed may influence the type of results that is provided. Leading or unclear questions are factors that can reduce the reliability and make it difficult to trust the answers given. To avoid low reliability of the results, the questions in the surveys were thoroughly designed. In addition, both of the surveys were quality checked by the supervisor.

2.5 Sources Used to Find Frequency of Possible Fume Events

To find events that could be categorized as “possible fume events”, organizations that record events or receive updates from pages that record events were used (Appendix A). The thesis contains an overview of how often fume events may have happened from January 2007 until December 2014, found from a variety of sites. The web pages used are found from both Michaelis’ Doctor’s degree (Michaelis, 2010, p 376-411) and by online search. The overview is not considered to be complete since, according to among others, Murawski and Supplee (2008) van Netten (2005) and Murawski (2011), few events are actually registered. It was not found a site where all the incidents throughout the world are registered by the responsible airlines or organizations. Different countries use different sites to register incidents, and at the same time they are assumed to be recorded by a variety of criteria. Hence, it was complicated to determine criteria of how relevant events could be found. A large part of the events occurred without including any investigation report, which means that they cannot be defined as fume events, even though it is a possibility.

As mentioned, Michaelis (2010) compiled an overview of incidents in the UK from 1985- mid 2006. It was therefore chosen to create an overview from the beginning of year 2007 and until the end of 2014. This overview also includes incidents that have occurred worldwide. This was a time consuming work, and it was therefore chosen to exclude the airlines own web pages, since there are many of them. As the focus in this thesis involves commercial aircraft, incidents on small aircraft have been excluded. The incidents have been included in the overview when any of the aircraft occupants noticed smell of dirty socks, unusual smell, smoke, haze, fumes or odour. Incidents noticed as “electrical failure” or “electrical smell” is not included, as these already have a presumed cause, which does not entail a fume event. Reports on languages included are Norwegian, Swedish, Danish and English. Appendix D includes a list of all the web pages considered to find possible fume events.

The database of the National Transportation Safety Board is used as an example of how the incidents were found (National Transportation Safety Board, n.d). The result covered 124 incidents when the search was limited to, “Airpane” under “Aircraft, Category” from 2007-2014 in the search field of the aviation accident database (Appendix B). To further limit the results, the type of aircraft was modified to only include the commercial ones under “Operation” in the search field. Below “Event details” in the search field, relevant keywords were inserted. The keywords used to find the flight incidents where fume events had occurred were: “smoke”, “oil and smoke”, “oil leakage”, “oil mist”, “fume”, “fume event”, “fumes”, “smoke and fumes” and “smell”. The incidents were quickly read through, and the ones considered relevant were added to the overview.

2.6 Ethical Aspects

The survey among cabin crew and pilots was in advance approved by Norsk Samfunnsvitenskapelig Datatjeneste (NSD), and guidelines to privacy information were followed. The assurance of informed consensus is important, and by letting Parat send out the survey, the respondents were completely anonymous. All the collected data were stored and handled in a way to ensure that unauthorized persons did not have access to the information. There were no intentions of publishing information about individuals, only the overall results. The participants were assured complete confidentiality and anonymity and it was informed that the respondents' answers would be deleted at the end of the project. It was not obtained any information about whether the respondents were pilots or cabin crew, and as a consequence, it should not be possible to identify them. Since the answers from the survey handed out to people on campus were not collected electronically, it was not necessary to notify NSD. The only sensitive information that was collected in both of the surveys was gender and age.

Information about the purpose of doing the surveys and how the results would be used was given to all the participants. This was done so that they had the opportunity to choose whether they wanted to participate. It was also informed that answering the questionnaire was voluntary and that they at any time could choose to not continue. A problem with providing information was the possibility of affecting the answers to the respondents. This could result from a more or less conscious change of their thoughts, where the information could lead the participants to answer what they thought was expected, instead of the truth. At the same time, it would have been difficult for the respondents to answer anything if they did not know the background of the questions.

A question regarding the participants experienced relevance of the topic may arise. Since pilots and cabin crew have aircraft as their working place, it is assumed that the relevance of the survey was obvious. It is conceivable that this was not as obvious to the participants at campus, which then could lead to completely random responses. By explaining why the study was conducted and how the results would be used, it was assumed that those who felt the study did not have any relevance, would choose not to participate.

3.0 Results

The results show whether the research questions in the thesis are answered. Following is the results from the surveys and overview of fume events. Results from the literature study are given in the introduction.

3.1 Survey Among Cabin Crew and Pilots

The survey was sent out to a total of 2 952 cabin crew and pilots. Of the 2952 persons who received the survey, there was lacking information about gender and age of 23 persons, leaving a population of 2929. 1233 (42.1 %) of these were males and 1696 (57.9 %) were females. The number of persons who opened the link to the questionnaire was 736, where 112 (15.2 %) of them did not complete the questionnaire. These were removed from the results. The actual number of respondents was 624, resulting in a response rate of 21 % (624/2 952). The respondents consisted of 317 (50.8 %) males and 307 (49.2 %) females, aged in groups from 20-30 years, 31-40 years, 41-50 years, and >50 years, where 31-40 years was the largest represented age group with 230 (34.7 %) respondents (Table 8). The question *"For how long have you been working as a pilot/cabin crew?"* has not been used in the analysis, since it gave the same tendencies as the age groups of the respondents; older age groups had increased working experience in most cases.

Table 8: Age distribution of respondents and total population of pilots and cabin crew.

Age distribution	**No. of respondents (N=624)**	**Total population (N=2929)**
20-30 years	117 (18.8 %)	595 (20.3 %)
31-40 years	219 (35.0 %)	911 (31.3 %)
41-50 years	194 (31.1 %)	922 (31.5 %)
>50	94 (15.1 %)	501 (17.1 %)

440 out of 624 (70.5 %) respondents are familiar with fume events, with most respondents in the age group 41-50 years. There is a correlation between familiarity of fume events and age. Older age groups have increased number of respondents who know about the phenomenon. There is a higher percentage of males who know about fume events than females, respectively 81.4 % and 59.3 % (Table 9).

Most of the respondents, 450 (72.1 %), have noticed an unusual smell/smoke in the cabin or cockpit. 246 (77.6 %) of the male respondents state that they have noticed an unusual smell/smoke in the cabin or cockpit, which is a higher percentage than females, 204 (66.4 %) (Table 9).

The question *"How often have you experienced contamination as smell/smoke in the cabin/cockpit (number of times)?"* was a follow-up question to *"Have you ever noticed a strange smell/smoke in the cabin?"*. The number of respondents was 450 (72.1 %), with 246 (77.6 %) males and 204 (66.4%) females.

The largest number of male respondents, 96 (30.3 %), state that they have experienced such contamination >10 times, while the largest number of female respondents, 94 (30.6 %), state that they have experienced such contamination 2-5 times. The largest group that constituted most respondents in total, are the group who have experienced such contamination 2-5 times, with a total of 188 (30.1 %) respondents (Table 9).

Of the 440 respondents who are familiar with fume events, most of the males, 162 (68.1 %), report to have heard about this from "Media" and most of the females, 124 (41.6 %), have heard about it from "Co-workers"(Table 9). Many of the respondents answered more than one response alternative, which is the reason why the total number of respondents exceed 440, and the total percentage is greater than 100 % when adding the alternatives together (Table 9). 272 (43.6 %) of the respondents consider air contamination a problem in the aircraft industry, represented by 159 (50.2 %) males and 113 (36.8 %) females.

Table 9: Cross tabulation of questions to pilots and cabin crew. The values are calculated from total number (N) of males, females and total respondents.

Question	**Response alternative**	**Male (N=317)**	**Female (N=307)**	**Total (N=624)**
Are you familiar with events where oil leakage has led to contamination in the cabin air and/or cockpit?	Yes	258 (81.4 %)	182 (59.3 %)	440 (70.5 %)
Have you ever noticed a strange smell/smoke in the cabin?	Yes	246 (77.6 %)	204 (66.4 %)	450 (72.1 %)
	No	53 (16.7 %)	75 (24.4 %)	128 (20.5 %)
	Uncertain	18 (5.7 %)	28 (9.1 %)	46 (7.4 %)
How often have you experienced contamination as smell/smoke in the cabin/cockpit?	Never	71 (22.3 %)	103 (33.6 %)	174 (27.8 %)
	1 time	18 (5.7 %)	33 (10.7 %)	51 (8.2 %)
	2-5 times	94 (29.7 %)	94 (30.6 %)	188 (30.1 %)
	6-10 times	38 (12.0 %)	16 (5.2 %)	54 (8.7 %)
	>10 times	96 (30.3 %)	61 (19.9 %)	157 (25.2 %)
Do you consider such air contamination a problem in the aircraft industry?	Yes	159 (50.2 %)	113 (36.8 %)	272 (43.6 %)
	No	76 (24.0 %)	81 (26.4 %)	157 (25.1 %)
	I don't know	82 (25.9 %)	113 (36.8 %)	195 (31.3 %)
Where have you heard about these events? [a)]	Media	162 (68.1 %)	76 (31.9 %)	238 (38.1 %)
	Co-workers	174 (58.4 %)	124 (41.6 %)	298 (47.8)
	Airline	129 (64.5 %)	71 (35.5 %)	200 (32.0 %)
	Others	59 (60.2 %)	39 (39.8 %)	98 (15.7 %)

a) The percentages are estimated from the number of males or females who have heard about fume events from a certain source (media, co-workers, airline, others), out of the total number of respondents who have heard of such events from the certain source. (Example: 162/238).

450 of the respondents have experienced contamination as smell/smoke in the cabin or cockpit. There is a positive correlation between those who consider the contamination a problem, and the number of times the respondents have experienced contamination (Table 10).

Table 10: Cross tabulation of two questions to pilots and cabin crew; "Do you consider such air contamination a problem in the aircraft industry?" and "How often have you experienced contamination as smell/smoke in the cabin/cockpit?".

Question	**Response alter-natives**	**How often have you experienced contamination as smell/smoke in the cabin/cockpit (number of times)?**				**Total (N=450)**
		1 time (N=51)	**2-5 times (N=188)**	**6-10 times (N=54)**	**>10 times (N=157)**	
Do you consider such air contamination a problem in the aircraft industry? [a)]	Yes	11 (21.6 %)	76 (40.4 %)	27 (50.0 %)	107 (68.2 %)	221 (49.1 %)
	No	20 (39.2 %)	49 (26.1 %)	13 (24.1 %)	14 (8.9 %)	96 (21.3 %)
	I don't know	20 (39.2 %)	63 (33.5 %)	14 (25.9 %)	36 (22.9 %)	133 (29.6 %)

a) The percentages are estimated from whether the respondents answered yes/no/I'dont know out of the total number of respondents who had experienced contamination as smell/smoke in the cabin/cockpit 1 times/2-5 times/6-10 times or >10 times.

418 (92.9 %) out of the 450 respondents who claim to have noticed an unusual smell/smoke in the cabin or cockpit, also express that they have registered someone else notice a strange smell/smoke.

No surveys or articles were found that directly describe the knowledge about fume events among the general public, or among pilots and cabin crew.

3.2 Survey Among People on Gløshaugen Campus

Of 106 persons asked, 100 chose to participate in the survey, which gives a response rate of 94.3 %. All of the respondents use aircraft as a mode of transport, hence the question *"Do you fly?"* has not been used in the analysis. Of the 100 respondents, 45 (45.0 %) were males and 55 (55.0 %) were females, with the majority in the age group 18-25 years, 93.3 % and 92.7 %, respectively. There were no male or female respondents in the age group 34-41 years.

The majority of both male and female respondents have never heard or read about fume events, 38 (84.5 %) and 47 (85.5 %), respectively. Most of the male respondents, 20 (44.4 %), and female respondents, 23 (41.8 %), travel 6-10 times per year (Table 11)

15 respondents have heard about fume events. Of the total 100 respondents, 5 (5.0 %) report to have heard about it either from the newspapers or internet. Most of the male respondents, 4 (8.9 %), have heard about it through television and internet, and most of the female

respondents, 3 (5.5 %), have heard about it from internet. 67 % of the 100 respondents report to not have noticed any smoke or unusual smell in the cabin (Table 11).

Table 11: Cross tabulation of questions to people on Gløshaugen campus. The values are calculated from total number (N) of males, females and respondents.

Question	**Response alternative**	**Male (N=45)**	**Female (N=55)**	**Total (N=100)**
Have you heard about oil leakage episodes on aircraft?	Yes	7 (15.6 %)	8 (14.5 %)	15 (15 %)
How often do you travel by aircraft?	Do not travel by aircraft	0 (0.0 %)	1 (1,8 %)	1 (1.8 %)
	1-5 times per year	19 (42.2 %)	23 (41.8 %)	42 (42.0 %)
	6-10 times per year	20 (44.4 %)	23 (41.8 %)	43 (43.0 %)
	11-15 times per year	4 (8.9 %)	9 (16.4 %)	13 (13.0 %)
	>15 times per year	2 (4.4 %)	0 (0.0 %)	2 (2.0 %)
Where have you heard/read about such contamination? (Oil leakage episodes)	Have not heard/read about oil leakage episodes	38 (84.5 %)	47 (85.5 %)	85 (85.0 %)
	Newspapers	1 (2.2 %)	2 (3.6 %)	3 (3.0 %)
	Television	1 (2.2 %)	1 (1.8 %)	2 (2.0 %)
	Internet	1 (2.2 %)	3 (5.5 %)	4 (4.0 %)
	Television and internet	4 (8.9 %)	1 (1.8 %)	5 (5.0 %)
	Newspapers and internet	0 (0.0 %)	1 (1.8 %)	1 (1.0 %)
Have you ever noticed a strange smell/smoke in the cabin?	Yes	2 (4.4 %)	4 (7.3 %)	6 (6.0 %)
	No	31 (68.9 %)	36 (65.5 %)	67 (67.0 %)
	Uncertain	12 (26.7 %)	15 (27.3 %)	27 (27.0 %)

3.3 Frequency of Possible Fume Events

There were found a total of 701 possible fume events between 2007 and 2014 (Appendix D), where 644 (91.9 %) of these were found from the web page "The Aviation Herald". In addition, AAIB and GCAQE each contained 14 (2.0 %) incidents of interest, Arie Adriaensen had 10 (1.5 %) reports from incidents of interest, ATSB had 6 (0.9 %) incidents, FAA 3 (0. 4 %), NTSB, TSB and AAIU each contained 2 (0.3 %) incidents of interest, whereas 1 (0.1 %) were found from CAA, Havkom Sverige, Aerotoxic.org and TAIC.

The least number of the 701 registered incidents occurred in 2007, where only 14 (2.0 %) were found. 2008, 2009 and 2010 followed with 84 (12.0 %), 95 (13.5 %) and 100 (14.3 %)

incidents, respectively. In 2011 there were found 133 (19.0 %), which was the year with the highest number of registered incidents. In 2012 there was a drop to 89 (12.7 %) incidents, in 2013 there were found 110 (15.7 %) and in 2014 76 (10.8 %) incidents were found.

To calculate the frequency of fume events per day, the average of the reported events per year from 2007-2014 has been estimated. The frequency of possible fume events was estimated to be 0.24 per day. Appendix E illustrates how the average has been calculated.

The incidents mainly occurred on Boeing and Airbus aircraft, with a total of 278 (39.7 %) of 701 on Boeing, and 167 (23.8 %) of 701 incidents on Airbus. Most of the incidents, 113 (16,1 %), occurred on the aircraft type Boeing 737.

The incidents are most often reported to be noticed in the cabin and cockpit (Table 12), respectively 253 (36.0 %) and 233 (33.2 %).

Table 12: Location of the incidents that were reported to be noticed in the aircraft.

Location of incident	No. of incidents (N=701)
Cabin	253 (36.0 %)
Cockpit (Flight deck)	233 (33.2 %)
On board	104 (14.9 %)
Cabin and cockpit	55 (7.9 %)
Unknown	47 (6.7 %)
Galley	9 (1.3 %)

Most of the reports following the incidents describe the flight phase when the incidents occurred while “grounded”, “initial climb”, “climb”, “en route”, “descent”, “landing”, and “unknown". The flight phase of most reported incidents was “en route”, with a total of 340 (48.5 %) incidents. In 6 (0.9 %) of the 701 incidents, there are no information about flight phase (Table 13).

Table 13: Different flight phases when incidents of possible fume events occurred.

Flight phase	No. of incidents (N=701)
En route	340 (48.5 %)
Climb	187 (26.6 %)
Initial climb	67 (9,6 %)
Descent	48 (6.8 %)
Grounded	44 (6.3 %)
Landing	9 (1.3 %)
Unknown	6 (0.9 %)

336 (47.9 %) of the 701 incidents contain no information about the cause, and these have been defined as “lack of information”. There were many different causes described in the other incidents, such as oil leaking into cabin from the air condition packs, and information about a malfunction of the air condition system.

The incidents are divided into groups according to how they were noticed; “smoke”, “smell”, “fumes”, “odour”, “smoke and smell”, “smoke and odour”, “smoke and fumes” or “unknown”. Most of the incidents were noticed as either “smoke” or “smell”, respectively 321 (45.8 %%) and 223 (31.8 %) (Table 14).

Table 14: Categorization of how the incidents were noticed.

Categorization of incident	No. of incidents (N=701)
Smoke	321 (45.8 %)
Smell	223 (31.8 %)
Fumes	50 (7.1 %)
Odour	49 (7.0 %)
Smoke and smell	34 (4.8 %)
Smoke and odour	14 (2.0 %)
Smoke and fumes	7 (1.0 %)
Unknown	3 (0.5 %)

In the reports, there are descriptions about decisions that were made subsequently to the incidents. These are divided into the groups: “return”, “divert”, “fly to the destination”, “rejected take-off”, and “unknown”. When the incidents occurred, most of the aircraft, 247 (35.2 %), returned to the departure airport (Table 15).

Table 15: Overview of the decision made after occurrence of incidence.

Decision made following the incident	No. of incidents (N=701)
Return	247 (35.2 %)
Divert	239 (34.1 %)
Fly to the destination	129 (18.4 %)
Unknown	53 (7.6 %)
Rejected take-off	33 (4.7 %)

4.0 Discussion

The discussion focuses on the results and findings from the literature study. Typically, there exist several explanations of the results, and these need to be discussed thoroughly. Hence, it is important to pay attention to several considerations to assess the validity before coming to any conclusions about the issue of fume events.

Survey Among Cabin Crew and Pilots

Certain actions were performed before sending out the survey to pilots and cabin crew to facilitate a high response rate of survey recipients, and thus to obtain high validity of the survey. This included planning on how to present the digital survey invitation. Information about the purpose of the study was sent together with a link to the survey. As no similar former survey had been found, it was hard to assess how much information would be appropriate. Focus was therefore set on providing clear and specific information. If too extensive, one could risk that the information had not been fully grasped by participants, whereas too little information could be inadequate to allow questions to be understood, or furthermore that the participants themselves had questioned the purpose or motives of the survey. By informing in an open and somewhat detailed manner, the goal was to establish a framework of the survey that allowed the participants to gain interest, quickly comprehend their task to complete the survey, and to not question its motives or purpose. By also sending out a reminder of the survey, more people responded to the questionnaire. The actions above were anticipated to optimize the validity of the survey.

The response rate of the survey that was sent out to pilots and cabin crew was 21 %. With this rate, it could be argued whether the group are representative of all cabin crew and pilots. The fact that 79 % of the persons who received the survey did not answer, may cause selection bias. Selection bias may arise if a systematic difference exists between the persons who participated in the survey and the persons who did not respond. It is possible that the persons who responded to the survey were familiar with fume events to a greater extent than the non-respondents, and therefore were more interested in the topic. If an absolute selection bias is assumed, where the respondents of the survey are the only persons who have any opinions regarding fume events, the percentage of the 2952 asked who have heard of fume events can be calculated to be 14.9 % (Appendix F). However, it is assumed that there are more than 14.9 % who are familiar with fume events of the 2952 persons who received the survey, due to the fact that the bias is not considered that high. If all the 2952 persons had answered the survey, the factual percentage would range between 14.9 % and 70.5 %.

There were received information from Parat Luftfart about gender and age for 2 929 out of 2952 persons, consisting of 1233 (42.1 %) males and 1696 (57.9 %) females. The majority of these were in the age groups 31-40 and 41-50 years. The same distribution of age also applied for the 624 respondents. In addition, there were almost an equal distribution of male and female respondents, 317 (50.8 %) and 307 (49.2 %) respectively. Hence, there are almost no difference between the respondents and the total population of 2952 persons with regard to gender and age. The respondents are assumed to be representative of the total population due to these characteristics.

No other studies with the purpose to investigate the knowledge about fume events were found, and for that reason, the results cannot be compared with previous studies. A question to be asked is whether the results are reliable and can be confirmed if a similar study is carried out at a later time. Whether the response rate is high enough to confirm statistical validity depends on the selection bias. In this thesis, a quantitative method was used. It can be argued whether or not qualitative methods should have been applied as well, and if such would have supplied additional information of relevance.

112 (15.2 %) of the participants did not complete the survey, which may be explained by the vulnerability and controversiality of the topic of oil leakage into aircraft cabin and cockpit. The topic of this thesis is assumed to be controversial, as people have different viewpoints on whether fume events pose any problem. Another reason may be that they found the questions uninteresting, or did not consider the topic as important.

Of the participants who completed the survey, 440 (70.5 %) of 624 are familiar with fume events in the cabin and cockpit. Possible explanations of the high percentage include discussions with co-workers, information given by airlines, media coverage, and other sources. Dagbladet has covered the phenomenon of fume events for some years, which might have been an information source for the pilots and cabin crew. A short time before the survey was sent out to cabin crew and pilots, an article about Richard Westgate, a pilot who died after supposedly being exposed to air contamination in the aircraft, was published in the newspaper (Hansen, 2015). 200 (32.0 %) of the respondents have heard about fume events from their airline, which is a somewhat low percentage. If the airlines do not consider it a problem, they probably do not find it necessary to provide any information to their employees. Another reason why airlines do not inform about it may be the lack of evidence on, and limited research of, the health effects following exposure to fume events. A larger number of the respondents in the older age groups have heard about fume events. An explanation of this may be that many of them are likely to have longer work experience than persons in younger age groups, and therefore possibly have experienced the events or read about them to a greater extent.

There are more male, 258 (81.4 %), than female respondents, 182 (59.3 %), who are familiar with fume events in the cabin and cockpit. 450 (72.1 %) of the 624 respondents report to have noticed a strange smell or smoke in the cabin/cockpit. Since many of the respondents are familiar with fume events in the cabin and cockpit, it may be assumed that they are more aware of the smell or smoke in the aircraft and hence more observant if fumes enter the aircraft. 128 (20.5 %) respondents report to never have noticed this, and 46 (7.4 %) are uncertain. The respondents who are uncertain may have noticed smell or smoke without knowing the source. The contaminants can also be odourless, which means that the respondents may have been oblivious to their expsosure.

It is a somewhat larger proportion of males, 246 (77.6 %), than females, 204 (66.4 %), who report to have noticed an unusual smell/smoke in the cabin or cockpit. As the results show, most of the male respondents have experienced smoke or smell more than 10 times, while the female respondents are highest represented in the group where the respondents have experienced it 2-5 times. The air that enters the cabin and cockpit passes through different engines, before the air is led to various locations of the aircraft for ventilation (SKYbrary, n.d.). This means that if a leakage occurs in one of the engines, the bleed air from this particular engine may be led to the cockpit and consequently will only be noticed by the pilots. In addition, the air that enters the aircraft is not evenly distributed. In the cockpit the air received is 100 % outside air, while the air in the cabin is 60/40 % recycled air (van Netten, 2005, de Boer et al., 2014). This means that pilots in the cockpit would to a larger extent be exposed to contaminated air from the engines. This, in combination with the fact that the majority of pilots are males while most cabin crew are females, may be one reason why more males in general are familiar with the phenomenon to a greater extent.

There are a total of 272 (43.6 %) respondents who consider air contamination by oil leakage a problem in the aircraft industry. If an absolute selection bias is assumed, where the respondents of the survey are the only persons who have any opinions regarding fume events, the percentage of the 2952 asked who consider fume events a problem can be calculated to be 9.2 % (Appendix F). However, it is assumed that there are more than 9.2 % who consider it a problem of the 2952 persons who received the survey, due to the fact that the bias is not considered that high. If all the 2952 persons had answered the survey, the factual percentage would range between 9.2 % and 43.6 %.

There is a correlation between those who consider fume events a problem, and the increased number of times the respondents have experienced contamination. According to Abou-Donia (2003), Harrison et al. (2009), Ross et al. (2006), van Netten (2005), among others, there have been reports of adverse health effects subsequent to possible fume events. It may for that reason be assumed that some of the respondents who consider this a problem, actually have noticed symptoms or suffered negative health effects following a fume event. A relatively high percentage (31.3 %) of the respondents are uncertain whether they consider such contamination a problem or not. This may be because they are not familiar with the topic, or due to its controversiality. 96 (21.3 %) of the respondents who report to have noticed smell or smoke do not consider air contamination a problem. They may have considered it insignificant if they assume that the smell normally occurs in an aircraft. 159 (50.2 %) of the male respondents and 113 (36.8 %) of the female respondents consider such contamination a problem. This may associate with the fact that more males than females are familiar with the events, and that more males report to have noticed smell/smoke in the cabin or cockpit.

Survey Among People on Gløshaugen campus

To obtain high validity of the results from the survey among people on Gløshaugen campus, certain actions were performed before handing it out. Simple questions were asked to avoid any misunderstanding when answering them. Few questions were asked, to limit the time required to respond the questionnaire, and so that as many as possible wanted to respond.

Given that the initial perception was that few people of the general population have heard of the phenomenon in advance, it was assumed that the result would be the same in the survey handed out to mainly academics. It is also believed that the group of the population who most likely had heard about the phenomenon, except flight crew, were academics. Since most of the surveyed academics (85 %) have not heard about fume events, it is reasonable to assume that the general public have even less knowledge about the phenomenon.

100 out of 106 persons agreed to participate in the survey, which gave a response rate of 94.3 %. Although this is a high response rate, the sample size may be somewhat low. Most of the people on campus are students aged 18-25 years. To get a better overview of the general population, people of all ages could have been asked the same questions. The results about knowledge of fume events among people on Gløshaugen campus cannot be generalized to the general public, but it is assumed that it can give tendencies regarding academics' knowledge about the topic.

As mentioned, 85.0 % of the respondents have not heard or read about fume events. These results are different from the survey among cabin crew and pilots, where most of the respondents were familiar with such events. However, because of the small sample of people on Gløshaugen campus, it is difficult to compare with the group of pilots and cabin crew, and make any explanation of why they answered differently. It could only be assumed that people on Gløshaugen (mainly students aged 18-25 years) are not concerned with the air quality on aircraft, since they probably are not exposed to fume events frequently. It is important to note that these assumptions needs further verification, and that studies on a greater number of people, not only academics, should be carried out.

There are not any trends regarding the respondents' frequency of travelling by air. There is no distinction regarding where the respondents have heard about fume events, but based on the perception that people use different information sources, such as television, newspaper, internet and others, it can be assumed that the outcome would have been the same with a larger sample size. Most of the respondents (67.0 %) have never noticed, or are uncertain (27.0 %) whether they have noticed smell or smoke in the cabin. This result was expected, considering that few of the respondents were familiar with fume events. The respondents may have noticed smell or smoke without having any second thoughts about it. The contaminants can also be odourless, which means that the respondents may have been oblivious to their expsosure.

Frecuency of Fume Events

It is assumed that pilots and cabin crew have different training in how registration of a fume event will take place, dependent on the policy of their airline, and that not all events that are detected will be published to the general public. In addition, the registered events are largely inconclusive, as they rarely contain any clarification of the actual cause of the incident. Hence, the overview presented in this thesis is believed to show only a small part of reality. It was nonetheless chosen to compile such a list, in an effort to show how and where events are registered, and to find out if any of the incidents could be categorized as possible fume events.

The overview of fume events may not include all the possible fume events that really have happened. The reported incidents may have used other words that is associated with fume events than those used throughout the search after incidents in our overview, as for example “haze”. There are neither a certainty that the 701 incidents found are fume events, since the description of cause is not fully detailed. In addition, reports are results of subjective interpretations of how fume events can be described.

Different databases were used to find possible fume events. Most of the incidents are found on the web page “The Aviation Herald”. On this site, one person registers aircraft incidents which are possibly interpreted and described subjectively. This may lead to incorrect information, and it was therefore necessary to view the site critically. In addition, a large part of the events occurred without any investigation report available, which means that some of them may not be fume events. However, the site is updated with new events regularly, and the events have detailed information about airline, flight type, its registration number and the destination of the aircraft. It was therefore assumed that the site could give a comprehensive overview of possible fume events. There are many databases in different countries that have not been reviewed due to the time it would have taken trying to find and critically assess all of them, considering the limited amount of time there was to complete this thesis. In addition, many of the databases are unavailable without user information/password, and some are available only in foreign languages.

There were found 701 incidents from 2007 to 2014 (Appendix D), and the results did not show any clear tendency of either increasing or decreasing number of incidents. In reality, there may be a pattern of changes through the years, but because of assumed underreporting of incidents, the results found in this overview will not be complete. When disregarding the fact that many of the events are not found, and that underreporting most probably occurs, the frequence of the events found in this thesis was calculated to be 0.24 events per day. Comparing this value with frequencies that have been found in previous studies, respectively 1-3.8 per 1 000 flights (U.S.) (van Netten, 2005), 0.05-1 % of flights (COT., 2007), , 0.86 events per day (U.S.) (Murawski and Supplee, 2008), and 0.2 per 1 000 flights (U.S.) (Shehadi et al., 2015), is complicated, due to the way the frequencies are presented. It is theresefore challenging to give an exact estimate of fume events happening in the world per year from the literature and the results presented. Estimates of the frequency vary due to lack of oversight of regulatory reporting system. Some studies show the percentage of fume events per flights, and others calculate the number of such events per day. In addition, the criteria to define an incident to be caused by fume events vary, and some of the studies have only found incidents in a specific country.

Airlines are believed to underreport events (FAA., 2011, Murawski and Supplee, 2008, Furlong, 2011, van Netten, 2005). In an article from van Netten (2005), it is claimed that underreporting occurs, and that the cause appears to be, among others, subjective assessment of the air quality within the aircraft. The flight crew may consider the temporary smell when engines start as “normal”, and since they are somewhat used to it, they do possibly not find it necessary to report. Another reason that was assumed is that there is an intimidating factor present, which results in underreporting. A pilot does not want to complain about his health to the co-pilot following exposure, because it would target his health status. Pilots should put on their oxygen masks with 100 % pure oxygen if an oil leakage occurs and once they notice unusual smell or smoke, to avoid possible symptoms of exposure.

In 336 (47.9 %) of the incidents in our overview, there was no description in the reports about the cause of the incidents. The same was found in the case study conducted by Murawski and Supplee (2008), where it was stated that many of the databases did not have any decription of cause. Since the cause of many of the incidents has not been updated in the databases, it is difficult to define all the incidents as fume events. In 40.2 % of the flights in the study done by Murawski (2011), the smell was described as “dirty socks”, which is a typical characterization of a fume event. In our overview, the reports have mostly described the incidents to be noticed by “smell” or “smoke” or a “smell of smoke”, without further details. For that reason, the smell could have other causes than oil leaking into the cabin. The incidents were nonetheless included in the overview; they may be fume events due to an assumed subjetivity of how the incidents were experienced. It was claimed that the reason why the cause of incidents are often not found, or is not identified until later, is that no monitors assist in identifying fume events, and that sense of smell by the flight crew is somewhat unreliable (Murawski and Supplee, 2008). They may sense the smell as electric, even though the cause is oil leakage. In addition, it was assumed to be due to the time required to find a cause, and that the airline do not want to provide information about the cause of an event with absence of exposure data. The cause should be found for as many incidents as possible to prevent them occuring again later, and to avoid diversion or cancellation that could be expensive for the airlines.

Boeing 737 is the aircraft that has been reported most frequently in the incident overview. Generally, Boeing and Airbus are the two aircraft occuring in most of the reported incidents, according to the results in this thesis. The reason for this may be the fact that these are two of the leading commercial aircraft manufacturers used by airlines around the world (Boeing, n.d., Airbus, n.d.).

48.5 % of the incidents in our overview with smell and/or smoke in the aircraft occurred while it was “en route”, and did not give any further information about the flight phase. In a study conducted by Murawski and Supplee (2008), 68 % of the events occurred while “en route”, in which the majority was specified to climb (42 %) or cruise (26 %). In our overview most of the incidents, 340 (48.5 %) occurred while the aircraft was “en route”, followed by 187 (26.6 %) incidents during climb. These results show the same tendency as the study done by Murawski and Supplee (2008). According to the study by Murawski (2011), the results of registered fume events showed that the smell was mainly present prior to take-off (50.6 % of the events), while in 39.1 % of the events, the unusual smell occurred while the aircraft was “en route”. 45 (6.4 %) of the 701 incidents in our overview occurred while the aircraft was on the ground, but there is no information about whether the aircraft had landed or if it was prior to take-off. When considering all results, it does not seem to be any pattern of when possible fume events occur, which means that they may occur during different phases of the flight.

There was almost no distinctions of whether the incidents were reported in cabin or cockpit. 253 (36.0 %) of the possible fume events occurred in the cabin while 233 (33.2 %) occurred in the cockpit. However, many of the incident descriptions did not comprise information on the specific location of where smoke or smell was noticed in the aircraft, and some reports wrote that the incident occurred “on board”. No former studies have been found to describe frequency by location or source of the fume event in the aircraft (Shehadi et al., 2015, Murawski and Supplee, 2008, Michaelis, 2010). However, given that oil leakage more frequently is noticed in the cockpit, it can be assumed that it occurs more often in this location of the aircraft.

In most of the incidents, when noticing smoke or smell in the aircraft, the aircraft either returned to the original airport (in 247 (35.2 %) of the incidents) or diverted to the nearest one (in 239 (34.1 %)). On basis of this, it is reasonably to assume that the problem with the aircraft was serious, since the crew chose to land. This may indicate that incidents with contamination of the cabin or cockpit are so serious that the flight crew would rather land the aircraft than risking the aircraft occupants to be exposed to anything. Nevertheless, some incidents have reported technical issues such as “faulty APU” or “engine failure”. This indicates that there may have been technical problems with one or more engines, which forced the aircraft to land. Hence, it is difficult to make any conclusion about why the aircraft landed before it reached final destination in almost all the incidents.

In the study by Murawski and Supplee (2008), 57 % of incidents that occurred while in-flight either returned or diverted to the nearest airport, and the aircraft on ground when the incident occurred rejected take-off, and were either delayed or cancelled. These decisions are consistent with the decisions made in most of the incidents found, where the aircraft in 69.3 % of the incidents either returned or diverted, and 4.7 % rejected take-off. In the case study of Murawski (2011), it was found that only about half of the flights where smell was reported prior to take-off were cancelled or delayed. It is hard to make any conclusion or explanations of why many of these aircraft flew to their planned destination, while the incident aircraft in our overview chose to land in most cases. One possible assumption may be that the number of incidents is not complete due to varieties in reporting among airlines, and that some of the databases required internal access.

Literature Study

It is a challenge to find and read all relevant literature that exist on the topic for the given amount of time. There are many databases which are possible to use, and even though the search words were used in various combinations and different search engines, there may still be relevant articles and documents not reviewed. Hence, some important results may have been missed during the research period, whereas some less significant material is omitted on purpose, due to the time limit and scope of this assignment.

There are discussions among scientists and professionals whether people can get negative health effect from possible contamination in jet engine oils and hydaulic fluids. HEPA filters in the air recirculation system do not remove gases and vapours from the ventilation air, due to their small molecular sizes, and contamination may thus enter the cabin and cockpit in aircraft along with the ventilation air (Hunt et al., 1995, Bull and Roux, 2010). Leakage, aging of materials and design flaws are some of the mentioned latent causes that may lead to exposure of components from oil or combustion products in the aircraft (Hocking, 2005, p 200, Spittle, 2003, Balouet et al., 1999). Leakage are sporadic and occur as a result of unexpected errors in the engine. A large number of health effects reported by pilots and cabin crew exists, which is believed to be a result of exposure to contaminated cabin air (Michaelis, 2010, Abou-Donia, 2003, Winder and Balouet, 2001, Winder and Michaelis, 2005).

There are disagreements about the cause of the health effects. Some researchers do not consider oil leaking into the cabin or cockpit, with especially focus on exposure to tricresyl phosphate (TCP), to pose any health risks to the aircraft occupants, due to results found in their studies. There have also been claimed that even though it has been measured harmful chemicals in aircraft, the concentrations are too low to have any impact on the health (de Ree et al., 2014, Hanhela et al., 2005, Daughtrey et al., 1996, Schindler et al., 2012, Liyasova et al., 2011). At the same time, there are pilots, cabin crew, passengers, physicians and researchers who claim that fume events actually happen, and that health effects are results from these events (Winder and Balouet, 2000, Michaelis, 2010, Abou-Donia et al., 2013, Murawski, 2011). Since the reported health effects are very general, and may be due to several different factors, it is difficult to prove any connection between fume events and health effects.

Measurements have been done to find chemical substances in aircraft, and hence proof of contamination from oil components. Oil leakages, which may cause fume events, are rare and sudden, and no measurements have been made at the time they arise, which means that it has only been done measurements on normal flights or before/after flights (De Nola et al., 2011, Hanhela et al., 2005, Schindler et al., 2012, de Ree et al., 2014). Conclusions from studies have in general been that TCP (especially TOCP) alone cannot cause the reported health effects after air contamination in aircraft. Further studies should include all components in the oils and fluids when evaluating their toxicity, and take possible combustion product and the synergistic effects of the components into account. This could reveal whether the reported negative health effects are related to exposure of contaminants during fume events.

Insufficient knowledge exists about which chemicals and combustion products that may enter the ventilation system, due to lack of specific information about ingredients and different by-products in the MSDS from the manufacturers. The MSDS of the jet engine oils and hydraulic fluids provides information about the substances found in the oils by use under “normal conditions”. By a reaction between two or more chemicals, it may be produced by-products with a synergistic effect. These by-products may thus be even more harmful, and it should therefore be informed in the MSDS about the possibility of production of them. The manufacturers should provide a complete list and amout of ingredients found in the oils and fluids, to measure their total toxicity. The base stocks in the jet engine oils are only described as synthetic esters, with no further details about which base stocks that can be found in the different oils. There are used words as “normal conditions of use”, which is very vague and could be interpreted differently.

Hovewer, it is known that about 95 % of the engine oils and hydraulic fluids are base stocks, which are mostly based on a synthetic polyol (Exxon Mobil, 2014g, Michaelis, 2010, p 70). Various additives are used to enhance the lubricant performance of the base stocks, and these make up about 3 % of the base stocks (Rudnick, 2006, STAMI, 2003). The remaining 5 % of the oils and hydraulic fluids are several different chemicals. Changes in product formulations of engine oils and fluids have been made, but still there exists concern about the potential toxicity that exposure to these materials may cause (Daughtrey et al., 1996, Winder and Balouet, 2002b, Abou-Donia, 2015). It is suggested by Michaelis (2010, p 70) and Abou-Donia (2015) that several substances give different by-products following combustion, which means that the air inhaled after a leakage may comprise a chemical cocktail. A number of researchers have attempted to describe the constituents of the oils and fluids used in aircraft engines, and their following pyrolytic degradation products (Daughtrey et al., 1996, van Netten, 1999, van Netten, 1998). Even though many of the chemicals that are used in jet engine oils and hydraulic fluids are known to cause adverse health effects, most of the studies reviewed regarding toxicity have focused on the organophosphate TCP.

Organophosphates are commonly used additives, and due to known negative health effects of especially tricresyl phosphate, the major focus of the additives in the literature is on this specific substance. Appearing neurological symptoms are mainly thought to be caused by isomers of tricresyl phosphate (Singh and Sharma, 2000, Abou-Donia, 2003, Winder and Michaelis, 2005). It has been known for many years that ortho-cresyl phosphates are the most toxic isomers of TCP, and that mono-ortho-cresyl phosphate (MOCP) and di-ortho-cresyl phosphate are more toxic than tri-ortho-cresyl phosphate (Henschler, 1958). Despite this, there is only one known study that has measured and discovered concentrations of MOCP, (De Nola et al., 2008). The reason why additional experiments including measure of MOCP have not been carried out, is uncertain. It is questionable why some researchers have been able to measure MOCP, while others claimed that the concentration of MOCP cannot be determined, due to unavailable analytic standard of the isomer (de Boer et al., 2014). Although most of the reviewed articles claim that concentrations of compounds in the oils, with focus on TCP, are not high enough to cause negative health effects, this does not imply that the concentrations never reach harmful levels. The total concentration of TCP should be measured to include all the ortho isomers for evaluation of the toxicity level.

There have been concerns about the potential reaction of ingredients in some base stocks, especially the organophosphate trimethylolpropane phosphate (TMPP), a potent neurotoxin, from the reaction of trimethylol phosphate (TMP) polyols and TCP, when they are subject for elevated temperatures (Centers, 1992). No concentrations of TMPP have been found in an aircraft to date, only during laboratory experiments (Kalman et al., 1985, Wyman et al., 1987, Centers, 1992). More research should therefore be conducted in an attempt to find out whether possible concentrations of this potent neurotoxin can become high enough to cause severe health effects if aircraft occupants get exposed. Automatic incident samplers, like the one developed by Solbu (2011) should be placed in all aircraft that use bleed air to detect the possible fume events. These samplers are easy to use, measures long-term air quality when activated, and will probably not require large amount of resources. By using these incidents samplers, the potential concentrations of TMPP could be found. A possible solution to find the concentrations when fume events happen, is to conduct long term measurements of the cabin and cockpit air.

Both passengers and cabin crew may be exposed to many different air contaminants in the aircraft cabin, including CO from engine exhaust, O_3 from outside air, and organic compounds of biological origins. These factors may explain the health effects related to exposure to cabin air contaminants, and must thus be considered. The combination and possible synergistic effects between several different factors, such as pressurized environment, humidity, and biological agents, are also suggested to play a part (National Research Council, 2002, p 52). The pressurized cabin and cockpit is achieved by supplying compressed outside air. The air is compressed within the engine, and 2-8 % is bleed air which is used for ventilation within the aircraft (Michaelis, 2010, p 47, GCAQE, 2014, van Netten, 2005). The proportion of oxygen in the air remains unchanged, as the oxygen level is constant at 20.9 % at increasing altitude (Dechlow and Nurcombe, 2005). The partial pressure of oxygen decreases, and it is proposed that people with certain medical conditions may not tolerate the environment of reduced pressure (Winder and Balouet, 2002a, WHO, n.d). Bagshaw (2014) have suggested that hyperventilation may be a plausible explanation of the experienced health effects of aircraft occupants, but no evidence exist to confirm this theory.

Due to the wide range of people with various sensibilities to all the possible contaminants in flights, they may respond differently during a fume event. Health effects are related to the general condition of people, where age, previous clinical picture, general health, and lifestyle, are of importance. Health effects from exposure to contaminants in the aircraft have been described as both short- and long-termed (Winder and Balouet, 2001). Winder and Balouet (2000) claimed that health effects may be reversible following brief exposures, but after a significant or long term exposure, a chronic syndrome may occur. Various health effects have been reported from studies of individual components from oils and hydraulic fluids used in jet engines. Disagreements regarding health effects exist on this area, since conclusions about the health effects of the components differ (Winder and Balouet, 2002b, Winder and Balouet, 2002a, National Transportation Safety Board, n.d, Lewis, 2008, Boman et al., 1980, Kalimo et al., 1989). Some of the health effects that have been reported from these studies may have a correlation with health effects reported by aircraft occupants.

Even though it has been over 50 years since the bleed air was taken in use, few regulations to either prevent or monitor exposure to oil fumes that sometimes contaminate the cabin and cockpit supply air, exist to date. A reason may be that there are so many different chemical components that may enter the ventilation air, and therefore it is difficult to set regulations. It could be argued whether the established threshold limits for the chemicals used in jet engine oils and hydraulic fluids are valid, as an 8-hour threshold for a “normal working day” will not equal the exposure for aircraft occupants.

Before 1962, there was used a bleedless technology called ram air, the outside air was drawn into the cabin by the use of turbo compressors or blowers. By the use of this technology, the possible contamination was only due to the external sources of the outside air. The argument for choosing bleed air rather than ram air was mainly of economic reasons (GCAQE, 2014, van Netten, 2005). The latest Boeing 787 has a bleedless technology, where the fresh air intake is by the wing roots, rather than through the engines. One may ask if this denotes that the aircraft manufacturers acknowledge there is a problem with the applied bleed air system. If so, why have not any solutions been presented to address the problem earlier?

5.0 Conclusions

Given that the response rate of the survey was 21.0 %, it can be argued whether the respondents are representative of all flight crew. The results of the survey among pilots and cabin crew indicate good knowledge about the phenomenon of fume events, where more than two out of three had heard about it. The actual percentage of knowledge among flight crew, if all of the 2 952 persons who received the survey responded, would be somewhere between 14.9 % and 70.5 % when considering the possibility of selection bias. The same would apply for the question about whether fume events are considered a problem, where the actual percentage would be somewhere between 9.2 % and 43.6 %. Although the response rate of the survey among people on Gløshaugen campus was 94.3 %, the number of respondents was low. The fact that only 15 % of the 100 respondents had heard about fume events indicates that academics have less knowledge and attention about such events than flight crew.

Fume events occurring worldwide between 2007 and 2014 were found from databases and media articles. The total number of these yielded an estimated frequency of 0.24 possible fume events per day. This frequency is assumed to be underestimated due to underreporting, difficulties to access databases, and different criteria of reporting events by airlines.

The ventilation air in the cabin and cockpit may get contaminated by jet engine oil and hydraulic fluid, forming what is known as a fume event. The phenomenon is facilitated by the characteristics of the bleed air system, which is used on most commercial aircraft. Much literature regarding fume events exists, but unanswered questions still remain. Frequent fliers and predisposed individuals may be vulnerable to long term repeated exposure, and serious leaks that enter the cabin air may result in high levels of hazardous chemicals. No measurements have been performed during a reported fume event. It is therefore not known whether concentrations of contaminants the aircraft occupants may be exposed to, are high enough to cause the reported adverse health effects.

5.1 Further Work

The exposure limits of contaminants should be adapted and adjusted to fit the aircraft environment. The limits need to be reduced due to the fact that humans are more susceptible of exposure to toxicants in the reduced pressure environment while in flight. Flight crew who may have been exposed to contaminants during a fume event should be inquired about symptoms. In addition, the use of human biomonitoring should be carried out to assess the exposure of contaminants from fume events. Incident samplers should be placed in all aircraft to compare the results from biomonitoring with the levels of contamination measured by the samplers. The suggestion is probably challenging to implement, but could provide answers to whether there is a connection between symptoms or health effects and fume events. Incident samplers could also be used to compare the levels of registered contaminants to find out if the concentrations of contaminants in the bleed air during fume events exceed the exposure limit values.

When evaluating the toxicity level of the jet engine oils and hydraulic fluids, all components that constitute the chemicals should be included. In addition, the possible combustion products and synergistic effects should be taken into account. To do this, manufacturers must provide a complete list and amount of ingredients in the oils and fluids.

Actions should be implemented to get an overall overview in as many countries as possible to estimate a frequency of how often fume events occur. A suggestion is implementation of an international incident reporting system, where airlines share a policy of when and how to register fume events. The survey among pilots and cabin crew indicated that a majority of this group consider fume events a problem in the aircraft industry. Mitigating measures should be implemented to prevent such event

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Appendix A: List of Web Pages Considered to Find Possible Fume Events

Name of agency	Area of registration	Limitations of search	Web page
Civil Aviation Authority (CAA). Referring to the site of AAIB	UK	**1. Search Titles and Descriptions:** Used keywords “Smoke”, “oil and smoke”, “oil leakage”, “oil mist”, “fume”, “fume event”, “fumes”, “smoke and fumes”, “smell”	http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11
Air Accidents Investigation Branch reports (AAIB)	UK	**Search:** “Smoke”, “oil and smoke”, “oil leakage”, “oil mist”, “fume”, “fume event”, “fumes”, “smoke and fumes”, “smell” **Aircraft category:** Commercial-fixed wing **Date interval**	https://www.gov.uk/aaib-reports
UK Contaminated Air Events Database (UKCAED)	UK	Could not find the database	Source found from Michaelis (2010)
British Airline Pilots Association (BALPA)	UK	Must log in to use	https://www.balpa.org/
Sveriges Statens Haverikommisjon (SHK)	Sweden	**Kategori:** Civil luftfart **Datumintervall:** Date interval **Sök fritext:** rök, olja och rök, läcker olja, oljedimma, rök, rök händelse, rök, lukt	http://www.havkom.se/Sok
Flight Attendant Authority of Australia (FAAA)	Australia	Must log in to use	http://faaa.net/
Australian Transport Safety Bureau (ATSB)	Australia	**Advanced search** **Occurrence date:** Date interval **Occurrence type:** “smoke”, “fumes”	http://www.atsb.gov.au/publications/safety-investigation-reports.aspx?mode=Aviation
Civil Aviation Safety Authority (CASA)	Australia	Could not find any place to search after relevant events	http://www.casa.gov.au/scripts/nc.dll?WCMS:HOMEPAGE:1179590987:pc=PC_90001
Aviation Safety Reporting System (ASRS)	US	Subjective, anonymous reports registered by anyone	http://asrs.arc.nasa.gov/overview/database.html

National Transportation Safety Board (NTSB)	US	**Date:** Interval **Aircraft category:** Airplane **Amateur Built:** No **Operation:** Non U.S, commercial **Enter your own word string below:** “Smoke”, “oil and smoke”, “oil leakage”, “oil mist”, “fume”, “fume event”, “fumes”, “smoke and fumes”, “smell”	http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx
Federal Aviation Administration (FAA). Name of data system: Accident and Incident Data System (AIDS)	US	**Narrative search:** “Smoke”, “oil and smoke”, “oil leakage”, “oil mist”, “fume”, “fume event”, “fumes”, “smoke and fumes”, “smell” **Date:** Interval **Flight conduct:** Scheduled aircraft/helicopter	http://www.asias.faa.gov/pls/apex/f?p=100:12:0::NO
Bundesstelle für Flugunfaluntersuchung (BFU)	Germany	**Select type of aircraft:** Airplanes 2000 kg-5700 kg, and >5700 kg **Sorted by date**	http://www.bfu-web.de/EN/Publications/Investigation%20Report/reports_node.html
Irish Accident Investigation Unit (AAIU)	Ireland	**Search site:** “Smoke”, “oil and smoke”, “oil leakage”, “oil mist”, “fume”, “fume event”, “fumes”, “smoke and fumes”, “smell” **Sorted by date**	http://www.aaiu.ie/reports/aaiu-investigation-reports
Statens Havarikommisjon for Transport (SHT)	Norge	**Flykategori:** Turbofan/turbojet Turboprop/turboshaft **Hendelsesdato:** Interval	http://www.aibn.no/Luftfart/Rapporter/Avansert-sok
Aeronautical Accidents Investigation and Prevention Center (CENIPA)	Brazil	Have to log in to get the site in English.	http://www.cenipa.aer.mil.br/cenipa/en/
Transportation Safety Board of Canada (TSB)	Canada	**Search through the aviation reports list:** “Smoke”, “oil and smoke”, “oil leakage”, “oil mist”, “fume”, “fume event”, “fumes”, “smoke and fumes”, “smell” **Sorted by date**	http://www.bst-tsb.gc.ca/eng/rapports-reports/aviation/index.asp
Transport Accident Investigation Commission (TAIC)	New Zealand	**Sorted by date** **Read through title and summary**	http://www.taic.org.nz/ReportsandSafetyRecs/AviationReports/tabid/78

			/language/en-US/Default.aspx
The Aviation Herald (Simon Hradecky registers aircraft incidents on this page)	World wide	**List by occurrence** **No filters** **Search:** "Smoke", "oil and smoke", "oil leakage", "oil mist", "fume", "fume event", "fumes", "smoke and fumes", "smell" **Sorted by date**	http://avherald.com/
The flight herald		Hard to navigate on the page. Not used as a source.	http://theflightherald.com/
Aviation safety		**(Contributory) cause index:** Airplane Airplane-Engines-Fuel contamination Airplane-Systems-Hydraulics	http://aviation-safety.net/database/events/event.php?code=AC
Airdisaster		**Search by keywords:** "Smoke", "oil and smoke", "oil leakage", "oil mist", "fume", "fume event", "fumes", "smoke and fumes", "smell"	http://www.airdisaster.com/cgi-bin/database.cgi
Global Cabin Air Quality Executive (GCAQE)		**No filter**. Some of the links did not work anymore. Found some of the reports elsewhere.	http://www.gcaqe.org/media.html
Arie Adriaensen			Reports received on e-mail directly from Arie Adriaensen

Appendix B: Aviation Accident Database of the NTSB

Accident/Incident Information

Event Start Date (mm/dd/yyyy)	
Event End Date (mm/dd/yyyy)	
Month	All
City	
State	Anywhere
Country	Anywhere
Investigation Type	All
Injury Severity	All

Aircraft

Category	All
Amateur Built	All
Make	
Model	
Registration	
Damage	All
Number of Engines	
Engine Type	All

Operation

Operation	All
Purpose of Flight	All
Schedule	All
Air Carrier	

NTSB Status

Accident Number	
Report Status	All
Probable Cause Issue Start Date (mm/dd/yyyy)	
Probable Cause Issue End Date (mm/dd/yyyy)	

Event Details

Airport Name	
Airport Code	
Weather Condition	None
Broad Phase of Flight	All

Enter your word string below: (Searches both synopsis and full narrative; will slow the query performance)

Location information available for most cases in the United States since 2002. Refer to query help for limitations of location information.

Latitude	
Longitude	within 0 miles

Appendix C: Information About the Survey Sent to Pilots and Cabin Crew

(The information was written and sent out in Norwegian to the respondents)

We are two students conducting a master in Health, Safety and Environment at NTNU (responsible institution), now we are writing our master's thesis. The topic of the thesis is possible oil contamination of air in aircraft cabin.

The air entering the cabin and cockpit is originally clean air from the environment outside the aircraft. This air goes through the engine before it is used as ventilation air, and is inhaled by people in the plane. In the engine, leakage may occur which may cause the oil to mix with the ventilation air that enters the cabin, commonly known as fume events. It has been questioned whether such contamination of ventilation air can have negative health effects. Air contaminated by oil may be noticed as the odour of engine/oil, wet dog or smelly socks, or it may appear as smoke.

Through this survey, we wish to find out whether cabin crew and pilots in Norway are aware that there may be contamination of the air in the cabin, caused by turbine oil. In addition, we want to find out how extensive this subject is, by considering how many who have experienced incidents of contaminated air in aircraft cabin. It is voluntary to participate in the survey and you can at any time choose to withdraw without justification. Responses to the questionnaire will be treated confidentially and all data will be anonymized by the end of the project. Individuals will not be recognizable in the final task.
The survey takes approximately 5 minutes to conduct.

The deadline for responding to the survey is Friday 17th of April 2015.
Expected completion of the project is 11.06.2015.

Responsible for the survey:

Tonje Trulssen Hildre (student)
Email: tonjetru@stud.ntnu.no

June Krutå Jensen (student)
Email: junekj@stud.ntnu.no

Professor Kristin Hirsch Svendsen (supervisor)
Email: kristin.svendsen@iot.ntnu.no

Click on the link below to open the survey:
https://survey.svt.ntnu.no/TakeSurvey.aspx?SurveyID=9lK34m21

Appendix D: Overview of Possible Fume Events

Date	Aircraft type	Flight phase	Contaminated area	Short summary	Description of cause
2014					
26. Dec	Boeing 737-800	Climb	Cabin	The crew reported smell of smoke in the cabin, but nothing visible. The aircraft returned to the departure airport.	Attending emergency services found no trace of fire, heat or smoke.
22. Dec	Airbus A319-100	Descent	Cockpit	The crew reported an unusual odour in the cockpit.	Emergency services found no trace of fire, smoke or heat.
18. Dec	Airbus A320-323	Initial climb	Cabin	The flight crew donned oxygen masks, and returned to airport. Flight crew noticed a musty smell as the aircraft climbed through 5000 feet. Cabin crew at the front and rear had noticed the smell. Some felt light headed and a little nauseous.	Hydraulic fluid was leaking from a hydraulic actuator, and ingested into the air inlet for the APU.
17. Dec	Airbus A319-100	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted for a safe landing.	Lack of information.
6. Dec	Airbus A330-200	Cruise	Unknown	The crew decided to divert, declaring a medical emergency after 11 crew and 2 passengers reported feeling ill and showing red eyes, a number vomited. All crew and the two ill passengers were taken to a hospital.	A malfunction of the aircraft's air-conditioning system was suspected, based on initial examination.
4. Dec	Boeing 757-300	Climb	Flight deck	The crew donned their oxygen masks due to smoke on the flight deck. The crew suspected the smoke was coming from oil in the left hand engine. The cause is not confirmed.	Lack of information.
29. Nov	Boeing 757-200	Cruise	Galley	The crew decided to divert due to smell of smoke near the aft galley.	The maintenance inspection did not find any problem. The aircraft was able to continue the flight.
21. Nov	Boeing 767-300	Initial climb	Cockpit	The crew reported smoke in the cockpit and returned to airport.	Emergency services did not find any smoke, but detected smell of smoke in the cockpit area.
13. Nov	Boeing 737-800	Climb	Flight deck	The crew decided to return to departure airport due to fumes on the flight deck. Nothing was noticed in the cabin.	Tests were conducted by maintenance, but nothing was found. Further tests were conducted after 16

					hours after landing the aircraft, again without any finding.
6. Nov	Boeing 777-200	Cruise	Cockpit	The crew reported smoke in the cockpit. Following the initial inspection by emergency services the crew requested to be followed to the gate, stating they had smoke and fumes in the cockpit and cabin.	Lack of information.
5. Nov	Boeing 767-300	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted. The occurrence aircraft was still on the ground 3.5 days after landing.	Lack of information.
3. Nov	Boeing 757-200	Cruise	On board	The crew decided to turn around due to fumes on board. Passengers reported an odour on board of the aircraft.	Technical problem.
31. Oct	Boeing 737-800	Cruise	On board	The crew donned their oxygen masks due to fumes on board.	Lack of information.
12. Oct	Airbus A320-200	Initial climb	Cabin	A burning smell developed throughout the cabin prompting the crew to stop the climb and return to airport.	Lack of information.
3. Oct	Airbus A340-300	Cruise	On board	The crew decided to return to the airport due to a strong odour on board. Passengers reported a strong odour on board, one passenger mentioned smoke on board.	Lack of information.
19. Sep	Airbus 320	Cruise	Cabin	An engine problem resulted in smoke entering the aircraft's cabin.	Probable cause was an engine problem.
19. Sep	Airbus A320-200	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted.	Attending emergency services found no trace of fire, heat or smoke.
13. Sep	Airbus A319-100	Descent	On board	The aircraft did an emergency landing due to fumes on board, with a number of passengers and cabin crew complaining of sore throats, headaches and eye irritations. Ambulance took three persons to an urgent care centre.	Lack of information.
5. Sep	Airbus A320-200	Initial climb	Cabin and cockpit	The crew donned their oxygen masks, declared emergency, stopped the climb and reported they had a strange smell in cockpit and cabin.	Lack of information.
1. Sep	Airbus A320-200	Cruise	Cockpit	The crew declared emergency reporting smoke in the cockpit.	Lack of information.
27. Aug	Transport Regional ATR-72-212A	Initial climb	Cabin	Smoke with a strong burning smell was detected in the aircraft cabin, the crew declared emergency and performed a normal landing. The occurrence was rated a serious incident.	An investigation was opened.
27.	Embraer ERJ-	Climb	Cockpit	The crew stopped the climb reporting smoke in the cockpit, and	Lack of information.

Aug	145			diverted.	
25. Aug	Boeing 767-300	Initial climb	Cabin	The crew stopped the climb due to what appeared to be white smoke in the aft cabin, and returned to the airport.	Attending emergency services did not find any trace of fire or heat.
22. Aug	Transport Regional ATR-72-212A	Initial climb	Cockpit	The crew stopped the climb, declared emergency reporting smoke in the cockpit, and returned to the airport.	Lack of information.
21. Aug	Embraer ERJ-145	Climb	Cabin	The crew stopped the climb, reported smoke in the cabin and diverted.	Lack of information.
18. Aug	Airbus A330-200	Cruise	On board	The crew decided to return to the airport, due to an unbearable odour on board. One passenger was treated at the airport, while four needed to be taken to a hospital with injuries.	Emergency services searched the aircraft, but were unable to identify a source of the odour.
15. Aug	Embraer ERJ-145	Initial climb	Cabin	The cabin crew reported smoke in the cabin and declared emergency. The crew requested to return to the airport for landing.	Lack of information.
12. Aug	Boeing 767-300	Cruise	Cockpit	The crew reported smoke in the cockpit and returned to the aircraft.	Responding emergency services found no trace of fire or heat.
31. Jul	Airbus A320-200	Climb	Galley	The cabin crew observed smell in the aft galley. Both galley ovens were switched off, but the smell continued and filled half of the cabin in the back of the aircraft. The crew decided to divert. Two of the cabin crew became incapacitated as result of the smell, and all of the crew members were taken to hospitals.	Lack of information.
30. Jul	Embraer ERJ-145	Initial climb	Cabin	The crew declared emergency reporting smoke in the cabin and requested to return immediately.	Lack of information.
29. Jul	Airbus A321-200	Descent	Cabin and cockpit	An odour of old socks was noticed in cabin and cockpit. All crew went to see the doctor after landing. (Same aircraft as 28.07.2014.)	Underwent maintenance. Lack of more information.
28. Jul	Airbus A320-200	Climb	Cockpit	The crew stopped the climb and diverted, reporting smoke in the cockpit.	Lack of information.
27. Jul	Airbus A321-200	Descent	Cabin and cockpit	There was highly intense fume (smell of old socks) in the cockpit and forward cabin, affecting all crew members including the pilots. Both pilots donned their oxygen masks. The return flight was postponed to perform a "Pack Burn" overnight on the airport. During the return flight the next day there was again highly noticeable fumes throughout the entire aircraft, though weaker than the day before. All crew members showed symptoms like headache, nausea and dizziness.	The incident was investigated by the BFU, and rated a serious incident.

26. Jul	McDonnell Douglas MD-88	Cruise	On board	The crew reported a smoky odour on board and decided to divert.	Lack of information.
26. Jul	Airbus A320-200	Cruise	Cabin	The crew donned their oxygen masks reporting a constant suspected oil smell in the cabin. The crew continued to use their oxygen masks until after vacating the runway.	Engineering issue.
22. Jul	Boeing 767-300	Climb	Cockpit	The crew reported smoke in the cockpit and returned to the airport.	Lack of information.
20. Jul	Boeing 737-500	Climb	Cabin	The crew stopped the climb, reporting smoke in the cabin and returned to the airport.	Lack of information.
14. Jul	Airbus A330-200	Climb	Unknown	The crew reported an odour of burning plastic, but decided to continue the flight. The aircraft was en route when the crew declared emergency reporting several flight attendants were reporting sick. One flight attendant was transported to a medical facility. The other flight attendants and one passenger were examined by medical staff at the airport.	Maintenance inspected the aircraft and was unable to reproduce the fumes.
9. Jul	McDonnell Douglas MD-88	Cruise	Cockpit	The flight crew donned their oxygen masks, declared emergency reporting smoke in the cockpit, and decided to divert. On approach to the runway, the crew advised that the smoke appeared to be dissipating after they had turned off some of the equipment.	Emergency services reported no trace of fire, smoke or heat.
3. Jul	Boeing 767-300	Climb	Cockpit	The crew stopped the climb reporting a burning smell in the cockpit, and returned to the airport.	The airline reported the aircraft encountered a minor Technical problem.
28. Jun	Airbus A320	Unknown	Unknown	The crew began noticed a strange smell and got dizzy shortly into the trip. A spokeswoman confirmed that three out of seven crews working on the flight were unable to work for weeks. The captain and co-pilot were not affected and the spokeswoman said no passengers had complained.	The problem was found to be caused by oil dripping into a motor at the rear of the plane.
28. Jun	Boeing 747-400	Cruise	Cabin	The crew reported smoke and fumes in the cabin.	Lack of information.
19. Jun	Havilland Dash 8-300	Climb	Flight deck	Smoke was observed on the flight deck prompting the crew to return to the airport.	Passengers were told a fan inside the cockpit was emitting smoke.
18. Jun	Boeing 767-300	Cruise	Cockpit	The crew noticed white smoke in the cockpit, which dissipated after about 15 seconds, the odour however remained.	A supplied pneumatic pressure to the aircraft due to the non-availability of the APU had broken down and possibly contaminated the pneumatic ducting.

9. Jun	Airbus A330-200	Climb	Cabin	Fumes were detected in the cabin, which affected two cabin crew. The two cabin crew were removed from service.	Lack of information.
5. Jun	Airbus A330-200	Cruise	On board	The crew reported fumes on board. While descending, the crew reported that the fumes had disappeared.	Lack of information.
31. May	Airbus A320-200	Grounded	Unknown	While turning off the runway, smoke was observed from the main landing gear.	Caused by hydraulic fluid dripping onto the hot brakes of the aircraft.
22. May	Avro RJ-85	Climb	Cockpit	The crew donned their oxygen masks and reported smoke in the cockpit. The aircraft returned to the airport.	Cause was investigated.
20. May	Havilland Dash 8-400	Descent	Cabin and cockpit	During the descent, the crew observed smoke in cockpit and cabin. The crew donned their oxygen masks.	Lack of information.
10. May	Airbus A330	Cruise	Unknown	The aircraft diverted because several of the flight attendants was feeling ill. Nine crew reported feeling 'nauseous and dizzy' while suffering from watering eyes.	The US National Transportation Safety Board (NTSB) as well as the Irish Air Accident Investigation Unit (AAIU) was to investigate the incident.
10. May	Boeing 757-200	Cruise	Cabin and cockpit	The crew decided to return to the airport reporting smoke in cockpit and cabin.	Lack of information.
6. May	Unknown	Grounded	Cabin	A spokesman commented that the cabin crew claimed that the smoke had an odour that occurs during flight training. He claimed it is not toxic or harmful in any way, and that a small amount of oil could lead to smoke, which then may be pulled into the cabin through the ventilation system from engines.	Lack of information.
28. Apr	Unknown	Cruise	Cockpit	The aircraft made an emergency landing at the airport after its crew smelled a burning odour in the cockpit.	An initial inspection by fire-fighters discovered no issues with the aircraft.
28.Apr	Airbus A321-200	Initial climb	Cabin	The crew stopped the climb due to smoke in the cabin and returned to the airport. Russia's Ministry of Interior initially reported the aircraft returned because of a fire indication for the right hand engine. The airline later reported the aircraft returned due to smoke in the cabin.	Lack of information.
24. Apr	Embraer ERJ-145	Climb	On board	The crew stopped the climb, donned their oxygen masks and decided to divert, reporting smoke on board.	Lack of more information.

20. Apr	Airbus A330-300	Initial climb	Cabin	Passengers reported that there was a strong burning smell, then visible haze and smoke about mid cabin. The smoke began to dissipate and was gone by the time of touch down.	Cabin crew fetched portable fire extinguishers and checked the cabin, including walls and overhead bins, for possible sources of heat or fire, but did not find any cause.
15. Apr	MD90	Grounded	Cabin and cockpit	Delta issued a statement saying, *"During the aircraft's taxi out, a smoky odour was observed in the cockpit and cabin. In an abundance of caution, the flight crew returned to the gate. Passengers were re-accommodated on a new aircraft."*	Lack of information.
13. Apr	Boeing 737-800	Descent	Cabin	The crew declared emergency, reporting a smell of burning rubber in the cabin. Emergency checked the aircraft on ground, the crew reported that the odour had subsided and everything was normal in the cabin.	Emergency checked the aircraft. Lack of more information.
11. Apr	Boeing 737-200	Cruise	On board	The crew reported the smell of smoke as well as haze on board. The flight crew received a #2 air conditioning system trip off indication; shut the system down, the haze and smell dissipated thereafter.	Lack of information.
6. Apr	Airbus A320-200	Cruise	Cockpit	The crew reported smoke in the cockpit. The passengers in the forward cabin noticed a strong smell prompting diversion.	Cause was investigated.
3. Apr	Embraer ERJ-145	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. When approaching the airport, the crew reported the smoke had subsided.	The airline stated a maintenance issue caused the diversion.
31. Mar	Embraer ERJ-190	Climb	Cockpit	Smoke in the cockpit prompted the crew to return to the airport. The airline confirmed smell of smoke on board of the aircraft. 6 passengers received medical assistance after landing. The FAA reported 6 passengers received injuries following smoke in the cockpit.	The source of the smoke was under investigation.
30. Mar	Boeing 757-300	Climb	On board	The crew reported an unidentified smell on board and requested emergency services on standby.	Lack of information.
21. Mar	Airbus A319-100	Descent	Cockpit	The crew declared emergency reporting oily fumes in the cockpit.	Lack of information.
21. Mar	Boeing 737-700	Cruise	Cabin	The crew reported a burning odour and smoke in the cabin. The crew shut down the cabin utility power after which smoke and odour subsided.	The Canadian TSB reported a recirculation fan was reported failed.

5. Mar	Airbus A320-200	Climb	On board	The crew stopped the climb and entered a hold. The crew subsequently initiated another climb to continue the flight but again aborted the climb, reporting fumes on board.	AAIB rated the occurrence as a serious incident and opened an investigation.
1. Mar	Boeing 737-700	Descent	Cabin and cockpit	The crew noticed strong fumes in the cockpit and cabin. The crew worked the relevant checklists after which the fumes dissipated.	Maintenance was unable to re-produce the problem. No further evidence of fumes was found, all systems operated normally, hydraulic and oil quantities were all found at serviceable levels.
26. Feb	Unknown	Descent	Unknown	Passengers had to make an emergency evacuation at the gate because of smoke in the plane.	A spokesperson claimed the source of the smoke came from an air conditioning pack.
23. Feb	Unknown	Initial climb	Cabin and cockpit	The aircraft returned short time after take-off, due to oil mist in the cabin and cockpit. Both crew and passengers got medical check.	Engine oil was the suspected cause.
20. Feb	Boeing 767-300	Climb	Cabin	About 5 minutes into the flight, a burning smell and white smoke appeared in the cabin.	A minor oil leak from the right hand engine was identified as source of the smell and smoke. The oil vaporized, got into the air conditioning system and thus was transported into the cabin.
15. Feb	Boeing 767-300	Cruise	Cabin and cockpit	Fumes were detected in the front of the cabin and in the cockpit. The crew decided to don their oxygen masks.	Lack of information.
11. Feb	Airbus A300-600	Climb	Cabin	Diversion was considered, due to cabin smoke smell/fumes.	On the ground, inspection was carried out on all the related systems including engine, air conditioning, hydraulics, and all found satisfactory.
3. Feb	Airbus A321-200	Descent	On board	The crew declared emergency reporting smoke on board of the aircraft. While taxiing to the terminal, emergency services were told there was smoke and vibrations from the right hand engine.	Lack of information.
31. Jan	Boeing 777-200	Cruise	On board	The crew reported the smell of smoke on board of the aircraft and decided to divert. Three passengers were taken to a hospital for check, after possible smoke inhalation.	Lack of information.
29. Jan	Canadair CRJ-700	Climb	On board	The crew initiated a rapid descent due to problems with the air conditioning system. The FAA reported smoke on board of the	Lack of information.

				aircraft.	
14. Jan	Canadair CRJ-900	Grounded	Cabin and cockpit	The crew rejected take-off about 10 seconds after applying take-off thrust, after the captain smelled smoke in the cockpit. Flight and cabin crew established there was smoke in cockpit and cabin. The occupants rapidly deplaned onto the runway while emergency services responded.	The cause of the smoke was investigated.
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10. Dec	Airbus A319-100	Descent	Cockpit	An odour of burning oil was noticed in cockpit causing irritation of respiratory tracts of all 3 pilots in the cockpit. All three donned their oxygen masks, queried the cabin where a similar odour was reported. The captain assumed control and continued for a safe landing. All three pilots and one flight attendant went for a medical examination, which was without findings according to feedback by the crew members receiving their test results.	An investigation was opened.
30. Nov	Transport Regional ATR-72-500	Climb	Cockpit	The crew reported smoke in the cockpit and returned to the airport for a safe landing.	The "smoke" was most likely steam out of the air conditioning system.
29. Nov	Airbus A380-800	Cruise	Unknown	Fume events during the flight caused a number of cabin crew to feel unwell. The crew received abnormally high indications of oil quantities for engine #3 and deactivated the bleed air supply from engine #3, the fumes dissipated thereafter. All cabin crew went to seek medical assistance, eight flight attendants were written sick.	An engine oil overfill was identified as cause of the fume event.
28. Nov	Havilland Dash 8-100	Climb	Cockpit	The crew noticed a vague burning odour on board, which was shortly followed by the #2 bleed air hot indication cycling on and off. The crew declared emergency reporting smoke in the cockpit.	It was suspected that de-icing fluid in the engine intakes was the source of the odour. The bleed system was investigated by maintenance.
26. Nov	McDonnell Douglas MD-90	Grounded	Unknown	While turning off the runway, the crew radioed tower they had an issue with the left hand engine, later adding there was smoke. Emergency services responded and checked the left hand engine.	The cause of the smoke was investigated.
14. Nov	Boeing 777-200	Cruise	Cabin	The crew declared emergency reporting a burning smell in the cabin and requested to turn around and divert.	Lack of information.
13. Nov	Canadair CRJ-900	Climb	On board	The crew reported a burning odour on board, donned their oxygen masks and advised they needed to return.	Lack of information.

9. Nov	Boeing 777-200	Cruise	Cockpit	The crew donned their oxygen masks, declared Mayday reporting smoke in the cockpit, and diverted.	Lack of information.
8. Nov	Airbus A321-200	Climb	Cockpit	The crew declared emergency reporting a burning odour in the cockpit. The airline reported a safety landing because of an unidentified odour.	Attending emergency services found no trace of fire, heat or smoke.
8. Nov	Boeing 737-800	Climb	Cabin	The airline reported that a passenger noticed fumes in the cabin. The crew stopped the climb and decided to divert.	Examination of the aircraft revealed three air conditioning ducts out of position in the area where the smoke originated. Maintenance determined an air conditioning fault causing a pipe to blow dust and/or debris into the cabin.
3. Nov	Airbus A319-100	Climb	Cabin	The aircraft was performing a positioning flight without passengers when smoke in the cabin forced the crew to use their oxygen masks.	Italy's ANSV was investigating this as a serious incident.
1. Nov	Boeing 777-300	Initial climb	Cabin	The crew stopped the climb reporting a strong smell of smoke in the cabin. The aircraft subsequently entered a hold to dump fuel before returning to the airport.	Lack of information.
31. Oct	Boeing 737-300	Climb	Cockpit	The crew reported smoke in the cockpit and diverted.	Lack of information.
29. Oct	Airbus A340-300	Descent	Cockpit	Crew noticed an unidentifiable smell in the cockpit, possibly burning rubber or burning plastics. The captain donned his oxygen mask for the remainder of the approach and landing. The aircraft lost the flight management system #1, about 5 minutes prior to the fumes and did not know if there was a link between the failure and the smell.	Lack of information.
24. Oct	Airbus A319-100	Climb	On board	The crew stopped the climb and returned to the airport reporting a smoky odour on board.	Lack of information.
22. Oct	Boeing 757-200	Cruise	Cockpit	Smoke started to fill the cockpit, and flight crew donned their oxygen masks. Passing through 10 000 feet, the smoke had dissipated enough to allow them to remove their masks.	Seal in a Low Pressure Fuel Pump had failed, allowing fuel to enter the oil system and the bleed air system. Maintenance found engine oil in the fan duct, the quantity in the oil reservoir had reduced by about 1/3.
13. Oct	Embraer ERJ-145	Climb	Cockpit	The crew donned their oxygen masks and stopped the climb. They declared emergency reporting smoke in the cockpit, and diverted.	Lack of information.

1. Oct	Embraer ERJ-145	Climb	Cockpit	The crew reported smoke in the cockpit and diverted.	Lack of information.
24. Sep	Airbus A319-100	Climb	Cockpit	The crew donned their oxygen masks, stopped the climb reporting smell of smoke in the cockpit and returned to the airport. The airline reported the following day that the crew detected the smell of smoke. However, there was no smoke in the cockpit.	Lack of information.
23. Sep	Boeing 777-200	Cruise	On board	The crew reported a burning smell on board and decided to divert.	Lack of information.
23. Sep	Boeing 757-200	Cruise	On board	The crew reported a burning smell on board and decided to divert. Later on approach the crew reported an unknown smoke in the cabin. Passengers reported a smell like burning plastics.	Lack of information.
20. Sep	Airbus A319-100	Climb	Cockpit	The crew stopped the climb, reporting smoke in the cockpit, donned their oxygen masks and returned to the airport. Passengers reported that during take-off, a smell like burning batteries appeared in the cabin, shortly after becoming airborne smoke entered the cabin from the cockpit.	Passengers were later told that a faulty air conditioning system was identified as cause of the smoke.
20. Sep	McDonnell Douglas MD-88	Climb	Cabin	Fumes in the cabin were getting the flight attendants irritated.	Emergency services did not find any trace of fire, heat or smoke.
20. Sep	Airbus A320-200	Initial climb	Unknown	The crew advised oil fumes were detected shortly after becoming airborne.	Lack of information.
19. Sep	Boeing 757-200	Cruise	Cabin	The crew reported smoke in the cabin and diverted.	The aircraft was examined to identify the source of the smoke.
18. Sep	Airbus A320-200	Cruise	Cockpit	The crew reported smell of smoke in the cockpit and diverted.	Lack of information.
10. Sep	Airbus A321-200	Cruise	Cabin	The crew noticed an unusual, unidentifiable smell near the lavatory. Two of the cabin crew members were taken to a hospital, and diagnosed with smoke inhalation.	It could not be identified where the smell came from.
3. Sep	McDonnell Douglas MD-90	Cruise	On board	The crew reported smell of smoke on board and decided to divert.	Attending emergency services found no trace of fire, heat or smoke.
28. Aug	Airbus A330-200	Climb	Cockpit	The crew stopped the climb reporting smoke in the cockpit.	Lack of information.
26. Aug	Boeing 757-300	Cruise	Cabin	The crew reported smell of smoke in the cabin and diverted.	Responding emergency services found no trace of fire, heat or smoke.

21. Aug	Boeing 767-300	Initial climb	Cabin	The crew stopped the climb, and decided to return to the airport due to smoke in the cabin. The smoke dissipated during the return.	The airline reported that a faulty air conditioning system was identified as source of the smoke.
16. Aug	Boeing 737-800	Grounded	Cockpit	The crew noticed a strong odour in the cockpit. Passengers were disembarked and switched to a replacement aircraft.	The aircraft was inspected by engineers and cleared to return to service.
14. Aug	Boeing 757-200	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted.	Lack of information.
30. Jul	Embraer ERJ-135	Cruise	Cockpit	The crew reported smell of smoke in cockpit and cabin, and decided to divert.	Attending emergency services found no trace of fire, heat or smoke.
29. Jul	Havilland Dash 8-300	Cruise	Cockpit	The pilot advised air traffic control of smoke in the cockpit.	The incident was investigated. Lack of information.
28. Jul	Boeing 777-300	Grounded	Cabin	People were boarding at the gate when the crew noticed a strong burning odour on board and saw smoke in the cabin.	Lack of information.
26. Jul	Boeing 737-800	Cruise	Unknown	The crew reported a smoke indication and decided to divert. On final approach the crew advised the fumes had dissipated, they requested emergency services to follow them to the gate.	Attending emergency service found no trace of fire, heat or smoke.
25. Jul	Havilland Dash 8-400	Climb	Cockpit	The crew reported smoke in the cockpit and decided to return to the airport.	The airport reported emergency services did not find visible smoke.
25. Jul	Boeing 757-200	Cruise	Cabin and cockpit	The crew reported a smoky odour on board and decided to return to the airport.	Lack of information.
23. Jul	Boeing 767-400	Cruise	Cabin and cockpit	The crew reported smoke in cockpit and cabin, turned the aircraft around and diverted.	Lack of information.
22. Jul	Embraer ERJ-140	Cruise	Cockpit	The crew reported the left hand engine needed to be shut down and decided to divert. The crew subsequently also reported smoke in the cockpit while descending towards the airport.	Lack of information.
16. Jul	Boeing 737-800	Cruise	Cockpit	The flight crew noticed a smell of burning plastics in the cockpit, checked with cabin crew who confirmed the smell was also present in the cabin.	The cause of the fumes could not be identified, despite extensive post incident maintenance inspection and engine run ups.
28. Jun	Airbus A340-600	Cruise	Cabin	The aircraft diverted, due to an irritating smell which made some passengers sick. Medics checked one passenger and three crew members.	Lack of information.
26. Jun	Airbus A320-	Landing	Cabin	The aircraft was about to vacate the runway when the crew advised	Lack of information.

	200			they had a strong smell in the cabin. The aircraft taxied to the gate, where passengers and crew disembarked normally. The crew underwent medical checks reporting dizziness, breathing difficulties, nausea and lack of concentration.	
21. Jun	Boeing 757-200	Cruise	Cockpit	The crew reported the smell of smoke in the cockpit and decided to divert. The crew advised on approach that the smell was dissipating.	The airline reported maintenance did not find anything out of the ordinary, and the aircraft was returned to service.
19. Jun	Boeing 767-300	Cruise	Cockpit	The crew reported smoke in the cockpit, turned around and diverted.	Lack of information.
17. Jun	Boeing 737-800	Climb	Cabin	Smoke appeared in the cabin obviously originating from the air conditioning outlets. The crew stopped the climb and decided to return to the airport.	Lack of information.
12. Jun	Boeing 757-200	Cruise	Cockpit	The crew reported smell of smoke in the cockpit and decided to divert.	Attending emergency services found no trace of fire or heat.
8. Jun	Boeing 757-200	Grounded	On board	Smoke appeared on board of the aircraft prompting the evacuation of the aircraft via slides.	There was no fire, the smoke originated from the APU.
7. Jun	Airbus A321-200	Cruise	On board	The cabin crew noticed a very strong, bad smell on board. Three flight attendants quickly developed symptoms like concentration problems described as "brain fog", tickling and irritation in the throat combined with a metallic taste, headache, dizziness and weakness of legs. The three flight attendants were taken to hospital. One flight attendant remained without symptoms. The hospital took blood and urine samples of the affected flight attendants and performed tests for blood oxygen levels, calcium, haemoglobin and other substances as well as tests for organophosphates, however, no markers were identified. The flight attendants were discharged 24 hours later.	Lack of information.
30. May	Airbus A320	Grounded	Cabin	Passengers disembarked shortly after boarding, after a "strong smell" was noticed in the cabin. Some passengers reported sore eyes and first aid treatment was offered.	According to a spokeswoman, the smell was believed to be related to the de-icing process that was occurring, due to the cold weather.
26. May	Havilland Dash 8-300	Cruise	Cabin	Flight attendant reported smoke in the cabin.	The incident aircraft underwent a series of checks according to the manufacturer's maintenance procedures, however no fault was identified. It was believed that a

					transient fault in the air conditioning system caused the smoke.
22. May	Airbus A320-200	Cruise	Cockpit	The crew reported fumes in the cockpit and decided to divert. On final approach to the airport, the crew advised they still had a smell "back there" but no smoke.	Lack of information.
17. May	Embraer ERJ-190	Climb	On board	The crew reported a burning smell on board and requested to return to the airport. The aircraft stopped the climb and returned, advising the smell was persistent and did not dissipate.	Responding emergency services found no trace of fire, heat or smoke.
14. May	McDonnell Douglas MD-82	Cruise	Cockpit	The crew reported smell of smoke in the cockpit together with a number of other indications.	Attending emergency services found no trace of fire, heat or smoke.
14. May	Havilland Dash 8-300	Cruise	Cockpit	The crew noticed light smoke in the cockpit and a burning odour, declared emergency and diverted.	The Canadian TSB reported maintenance was examining the aircraft to determine the source of the smoke.
12. May	Airbus A319-100	Initial climb	Cockpit	The crew stopped the climb at about 4000 feet reporting smoke in cockpit, and returned to the airport.	Emergency services found no trace of fire or heat.
12. May	Airbus A319-100	Cruise	Cockpit	The crew donned their oxygen masks, declared emergency reporting fumes in the cockpit and diverted. The crew was still wearing oxygen masks during landing.	Lack of information.
7. May	Embraer ERJ-145	Cruise	Cockpit	The crew reported an odour in the cockpit and decided to divert. The airline reported passengers had smelled an odour similar to a nail polish remover.	Lack of information.
7. May	Boeing 767-300	Cruise	Cockpit	The auto throttle disconnected unexpectedly. The crew worked the relevant checklists and consulted with dispatch, then reengaged auto throttle. Seconds later a burning smell developed in the cockpit, dissipated and reappeared. Suspecting a causal link between the auto throttle disconnect and the burning smell the crew disengaged auto throttle, the burning smell dissipated again. Sometime later the burning smell appeared again, one of the cabin crew reported feeling unwell prompting the flight crew to don their oxygen masks and divert. The aircraft landed without further incident. The cabin crew member did not require medical treatment.	A preliminary investigation did not identify any problem with auto throttle. However, a recirculation fan of the air conditioning system was found seized due to a defective bearing causing the burning smell. The occurrence was rated a serious incident, the investigation was continued.

7. May	Canadair CRJ-200	Climb	Cabin and cockpit	A loud bang occurred, the left hand engine showed vibrations and rolled back, and thick black smoke appeared in cockpit and cabin. The crew donned their oxygen masks, stopped the climb at about 11,000 feet reporting smoke in the cockpit and reduced both engines to idle thrust. The passengers oxygen masks was released, and the aircraft returned - with both engines still running.	Lack of information.
6. May	Airbus A320-200	Descent	Cabin	A burning odour was noticed in the business class cabin. The aircraft continued for a safe landing. The crew reported that after landing smoke became visible in the cabin, but they did not report further details.	Lack of information.
26. Apr	Embraer ERJ-190	Grounded	Cockpit	A strong odour and white smoke appeared in the cockpit. The smoke dissipated after the engine thrust had been reduced to idle.	The Canadian TSB reported maintenance identified the left hand air cycle machine as source of the odour and smoke, and replaced the machine, the recirculation fans and filters. Following engine ground runs went without residual odour.
24. Apr	Boeing 767-300	Cruise	Cabin	The crew reported smoke in the aft cabin and decided to divert.	Lack of information.
24. Apr	Boeing 757-200	Climb	On board	The crew reported fumes on board and decided to divert. On approach to the airport the crew reported the fumes were getting stronger and requested parking as close as possible to the runway, so that people could disembark as quickly as possible.	Lack of information.
21. Apr	Airbus A320-200	Climb	On board	The crew stopped the climb reporting a burning odour on board, and decided to return to the airport.	Lack of information.
18. Apr	Boeing 777-200	Descent	Galley	The crew in the forward business galley noticed a burning smell prompting the flight crew to declare emergency.	An inspection found no anomaly.
17. Apr	Canadair CRJ-200	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. On final approach, the crew, audibly on oxygen masks, advised they had an aft lavatory fire indication.	Lack of information.
14. Apr	Boeing 777-300	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert.	The incident was investigated.
14. Apr	Boeing 737-800	Climb	Unknown	The crew declared emergency, reporting an unidentified smoky smell throughout the entire aircraft and requested to return to the aircraft.	The airline claimed the cause of the smell was under investigation.

10. Apr	Airbus A320-200	Initial climb	Cabin	A strong burning smell became noticeable in the aft cabin shortly followed by visible smoke. The crew stopped the climb and returned to the airport.	A malfunction of the air conditioning system was suspected as cause of the smell and smoke.
10. Apr	Airbus A319-100	Initial climb	On board	The crew reported smoke on board and decided to return to the airport.	Lack of information.
8. Apr	Havilland Dash 8-400	Descent	On board	The crew reported smell of smoke on board.	Emergency services found no trace of fire, heat or smoke.
31. Mar	British Aerospace ATP	Cruise	On board	The crew decided to divert, due to a smell of smoke on board.	Sweden's accident investigation was investigating.
30. Mar	Airbus A320-200	Cruise	Cabin	An odour developed in the cabin causing four passengers to feel unwell, one required medical attention.	Lack of information.
22. Mar	Boeing 737-800	Initial climb	Cabin	The cabin crew alerted the flight crew of smoke in the cabin. Shortly after, the smoke became also visible on the flight deck.	The Canadian TSB reported maintenance determined de-icing fluid had been ingested into the APU resulting in the smoke.
22. Mar	Boeing 757-300	Descend	On board	An odour on board made three flight attendants feel unwell, two flight attendants became temporarily unconscious. The first officer donned his oxygen mask. On Mar 18th 2014 the CIAIAC released an interim statement stating: *"In April 2013 the health of one of the flight attendants who had been on board during the flight of 22 March 2013 worsened, requiring hospitalization. The medical report from the hospital indicated poisoning caused by some type of neurotoxin."*	After landing the crew activated the APU to determine the cause of the odour, following the activation the odour re-intensified. Spanish and German Authorities are investigating the cause.
20. Mar	Boeing 767-300	Climb	On board	The crew decided to return to the airport reporting a smell of smoke on board.	Lack of information.
19. Mar	Airbus A300-600	Climb	Cockpit	The crew reported smoke in the cockpit, stopped the climb and returned to the airport. On approach, the crew reported they had received a fire indication for the avionics bay and had observed a light odour in the cockpit, and that the indication had extinguished in the meantime.	Emergency services reported seeing no smoke around the aircraft. They did not detect any hot spots.
17. Mar	Embraer EMB-120	Cruise	Cabin	The crew reported light haze and an odour in the cabin and decided to divert.	The airline reported the air conditioning system was identified as cause of the odour.

14. Mar	Airbus A321-100	Cruise	Cabin	The crew decided to return to the airport, due to a strange odour in the cabin. A number of passengers described the smell as electric/electronic, others characterised the smell similar to oil fumes. The smell was light, but clearly detectable.	The airline confirmed a strange smell on board, and prompted the return to the airport. The cause of the smell was not determined.
9. Mar	McDonnell Douglas MD-88	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. On approach, the crew advised they did have a smoke event, however the smoke had dissipated and a normal landing would commence.	The airline reported that smoke appeared in the cockpit when some anti-ice equipment was activated, and dissipated when the system was turned off again.
8. Mar	Boeing 747-400	Cruise	On board	The crew reported smoke on board of the aircraft and decided to divert.	Lack of information.
6. Mar	Unknown	Cruise	Cockpit	Pilots reported a smell of smoke in the cockpit, the aircraft diverted.	Lack of information.
4. Mar	Airbus A321-200	Cruise	On board	The crew reported fumes on board and decided to divert to Phoenix. All crew were medically checked at the airport, but did not need treatment.	The airline claimed the cause of the fumes was under investigation.
4. Mar	Boeing 737-800	Initial climb	Cockpit	The crew donned their oxygen masks, stopped the climb at 2000 feet reporting smoke in the cockpit and cabin.	Lack of information.
2. Mar	Boeing 737-500	Initial climb	Cockpit	NTSB reported that the odour of old socks was present immediately after take-off for about 3 minutes, and about 5 minutes prior to landing, again for 3 minutes. Both of the flight crew donned their oxygen masks while the smell was present in the cockpit and front galley.	The airline confirmed that the left hand engine was replaced after landing. It was determined that anti-ice fluid had caused the odour. Austria's VERSA was investigating the incident.
26. Feb	Boeing 737-800	Initial climb	Cabin	The crew stopped the climb, reporting an unusual odour in the cabin and decided to return to the airport.	Lack of information.
26. Feb	Embraer ERJ-140	Initial climb	Cabin	The crew reported a smell/smoke in the cabin and requested an immediate return to the airport.	Lack of information.
23. Feb	Airbus A320-200	Climb	Cabin	An acrid odour and haze developed in the cabin, prompting the crew to don their oxygen masks and stop the climb, indicating they wanted to return to the airport. About 4 minutes later, the crew reported they had smoke in the cockpit, which had started to dissipate at that point.	Lack of information.
20. Feb	Embraer ERJ-140	Initial climb	Cockpit	The crew declared emergency reporting smoke in the cockpit. A passenger reported that immediately after becoming airborne the cabin started to fill with smoke, that appeared to come from the	Lack of information.

				cockpit area, the smoke quickly dissipated again and was gone by the time of landing.	
20. Feb	Havilland Dash 8-200	Descent	Unknown	The airline reported the aircraft was still at cruise level when smoke occurred.	Emergency services found no trace of fire or heat.
20. Feb	Boeing 737-500	Climb	Cockpit	Autopilot disconnected, followed by the smell of smoke in the cockpit.	Lack of information.
17. Feb	Airbus 320-200	Initial climb	Cabin	The cabin crew reported acrid hazy and oily fumes in the cabin, prompting the crew to don their oxygen masks, declare emergency, stop the climb at 6000 feet, shut the bleed air systems down and return to the airport. During positioning for a landing on the runway the fumes began to subside. All 6 crew went for a medical check after landing.	The right hand engine was replaced. Lack of more information.
17. Feb	Boeing 737-700	Grounded	Cockpit	The aircraft had been de-iced prior to taxiing. The aircraft had been instructed to line up and wait, the aircraft was waiting for take-off clearance when heavy smoke developed in the cockpit. The crew requested emergency services to attend the aircraft and worked the relevant fire/smoke checklists, after switching the APU off the smoke quickly dissipated.	The Canadian TSB reported maintenance determined de-icing fluid had entered the APU's bleed air system, and became the source of the smoke. No other problem was identified.
15. Feb	Airbus A320-200	Climb	Cabin	The crew declared emergency reporting smoke in the cabin, and decided to return to the airport.	Lack of information.
14. Feb	Boeing 747-400	Cruise	On board	The crew decided to return to the airport, due to fumes on board. The crew donned their oxygen masks and diverted the aircraft, requesting medical assistance to await the aircraft. They had four crew members feeling unwell.	Lack of information.
10. Feb	Boeing 777	Cruise	Unknown	A pilot became nauseous and incapacitated after smelling toxic oil fumes. Despite the fumes causing eye- and throat irritation, the pilots were able to divert. Oxygen masks were used.	Lack of information.
8. Feb	Boeing 777-200	Cruise	Cockpit	The crew turned around reporting smoke in the cockpit, dumped fuel and diverted.	Emergency services advised nothing abnormal was seen.
8. Feb	Boeing 737-800	Climb	On board	The crew stopped the climb, due to smell of smoke on board, and decided to return to the airport.	Lack of information.
6. Feb	Airbus A340-300	Climb	Cockpit	The crew donned their oxygen masks and decided to return to the airport, due to smoke in the cockpit.	There was no damage to the aircraft. Spanish Authorities was investigating the incident as a serious incident.

4. Feb	Embraer ERJ-145	Climb	Cockpit	The crew stopped the climb reporting smoke in the cockpit. The crew donned their oxygen masks.	Lack of information.
24. Jan	Airbus A321-200	Climb	Cabin	The crew stopped the climb at about 9000 feet, reporting smoke in the cabin, and decided to return to the airport.	Lack of information.
21. Jan	Havilland Dash 8-100	Climb	Cabin and cockpit	The crew received a smoke indication followed by an odour in cockpit and cabin. The crew stopped the climb, closed the bleed air valves, shut the recirculation fans down, and returned to the airport.	The Canadian TSB reported maintenance investigated to identify the source of the odour.
21. Jan	Boeing 737-500	Cruise	Cabin	Smell of smoke was detected in the cabin, prompting the crew to turn around and divert.	Lack of information.
16. Jan	Airbus A320-200	Climb	Cabin and cockpit	The crew stopped the climb at 8000 feet, reporting smell of smoke in cockpit and cabin.	Lack of information.
7. Jan	Dash 8-100	Cruise	Cockpit	The crew donned their oxygen masks and declared emergency, reporting a loud noise of unknown origin and smoke in the cockpit. The crew shut down both bleed air systems and observed the smoke lighten afterwards. (Same aircraft as 10.01.2013)	Maintenance determined that oil had entered the environmental control system at the left hand engine, resulting in oil related haze.
5. Jan	Embraer ERJ-175	Cruise	On board	The crew reported smell of smoke on board and diverted.	Lack of information.
4. Jan	Dash 8-100	Cruise	Cabin and cockpit	The crew donned their oxygen masks and declared emergency reporting smoke in the cockpit. Cabin crew informed the flight deck about intensifying smoke in the cabin, passengers were breathing through articles of clothing.	Maintenance identified oil had entered the environmental control system and produced haze, due to a leaking seal at the right hand engine. The engine was replaced.
1. Jan	Airbus A319-100	Climb	Cabin	The crew stopped the climb, reported smell of smoke in the cabin and returned to the aircraft.	The aircraft was examined.
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14. Dec	Lufthansa A321	Climb	Cabin and cockpit	Reporting of smell and smoke in cockpit and cabin. The aircraft returned to the airport for a safe landing.	The incident was investigated.
9. Dec	Condor Airbus A320-200	Cruise	Cabin and cockpit	The crew declared emergency reporting smoke in cockpit and cabin. The aircraft diverted and the passenger disembarked via stairs after landing. The airport reported there was smell of burning plastics and smell of smoke in cockpit and cabin, the flight crew had donned their oxygen masks. Two of the four flight attendants were taken to a hospital with breathing problems.	The incident was investigated.

6. Dec	Jetblue E190	Climb	Cabin	The crew reported a smoky odour in the back of the cabin. The crew requested to return to the airport. On approach, the crew reported the smell had subsided and the aircraft landed safely.	Lack of information.
3. Dec	Boeing 737-800	Climb	Cabin	A passenger reported a distinct smell of exhaust fumes in the cabin. The crew announced Technical problems and returned to the airport.	Technical problem.
2. Dec	Boeing 777-236	Cruise	Flight deck	The flight crew experienced a series of smoke events on the flight deck. They declared an emergency and the First Officer donned his oxygen mask. The aircraft diverted.	The cause of the smoke was identified as a bearing failure of the primary equipment cooling supply fan.
28. Nov	GROB G115	Landing	Cockpit	Smoke was coming from behind the instrument panel with associated burning smell. A/C was stopped and crew vacated, while fire crew attended the scene.	Lack of information.
17. Nov	Airbus A320-200	Cruise	Unknown	The aircraft suffered a fume event at some point of the flight. Germany's BFU made the fumes event stated that the occurrence was rated an accident in December 2014, after it became known that a flight attendant received permanent and serious injuries as result of the fumes event. The flight attendant had since been unable to work and was declared unfit to fly.	The BFU reported that a preliminary investigation had been initiated immediately after the first notice of the occurrence was received. Lack of more information.
12. Nov	Boeing 747-400	Cruise	Cockpit	The cabin crew entered a holding due to fumes in the cockpit. The crew subsequently decided to return to the airport, dumped fuel and landed safely.	Lack of information.
8. Nov	Boeing 737-300	Cruise	Galley	The cabin crew decided to don their oxygen masks and to turn around and return to the airport, after a flight attendant in the forward galley observed blue haze and a pungent chemical odour near the ceiling of the galley, confirmed by other flight attendants. The flight attendant working in the forward galley felt unwell. At the time of the haze and odour the ovens were not in use and the galley lighting had been dimmed down to about 50%.	Lack of information.
5. Nov	Boeing 747-400	Cruise	Cabin	The crew declared emergency reporting an unidentified smell of smoke in the cabin, and requested to divert.	Lack of information.
1. Nov	Boeing 737-800	Climb	Cabin	The crew decided to stop the climb, due to fumes in the cabin. The aircraft landed safely back on the airport.	Engine wash prior to flight.
31. Oct	Airbus A380-800	Cruise	On board	The crew decided to return to the airport, due to a strong smell on board.	The incident was investigated.
29. Oct	Boeing 737-800	Cruise	Unknown	The crew decided to divert, due to a smell of fuel.	Lack of information.

29. Oct	Airbus A320-200	Descent	Cabin	The cabin crew detected a burning smell in the cabin, prompting the flight crew to declare emergency.	Lack of information.
26. Oct	Airbus A320-200	Climb	Cockpit	The crew stopped the climb and returned to the airport, due to a smoky odour in the cockpit.	Lack of information.
21. Oct	Airbus A321-131	Landing	Cabin and flight deck	Whilst on the approach to the airport, a strong smell became apparent on the flight deck, which resulted in eye and throat irritation experienced by both pilots. Having established that there was a similar problem in the cabin; both pilots donned oxygen masks and landed the aircraft without further incident. Despite medical examinations of the affected crewmembers and an investigation of the engines and air conditioning system, no explanation for the odour or symptoms experienced by the crew could be found.	Lack of information.
20. Oct	Boeing 737-800	Cruise	On board	The crew decided to divert, due to a pungent odour of melting plastics on board. Two passengers required medical attention, were treated by a doctor at the airport and recovered quickly.	Emergency services found no trace of fire.
19. Oct	Boeing 767-300	Cruise	Cockpit	The crew declared emergency reporting smoke in the cockpit, and requested to divert.	Minor technical issue.
19. Oct	Boeing 737-804	Grounded	Cockpit	As the aircraft commenced its take-off roll, both pilots commented on a strange smell. A few seconds later, due to what appeared to be smoke in the cabin, the Cabin Service Director (CSD) alerted the flight crew to an emergency situation. The take-off was abandoned and the aircraft stopped on the runway. Visual inspection by the commander confirmed the appearance of a significant amount of smoke in the cabin. No source for the smoke was identified, but excessive moisture in the air conditioning system was identified as a possible factor.	Excessive moisture in the air conditioning system.
18. Oct	Boeing 737-400	Grounded	Cockpit	The crew smelled strong odour of oil in the cockpit.	Oil entering the right hand engines bleed air system.
13. Oct	Boeing 717-200	Cruise	On board	The crew reported smell of smoke on board and diverted.	Lack of information.
12. Oct	Airbus A340-600	Cruise	Galley	Two flight attendants working in the aft galley began to complain about serious headache, that they thought was caused by glue like fumes in the galley.	Emergency services identified a container containing Polyalkyl amines (derivative of ammonia) as possible source of the fumes. The container, however, showed no indication of damage or leakage.

11. Oct	Boeing 777-200	Cruise	Cabin	The crew declared emergency reporting visible smoke in the cabin. The aircraft dumped fuel, and returned to the airport.	Steam from the air conditioning system.
11. Oct	Boeing 757-28A	Grounded	Cabin and flight deck	Smoke and fumes entered the flight deck and cabin during passenger disembarkation. Both engines were shut down at the time, but the Auxiliary Power Unit (APU) was running.	A faulty APU was identified as the source of the smoke and fumes. It was suspected that residual oil may have remained in the air conditioning- or equipment cooling systems.
9. Oct	CRJ-700	Grounded	Cabin	While take-off, the crew reported smoke in the cabin, and the take-off was rejected.	Lack of information.
2. Oct	Boeing 737-700	Cruise	Cabin	The crew reported smoke in the cabin and diverted, advising the smoke was subsiding.	Lack of information.
1. Oct	Airbus A320-200	Climb	Cockpit	The crew reported smoke in the cockpit, stopped the climb, and returned to the airport.	Lack of information.
29. Sep	Boeing 757-200	Climb	Cockpit	The crew donned their oxygen masks, declared emergency reporting fumes in the cockpit and returned to the airport.	Lack of information.
26. Sep	Airbus A330-300	Climb	Cockpit	The crew reported a strong acrid smell, thin visible smoke and a temperature rise in the cockpit and requested an immediate return to the airport.	Air conditioning system.
23. Sep	ERJ-145	Climb	On board	A strong burning smell developed on board. The crew declared emergency and returned to the airport.	Lack of information.
9. Sep	Dash 8-200	Climb	Cabin	Passengers and cabin crew smelled smoke in the cabin, prompting the flight crew to stop the climb and divert.	Emergency services found no trace of fire or heat.
3. Sep	Boeing 737-800	Landing	On board	Passengers reported the smell of kerosene on board, and smoke appeared. 11 passengers needed treatment by medical service at the airport. The airline reported that upon touchdown, smoke exited the air conditioning vents for a couple of seconds. There was no smoke, but a vapour of hydraulic fluid that produced a pungent odour.	The airline claimed that a defective hydraulic check valve near the wheel well was found.
28. Aug	Boeing 737-200	Climb	Cabin	The crew reported smoke in the cabin, stopped the climb, and returned to the airport.	Lack of information.
19. Aug	Boeing 757-200	Climb	Cockpit	The crew decided to return to the airport, reporting smoke in the cockpit. During the descent, the crew reported that the smoke appeared to dissipate and indicated they would be able to vacate the runway.	The airline said the aircraft returned to the airport due to an unusual odour aboard, which was later linked to the air conditioning system.

16. Aug	Airbus A321-200	Cruise	On board	A burning odour developed on board, prompting the crew to return to the airport.	Malfunction of the air conditioning system.
5. Aug	Boeing 747-400	Climb	Cabin	A burning odour developed in the cabin, prompting the crew to return to the airport. Passengers reported that after the burning smell developed the cabin lights went out temporarily.	Vapour from the air conditioning system.
3. Aug	Embraer ERJ-190	Climb	On board	The crew declared emergency, reporting a strange fume on board and returned to the airport.	Lack of information.
29. Jul	Airbus A321-200	Cruise	Cabin	The crew reported smoke in the cabin and diverted.	Responding emergency services found no trace of fire or heat.
27. Jul	Airbus A319-100	Climb	Cockpit	The crew reported smoke in the cockpit, stopped the climb and diverted.	Lack of information.
27. Jul	Airbus A320-200	Cruise	On board	A smell of fuel developed on board, and the crew told ATC they suspected a fuel leak at the left hand systems. The aircraft diverted for a safe landing.	A fuel transfer valve had failed.
23. Jul	Dash 8-100	Cruise	Unknown	The crew noticed the right hand engine's temperature had risen above 1000 degrees Celsius. The flight crew requested cabin crew to check the engine. The cabin crew reported light smoke coming from a vent tube. The crew shut the engine down and returned to the airport.	Lack of information.
21. Jul	Airbus A319-100	Descent	Cockpit	The crew declared emergency reporting smell of smoke and loose plastic parts in the cockpit while descending. 2 minutes later, the crew reported smoke in the cockpit.	Lack of information.
18. Jul	Boeing 757-300	Climb	On board	The crew stopped the climb due to an unidentifiable smell on board, and returned to the airport. The aircraft returned to the gate, boarded the passengers again for a second time, and departed. The aircraft returned to the airport due to the same unidentifiable smell.	Lack of information.
10. Jul	Airbus A330-300	Cruise	Cabin	The aircraft diverted due to an odour in the cabin, and on the way reported medical issues. The airline reported 5 cabin crew were taken to a hospital feeling nauseous as result of fumes in the cabin.	Lack of information.
8. Jul	Boeing 757-200	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted, subsequently reporting that the smoke had dissipated.	Lack of information.
4. Jul	CRJ-900	Grounded	Cabin and cockpit	The crew rejected take-off after smoke and a burning smell was observed in the cockpit and cabin.	Air conditioning system.
2. Jul	Boeing 767-300	Cruise	On board	A strong burning smell developed on board, prompting the crew to declare emergency.	No trace of fire or smoke was detected.

20. Jun	Airbus A330-300	Cruise	Cabin and cockpit	The crew decided to divert, due to visible smoke in the cabin and smell of smoke in the cockpit. While manoeuvring to the runway, the crew reported smoke was no longer visible in the cabin.	Lack of information.
12. Jun	Boeing 737-700	Climb	Cockpit	The crew reported fumes in the cockpit, declared a precautionary emergency and returned to the airport.	Lack of information.
12. Jun	Boeing 757-200	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert.	Lack of information.
9. Jun	Boeing 757-300	Cruise	On board	The crew reported a burning odour on board and diverted.	Responding emergency services found no trace of fire or smoke. However, it was confirmed an abnormal smell in the cockpit, and a source of heat.
8. Jun	Airbus A320-200	Cruise	Flight deck	The crew reported smell of smoke on the flight deck, and declared emergency. While on final approach to the runway, the crew reported that the smell had dissipated and there was no longer smell of smoke present.	Lack of information.
3. Jun	Airbus A319-100	Initial climb	Cabin and cockpit	The captain noticed oil fumes in the cockpit shortly after take-off. The first officer, pilot flying, donned his oxygen mask as a precaution. The odour of oil was subsequently also reported from the front of the cabin, but seemed to subside en route. During the descent the odour intensified again, both pilots now used their oxygen masks while continuing for a safe landing.	Lack of information.
21. May	Airbus A320-200	Cruise	Cabin	The crew reported smoke in the cabin and decided to divert.	Technical problem.
9. May	Boeing 777-300	Cruise	Cabin	The crew reported smoke in the cabin and decided to divert. On approach the crew reported the smoke had subsided.	Lack of information.
1. May	Boeing 767-400	Cruise	Cabin	The crew reported a smoky odour in the cabin, turned around and diverted. On approach, the crew advised they didn't need any assistance.	Lack of information.
30. Apr	Airbus A319-100	Cruise	Cockpit	The crew donned their oxygen masks, reported smell of smoke in the cockpit, turned around and diverted.	Lack of information.
26. Apr	Airbus A321-200	Climb	On board	Shortly after becoming airborne and activation of the air conditioning system, a strong odour developed on board. The flight crew assessed the circumstances and decided to continue the flight using their oxygen masks.	Lack of information.

25. Apr	Boeing 737-800	Initial climb	Cabin	A strong acrid smell was noticed in the cabin. The crew levelled off and returned to the airport.	Lack of information.
20. Apr	Fokker 50	Climb	Cabin and cockpit	The crew received a fire indication for the right hand engine, associated with a strong burning smell in cockpit and cabin. They stopped the climb, shut the engine down, activated the fire suppression system and diverted.	The incident was investigated.
17. Apr	Boeing 737	Climb	Cockpit	The captain reported a burning smell in the cockpit during take-off, and dissipated at the top of climb. The cabin supervisor and the other cabin crew member reported they suffered minor side effects of the fumes.	Recent engine wash.
14. Apr	McDonnell Douglas MD-88	Climb	Cabin	Cabin crew noticed a smell of smoke in the cabin, prompting the flight crew to return to the airport.	Lack of information.
3. Apr	ERJ-145	Landing	Cockpit	The crew reported smoke in the cockpit, and the aircraft was evacuated. One passenger was taken to a hospital. The extent of injuries was not known.	Engine seal leak.
20. Mar	McDonnell Douglas MD-83	Climb	Cabin	The crew declared emergency reporting they had smoke in the cabin out of the air conditioning vents, no trace of fire. The aircraft stopped the climb and returned to the airport.	Lack of information.
16. Mar	Boeing 737-700	Initial climb	On board	A strong rotten smell developed on board, which slowly dissipated during cruise. Germany's BFU reported that during the flight, one cabin crew member already complained about severe headache, after landing the entire crew complained about nausea and went to see the airport's doctor.	The incident was investigated.
12. Mar	Boeing 767-300	Initial climb	Cabin and cockpit	The crew received an aft toilet smoke warning, and a strong smell of burnt oil developed in cockpit and cabin. The pilot flying donned his oxygen masks, the third flight crew member was sent back to the cabin to assess the situation and returned reporting there was no trace of smoke in that area. Germany's BFU reported that a number of cabin crew reported headache and burning eyes.	Lack of information.
12. Mar	McDonnell Douglas MD-88	Climb	Cabin	The crew reported smoke in the cabin and decided to return to the airport.	Lack of information.
5. Mar	Airbus A330-300	Grounded	Cabin	The crew was preparing for departure, when a strong smell of oil fumes developed in the cabin. The departure preparations were continued and the aircraft departed. Following take-off, oil fumes were noticed in the aft cabin, about 30 minutes after departure a	Lack of information.

				number of crew complained about headache, racing heart, dazed feelings as well as irritations of eyes and noses.	
24. Feb	Airbus A319-100	Cruise	Cockpit	The crew initiated a diversion reporting fumes in the cockpit.	Lack of information.
21. Feb	Beechcraft B100v	Climb	Cabin	The flight crew noticed very light smoke in the cabin. The flight crew declared an emergency and requested a return to the airport.	Lack of information.
18. Feb	Airbus A320-200	Cruise	On board	The crew reported smell of smoke on board, and decided to divert.	Responding emergency services found no trace of fire, heat or smoke.
12. Feb	Canadair CRJ-900	Climb	On board	Increasing oil fumes on board prompted the flight crew to don their oxygen masks, stop the climb and return to the airport.	Lack of information.
11. Feb	Boeing 737-33V	Climb	Cabin	During the climb the flight crew noted the sudden onset of airframe vibration. There were no abnormal engine or system indication, but a burning smell was reported in the cabin. The commander declared MAYDAY and initiated a diversion back to the airport. The source of the vibration and burning smell was subsequently identified to be a failed bearing assembly in the right air conditioning pack turbofan.	Failed bearing assembly in the right air conditioning pack turbofan.
6. Feb	Boeing 737-800	Climb	Cabin	The crew reported smell of smoke in the cabin and decided to return to the airport.	Responding emergency services found no trace of fire, heat or smoke.
2. Feb	British Aerospace Avro-146-RJ100	Climb	Unknown	About five minutes after take-off, the commander noticed nausea and dizziness and handed over the controls to the co-pilot. The flight was cancelled and the aircraft returned to the airport. The Assistant driver handled the remaining time of the flight with only sporadically participation from the commander. The commander was taken to hospital for examination.	Presumed to be TCP-contamination.
27. Jan	Boeing 757-200	Initial climb	Cabin	The crew stopped the climb, reporting smoke in the cabin and returned to the airport.	Technical problem.
24. Jan	Boeing 777-200	Cruise	Cabin	Smoke became visible in the cabin. The crew declared emergency, turned around, and diverted. On the way back, the aircraft dumped fuel. The crew reported they believed the incident was due to an air conditioning re-circulation fan. The fan was turned off and the smoke dissipated shortly thereafter. The crew requested a full turn out of emergency services to check for any indication of smoke on	Air conditioning re-circulating fan was suspected as cause.

				the outside of the aircraft.	
21. Jan	CRJ-440	Climb	Cockpit	One of the pilots donned his oxygen mask and declared emergency reporting they had smoke in the cockpit.	The incident was investigated.
20. Jan	CRJ-200	Initial climb	Cabin	Cabin crew reported burning smell/fumes in the cabin. While the flight crew initiated a diversion and actioned the "Smoke and Fumes" quick response check, cabin crew attempted to identify the source of the smell. After the flight crew had completed the quick response check the smell dissipated.	Lack of information.
15. Jan	Boeing 737-300	Initial climb	Cockpit	The crew reported smoke in the cockpit and returned to the airport.	Lack of information.
13. Jan	Airbus A330-200	Climb	Cabin	A burning odour became noticeable in the aft cabin, followed by visible smoke. The BFU reported that the rotor of an air cycle machine, usually rotating at 35 000 revolutions per minute (to prepare engine bleed air for use in the air conditioning system), had seized. The turbine had overheated and unprocessed, humid engine bleed air had entered the cabin. Later a valve closed, automatically preventing such bleed air to enter the air conditioning system.	The rotor of an air cycle machine had seized.
13. Jan	Havilland Dash 8-400	Climb	Cockpit	The crew detected a burning smell in the cockpit, and shortly afterwards saw wisps of smoke. The crew performed the smoke drill, donned oxygen masks and goggles, declared emergency and returned to the airport.	Overheated and damaged engine intake heater adapter, which caused the odour to develop and distribute through the engine intake, via the bleed air and the air conditioning system into the aircraft.
11. Jan	Havilland Dash 7-100	Climb	Cabin and cockpit	The lavatory smoke detector triggered, and smell of smoke was noticed in cabin and cockpit.	Fluid evaporated in the air condition system.
8. Jan	Canadair CRJ-200	Climb	Cockpit	The crew reported smoke in the cockpit.	Ingestion of anti-ice fluid that had been applied prior to departure.
8. Jan	Embraer ERJ-145	Cruise	On board	The crew reported an oil leak on the #1 engine and smell of smoke on board, shut the engine down and diverted.	Oil leak from the #1 engine.
8. Jan	McDonnell Douglas MD-11	Climb	Cabin and cockpit	The crew reported they had smoke in the cabin and cockpit. The aircraft dumped fuel and returned to the airport.	Lack of information.
7. Jan	Airbus A320	Cruise	Unknown	The flight crew detected a strong chemical odour, unable to determine its origin. The flight crew donned oxygen masks and declared emergency.	Air distribution system.

4. Jan	McDonnell Douglas MD-82	Climb	Cabin	Crew reported light smoke in the cabin, stopped the climb and returned to the airport. The smoke dissipated on approach.	Responding emergency services found no trace of fire or heat.
1. Jan	Boeing 737-800	Grounded	Cockpit	During take-off, fumes entered the cockpit via the air-vents, which were accompanied by a very foul smell. The fumes and the smell seemed to ease slowly after reaching cruising altitude, but occurred again during landing phase with the results of both pilots having headaches.	Lack of information.
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31. Dec	Boeing 777-200	Cruise	Cabin	A smell of smoke was detected in the cabin prompting the crew to return to the airport.	Technical problem. No traces of fire, heat or smoke were found.
30. Dec	Canadair CRJ-400	Grounded	Cockpit	Rejected take-off from due to smoke entering the cockpit.	De-icing fluid entered the air conditioning packs.
27. Dec	Boeing 757-200	Cruise	Cabin	The crew observed a strong burning smell in the cabin near the forward galley and in the cockpit with smoke becoming visible in the galley. The aircraft landed safely.	The incident was The incident was under investigation.
24. Dec	Boeing 747-400	Cruise	Cockpit	The aircraft was en route when the crew reported smoke in the cockpit and diverted the airport for a safe landing.	Lack of information.
22. Dec	Fokker 100	Initial climb	Cockpit	The crew reported smoke in the cockpit, and returned to the airport for a safe landing.	Lack of information.
21.Dec	Bombardier Challenger CL-600	Climb	Cockpit	Smoke accompanied by an acrid odour entered the cockpit on departure. The smoke subsequently cleared.	Maintenance found glycol in the APU area.
16. Dec	Boeing 737-300	Climb	On board	The crew requested to return to due to a burning smell on board.	Responding emergency services found no trace of fire, heat or smoke.
15. Dec	Boeing 757-200	Cruise	Cabin	Passengers and cabin crew smelled smoke in the cabin prompting the flight crew to divert for a safe landing.	Lack of information.
11. Dec	Airbus A319-100	Cruise	Cockpit	The crew reported smoke in the cockpit, and the aircraft landed safely.	Lack of information.
10. Dec	Canadair CRJ-200	Cruise	Cabin	Passengers reported smoke began to appear in the cabin. The aircraft landed safely.	Engine failure.
9. Dec	Boeing 747-400	Grounded	Cabin	Smoke appeared in the cabin prompting the captain to initiate an evacuation of the aircraft.	Lack of information.
8. Dec	Boeing 747-401	Cruise	Cockpit	The crew reported fumes in the cockpit and diverted for a safe landing.	Lack of information.

7. Dec	Boeing 737	Climb	Cabin	The crew reported an in-flight electric or plastic burning odour, verging on intense, from the aft cabin vent. The crew declared an emergency and returned to the airport without further incident.	Maintenance determined that the right pack ACM was the source of the smell.
7. Dec	Airbus A320-200	Climb	Cabin and cockpit	The crew reported the smell of dirty socks in the back of the aircraft which could even be smelled in the cockpit. The aircraft returned for a safe landing.	Lack of information.
3 .Dec	Boeing 737-700	Climb	Cabin and cockpit	The crew reported smoke in cabin and cockpit, and returned for a safe landing.	Flight lubrication applied to baroscopic plugs may have leaked onto the engine.
2. Dec	McDonnell Douglas DC-9	Initial climb	Unknown	The crew reported smoke after take-off. The pilots declared emergency, and the flight returned to airport.	Technicians found excessive residual oil from the APU.
01. Dec	Boeing 737	Landing	Cabin	A flight attendant detected a burning plastic or rubber odour in the front main cabin. The pilots declared an emergency and continued the landing.	Maintenance replaced air circulation filters that were found clogged.
31. Nov	Boeing 757-200	Climb	Unknown	The crew noticed a strong odour and a burning feel in eyes and throat. Both crew donned their oxygen masks, and returned to the airport for a safe landing.	Lack of information.
30. Nov	Fokker 70	Climb	On board	The crew reported a burning smell on board and decided to return to the airport. The aircraft landed safely.	Lack of information.
28. Nov	Boeing 737-800	Cruise	Cabin	The cabin crew reported burning smell/fumes in the cabin.	Lack of information.
26. Nov	Airbus A320-200	Climb	Cabin	The crew reported an acrid smell in the cabin and returned to the airport. The aircraft landed safely.	APU bleed.
24. Nov	Boeing 767	Cruise	Unknown	A flight attendant reported a burning rubber odour, and it became stronger. The airplane returned to the airport and landed without further incident.	Maintenance replaced air circulation filters that were found clogged.
23. Nov	Boeing 767-200	Climb	On board	The crew reported a burning smell on board, and returned to the airport for a safe landing.	The incident was The incident was under investigation.
20. Nov	Avia Yakovlev Yak Yak-42	Climb	On board	A burning smell developed on board. The engine was shut down, and the crew burned off fuel and landed safely.	One of the engines failed while climbing, and caused a temperature rise, and a burning smell in the cabin.
20. Nov	Embraer ERJ-145	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted to Pittsburgh for a safe landing.	Lack of information.

18. Nov	Boeing 737-700	Climb	On board	A pungent smell developed on board of the aircraft. With the increasing intensity of the fumes the health condition of the first officer, pilot flying, deteriorated, about 5 minutes into the flight the first officer suffered from a sudden and strong nausea.	The investigators consider an overfilling of engine oil possible.
18. Nov	Boeing 777-200	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted for a safe landing.	Responding emergency services found no trace of fire or heat.
18. Nov	Airbus A319-100	Cruise	Cabin	The crew decided to divert due to smoke in the cabin. The aircraft landed safely.	The incident was under investigation.
15. Nov	Saab 340A	Cruise	On board	A burning smell was observed on board.	Maintenance replaced the right air cycle machine due to a suspected bearing failure. Responding emergency services found no trace of fire or heat, and the aircraft taxied to the apron.
14. Nov	Canadair CRJ-100	Grounded	Cabin	Smoke appeared in the cabin.	Fault in the air conditioning system is assumed.
12. Nov	Boeing 757-200	Climb	Cabin	The crew reported smoke in the cabin and diverted for a safe landing.	Did not find any Technical problem. by inspection.
11. Nov	McDonnell Douglas DC-9	Climb	Cabin	The right air conditioning pack began overheating with smoke in the cabin and did not react to "auto" selection. The flight returned to the airport.	Cabin cooling system.
11. Nov	Embraer EMB-145LR	Climb	Cabin	Crew reported that, after ice protection test, smoke came into the cabin and cockpit along with a loud humming sound over the wing root area. The crew declared emergency and returned to the airport.	Maintenance removed and replaced on of the air cycle machines (ACM).
10. Nov	McDonnell Douglas MD-88	Climb	Cabin	A loud bang was heard from the right hand engine followed by smoke entering the cabin through the air conditioning system. The crew returned to the airport for a safe landing.	Engine failure.
5. Nov	Airbus A321-200	Cruise	On board	A number of passengers noticed a burning smell on board, which was confirmed by cabin crew prompting the flight crew to declared emergency and to accelerate approach and land. The aircraft landed safely.	Responding emergency services found no evidence of fire, heat or smoke.
3. Nov	Embraer ERJ-170	Climb	Cabin	The crew reported smell of smoke in the cabin. About a minute later the smell dissipated, the aircraft however returned to the airport for a safe landing.	One of two air conditioning modules had failed.

18. Oct	McDonnell Douglas MD-88	Cruise	Cabin	The crew decided to divert due to a smell of smoke in the rear of the cabin. The aircraft landed safely.	Emergency services found no trace of fire, smoke or heat. The incident was under investigation.
13. Oct	Airbus A321-100	Descent	Cockpit	The aircraft diverted after the crew reported smoke in the cockpit.	Lack of information.
13. Oct	McDonnell Douglas MD-83	Climb	Cabin	The crew reported smoke in a lavatory and the aircraft returned to the airport for a safe landing.	Lack of information.
10. Oct	Canadair CRJ-900	Cruise	Cockpit	A passenger on board reported the captain announced a burning smell in the cockpit forced them to return.	Lack of information.
8. Oct	Airbus A388-800	Climb	Cabin and cockpit	A strong chemical odour of dirty socks was noticed in cockpit and cabin. The cabin crew was told that the bleed air supply was deactivated on that engine and the odour dissipated. The aircraft continued the flight. During the descent, the odour re-appeared, and the aircraft landed safely at the destination.	Lack of information.
3. Oct	Boeing 737-800		Cabin	The crew reported smoke in the cabin. The aircraft returned for a safe landing.	Excess lubricant burning off from the fan blades.
30. Sep	Canadair CRJ-200	Cruise	Cabin and cockpit	The crew reported smoke in the cockpit. Passengers reported they could smell but not see smoke. The aircraft continued for a safe landing.	Lack of information.
26. Sep	Douglas DC-9-30	Climb	Cabin	Passengers saw smoke in the cabin prompting the return of the aircraft for a safe landing.	The aircraft suffered a hydraulic leak due to the high pressure the fluid evaporated causing the impression of smoke.
25. Sep	Airbus A330-200	Climb	Cabin and cockpit	An unusual odour of wet pullovers was observed in the cockpit and cabin, especially in the forward area of the cockpit. The crew identified a loss of 4 quarts of oil for the left hand engine with the right hand engine's oil consumption remaining normal.	Carbon seals at the left engine's spinner were leaking substantial amounts of oil.
19. Sep	Airbus A320-233	Cruise	Cockpit	The aircraft experienced smoke in the cockpit. The airplane landed uneventfully at its original destination.	The incident was under investigation.
13. Sep	Airbus A321-100	Climb	Cabin	Grey smoke with the smell of burning plastics was observed in the cabin. The crew levelled off and returned to the airport for a safe landing.	The incident was under investigation.
12. Sep	Embraer ERJ-145	Climb	Cockpit	The crew reported a popping sound followed by smoke in the cockpit. The crew decided to divert for a safe landing.	Lack of information.

10. Sep	Airbus A320-200	Climb	Cabin	The crew reported smoke in the cabin, levelled off and diverted for a safe landing.	Emergency services found no trace of fire or heat. The passengers deplaned normally via stairs.
8. Sep	Airbus A321-200	Cruise	Cabin	The crew reported smoke in the cabin and decided to divert for a safe landing.	Emergency services utilizing thermal imaging found no trace of fire, heat or smoke.
8. Sep	de Havilland Dash 8-400	Cruise	Cabin	Smell of smoke was observed about mid-cabin. The crew to divert for a safe landing.	Attending emergency services found no trace of fire, heat or smoke.
1 . Sep	Boeing 737-700	Cruise	Cabin	The crew requested priority reporting a smoke problem in the back of the cabin. The aircraft continued for a safe landing.	The incident was under investigation.
30. Aug	Airbus A320-200	Cruise	Cabin	The crew reported smoke in the cabin and diverted for a safe landing.	Lack of information.
30. Aug	Boeing 737-800	Cruise	On board	The crew decided to divert after a passenger complained about smell of smoke on board. The aircraft landed safely.	Lack of information.
14. Aug	Embraer ERJ-170	Initial climb	Cabin	The crew declared emergency reporting they apparently had smoke in the cabin. The aircraft levelled off and diverted for a safe landing.	Lack of information.
14. Aug	Cityhopper Fokker 70	Cruise	On board	The crew decided to divert due to fumes on board. The crew reported both pilots feeling unwell. The aircraft landed safely.	Lack of information.
13. Aug	Boeing 767-200	Cruise	On board	The crew donned their oxygen masks and declared emergency reporting smoke on board of the aircraft. The crew decided to divert and the aircraft landed safely. The crew told attending emergency services that they had been on oxygen masks for about 10 minutes due to smoke in the cabin.	Fire fighters reported no trace of smoke.
12. Aug	Boeing 767-300	Cruise	Cabin	The crew reported smoke in the cabin and accelerated the approach. The aircraft landed safely.	Lack of information.
8. Aug	Boeing 767-300	Climb	Unknown	Cabin crew reported fumes from the air conditioning system. Cabin crew began reporting dizziness, sickness, pale complexion and hypoxia. The aircraft landed safely. The Canadian TSB reported the affected cabin crew members were sent to the hospital for medical attention.	Air conditioning system.
7. Aug	Boeing 757-200	Climb	Cockpit	The crew reported smoke in the cockpit, levelled off at returned to the airport for a safe landing.	Lack of information.
31. Jul	Airbus A320-200	Cruise	Cabin and cockpit	Passengers reported an unusual smell in the cabin and the crew reported a burning smell in the cockpit. The crew decided to divert	Lack of information.

				for a safe landing.	
30. Jul	McDonnell Douglas MD-83	Initial climb	Cabin	The crew reported smell of smoke in the cabin, levelled off and returned to for a safe landing.	Lack of information.
29. Jul	Embraer ERJ-145	Grounded	Cockpit	The aircraft rejected take-off when smoke entered the cockpit.	Oil in the left hand engine. Germany's BFU reported that due to defective strip seal in an engine. Oil ingress into the air conditioning system. Emergency services found no trace of fire or heat.
27. Jul	Boeing 737-300	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. The aircraft landed safely.	Responding emergency services found no trace of fire or heat.
27. Jul	Avion de Transport Regional ATR-72	Cruise	Cabin	The crew reported smoke in the cabin. The crew continued for a safe landing.	The incident was under investigation.
26. Jul	Boeing 737-800	Cruise	Cabin	The crew reported smell of smoke in the cabin and decided to divert to Omaha, where the aircraft landed safely.	The incident was under investigation.
19. Jul	Airbus A330-200	Cruise	Cabin	The crew declared emergency, reported smell of smoke in the cabin and requested to divert. The airplane landed safely.	Technical problem.
17. Jul	Avion de Transport Regional ATR-72-200	Descent	Cabin	A smell of fuel developed in the cabin followed by smoke. The crew declared emergency and accelerated approach for a safe landing.	Attending emergency services found no trace of fire or heat.
15. Jul	Boeing 737-300	Cruise	On board	Passengers reported the crew announced there were problems with the air conditioning system, and oxygen masks were released. A burning smell developed on board and it became very hot in the cabin.	Air conditioning system.
6. Jul	Boeing 747-400	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert for a safe landing.	Attending emergency services found no trace of fire or heat.
4. Jul	Boeing 737-800	Cruise	On board	The crew decided to return to the airport due to engine trouble. The aircraft landed safely. Passengers reported they heard strange sounds, a burning smell developed on board shortly afterwards.	Technical problem with an engine.

4. Jul	Boeing 737-800	Cruise	Unknown	The flight crew began to feel unwell (slight breathing anomaly, headache, lack of concentration). Almost at the same time cabin crew inquired whether the air conditioning was working okay reporting all passengers behaved conspicuously quiet, cabin crew also complained about headache. The flight crew rearranged air conditioning, descended the aircraft to FL330 in order to improve cabin air however without noticeable improvement, cabin crew reported smelling oil fumes in the cabin. The crew therefore decided to divert where the aircraft landed safely. Flight and cabin crew were taken to a local hospital for blood tests.	Inoperative APU.
28. Jun	Boeing 737-800	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to return to the airport. The aircraft landed safely	Not identified.
27. Jun	Airbus A319-100	Cruise	On board	One of the crew donned the oxygen mask, the crew subsequently reported a burning smell on board and decided to divert. The aircraft landed safely.	Lack of information.
27. Jun	ERJ 190-200 LR Embraer 195	Cruise	Flight deck	The aircraft had departed with a single air conditioning pack operating, as permitted by the Minimum Equipment List. When passing FL100, the flight crew noticed smoke and a strong sulphurous smell in the flight deck. They donned oxygen masks, declared a PAN and elected to return to gate. After approximately five minutes the smoke and smell had cleared and the aircraft landed without further incident.	Failed second stage turbine rotor.
15. Jun	Airbus A319-100	Descent	Cabin and cockpit	The crew reported they were on oxygen due to fumes in the cockpit and requested emergency services available at the gate. The crew continued for a safe landing on runway. While taxiing to the gate still on oxygen the crew requested paramedics at the gate reporting they had burning fumes in the cockpit and some odour in the cabin, the flight crew was suffering from burning eyes and a burning in the nose. One of the flight crew was subsequently taken to a local hospital.	Not yet identified.
10. Jun	Boeing 757-200	Cruise	Galley	The crew reported medium smoke in the area of the forward galley. The crew continued for a safe landing.	The incident was under investigation.
9. Jun	Embraer ERJ-145	Initial Climb	Cockpit	The crew donned their oxygen masks and declared emergency reporting smoke in the cockpit. The aircraft levelled off and returned to the airport for a safe landing.	Lack of information.

5. Jun	Embraer ERJ-170	Cruise	Cockpit	The crew donned their oxygen masks, declared emergency reporting smoke in the cockpit and diverted. The aircraft made an emergency descent to 9000 feet. The crew declined any instrument navigation reporting the cockpit was filling with smoke.	Lack of information.
21. May	Douglas DV-9-50	Cruise	Galley	The crew reported a strange odour/smell of smoke in the forward galley and decided to divert for a safe landing.	Emergency services found no trace of fire, heat or smoke.
16. May	McDonnell Douglas MD-83	Climb	Cockpit	The crew reported smoke in the cockpit and decided to return to the airport. The aircraft levelled off and landed safely.	Lack of information.
15. May	McDonnell Douglas MD-82	Initial climb	Cockpit	The crew reported smoke in the cockpit, stopped the climb at 5000 feet and decided to return to the airport for a safe landing.	Small fluid leak in the APU.
13. May	Airbus A319-100	Cruise	Cabin	The crew reported smoke in the cabin and diverted for a safe landing.	Lack of information.
6. May	Embraer ERJ-145	Cruise	Cockpit	The crew reported smoke in the cockpit and returned to the airport, where the aircraft landed safely.	Responding emergency services found no trace of fire, heat or smoke.
6. May	Boeing 757-200	Cruise	Cockpit	The crew reported smell of smoke in the cockpit and decided to divert, and it landed safely.	Attending emergency services found no trace of fire, heat or smoke. The incident was under investigation.
5. May	Boeing 737-800	Initial Climb	Cabin and cockpit	The crew reported a smell of fuel throughout the entire cabin and cockpit and decided to return to the airport, where the aircraft landed safely.	Lack of information.
5. May	Canadair CRJ-200	Climb	Cabin	The cabin started to fill with smoke. The crew decided to return to the airport for a safe landing.	Lack of information.
3. May	Airbus A318-100	Climb	Cabin	Passengers observed a strong burning smell soon followed by visible smoke in the cabin. The crew returned to the airport for a safe landing.	Lack of information.
1. May	Boeing 757-200	Cruise	Cockpit	The crew decided to divert due to a smoky odour in the cockpit. The airplane landed safely.	Lack of information.
28. Apr	Airbus 319-100	Cruise	Cockpit	The crew reported a burning smell in the cockpit and decided. The aircraft landed safely.	Responding emergency services found no trace of fire or heat.
25. Apr	Boeing 737-800	Cruise	Cabin	The crew reported passengers had smelled smoke in the aft section of the aircraft. The crew decided to divert and landed safely.	Responding emergency services found no trace of fire, heat or smoke.

23. Apr	Airbus A320-200	Initial Climb	Cabin and cockpit	The crew donned their oxygen masks and declared emergency reporting smoke in the aircraft later adding there was smoke in cockpit and cabin. The airplane levelled off and returned for a safe landing.	Emergency services reported on crew request to see no smoke from the aircraft.
22. Apr	Boeing 737-700	Cruise	Cabin	The crew decided to divert due to a burning smell in the cabin. The aircraft landed safely.	Lack of information.
18. Apr	Avion de Transport Regional ATR-72	Climb	Cockpit	The crew reported a burning smell in the cockpit and set course to divert, where the aircraft landed safely.	Lack of information.
14. Apr	Embraer ERJ-190	Initial Climb	Cabin and cockpit	The crew reported smoke in cockpit and cabin, levelled off at 4000 feet, joined a right hand pattern and returned to the airport for a safe landing.	Lack of information.
13. Apr	Boeing 747-400	Cruise	Cockpit	Smoke appeared in the cockpit. The crew donned their oxygen masks, declared emergency and diverted to the airport for a safe landing.	Defective strip seal in an engine.
13. Apr	Embraer ERJ-190	Cruise	Cockpit	The crew observed smoke in the cockpit, donned their oxygen masks, declared emergency and returned to the airport for a safe landing.	Suspecting a failure of #1 air conditioning system.
11. Apr	Boeing 777-300	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted for a safe landing.	Technical problem.
9. Apr	Airbus 330-200	Cruise	On board	The crew considered to return to the airport due to strong smell of oil on board. The airplane landed safely.	Not yet identified.
8. Apr	Airbus A330-200	Cruise	On board	The crew observed smell of oil on board. The flight was continued for a safe landing.	Not yet identified.
5. Apr	Boeing 757-300	Climb	On board	The crew reported a burning smell on board and stopped the climb at 16,000 feet. The airplane returned to the airport for a safe landing.	Lack of information.
3. Apr	Boeing 737-300	Cruise	Cabin	A burning smell developed in the cabin prompting the crew to divert for a safe landing.	Technical problem.
2. Apr	Airbus A330-200	Cruise	Cabin	The crew reported the left hand engine had to be shut down and decided to divert for a safe landing. A passenger reported that there was smoke in the cabin. Other passengers tweeted about smoke, burning smell and failed lights in the cabin after a sound like an explosion.	Technical failure in an engine.

30. Mar	Boeing 747-400	Climb	Cabin	The crew declared emergency reporting smoke in the cabin and returned to the airport for a safe landing. Passengers reported there had been smoke in the rear of the aircraft.	Technical problem.
30. Mar	McDonnell Douglas MD-82	Cruise	Cabin	The crew reported an odour of smoke without any visible smoke in the cabin and due to a thunderstorm front in their south decided to divert. During the approach to place of diversion, the crew reported the odour was dissipating. The aircraft landed safely.	Lack of information.
28. Mar	Avro RJ-85	Cruise	On board	The crew donned their oxygen masks and declared emergency reporting smoke on board. The crew continued for a safe landing.	The incident was under investigation.
22. Mar	Embraer ERJ-135	Initial Climb	Cockpit	The crew reported smoke in the cockpit and decided to return to Louisville. The airplane landed safely on the runway about 8 minutes after departure.	Lack of information.
22. Mar	Boeing 757-200	Cruise	Galley	The cabin crew noticed an acrid smell of smoke in the rear galley, however no smoke was visible. The flight crew decided to return to the airport. The airplane landed safely.	Lack of information.
15. Mar	Boeing 737-800	Initial Climb	Cabin	The crew requested to level off at 7000 feet and return to the airport reporting a strong burning smell in the cabin. The airplane returned for a safe landing.	Possibly from the left hand engine.
4. Mar	Embraer ERJ-145	Climb	Cockpit	The crew noticed smell of smoke in the cockpit and decided to divert for a safe landing.	Responding emergency services did not find any trace of fire, heat or smoke.
28. Feb	Boeing 737-800	Cruise	Cabin	A passenger reported seeing smoke. The crew decided to divert for a safe landing.	Emergency services found no trace of fire, heat or smoke.
21. Feb	McDonnell Douglas MD-88	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted o for a safe landing.	Lack of information.
21. Feb	Airbus A340-300	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to return to the airport where the aircraft landed safely.	Technical problem.
19. Feb	Boeing 757-200	Cruise	On board	The crew reported a burning smell on board and decided to turn around and divert. The airplane landed safely.	Lack of information.
14. Feb	Boeing 777-300	Cruise	Cabin	The crew diverted reporting smoke in the cabin. The aircraft dumped fuel and landed safely.	The incident was under investigation.
14. Feb	Airbus A320-200	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. The aircraft landed safely.	Emergency service found no trace of fire or heat.
1 3. Feb	Embraer ERJ-145	Climb	Cabin	The crew declared emergency reporting a lavatory smoke alert and smell of smoke in the cabin. The aircraft levelled at 5000 feet and set	Engine #2 produced smoke in the bleed air system.

				up for an approach to the airport.	
11. Feb	Boeing 737-800	Climb	Cockpit	The crew declared emergency reporting fumes in the cockpit and requested an immediate return to the airport, however did not request emergency services on standby. The airplane landed safely.	Lack of information.
9. Feb	Boeing 737-500	Climb	Cockpit	The crew reported smell of smoke in the cockpit and decided to return to the airport for a safe landing.	Lack of information.
3. Feb	Boeing 737-700	Cruise	On board	The crew decided to divert due to an unusual smell on board. The aircraft landed safely.	Lack of information.
29. Jan	Boeing 777-300	Cruise	Cabin	The aircraft returned to the airport after smoke was seen in the cabin. The airplane landed safely.	Lack of information.
29. Jan	Boeing 777-200	Cruise	On board	The crew decided to turn around and divert reporting no serious problem and no assistance required after smell of fuel was noticed on board. The airplane landed safely on runway. After touchdown the crew reported they had quite some strong fumes on the flight deck and requested emergency services to follow them to the apron.	Oil leaked from the APU into the air conditioning system.
26. Jan	Boeing 737-900	Initial Climb	Cockpit	Smoke became visible in the aircraft prompting the crew to don their oxygen masks, declare emergency reporting smoke in the cockpit, level off at 3000 feet and return to the airport.	Suspected to be related to the de-icing procedure before take-off.
26. Jan	Boeing 737-700	Climb	Cockpit	The crew donned their oxygen masks, declared emergency reporting smoke in the cockpit and requested an immediate return. The airplane levelled off at 3000 feet, the crew reported the smoke seemed to subside.	Lack of information.
25. Jan	McDonnell Douglas MD-83	Climb	Cockpit	The crew declared emergency reporting smoke in the cockpit and decided to divert. On approach the crew reported the smoke was dissipating, a short time later they advised the smoke was returning, during final approach the crew reported the smoke had again dissipated with just smell of smoke remaining, no smoke had been observed in the cabin, they would advise after landing whether an evacuation would be necessary. The crew continued for a safe landing.	Lack of information.
24. Jan	Avions de Transport Regional ATR-72-200	Grounded	Cabin and cockpit	The crew noticed white smoke from on board and almost simultaneously fire alerts activated.	De-icing fluid entering the air condition system.

18. Jan	Airbus A319-100	Initial Climb	Cabin	The cabin crew advised of smoke with a smell of glycol in the cabin. The flight crew levelled off at 4000 feet and returned to the airport for a safe landing.	Found no anomaly.
15. Jan	Canadair-bombardier/ challenger		Cabin and cockpit	Smoke and burning odour in the cockpit and the rear of the aircraft. Evacuation after returning to the gate. High carbon monoxide levels in the SIC after medical examination.	Lack of information.
12. Jan	Boeing 737-700	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. The airplane landed safely.	Lack of information.
11. Jan	Boeing 737-300	Climb	Cockpit	The crew reported smoke in the cockpit and decided to return to the airport for a safe landing.	The incident was under investigation.
6. Jan	Airbus A319-111, G-EZFI	Grounded	Cabin	The airport's runway and taxiways had been treated with de-icing chemicals. After landing, the aircraft vacated the runway, with reverse thrust still deployed. Smoke began to enter the cabin and the cabin manager advised the flight crew. As the smoke became thicker, the cabin manager recommended to the flight crew that an evacuation was necessary.	De-icing chemicals were most probably the source of the smoke, the density of which was probably exacerbated by the prolonged use of reverse thrust.
6. Jan	Boeing 737-700	Cruise	Cockpit	The crew reported smell of smoke in the cockpit and decided to divert for a safe landing.	Responding emergency services found no trace of fire, heat or smoke.
3. Jan	Airbus A320-200	Climb	Cabin and cockpit	An unusual odour was observed in the cockpit and cabin of the aircraft. The crew decided to return to the airport for a safe landing.	Lack of information.
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31. Dec	Airbus A320-200	Climb	Cabin	The crew reported visible smoke in the cabin as well as cargo and lavatory fire alerts. The aircraft returned to the airport for a safe landing.	APU failure.
25. Dec	Jazz de Havilland Dash 8-300	Cruise	Cabin	Mist and an acrid smell entered the cabin. The crew declared emergency and diverted. The airport closed all runways to accommodate the aircraft. The airplane landed safely.	Engine fault.
21. Dec	Boeing 737-8AS	Landing	Cabin and cockpit	Smoke was observed in both the cockpit and cabin. The aircraft was stopped, the engines were shut down and an evacuation was carried out. No technical defect was found during the subsequent examination.	It is probable that the smoke was caused by the engines ingesting granular urea, which had been used to de-ice the runway during a very cold weather period.

20. Dec	Boeing 737-700	Grounded	Cabin	Haze developed in the cabin. The crew aborted the climb and prepared for a possible return, but were able to clear the haze and identify by the smell that de-icing fluid had entered the air conditioning system. The crew therefore decided to continue the flight and climbed the aircraft to FL300 before they decided to divert, where the aircraft landed safely.	De-icing fluid had entered the air conditioning system.
19. Dec	Airbus A319	Cruise	Cockpit	The two pilots noticed an abnormal smell after turning on to the base leg. Noticed adverse effect on their physical and cognitive performance a short time later. They donned their oxygen masks and declared emergency. Both sought medical treatment after landing. None of the passengers noticed any of the events in the cockpit.	Not revealed any indication of a technical malfunction.
17. Dec	Dornier D-328-300	Climb	Cabin	The crew noticed a chemical odour and smoke like haze around the map and instrument lights. At the same time the flight attendant called the flight deck reporting smoke and odour in the cabin. At the same time a smoke indication for the rear toilet illuminated. The crew declared emergency, stopped the climb and decided to return to the airport.	Worn and slightly damaged carbon seal in the right hand engine.
16. Dec	Boeing 737-800	Cruise	On board	The crew decided to turn around and return to the airport after some passengers and cabin crew complained about nausea as well as some fumes on board. During the approach to the airport the crew initially reported they had 4 people complaining upgrading the count to 30 people some time later. The airplane landed safely, where medical services were awaiting the aircraft and took care of the affected people.	De-icing before departure.
16. Dec	Boeing 777-200	Cruise	Cabin	One of the air conditioning system emitted smoke into the cabin. The airplane returned to airport, and landed safely.	Lack of information.
16. Dec	Airbus A319-100	Cruise	On board	The crew reported smell of smoke on board. The crew continued for a safe landing.	Responding emergency services found no trace of fire, heat or smoke.
14. Dec	de Havilland Dash 8-400	Initial Climb	On board	The crew decided to return to the airport due to an acrid smell on board. The airplane landed safely.	Lack of information.

11. Dec	Airbus A319-100	Descent	Cockpit	The crew donned their oxygen masks and declared emergency reporting smoke in the cockpit. The aircraft continued for a safe landing and vacated the runway, where responding emergency services examined the aircraft. The crew was subsequently able to taxi to the gate, where passengers disembarked normally. The first officer and a flight attendant were treated at the airport for smoke inhalation.	Lack of information.
6. Dec	Canadair CRJ-100	Grounded	Cabin and flight deck	The aircraft rejected take-off because of smoke in the cabin and flight deck. The airplane slowed safely, the smoke dissipated after engines spooled down.	De-icing ingested into the aircraft bleed system. Responding emergency services found no trace of fire, heat or smoke.
29. Nov	Avions de Transport Regional ATR-72-500	Climb	Cockpit	The crew reported smell of smoke in the cockpit and returned to the airport for a safe landing.	Lack of information.
23. Nov	Airbus A340-300	Climb	On board	A strong oily odour on board convinced the crew to return to the airport. The airplane levelled off at 6000 feet and performed a safe landing.	New inboard left hand engine.
22. Nov	McDonnell Douglas MD-11	Descent	Unknown	The crew reported they had smoke coming from the back of their airplane and requested emergency services.	Lack of information.
19. Nov	Boeing 737-300	Initial Climb	On board	The crew noticed an abnormal odour on board prompting the return to the airport. The airplane landed safely.	Newly changed engine.
18. Nov	Boeing 757-200	Climb	Cockpit	The crew donned their oxygen masks, reported smoke in the cockpit and decided to return to the airport. The airplane landed safely.	Lack of information.
17. Nov	Canadair CRJ-200	Grounded	Cabin	The aircraft rejected take-off from runway after passengers smelled smoke and a smoke detector triggered. The crew requested emergency services to attend the aircraft reporting a possible fire on board.	De-icing fluid into the air conditioning system.
6. Nov	Boeing 717-200	Cruise	Cabin	The crew reported an odour and some smoke in the cabin. The crew diverted for a safe landing.	Lack of information.
31. Oct	Boeing 767-200	Cruise	Cabin	The crew reported a smell of smoke in the cabin and diverted for a safe landing.	Lack of information.
29. Oct	Boeing 767-300	Cruise	Unknown	The crew declared emergency and returned due to smoke throughout the aircraft. The airplane descended for a safe landing.	Internal oil leak in the right hand engine.
28. Oct	Boeing 747-400	Climb	Cockpit	The crew reported smoke in the cockpit and decided to return to the	Lack of information.

				airport for a safe landing.	
25. Oct	de Havilland Dash 8-200	Cruise	Cabin	The crew received a fire alert for the lavatory, a short time later smoke was observed in the lavatory and in the passenger cabin. The flight crew decided to return to the airport. The airplane landed safely.	Oil leak in the bleed air system.
24. Oct	Boeing 757-200	Cruise	Cabin	The crew reported smoke in the cabin and diverted for a safe landing.	Lack of information.
16. Oct	Boeing 777-200	Cruise	Cabin	Passengers thought to smell fireworks. As a precaution the captain decided to divert for a safe landing.	Air conditioning system.
10. Oct	Boeing 737-300	Climb	Cabin	A smoke detector triggered and a smell of smoke developed in the cabin. The crew immediately returned to the airport for a safe landing.	Lack of information.
8. Oct	Embraer ERJ-170	Cruise	Cabin	Smoke was observed in the cabin. The crew diverted for a safe landing, the passengers were evacuated.	Problem with the right hand air conditioning system.
4. Oct	Embraer ERJ-190	Cruise	Cabin	The crew reported smoke in the cabin and diverted for a safe landing.	Lack of information.
27. Sep	McDonnell Douglas MD-88	Climb	Cockpit	The crew detected smoke in the cockpit shortly after take-off. The airplane landed safely.	Lack of information.
19. Sep	McDonnell Douglas MD-88		Cockpit	The crew reported smoke in the cockpit and decided to divert. The smoke began to appear in the cabin as well. The crew managed a safe landing.	Lack of information.
17. Sep	Boeing 757-200	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. On approach the crew reported that the smoke had dissipated. The airplane landed safely.	Lack of information.
17. Sep	Airbus A319-100	Cruise	Cabin	A smell of smoke was noticed in the cabin prompting the crew to return to the airport for a safe landing.	Lack of information.
10. Sep	Embraer ERJ-190	Cruise	Cabin	The crew reported smoke in the cabin and returned to the airport for a safe landing.	Lack of information.
6. Sep	Aerospatiale ATH-72-500	Cruise	Cabin	The aircraft diverted after a smell of fuel developed in the cabin. The airplane landed safely. All occupants were checked by medical services, one crew member was taken to a hospital as a precaution.	Lack of information.
3. Sep	Boeing 767-400	Cruise	Cockpit	The crew decided to divert due to a smell of smoke in the cockpit. The airplane landed safely.	Lack of information.
30. Aug	Embraer-170	Cruise	Cabin and cockpit	Reporting of smoke/fumes in cockpit. Crew reported faint visible smoke in cabin as well, with smoke/sulphur smell throughout the	Pack 2 failure.

				cabin. Aircraft landed without incident.	
29. Jul	Airbus A340-300	Grounded	Cockpit	The crew reported smoke in the cockpit, levelled off at 5000 feet and returned to the airport for a safe landing. The smoke dissipated before touchdown.	Lack of information.
27. Jul	Boeing 757-200	Cruise	Cabin and cockpit	The airport said that the crew declared emergency reporting smoke in the cockpit. Passengers reported, that smell of smoke was noticed in the back of the cabin.	Hydraulic leak.
24. Jul	McDonnell Douglas MD-83	Cruise	Cabin	Passengers saw smoke in the back of the aircraft. The crew diverted where the airplane landed safely.	The incident was under investigation.
23. Jul	Boeing 757-200	Climb	Cabin and cockpit	The crew stopped the climb, donned their oxygen masks, declared emergency reporting a strong smell of smoke in cockpit and cabin but no visible smoke and diverted. The airplane landed safely.	Lack of information.
23. Jul	Boeing 737-700	Climb	Cockpit	The crew declared emergency reporting smoke in the cockpit and returned to the airport for a safe landing.	Lack of information.
22. Jul	Boeing 767-300	Cruise	Cockpit	The crew reported they had a strong smell of smoke in the cockpit but were unable to locate the source. In the meantime the smell had subsided.	Lack of information.
17. Jul	Fokker 70	Climb	Cabin	The crew reported smoke in the back of the aircraft and requested to return to the airport as a precaution. The airplane landed safely.	Lack of information.
14. Jul	Airbus A320-200	Cruise	Cabin	The cabin crew reported a hot oily smell in the cabin prompting the flight crew to return to the airport. The airplane landed safely.	Lack of information.
10. Jul	Airbus A321-200	Cruise	On board	The crew reported smell of smoke on board and decided to divert. The airplane landed safely.	Lack of information.
9. Jul	Aerospatiale ATR-72-500	Cruise	On board	The aircraft diverted to Dunedin after a burning smell was noticed on board. The airplane landed safely.	Not yet identified.
6. Jul	Boeing 757-200	Cruise	Cabin	The crew decided to divert due to a burning smell in the rear of the cabin. The airplane landed safely.	Not any information
1. Jul	Airbus A320	Cruise	Cockpit	The crew reported smoke in the cockpit and returned to the airport. The airplane landed safely.	The incident was under investigation.
30. Jun	Boeing 737-200	Cruise	Cockpit	The crew reported smoke in the cockpit and diverted for a safe landing.	Lack of information.
29. Jun	Boeing 737-700	Cruise	Unknown	The crew received an abnormal indication for the right hand engine's generator, smell of oil developed in the aircraft. The crew throttled the engine back and decided to divert for a safe landing.	Malfunction of one generator in engine.

27. Jun	Canadair CRJ-200	Climb	Cockpit	The crew reported smoke in the cockpit and returned to the airport for a safe landing 19 minutes after departure.	Lack of information.
21. Jun	Embraer EMB-190	Descent	Cabin	The flight attendants reported smoke and fumes in the cabin, and shortly after a smell on the flight deck. The crew donned oxygen masks.	Lack of information.
20. Jun	Boeing 737-700	Cruise	Cabin	The crew reported smell of smoke in the cabin, levelled off at 3000 feet and returned to the airport for a safe landing.	Residual engine cleaning fluid.
16. Jun	Airbus A320-200	Cruise	Cabin	The crew reported smell of smoke in the cabin and requested to divert, where the airplane landed safely.	Lack of information.
13. Jun	McDonnell Douglas MD-88	Cruise	Cabin	The crew reported smoke in the cabin and decided to divert. The airplane landed safely.	Unknown cause.
11. Jun	Boeing 767-400	Cruise	Cabin	The crew reported a bit developing smoke in the cabin, declared emergency and decided to dump fuel, turn around and divert. The airplane landed safely.	Lack of information.
8. Jun	Aerospatiale ATR-72-500	Climb	Cabin	The aircraft was about 5 minutes into the flight when smoke became visible in the cabin. During the return to the airport the air conditioning system failed. The airplane landed safely.	Air conditioning system had failed.
1. Jun	Boeing 767-300	Descent	Cabin	Three flight attendants noticed some fumes in the cabin and shortly afterwards began to feel unwell complaining about nausea and stinging eyes. The airplane continued for a safe landing at the destination, the flight attendants were taken to a local hospital.	The incident was under investigation.
29. May	Airbus A320-200	Descent	Cabin	The airport reported that the flight crew had donned their oxygen masks and reported cabin pressure problems as well as possible fumes in the cabin causing a number of people to feel unwell. Two flight attendants needed medical assistance after landing.	Lack of information.
15. May	McDonnell Douglas MD-90-3	Climb	Cockpit	The crew reported smoke in the cockpit. The airplane returned, and landed safely.	Lack of information.
11. May	Boeing 737-800	Climb	On board	The cabin crew noticed an oily smell on board prompting the flight crew to return to the airport for a safe landing.	Cleaning agent used to remove ash from the engine.
7. May	Aerospatiale ATR-72-500	Cruise	Cabin	The aircraft returned to the airport when smoke entered the cabin shortly after take-off.	Lack of information.
27. Apr	Canadair CRJ-200	Cruise	Cockpit	The crew reported smell of smoke in the cockpit updating audibly on oxygen masks a short time later that visible white haze developed in the cockpit. The airplane landed safely.	Hydraulic leak.

26. Apr	Avro RJ-85	Cruise	Cabin	The crew declared emergency reporting smoke in the cabin. The airplane continued for a safe landing.	Lack of information.
21. Apr	Boeing 757-200	Climb	Unknown	The crew reported engine bleed air problems, possibly through a contaminated valve, and a strong smell of ashes. The crew decided to return to the airport, where the aircraft landed safely.	Engine bleed air problem, a contaminated valve.
16. Apr	Airbus A320-200	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert. While the airplane was on approach to the place of diversion, the smoke started to dissipate. The airplane landed safely.	Lack of information.
14. Apr	Boeing 757-200	Cruise	On board	The crew reported a smell of smoke on board and diverted to Sioux Falls, where the airplane landed safely 20 minutes later.	Lack of information.
8. Apr	Boeing 757-200	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert to Tampa. The airplane landed safely about 25 minutes later.	Lack of information.
8. Apr	Canadair CRJ-200	Cruise	Cockpit	The crew smelled smoke in the cockpit and decided to divert. The airplane landed safely.	Lack of information.
4. Apr	Embraer ERJ-145	Cruise	Cockpit	The aircraft diverted after the crew reported smell of smoke in the cockpit. The airplane landed safely.	Lack of information.
4. Apr	Boeing 737-200	Climb	Cockpit	The crew reported smoke in the cockpit and decided to return. The airplane landed safely.	Generator control unit failure.
31. Mar	Airbus A320-211	Cruise	Cabin	In cruise, 1 of the 3 hydraulic systems failed. The flight continued toward destination where the flight made an uneventful landing. While stopped on the runway awaiting a tow, smoke entered the cabin and an evacuation was ordered. Two crew members and 2 passengers received minor injuries during the evacuation.	1 of the 3 hydraulic system failed.
26. Mar	de Havilland Dash 8-400	Grounded	Cockpit	The crew reported an irregular smell in the cockpit shortly after take-off and returned to the airport for a safe landing.	The incident was under investigation.
24. Mar	Boeing 737-300	Climb	On board	The crew reported a burning smell on board and decided to return to the airport. The airplane landed safely.	Lack of information.
23. Mar	Airbus A320-200	Cruise	Cabin	The airline reported that there had been an acrid smell in the passenger cabin. Upon touch down the crew noticed a steering problem related to a hydraulics problem. Passengers reported that there had been acrid smell in the cabin. Some time into the flight the crew announced the airplane had hydraulics problem, but a normal landing would follow, emergency services would be on standby. After touch down the acrid smell worsened and smoke became visible in the cabin.	Hydraulic leak.

23. Mar	Canadair CRJ-100	Climb	On board	The crew decided to return to the airport reporting an unusual odour on board. The airplane landed safely.	Remains of a cleaning fluid in the engines following an engine wash.
13. Mar	Airbus A330-300	Cruise	Cockpit	The crew reported light continuous smoke in the cockpit coming out of a shielding, declared emergency and turned around to divert. The airplane landed safely.	Lack of information.
12. Mar	Airbus A320-200	Departure	Cabin	The aircraft has just departed, when a strong smell of burned plastics and smoke began to fill the cabin prompting the crew to return to the airport. The airplane landed safely.	Lack of information.
11. Mar	Airbus A320-200	Descent	On board	Passengers started to complain about chemical chlorine like smell on board. Later six passengers and as well as four cabin crew felt light headed and complained about nausea. Two doctors on board monitored their health status. The flight crew continued to the destination for a safe landing, where medical services were awaiting the aircraft.	The incident was under investigation.
9. Mar	Canadair CRJ-700	Climb	Cockpit	The crew reported smoke in the cockpit and return to the airport for a safe landing.	Lack of information.
8. Mar	Airbus A320-200	Cruise	On board	Passengers reported an unusual smell on board prompting the crew suspecting a technical defect to divert. The airplane landed safely.	Possible technical defect.
6. Mar	Embraer ERJ-190	Climb	Cabin	The crew reported smoke in the cabin and decided to return to the airport. While on approach to the runway, the crew reported that the smoke had not cleared. The aircraft landed safely.	Lack of information.
4. Mar	Avro RJ-100	Cruise	On board	The crew reported a fuel leak and smoke on board. The airplane landed safely.	Lack of information.
22. Apr	Embraer ERJ-190	Climb	Unknown	The flight crew smelled some strange fumes and decided to return. The airplane landed safely.	Lack of information.
17. Apr	Boeing 757-200	Cruise	Cabin	The cabin crew reported a smoky smell in the cabin prompting the flight crew to return to the airport. The airplane landed safely.	Lack of information.
8. Apr	Canadair CRJ-200	Cruise	Cockpit	The crew smelled smoke in the cockpit and decided to divert. The airplane landed safely.	Lack of information.
7. Apr	Boeing 737-300	Cruise	Cabin	The crew donned their oxygen masks due to smoke in the cabin.	Emergency services checked the airplane but found no smoke, fire or heat.
25. Feb	Embraer ERJ-145	Initial climb	On board	The crew reported a smoky odour on board, levelled off at 2500 feet and returned to the airport for a safe landing.	Recently de-icing of aircraft.

18. Feb	Boeing 757-200	Climb	Cockpit	The crew donned their oxygen masks reporting fumes in the cockpit and returned to the airport for a safe landing.	Lack of information.
14. Feb	Airbus A380-800	Cruise	Cockpit	The crew reported smoke in the cockpit, stating a bit later that the smoke had cleared. They decided to return to the airport while dumping fuel. The airplane landed safely.	Lack of information.
12. Feb	Boeing 757-200	Cruise	On board	The aircraft returned to the airport after the crew reported fumes on board. The airplane landed safely.	Lack of information.
10. Feb	Embraer ERJ-145	Climb	Cabin	The crew reported smoke in the cabin shortly after take-off and returned to the airport for a safe landing.	Lack of information.
1. Feb	Boeing 757-200	Cruise	On board	The crew reported smell of smoke on board and set course to divert, where the airplane landed safely.	Oil through the air conditioning system.
1. Feb	de Havilland Dash 8-400	Descent	Cockpit	The crew donned their oxygen masks, reported smoke in the cockpit and continued for an accelerated landing at the destination. The airplane touched down safely and stopped on the runway, the passengers were evacuated.	The incident was under investigation.
27. Jan	Canadair CRJ-100	Cruise	On board	The crew reported a smoky odour on board and decided to divert. The airplane landed safely.	Attending emergency services found no trace of fire or heat.
25. Jan	de Havilland Dash 8-100	Climb	Cockpit	The crew observed smoke in the cockpit, declared emergency and returned to the airport.	Lack of information.
9. Jan	de Havilland Dash 8-400	Climb	Cockpit	The crew donned their oxygen masks and declared emergency reporting smoke in the front of the cockpit. The airplane returned to the airport for a safe landing.	Lack of information.
8. Jan	Embraer ERJ-145	Grounded	Unknown	The aircraft rejected take-off due to a smell of smoke during the take-off run, slowed safely and turned left off the runway and stopped.	The incident was under investigation, suspects of de-icing fluid.
2. Jan	Embraer ERJ-145	Grounded	Cabin	The crew reported they needed an emergency return to the airfield because of smoke in the cabin. The crew donned their oxygen masks. On downwind the crew reported that they had pretty good smoke in the cabin which was now dissipating.	Lack of information.
2. Jan	McDonnell Douglas MD-88	Climb	Cabin and cockpit	The crew reported they had smoke in the cabin and needed to return immediately. The crew later explained that they had seen light smoke in the cockpit and smoke in the cabin, which appeared to be under control and dispersing by then. The airplane landed safely.	Lack of information.
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30. Dec	Boeing 737-700	Initial climb	Cockpit	The crew reported smoke in the cockpit and decided to return to the airport.	Lack of information.
20. Dec	Boeing 737-800	Cruise	Cockpit	The crew reported smoke in the cockpit. The airplane landed safely, the passengers quickly disembarked.	Lack of information.
19. Dec	Bombardier Dash 8 Q400	Cruise	Cockpit	During the cruise a warning caption in the cockpit illuminated and a burning smell was noted. The Commander decided to divert.	Overheated and mechanical failure of right engine air intake heated adapter.
17. Dec	Canadair CRJ-100	Climb	Unknown	The crew observed sparks and a puff of smoke coming from the overhead panel. The smoke dissipated quickly, the crew nonetheless declared emergency and returned to the airport for a safe landing.	Lack of information.
16. Dec	Dash 8-400	Cruise	Cockpit	The crew reported smoke in the cockpit following a smoke detector alert. The airplane diverted, and landed safely.	Lack of information.
29. Nov	Avro RJ-85	Climb	Cabin and cockpit	The aircraft returned to the airport when smoke developed in the cockpit and became also visible in the forward rows of the passenger cabin shortly after take-off. The airplane landed safely.	De-icing fluid had entered the air conditioning system.
25. Nov	Airbus A319-100	Cruise	Cockpit	A smoke detector triggered prompting the crew to declare emergency reporting smoke in the cockpit and to divert. The airplane landed safely.	Emergency services did not find any traces of smoke or fire.
12. Nov	McDonnell Douglas MD-11	Cruise	Cockpit	The crew reported smoke in the cockpit when the airplane was en route.	A thrust reverser actuator on the left hand engine leaked hydraulic fluid onto a bleed air duct.
1. Nov	Airbus A319-100	Cruise	Cockpit	The crew reported smoke in the cockpit, and returned to the airport. The airplane landed safely, the passenger disembarked normally.	The incident was under investigation.
31. Oct	BA184	Unknown	Unknown	More than 200 passengers were at the centre of a fumes alert at the airport after at least six fainted during a transatlantic British Airways flight.	Lack of information.
27. Oct	de Havilland Dash 8-300	Cruise	Cockpit	The crew declared emergency reporting a smell of smoke in the cockpit about 10 minutes into the flight. The crew donned their oxygen masks and managed a safe landing.	Lack of information.
12. Oct	Embraer ERJ-145	Climb	Cockpit	The crew reported smoke in the cockpit and decided to divert. The airplane landed safely.	The incident was under investigation.
6. Oct	Boeing 777-300	Climb	Cockpit	The crew reported smoke in the cockpit while climbing through 15 000 feet departing the airport about 8 minutes into the flight and decided to return.	Left engine pressure regulating/shut off valve.

2. Oct	Embraer ERJ-195	Descent	Cabin	A burning smell developed in the cabin. The crew declared emergency and accelerated descent, approach and landing for a safe touchdown.	Attending emergency services identified an overheated bearing in the air conditioning system as cause of the smell.
20. Sep	Fokker 100	Cruise	Cabin	The aircraft diverted after the crew reported smoke in the cabin. The airplane landed safely.	Lack of information.
19. Sep	Airbus A321-200	Cruise	On board	The aircraft diverted due to smoke on board. The airplane landed safely.	Lack of information.
18. Sep	Airbus A320-200	Cruise	Unknown	The crew reported smell of smoke and strange sounds and diverted. The airplane landed safely.	Lack of information.
12. Sep	Embraer ERJ-145	Cruise	Cockpit	The aircraft diverted after the crew reported smoke in the cockpit. The airplane landed safely.	No trace of fire or heat was found.
9. Sep	Embraer ERJ-145	Cruise	On board	The crew noticed a smell of smoke on board. The airplane landed safely.	Lack of information.
2. Sep	Boeing 737-300	Cruise	On board	The aircraft diverted after cabin crew noticed a smell of smoke on board. The airplane landed safely.	Failed seal of the air conditioning system.
2. Sep	Embraer ERJ-135	Cruise	Cockpit	The crew declared emergency reporting smoke in the cockpit and decided to divert, where the airplane landed safely.	Lack of information.
26. Aug	Boeing 737-700	Cruise	On board	The aircraft returned to the airport after the crew reported smell of smoke on board. The airplane landed safely.	Lack of information.
26. Aug	Canadair CRJ-200	Cruise	On board	The crew reported smoke on board while on approach to the destination. The airplane landed safely.	Lack of information.
25. Aug	Boeing 747-400	Cruise	On board	A burning smell developed on board. The airplane landed safely.	Lack of information.
23. Aug	Embraer ERJ-145	Climb	Unknown	A burning smell developed about 10 minutes into the flight followed by a smoke detector triggering. The airplane returned to the airport and landed safely.	Lack of information.
21. Aug	Boeing 757-200	Cruise	Unknown	The crew reported fumes in the aircraft and requested emergency services on standby for their diversion. The aircraft landed safely.	Lack of information.
19. Aug	DHC-8-402 Dash 8	Grounded	Cabin	Smoke entered the cabin and flight deck soon after take-off. The aircraft returned to the airport and a successful evacuation was carried out on the runway after landing.	Failed internal oil seal in the left engine.
19. Aug	Airbus A320-200	Cruise	Cabin	The flight crew decided to divert after passengers noticed a strong smell of burning oil in the cabin. The airplane landed safely.	Fire services could not find any source of heat, fire or smoke.

18. Aug	Boeing 767-300	Cruise	Cabin	The aircraft returned to the airport after the sound of the air conditioning system changed becoming nerve wrecking, a burning smell developed in the cabin and light white haze became visible a few minutes after departure. The crew dumped fuel before landing safely.	Attending fire services could not find any source of heat or fire.
17. Aug	Embraer ERJ-190	Cruise	Cabin	Passengers reported that they had smelled smoke about 30 minutes into the flight shortly after the airplane had reached cruise level. Later smoke became visible and developed into thick smoke, and then the oxygen masks came down followed by announcements to use the masks. About 10 minutes later the airplane levelled off.	Failure of air conditioning system.
17. Aug	McDonnell Douglas MD-83	Cruise	Cabin and cockpit	The aircraft diverted to the airport after the crew reported smell of smoke in the cabin and later in the cockpit. The airplane landed safely.	The incident was under investigation.
16. Aug	Boeing 757-200	Cruise	Cabin	The crew declared emergency and decided to return to the airport, when cabin crew reported smoke in the cabin. The airplane landed safely back to the airport.	Lack of information.
2. Aug	Boeing 757-200	Climb	Cockpit	The crew donned their oxygen masks, declared emergency reporting smoke in the cockpit and returned to the airport. The airplane landed safely.	The incident was under investigation.
2. Aug	Boeing 737-800	Cruise	Cabin	The right hand engine failed about 30 minutes into the flight. The airplane landed safely. Passengers reported, they noticed a sharp bang followed by a burning smell.	Technical problem. The incident was under investigation.
2. Aug	Boeing 757-236	Descent	Cabin	The aircraft declared an emergency during descent. A status message was seen on the flight deck along with smoke in the cabin. An acrid smoke was also smelled on the flight deck. The flight crew went on oxygen and declared emergency. The flight landed normally.	Lack of information.
30. Jul	Airbus A330-200	Climb	Cabin	Light haze appeared in the cabin due to an air conditioning problem. The crew declared emergency and returned to the airport, where the airplane landed safely.	Air conditioning problem.
26. Jul	Boeing 757-200	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to divert, where the airplane landed safely.	Lack of information.
25. Jul	Boeing 757-200	Cruise	Cabin	The crew declared emergency, reported smoke in the cabin, and requested to return to the airport. About 5 minutes later the crew reported that the source of the smoke had been put out.	Lack of information.

24. Jul	de Havilland Dash 8-400	Cruise	Cabin	The aircraft diverted when haze/smoke began to come down from the ceiling of the cabin. The airplane landed safely.	Technical failure.
20. Jul	Boeing 767-300	Cruise	Cabin and cockpit	The aircraft diverted after the crew declared emergency and reported smoke in both cabin and cockpit. The airplane landed safely.	Lack of information.
19. Jul	Boeing 747-400	Cruise	On board	The aircraft diverted after smell of smoke developed on board followed by white haze appearing at the ceiling of the airplane. The airplane landed safely.	Leak from air conditioning system.
17. Jul	Boeing 757-200	Cruise	Cockpit	The aircraft diverted after the crew reported smoke in the cockpit. The airplane landed safely.	Attending fire fighters found some haze, but no fire or heat.
17. Jul	Embraer ERJ-145	Cruise	Cabin	The aircraft returned to the airport after smell of smoke was detected in the cabin. The airplane landed safely.	Lack of information.
17. Jul	Airbus A320-200	Cruise	Cabin	A strong noxious ammonia smell developed causing nausea to some cabin crew and passengers. The airplane landed safely.	Found no explanation
14. Jul	CRJ-900	Cruise	On board	Smell of smoke was noticed on board. The crew decided to divert, where airplane landed safely.	Lack of information.
11. Jul	Boeing 747-436	Unknown	Cabin	Fumes and smoke were noticed in the cabin when the engines were being started during pushback. The intensity of the fumes increased and as the aircraft came to a halt on the stand an emergency evacuation was carried out.	Found no explanation.
7. Jul	McDonnell Douglas MD-88	Cruise	Cockpit	The aircraft diverted after the crew declared emergency and reported smoke in the cockpit. The airplane landed safely.	Lack of information.
6. Jul	McDonnell Douglas MD-83	Cruise	Cabin	The airplane diverted when a smoky odour was noticed in the cabin. The airplane landed safely after the crew considered diverting.	Lack of information.
3. Jul	Airbus A320-200	Cruise	Cabin	The airplane diverted due to smoke in the cabin. The airplane landed safely, a passenger needed to be treated at the airport.	Lack of information.
2. Jul	Boeing 757-200	Cruise	Cockpit	The crew declared emergency due to smoke in the cockpit. Attending emergency services observed fire detectors going off. However, they saw no smoke.	Lack of information.
2. Jul	Airbus A320-200	Climb	Cabin	Smoke started to appear in the cabin. The crew declared emergency and returned to the airport, where the airplane landed safely.	Lack of information.
30. Jun	Airbus A319-100	Cruise	On board	A flight attendant detected a burning acrid smell on board. The crew decided to divert. In the meantime passengers in the first 10 rows started to cough. The airplane landed safely. Three passengers complaining about shortness of breath and burning eyes were taken to a hospital.	Lack of information.

30. Jun	de Havilland Dash 8-100	Climb	Cabin	The aircraft returned to the airport after an engine showed a temperature indication shortly after take-off and had to be shut down. The airplane landed safely. Passengers reported a strong smell of burning rubber in the cabin developing after take-off.	Lack of information.
29. Jun	Boeing 737-500	Cruise	Cabin	Smoke filled the cabin. The airplane diverted and landed safely, no injuries occurred.	Technical defect.
29. Jun	Boeing 737-800	Cruise	Cockpit	The crew reported smoke in the cockpit and decided to return to the airport, where the airplane landed safely shortly after take-off. The airline reported, that there was no fire on board, some light haze smelling of oil was visible and an oil indication illuminated.	Oil leakage.
28. Jun	Airbus A310-300		Cabin	Smoke started to fill the cabin. The crew declared emergency and returned to the airport, where the airplane landed safely.	Air conditioning system.
27. Jun	Airbus A320-200	Climb	Cabin	The crew declared emergency reporting smoke in the rear of the cabin shortly after take-off from the airport and decided to return. The airplane landed safely.	Lack of information.
27. Jun	Airbus A330-300	Cruise	Cabin	The aircraft diverted after smoke became visible in the cabin about 50 minutes into the flight and a source of the smoke could not be determined by the flight attendants. The airplane diverted and landed safely.	Attending fire services could not detect any source of heat or fire.
22. Jun	McDonnell Douglas MD-83	Landing	Cabin	The crew started the auxiliary power unit (APU) after landing. Smoke appeared in the cabin immediately thereafter prompting the crew to initiate an evacuation.	APU.
21. Jun	Airbus A319-100	Climb	Cabin	A smell of smoke developed in the cabin. The aircraft returned to the airport.	The airplane landed safely, emergency services could not establish any fire or heat.
5. Jun	Boeing 737-800	Cruise	Cabin	Intermittent smell in the rear of the cabin while cruising. Did not detect the source. Cabin crew presented various symptoms on descent prior to landing. Two of them used oxygen before recovering sufficiently to resume their duties.	No explanations of the cause.
4. Jun	Boeing 757-200	Cruise	Cabin	A loud bang was heard from the left hand engine. Shortly thereafter smoke began to fill the cabin. The crew shut down the engine, declared emergency and diverted, where the airplane landed safely.	Oil leakage.
2. Jun	Boeing 757-200	Cruise	On board	The crew declared emergency reporting smoke on board and diverted. The airplane descended and landed safely.	Lack of information.
1. Jun	Embraer ERJ-	Initial	Cabin	A burning smell of rubber developed in the cabin. The airplane	Fluids entering the cabin via the air

	170	climb		returned and landed safely.	conditioning system.
20. May	McDonnell Douglas MD-83	Landing	Cabin	Smell of burning plastics was noticed in the cabin. While the airplane taxied to the gate, thick smoke entered the cabin appearing to come from the air conditioning vents. The airplane was stopped and evacuated onto the taxiway. Passengers reported that the smoke affected respiration and eyes.	Technical problem.
18. May	McDonnell Douglas MD-83	Cruise	Cockpit	The crew reported smoke in the cockpit. The airplane landed safely on runway and taxied to a gate, where passengers disembarked normally.	Lack of information.
15. May	Boeing 757-300	Cruise	Cockpit	The crew declared emergency reporting smoke in the cockpit and diverted. The airplane made a safe visual landing. The smoke dissipated after landing.	Emergency services could not establish a source of fire or heat. Engineers are currently examining the aircraft to find the source of the smoke.
12. May	Boeing 767-300	Cruise	Cabin	The aircraft was en route, when cabin crew observed smoke in the cabin. The flight crew declared emergency and diverted for a safe landing.	Emergency services could not establish a source of fire or heat.
12. May	Canadair CRJ-200	Cruise	Cockpit	The crew rearranged the bleed transfer resulting in smoke appearing in the cockpit and in the lavatory. The crew declared emergency, reset the bleed transfer to the previous setting and shut the APU down. The smoke dissipated again, the aircraft landed safely.	The incident was under investigation.
6. May	Avro RJ-85	Cruise	Cabin	The aircraft initiated an emergency descent due to smoke in the cabin.	Lack of information.
29. Apr	Embraer ERJ-170	Climb	Cabin	Smoke originating from the air conditioning system entered the cabin shortly after take-off. The airplane landed safely. The airplane taxied to the gate, passengers disembarked normally.	Lack of information.
24. Apr	Embraer ERJ-135	Descent	Cockpit	The crew reported smoke in the cockpit about 7 minutes prior to estimate landing. The landing was accelerated, the airplane landed safely.	Technical defect.
1. Apr	Boeing 767-300	Climb	Cockpit	The crew declared emergency reporting smoke in the cockpit and diverted. The airplane landed safely.	Emergency services found no trace of heat or fire, the cause of the smoke is being investigated.
29. Mar	McDonnell Douglas MD-82	Climb	Cockpit	The crew declared emergency reporting smoke in the cockpit. The airplane landed safely.	Fire-fighters could not establish any source of fire or heat.

13. Mar	Airbus A330-200	Climb	Cabin and cockpit	The aircraft returned to the airport after thick smoke entered cockpit and cabin after take-off.	Problem with the air conditioning system.
12. May	British Aerospace BAe146-300	Climb	Cockpit	An acrid smell and visible haze developed in the cockpit. Both pilots started to feel unwell, the captain noticed deterioration in his own performance. Both pilots donned their oxygen masks, declared emergency and returned to gate for a safe landing.	The incident was under investigation.
12. May	Aerospatiale ATH-42-300	Cruise	Cabin	The aircraft returned to the airport when a strong burning smell developed in the cabin about 15 minutes into the flight followed by visible smoke out of the air conditioning system shortly thereafter.	Lack of information.
30. Apr	Boeing 747-400	Cruise	On board	The passengers noticed a burning smell on board about 2 hours prior to expected arrival. The crew declared emergency and decided to divert. The airplane landed safely.	Hydraulic leak.
14. Apr	Embraer ERJ-190	Grounded	Cabin	The crew reported smoke in the cabin after take-off and requested to return to the airport. The crew reported, that the smoke started to dissipate, but there was still haze in the mid cabin and it was still warm there. The airplane landed safely.	Lack of information.
14. Mar	Boeing 737-800	Cruise	Cockpit	The aircraft returned to gate after a burning smell developed in the cockpit during climb. The airplane landed safely.	Lack of information.
26. Feb	Embraer ERJ-145	Cruise	Cabin	The crew declared emergency after a smoke detector went off in the cargo department and passengers reported smelling smoke shortly before touchdown. The airplane landed safely.	Lack of information.
21. Feb	Embraer ERJ-170	Cruise	Cabin and cockpit	The aircraft returned to the airport after smoke was noticed in both cabin and cockpit. The landing was safe.	Malfunction of the air conditioning system.
19. Feb	Boeing 737-800	Grounded	Cabin	The aircraft rejected take-off when smoke entered the cabin.	Malfunction of the air conditioning system.
15. Feb	Canadair CRJ-200	Cruise	Cabin	The crew declared emergency reporting smoke in the cabin and diverted for a safe landing.	The incident was under investigation.
13. Feb	Aerospatiale ATR-72-500	Cruise	Cockpit	The aircraft was evacuated right before departure due to smoke in the cockpit.	Air conditioning system.
10. Feb	Embraer ERJ-145	Cruise	Cabin	The crew declared emergency reporting smoke in the cabin and diverted for a safe landing.	Lack of information.
5. Feb	Embraer ERJ-145	Cruise	Cabin	The aircraft diverted due to smoke in the cabin.	Lack of information.
28. Jan	Boeing 737-800	Grounded	Cabin	Strange fumes in the cabin prompted the crew to return to the gate.	Lack of information.

24. Jan	Boeing 777-200	Cruise	Cabin	The crew declared emergency and diverted to the nearest when smoke became visible in the cockpit and smell of smoke was noticed in the first class cabin. The flight crew donned their oxygen masks, and the passenger oxygen masks were not deployed.	Lack of information.
24. Jan	Boeing 737-300	Cruise	Cockpit	The crew declared emergency reporting smoke in the cockpit and diverted for a safe landing.	Lack of information.
15. Jan	Airbus A320-200	Cruise	Cabin	The crew declared emergency and diverted after passengers reported to have smelled smoke. The airplane landed safely.	No traces of fire or smoke were found.
15. Jan	de Havilland Dash 8-100	Cruise	Cabin	The flight crew smelled smoke and shortly thereafter saw smoke. The cabin crew confirmed seeing smoke in the cabin, too. The crew requested to descend and return to the airport.	While at 11 000 feet the crew turned off both bleed air valves, which brought the smoke to dissipate.
11. Jan	Embraer ERJ-190	Cruise	Cockpit	Smoke appeared in the cockpit while the airplane was en route. The aircraft diverted and landed safely.	Lack of information.
6. Jan	Boeing 777-200	Cruise	Unknown	The aircraft returned to the airport after the left hand engine failed with a loud metallic sound while climbing through 8000 feet, followed by an acid burning smell and a fire warning for the left engine.	Lack of information.
5. Jan	Embraer ERJ-145	Cruise	Cockpit	The crew declared emergency reporting smoky haze in the cockpit. The haze dissipated before the landing. The landing was safe, and the passengers disembarked normally.	The incident was under examination.
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29. Des	Canadair CRJ-200	Initial climb	Cockpit	Crew reported smoke in the cockpit.	Lack of information.
26. Des	Canadair CRJ-700	Initial climb	Cabin	Crew declared emergency reporting a smoke detector had gone off shortly after take-off. The airplane returned or a safe landing. Passengers reported that smoke became visible in the cabin.	Lack of information.
25. Des	de Havilland Dash 8-100	Cruise	Cockpit	Crew declared emergency reporting smoke filling the cockpit and diverted.	Emergency services found no trace of fire.
24. Des	Boeing 737-800	Grounded	Cabin and cockpit	The flight crew reported that the de-icing began before the airplane had completed the push back. The APU was running at the time. Smoke began filling the cockpit and cabin. The flight crew got the de-icing crew to stop, and began smoke removal procedures. FAA spokesman reported at least 23 people complaining about eye irritation were brought to hospital. The airport had earlier reported 2	The airplane filled with smoke while the de-icing was in progress. Maintenance was investigating how the fumes could enter the cabin.

				people in critical condition.	
11. Des	Boeing 767-300	Initial climb	Cabin	Crew declared emergency about one minute after take-off, reporting a smoke detector had just gone off. The airplane returned for a safe landing about 10 minutes after take-off. The airplane was inspected by emergency services. A passenger reported that a strange smell appeared and white smoke swept along the ceiling.	Lack of information.
7. Des	Boeing 737-800	Climb	Cabin	Toxic smoke began to emerge from the air conditioning outlets, with passengers panicking and showing first indications of suffocating. The oxygen masks in the cabin were not released. As the airplane descended, the smoke began to disperse. The landing 15 minutes later was safe, medical emergency services immediately entered the aircraft to provide help.	The smoke was likely caused by hydraulics oil. The problem was within the air conditioning system.
5. Des	Boeing 767-300	Cruise	Cockpit	Crew declared emergency and diverted after a smell of smoke developed in the cockpit of the airplane.	Lack of information.
3. Des	Embraer EMB-120	Initial climb	Cockpit	Shortly after take-off, smoke started to fill the cockpit.	Fire services did not find any trace of fire, but had to remove the smoke from the cockpit. The cause of the smoke has not yet been determined.
30. Nov	Boeing 737-800	Cruise	Cabin	Crew declared emergency following engine problems and decided to divert. During the diversion the cabin started to fill with smoke.	Lack of information.
28. Nov	Canadair CRJ-200	Climb	Cockpit	Crew smelled smoke in the cockpit.	Attending fire services found no trace of fire.
25. Nov	de Havilland Dash 8-400	Climb	Cabin	A smell of smoke developed on board. The cabin started to fill with white haze.	Lack of information.
24. Nov	Canadair CRJ-200	Cruise	Cabin and cockpit	Crew declared emergency due to smoke filling both cockpit and cabin and returned to the airport.	Attending fire services found no trace of fire, the source of the smoke is unclear.
19. Nov	Airbus A320-200	Climb	Cabin	Crew declared emergency due to smell of smoke in the cabin. The airplane landed safely.	British Midland claimed the aircraft would be checked to find the source of the smell.
18. Nov	de Havilland Dash 8-200	Descent	Cockpit	Crew declared emergency about 10 minutes prior to landing at the destination because of smoke in the cockpit.	Engineers were inspecting the aircraft.
11. Nov	Boeing 717-200	Cruise	Cabin	Crew declared emergency and diverted due to smoke in the cabin.	Lack of information.

5. Nov	Airbus A319-100	Initial climb	Cockpit	Crew declared emergency shortly after take-off due to a smell like burning rubber in the cockpit, stopped climbed and returned to Winnipeg.	Air Canada reported, that the air conditioning units had been serviced and residual lubricant produced a burning smell in the aircraft.
24. Oct	Airbus A320-200	Climb	Cabin	Aircraft returned to the airport after a chemical smell, also described as fuel smell, was noticed in the cabin after take-off.	Lack of information.
23. Oct	Embraer EMB-170LR	Cruise	Cockpit	Crew declared emergency and diverted after the crew noticed smoke in the cockpit.	Lack of information.
16. Oct	Airbus A340-500	Cruise	Cabin	The aircraft returned after a chemical odour, also described as burning smell, was detected in the cabin. Passengers reported that no smoke or haze was visible inside the cabin. A flight attendant had smelled the odour in the back of the cabin.	The Civil Aviation Safety Authority (CASA) indicated to open an investigation into the incident.
13. Oct	Boeing 757-200	Descent	Cabin	The crew declared emergency while approaching the destination due to fumes in the cabin.	Lack of information.
11. Oct	Boeing 777-300	Cruise	Cabin	The aircraft returned after smoke was detected in the cabin.	The cause of the smoke was investigated.
10. Oct	Airbus A340-300	Cruise	Cockpit	Aircraft returned after smoke appeared in the cockpit.	The airplane was examined by emergency services after it stopped.
2. Oct	Aerospatiale ATR-72-200	Initial climb	On board	The aircraft returned after take-off due to smell of smoke on board.	No traces of fire or technical malfunctions were found. The smell was identified to come from the air conditioning system due to overload.
29. Sep	McDonnell Douglas MD-11	Cruise	Cabin	Passengers noticed a smell of smoke coming from the air-conditioning. While cabin crew started to search the cabin for the source of the smell, the flight crew was able to isolate the faulty air conditioning unit and brought the smell to dissipate.	The airline confirmed a break down in one of the airplane's air conditioning system.
28. Sep	Boeing 737-700	Descend	On board	Crew declared emergency because of a strong burning plastics like smell on board.	The airplane was checked out by fire services. No fire was detected.
26. Sep	Embraer ERJ-135	Cruise	Cockpit	Crew declared emergency and diverted after smoke was smelled in the cockpit.	Fire fighters did not find any trace of fire, the source of the smoke was unclear.
18. Oct	Airbus A320-200	Climb	Cockpit	Crew declared emergency and returned to the airport due to smoke in the cockpit.	Emergency services standing by the arrival determined that there

					was no fire. The source of the smoke was unclear.
14. Sep	Boeing 737-300	Cruise	Cabin	Crew declared emergency and diverted due to fumes in the cabin.	Lack of information.
13. Sep	Airbus A319-100	Climb	Cabin	The passengers reported that about 15 minutes into the flight a burning smell developed in the cabin. The aircraft returned to the airport.	Oil lubrication problem developed in one of the engines.
13. Sep	Embraer ERJ-135	Cruise	Cabin	Crew declared emergency because of smoke in the cabin about 20 minutes into the flight and diverted.	The cause of the smoke was unknown.
10. Sep	Airbus A319-100	Climb	Cockpit	Cockpit crew smelled smoke in the cockpit, apparently coming from the air conditioning. The crew decided to return to the airport for a safe landing.	Lack of information.
8. Sep	Airbus A320-200	Climb	Unknown	Crew noticed a hydraulics leak shortly after take-off from the airport and decided to return.	The airline confirmed a hydraulics leak, the fluid of which entered engines and air conditioning systems causing the smell on board.
4. Sep	McDonnell Douglas MD-82	Cruise	Cockpit	Crew declared emergency due to an acrid smell and haze in the cockpit. The airplane returned to the airport for a safe landing.	American Airlines reported that apparently residual oil in the Auxiliary Power Unit (APU) was heated up causing the smell and haze.
4. Sep	Boeing 767-300	Grounded	Cabin and cockpit	White smoke developed in the cockpit and the cabin.	Engineers are currently conducting a thorough investigation into the cause of the incident, which is understood to be related to a cooling fan malfunction, which was immediately deactivated."
23. Aug	Airbus A319	Descend	Cockpit	Crew declared emergency reporting smoke in the cockpit while approaching the destination.	No trace of fire was found.
15. Aug	Boeing 737-800	Grounded	Unknown	The aircraft was evacuated shortly before take-off, when dense smoke appeared in the rear of the airplane.	Lack of information.
7. Aug	Boeing 737-700	Climb	Unknown	Crew declared emergency and returned to the airport after they smelled smoke.	Responding fire fighters found no trace of fire.

6. Aug	Airbus A320-200	Descent	Cockpit	Crew declared emergency reporting smoke in the cockpit and an active fire alert while approaching the destination.	When the airplane was entered by fire fighters, there was no report of fire, only a strange smell on board. The cause of the fire alert was investigated.
6. Aug	Boeing 767-200	Unknown	On board	Burning smell on board. The crew requested to return to the airport.	Lack of information.
6. Aug	Boeing 777-200	Grounded	Cabin	Crew rejected take-off, when smoke was detected in the cabin. One passenger, who left his seat in panic while the airplane was still moving, received minor injuries.	It was assumed, that the smoke came from the engine exhaust.
5. Aug	Boeing 757-200	Cruise	Cabin	Aircraft returned to the airport after smoke appeared in the cabin. Passengers reported that they smelled smoke about 20 minutes into the flight, then haze started to fill the cabin. Oxygen masks were deployed.	The FAA reported that a broken oil seal had allowed oil to spray into the engine, contaminating bleed air supplying the air conditioning system with haze.
1. Aug	Embraer ERJ-195	Cruise	Unknown	Crew declared emergency and diverted after smell of smoke was noticed by the flight crew.	Flybe reported that a failure of the air conditioning system was suspected as cause of the smell.
31. Jul	Boeing 757-200	Cruise	Cockpit	Crew declared emergency and diverted reporting smoke in the cockpit.	No evidence or indication of fire was discovered on board of the aircraft.
28. Jul	McDonnell Douglas MD-88	Cruise	Cockpit	Aircraft diverted due to smoke in the cockpit.	Lack of information.
22. Jul	Boeing 737-600	Initial climb	Cockpit	Crew declared emergency and returned to the airport shortly after take-off, when the crew reported smelling smoke in the cockpit.	Westjet said the problem was a strange odour. The airplane was thoroughly checked to identify the source of the smell.
16. Jul	Canadair CRJ-700	Cruise	Cockpit	Crew reported light smoke in the cockpit and decided to divert. When the crew switched the air conditioning off in flight, the smoke dissipated.	Lack of information.
14. Jul	Boeing 737-800	Grounded	Cabin	A severe thunderstorm arrived over the airport. The crew decided to delay departure until the thunderstorm had passed, when suddenly smoke appeared in the cabin. The passengers were evacuated.	Engineers suspected a fault in the air conditioning system as cause of the smoke.
13. Jul	Canadair CRJ-900	Descend	Cabin	Passengers smelled and saw smoke in the cabin.	Lack of information.

24. Jun	Boeing 757-200	Cruise	Galley	Crew diverted due to smoke in the galley.	Lack of information.
23. Jun	Boeing 757-200	Cruise	Cockpit	The crew noticed smoke and smell of fuel in the cockpit. As the airplane had loaded hydrochloric acid, a hazmat material, hazmat crews were dispatched, but found the container intact and no fluid spilled.	The cause of the smoke and smell of fuel in the cockpit has not been identified.
19. Jun	Boeing 757-200	Climb	Cabin	Passengers and crew noticed a strange odour inside the aircraft. Many passengers complained about the fumes saying they were sickened by the odour.	Lack of information.
18. Jun	Embraer ERJ-145	Descend	Cabin	Crew declared emergency while on approach to the destination reporting smoke in the cabin.	The airplane was checked out by fire services, but no trace of fire was found.
17. Jun	Boeing 747-400	Cruise	Cabin	Fumes in the cabin were noticed about one hour into the flight.	Lack of information.
16. Jun	Embraer 120 Brasilia	Cruise	Cabin	Crew declared emergency and diverted after smoke developed in the passenger cabin.	Lack of information.
14. Jun	Boeing 737-700	Descend	Unknown	Crew reported that they smelled smoke. The landing was safe.	Lack of information.
8. Jun	Boeing 737-300	Cruise	Cabin	Passengers smelled smoke in the cabin.	Southwest sent a maintenance team to inspect the airplane. Lack of information.
6. Jun	Boeing 737-700	Initial climb	Cabin	Shortly after take-off after passengers in the rear of the cabin smelled smoke. The smoke stopped and dissipated before landing.	Origin and cause of the smoke were investigated.
5. Jun	Fokker 100	Descend	Cabin	The crew performed an emergency descent due to a leaking door seal causing rapid loss of pressurization. Oxygen masks in the cabin were manually deployed by the crew. Passengers reported smell of smoke a bit later, which dispersed again as the airplane levelled off.	Lack of information.
2. Jun	de Havilland Dash 8-300	Cruise	Cabin	Crew reported problems with the left hand engine, subsequently followed by smell of smoke in the cabin.	Lack of information.
30. May	Boeing 737-700	Descend	Cockpit	Crew declared emergency because of smell of smoke in the cockpit.	The smell was found to originate from a re-circulator of the air conditioning system.
11. May	Aerospatiale ATR-72	Grounded	Cockpit	Smoke developed in the cockpit.	Lack of information.
8. May	Boeing 757	Cruise	Cabin	Smell of smoke in the cabin.	No sign of fire was found on the aircraft.

2. May	Boeing 737-300	Descend	Cabin	Smoke and strong burning smell developed in the cabin. The crew managed a safe landing followed by an immediate evacuation.	Lack of information.
30. Apr	Boeing 707	Initial climb	Unknown	Aircraft returned to the airport after burning smell developed immediately after take-off.	Lack of information.
27. Apr	Boeing 737-800	Initial climb	Cockpit	Fumes were detected in the cockpit.	Lack of information.
22. Apr	Embraer ERJ-145	Cruise	Cockpit	Flight crew noticed smoke in the cockpit.	The smell was traced back to Trichlorpropylane, which got into the engine bleed air.
17. Apr	Boeing 757-200	Grounded	Cabin	Passengers noticed some strange smell when they boarded the airplane. Maintenance workers and the captain told them that the smell would clear once in flight with the air conditioning system working. The smell didn't subside after departure, and about 20 minutes into the flight smoke appeared and the airplane returned for a safe landing.	Lack of information.
16. Apr	Boeing 737-300	Cruise	Cabin	Aircraft diverted after smoke was seen in the rear of the airplane.	Result of a hydraulics problem.
14. Apr	MD-87	Climb	On board	A smell of smoke was noticed on board of the airplane. After landing the smell subsided, fire brigades could not find any source of smoke.	Lack of information.
4. Apr	MD-88	Cruise	Cockpit	Aircraft diverted after smoke developed in the cockpit.	Lack of information.
3. Apr	Boeing 737-200	Initial climb	Cabin and cockpit	Shortly after take-off smoke poured out of the air conditioning outlets.	According to the crew there was a problem with one of the engines.
1. Apr	Boeing 757-200	Unknown	Cabin	Aircraft returned to the airport after a pressure warning illuminated and passengers and flight attendants reported a chemical smell in the cabin.	Lack of information.
30. Mar	Embraer 145	Descent	Cockpit	Crew declared emergency while on approach to Indianapolis after smoke appeared in the cockpit.	Lack of information.
30. Mar	MD-82	Climb	Cabin	Passengers noticed a smoky smell in the cabin.	Lack of information.
28. Mar	MD-82	Initial climb	Cabin	Passengers noticed a smoky smell in the cabin.	Lack of information.
20. Mar	Embraer 145	Initial climb	Cockpit	Smoke appeared in the cockpit.	Lack of information.
18.	B777-300ER	Cruise	Cockpit	Crew smelt smoke in the cockpit.	No cause for the smoke was found.

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9. Mar	ATR-42	Grounded	Unknown	A burning smell was noticed in the aircraft. The crew elected to not begin take-off and evacuated the airplane on the spot.	The air conditioning system had a malfunction.
27. Feb	Dash 8-100	Cruise	Unknown	The aircraft returned to airport after a strange smell developed inside.	Lack of information.
27. Feb	Boeing 37-200	Cruise	Cabin	Aircraft diverted after smoke developed in the cabin that was released by a faulty air conditioning system.	Faulty air conditioning system.
26. Feb	Boeing 747-400	Cruise	Cabin	Smoke appeared in the cabin.	No fire was found.
4. Feb	Boeing 767-300	Cruise	Unknown	Flight attendant reported smell of smoke.	The origin or cause of that smell could not be established.
31. Jan	Boeing 757-200	Cruise	Cabin	Smoke developed in the cabin, apparently stemming from the back of the plane.	Lack of information.
22. Jan	Airbus A320-200	Unknown	Cockpit	The crew reported visible light smoke in the cockpit	Lack of information.
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31. Des	Boeing 777-200	Cruise	Cabin	The left hand engine started to run rough with "terrible" noises (according to passenger reports) and a smell of burning oil developed in the cabin.	Lack of information.
21. Des	Airbus A319	Descent	Cabin	Smoke developed in the cabin.	Lack of information.
21. Des	Boeing 777	Cruise	Cockpit	Smoke developed in the cockpit about one hour into the flight.	Lack of information.
14. Des	Boeing 777-200	Descent	Cabin	Smoke was filling the cabin. The crew was unable to determine the source of the smoke. The first officer noticed a low engine oil indication of engine #2.	The NTSB released their final report stating that the probable cause of the accident was: *"...the failure of an engine bearing, allowing oil to migrate into the environmental system, and resulted in the smoke in the cabin."*
23. Nov	Airbus A319	Initial climb	Cabin	Dense smoke appeared in the rear passenger cabin, accompanied by a smell of burnt plastic. During return to land, the smoke cleared.	The source of the smoke has not been identified.

23. Nov	Boeing 767	Cruise	Cabin	A passenger reported to a flight attendant that he could smell fumes coming from the gasper air vent above his seat. The passenger later reported that the fumes smelled like jet exhaust. The passenger became unconscious, and was administered oxygen. He regained consciousness within a few seconds of being administered oxygen. A second passenger, seated in the area, also reported feeling nauseous at the time. There were no other reports of adverse effects from any of the other passengers or crew on board the flight.	Application of corrosion inhibiting compounds in the aircraft's cargo bays. The investigation could not determine whether the passengers' symptoms were as a result of fumes in the aircraft cabin, or whether there were other unidentified medical conditions that may have contributed to the symptoms exhibited by the two passengers.
6. Sep	BAe 146-300	Cruise	Unknown	The flight crew became aware of an unusual smell, and there was no smoke or haze. The commander later described how he felt as similar to being inebriated and that he found it difficult to concentrate. The co-pilot initially felt she had a reduced capacity to fly the aircraft, but this feeling quickly passed. One cabin crew member felt light headed, sick and distressed. The other cabin crew member felt tired and slightly sick. The origin of the fumes was traced to the forward toilet and was probably due to a chemical in the toilet. It was not possible to positively determine to what extent the symptoms of the crew were a result of the fumes or of the stress associated with the in-flight fumes emergency, or a combination of both.	The fumes may have been as a result of formaldehyde, released as a degradation product of a toilet chemical added during maintenance.
5. Aug	S.A.A.B Aircraft AB 340B	Initial climb	Cabin and cockpit	First flight after a routine compressor wash carried out on the engines. An odour, which had been apparent inside the aircraft during the pre-flight procedure and taxi, and which was described as 'similar to curry', became much stronger from just before rotation until about two minutes after take-off. The operator reported that their compressor wash procedure had been followed, and was unable to explain the subsequent ingress of fumes to the cockpit and cabin of the aircraft.	Compressor wash fluid was heated.
23. Jul	Fokker 27	Initial climb	Cabin	During the initial climb, the cabin crew advised the flight crew that there was smoke haze in the cabin.	An examination of the right engine indicated that the number-4 bearing air/oil seal had failed.

22. May	Airbus A320-200	Descent	Cabin	Smoke developed in the cabin during final approach.	German authorities said that the cause of the incident was oil fumes developing in an engine, which were distributed into the cabin through the air conditioning system, rating the incident as "harmless".
30. Mar	Dornier 228-202	Cruise	Unknown	The 2-pilot crew became light-headed and felt faint. They subsequently made a full recovery. The safety issues identified were the failure of the cockpit voice recorder to function as designed and the lack of portable oxygen for sustained flights at moderate altitudes.	No cause could be identified.
16. Mar	McDonnell Douglas MD-80	Descent	Flight deck	Smoke on the flight deck.	Lack of information.
19. Feb	BAe 146-300	Climb	Cockpit	The flight crew noticed an unusual smell in the cockpit and shortly thereafter began to feel unwell. They immediately donned oxygen masks, after which their condition improved significantly. An emergency was declared and the aircraft returned, where an uneventful landing was completed.	Oil leak from the No 1 engine, which had allowed oil fumes to enter the cockpit and cabin air supply.
19. Feb	Boeing 747-400	Cruise	Cockpit	Smoke occurred in the cockpit.	Engineers dismantled the left hand side of the cockpit to find the cause of the smoke.

Appendix E: Calculations - Frequency of Possible Fume Events

2007: 14 incidents/365 days = 0.038 events per day
2008: 84 incident/365 days = 0.23 events per day
2009: 95 incident/365 days = 0.26 events per day
2010: 100 incident/365 days = 0.27 events per day
2011: 133 incident/365 days = 0.36 events per day
2012: 89 incident/365 days = 0.24 events per day
2013: 110 incident/365 days = 0.30 events per day

The average (2007-2014) = $\frac{0.038+0.23+0.26+0.36+0.24+0.30}{7\ years}$ = 0.24 events per day

Appendix F: Calculations - Selection Bias

Knowledge about fume events:

$$\frac{x}{100} \times 2952 = 440$$

$$x = \frac{440 \times 100}{2952}$$

$$\underline{\underline{x = 14.9\ \%}}$$

Considered fume events a problem:

$$\frac{x}{100} \times 2952 = 272$$

$$x = \frac{272 \times 100}{2952}$$

$$\underline{\underline{x = 9.2\ \%}}$$

Where:

2952= No. of pilots and cabin crew who received the survey

440= No. of respondents who had heard about fume events

272= No. of respondents who considered fume events a problem