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Civil Aviation Safety Authority

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2008 to 2012



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Addendum

Pages	Change	Date
4, 8, 19, 20, 22, 58	Bureau of Infrastructure, Transport and Regional Economics (BITRE) hours flown data corrected to include charter hours inadvertently excluded from some aircraft types.	23 Oct 2014

Safety summary

Why did we do this research

This study has been undertaken in order to further understanding of the nature and impact of fumes and smoke related occurrences in relation to the safety of aircraft operations in Australia and, in doing so, evaluate associated data availability and suitability. This report also addresses recommendations from a 2011 report commissioned by the Civil Aviation Safety Authority (CASA) by an Expert Panel on Aircraft Air Quality that aviation safety agencies work together to provide a comprehensive study of cabin air contamination incidents.

The study was undertaken in two parts; the first involved an in-depth analysis of aviation safety data sets held by the Australian Transport Safety Bureau (ATSB), CASA and the Department of Defence for the 2008-2012 period. The second part of the study involved a basic risk analysis of smoke/fumes safety events using the bowtie risk model.

What the research found

There were over 1,000 fumes/smoke events reported to both the ATSB and CASA over the 5-year period. From a flight safety perspective, most were found to be minor in consequence. There was a single flight crew incapacitation event and a further 11 minor injury events to crew. In the higher risk occurrences, precautionary defences (most commonly diversions) were found to be effective in avoiding escalation of the event.

The British Aerospace BAe 146 was the aircraft type most commonly involved in fumes/smoke events when taking into account flying activity. The Airbus A380, Boeing 767, Embraer EMB-120 and E-190 were among other aircraft types that also had a higher than average rate of fumes/smoke occurrences over the period.

The most common source of fumes/smoke was aircraft systems issues, primarily relating to failure or malfunction of electrical and auxiliary power unit (APU) systems. Equipment and furnishings also featured highly as a source of fumes and smoke. Within this category, air conditioning and galley equipment were the most common sources of fumes/smoke. External sources of fumes/smoke and cargo/baggage related events were relatively rare.

The matching of CASA and ATSB data records provided valuable information on the issue of fumes/smoke which enabled visibility of occurrences from both an engineering and operational perspective. However, many reports of fumes/smoke events contained insufficient detail for coding of the source or affected components.

Safety message

Fume and smoke events are generally appropriately managed by flight and cabin crew resulting in little consequence. Good reporting by aircraft operators, with sufficient detail, to both the ATSB and CASA where relevant will assist ongoing efforts to monitor the risk of fume and smoke events.

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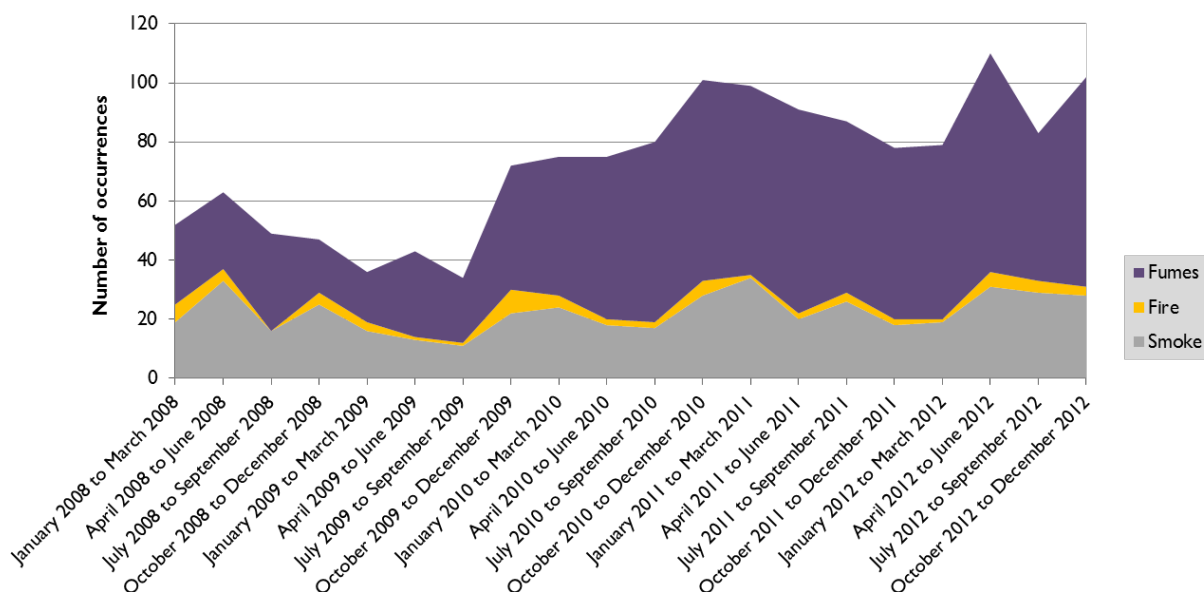
Context

The topic of cabin air quality has received considerable attention over the past 20 years. Much of this has been directed towards understanding the possible health effects of exposure to fumes on-board aircraft. In response to this issue, in 2008 the Civil Aviation Safety Authority (CASA) established an Expert Panel on Aircraft Air Quality (EPAAQ) to review the evidence regarding any linkage between exposure to fumes from heated engine and hydraulic oils and crew health. The scope of that review was limited to the internal leakage of chemicals into aircraft air conditioning systems. The report produced by the EPAAQ in 2011, *Contamination of aircraft cabin air by bleed air – a review of the evidence*, provides a comprehensive summary of the evidence and literature surrounding this issue to date, and based on its findings, a number of recommendations were made by the EPAAQ for further research into fumes on-board aircraft to increase understanding of their effects.

The EPAAQ report contained a number of recommendations. In response to three recommendations related to data and analysis (numbers 8, 10 and 11, see Appendix A), the Australian Transport Safety Bureau (ATSB), CASA, and the Directorate of Defence Aviation and Air Force Safety (DDAAFS) (representing the Department of Defence) agreed to work together to analyse fumes data for trends and common features through the Joint Agency Aviation Safety Analysis Coordination Group (JAASACG)¹.

Additionally, through separate routine trend monitoring of aviation safety incident reporting, both the ATSB and CASA had identified a statistically significant increase in fumes reporting since mid-2011. Figure 1 below shows the increase in the number of safety occurrences recorded as a result of notifications to the ATSB over the 5 years between 2008 and 2012 where pilots, cabin crew, or passengers detected fumes. The increase in fumes occurrences has been associated with a slight increase in occurrences involving smoke, though there has been little change in the number of reported fires on-board aircraft. The following graph (Figure 2) shows that in high capacity air transport operations², this increase in fumes reports is independent of growing flying activity³ over this period.

Figure 1: Fumes, smoke, and fire reporting to the ATSB (ASIRs), 2008 to 2012

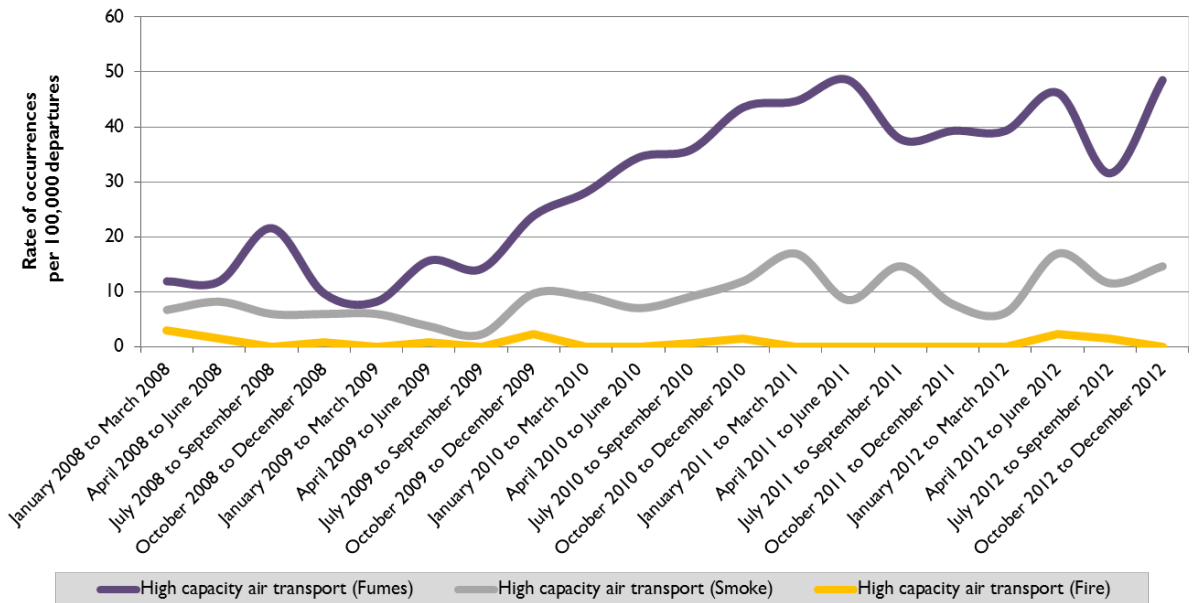


¹ The Joint Agency Aviation Safety Analysis Coordination Group (JAASACG) is a cross-Australian Government agency steering group of safety data managers, researchers and analysts from the ATSB, CASA, Airservices Australia, Department of Defence, and Department of Infrastructure and Transport. It was established in 2011 to encourage and facilitate co-ordinated research into aviation safety issues, and to better share transport safety data across government.

² High capacity air transport operations refers to operations in an aircraft that is certified as having a maximum capacity exceeding 38 seats, or having a maximum payload capability that exceeds 4,200 kg.

³ Activity data (departures) is sourced from the Bureau of Infrastructure, Transport and Regional Economics (BITRE). Departures for 2012 are estimated.

Figure 2: Fumes, smoke, and fire reported to ATSB (ASIRs) in high capacity air transport operations, 2008 to 2012, per 100,000 departures



In response to both occurrence trend monitoring results and the EPAAQ recommendations, CASA and the ATSB agreed on the need to explore the issue of fumes events more completely in order to understand the potential risk to flight safety.

Background: Fumes and aviation safety

Fumes on aircraft are wide ranging in nature as there are many potential sources for cabin air contamination. These sources include bleed air contamination, which is the subject of many Australian and international studies. The ATSB reviewed fumes events reported to the ATSB and CASA between 2008 and 2012, and found that more common sources of fumes are odours from electrical failures, air conditioning system and auxiliary power unit (APU) odours, galley fumes from ovens, food and coffee brewers, cleaning products, and from items packed in passengers' cabin luggage.

Most fumes events have little impact on normal operations and do not result in illness or injury to passengers. Many types of fumes are benign in nature – such as fumes from burnt food, or damp/musty fumes from air conditioning systems. Some types of fumes, such as those relating to electrical failures, plastics, dangerous goods carriage, and burnt engine by-products entering the air supply system, may have the potential to pose a health risk through eye/skin irritation, breathing difficulties, incapacitation or illness. This is especially the case when these fumes are associated with particulates (smoke) or fire.

In its report, the CASA Expert Panel on Aircraft Air Quality (EPAAQ) recommended a number of ways in which cabin air contamination incidents (and fumes/smoke occurrences more generally) could be analysed to better inform airlines and aviation safety organisations to reduce the incidence of these events. These included an analysis of fumes/smoke events with respect to the:

- number of incidents
- type of incidents
- aircraft types involved
- engine types involved
- flight phases involved
- companies involved
- dates and times
- witness statements.

The current report aims to document as much of the above as is available. To do this, it uses available data sources from:

- Operational notifications that may indicate that the event posed a risk to the safety of flight. These considered the nature of the fumes event and its outcomes – what the fumes/smoke smelt like, and what effect they had on the flight, passengers or crew.
- Maintenance notifications of aircraft defects which were linked to fumes and smoke events. These considered the root cause of the fumes event – where the fumes/smoke came from, and what generated them.

Further to this, it explored in depth those situations where both an operational and a maintenance notifications of a fumes event matched. This allowed a link to be established between operational notifications of fumes, and aircraft defects indicating the source of the fumes. The purpose of this matching exercise was to consider the likelihood and nature of normally reported aircraft defects that developed into a potential safety of flight issue through an effect on operations. The matched data was used to look at how often different precursors of fumes events led to an undesired outcome, and is discussed further in Appendix B.

This report looks at all notifications of fumes and smoke events to Australia's aviation safety regulators and investigators over the 5-year period between January 2008 and December 2012. As fumes can occur in association with smoke, or can be reported as 'smoke' or 'haze', both fumes and smoke occurrences were reviewed in this report.

The datasets interrogated were those of the:

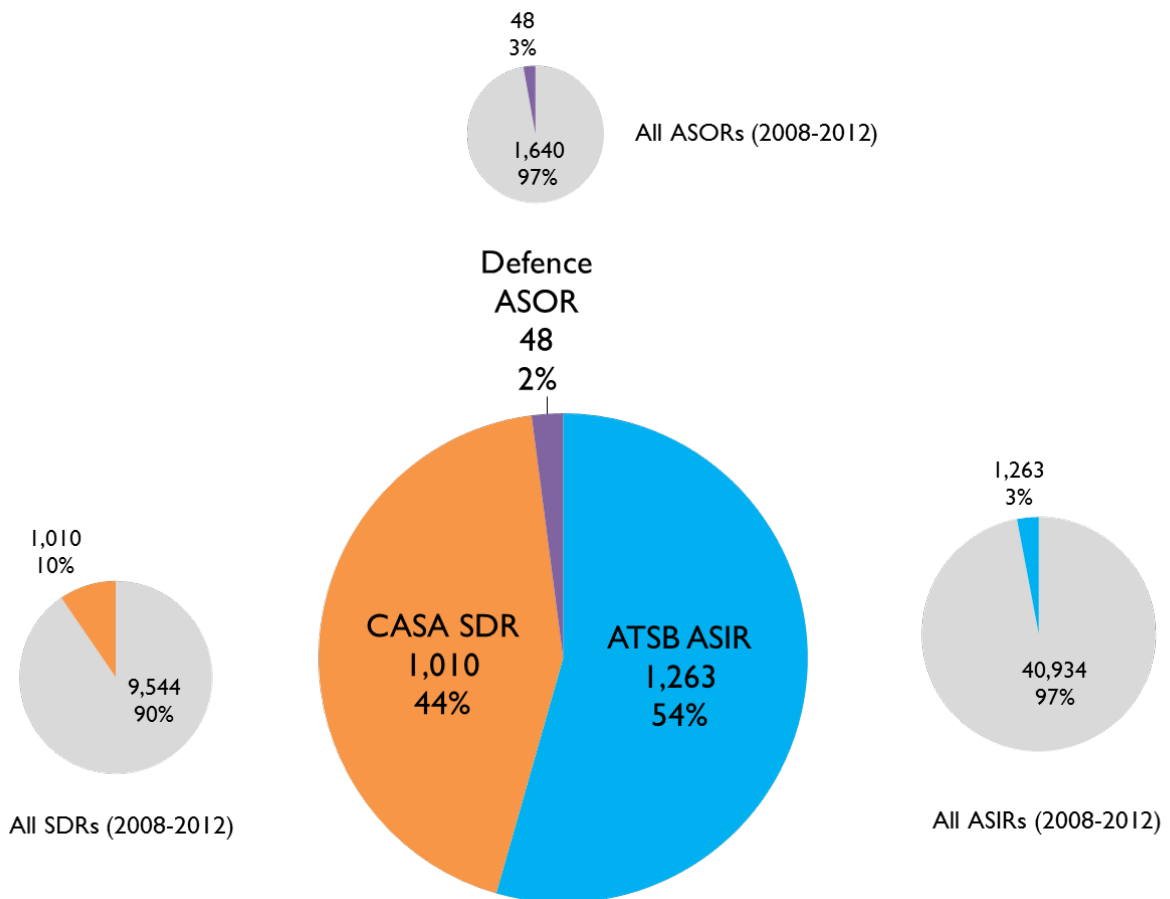
- ATSB (aviation safety incident reports, or ASIRs) for operational notifications of fumes/smoke events affecting Australian civil aircraft

- CASA (service difficulty reports, or SDRs) for maintenance notifications of fumes/smoke events affecting Australian civil aircraft
- the Department of Defence (aviation safety occurrence reports or ASORs) for operational and maintenance notifications of fumes/smoke events affecting Australian Defence Force-operated aircraft operations within Australia. Defence-related fumes/smoke notifications were provided by DDAAFS.

See Appendix C for explanations of the mandatory reporting requirements for these three agencies.

Figure 3 below shows the relative number of fumes/ smoke notifications of interest identified in each of these datasets between 2008 and 2012.

Figure 3: Fumes/smoke event reporting in Australia by agency, 2008 to 2012



Data analysis by agency

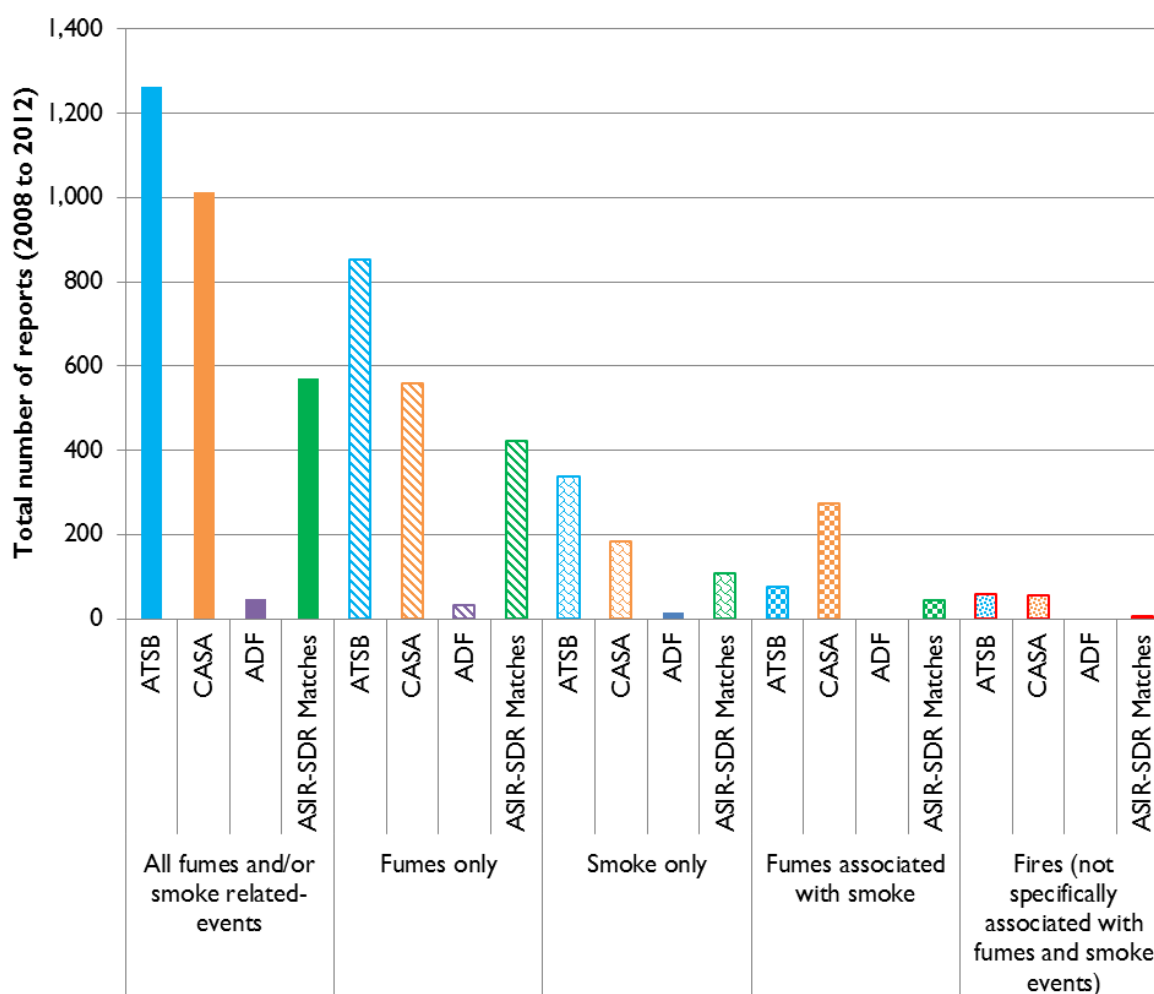
Fumes and smoke occurrences make up less than 5 per cent of aviation safety occurrences and maintenance events reported in Australia, as was shown in Figure 3. The following graph indicates the total number of events reported to the ATSB, CASA, and the Department of Defence over the 2008 to 2012 period involving fumes, smoke or fire, both as they occur either independently or together.

This graph shows that less than a third of fumes/smoke occurrences involved smoke; the majority were fumes only. Of this third, only a small proportion was associated with both fumes and smoke.

Fire events, regardless of association with smoke or fumes, were very rare relative to the other categories.

To draw a link between operational notifications of fumes/smoke, and aircraft defects indicating their source, ASIR and SDR fumes/smoke notifications were matched where possible. Further details on the matching method are provided in Appendix B.

Figure 4: Fumes, smoke and fire events reported by agency, 2008 to 2012⁴



There are some very good reasons why all ASIRs do not have an equivalent SDR, and vice versa. Many fumes/smoke notifications to the ATSB are followed up by a maintenance inspection that does not find a potential source or defect causing the fume/smoke, in which case an SDR would not be submitted to CASA. There are also other fumes/smoke detected that do not relate to an aircraft or equipment problem (such as fumes from cabin baggage or cargo, or smells from food) that are regularly reported to the ATSB, and would not have an accompanying SDR. Conversely, SDRs should be raised for all

⁴ SDR notifications to CASA referring to 'sparking' were classified in this report as fires.

aircraft defects that have the potential to impact safety, not just those that have resulted in an operational problem that has increased the risk of a safe flight. For example, unmatched SDRs include defects related to smoke detectors, or smoke occurrences that did not contaminate cabin air (such as excessive APU exhaust observed by ground personnel). These sorts of defects, which are often identified in routine maintenance tasks, are not normally reported to the ATSB, nor are they required to be unless the aircraft is boarded for flight. Some level of error is also expected in the data due to underreporting of fumes and smoke events.

The graphs below show the total number of ASIRs (Figure 5) and SDRs (Figure 6) relating to fumes/smoke reported by operation type between 2008 and 2012, and how many of those matched (that is, a notification was submitted to both agencies for the same fumes/smoke event).

They show that the vast majority of fumes/smoke-related ASIRs and SDRs are reported by air transport operators. This is also where the highest proportion of matched notifications was found (a mean of 45-55 per cent of relevant notifications matched across each of the 5 years). In both cases, the number of reported occurrences, and the number of matched notifications increased notably in the last few years (2010-12).

Figure 5: Fumes/smoke ASIRs reported to ATSB by operation type, 2008 to 2012

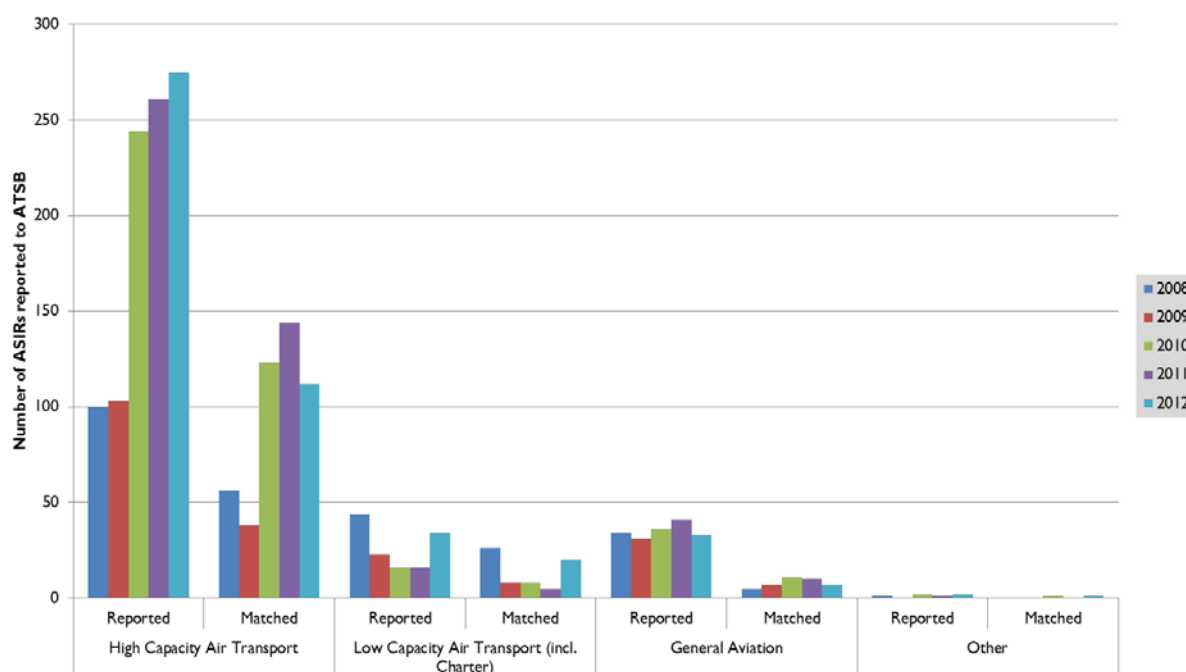


Figure 6: Fumes/smoke SDRs reported to CASA by operation type, 2008 to 2012

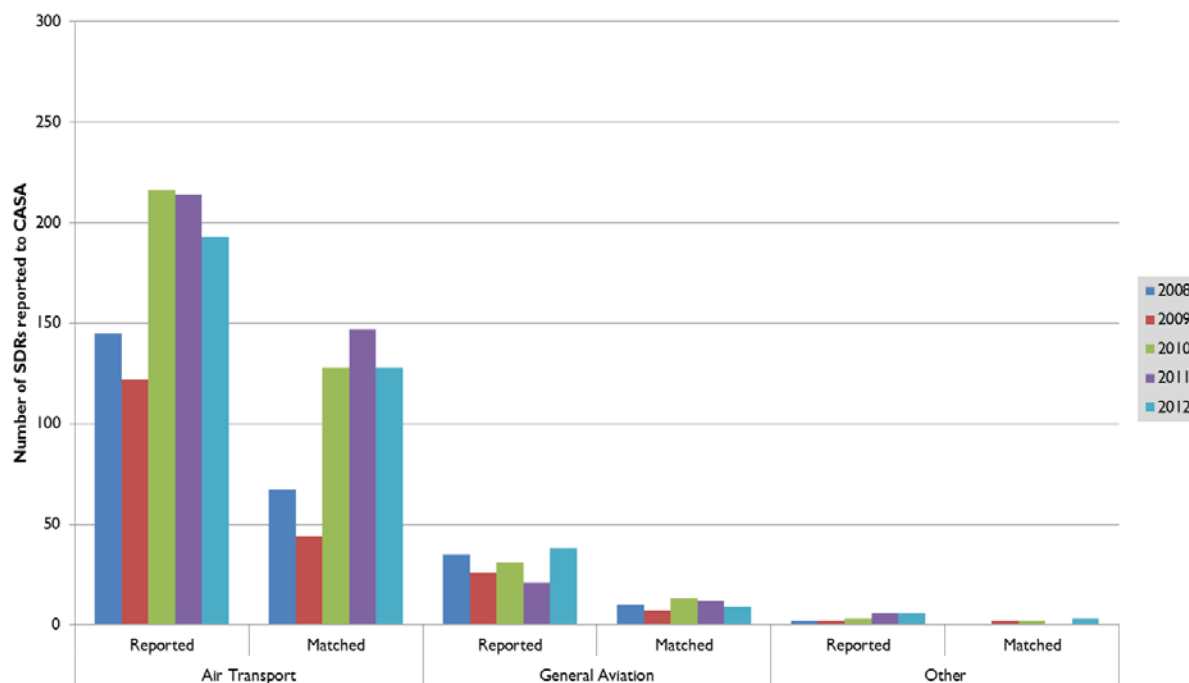
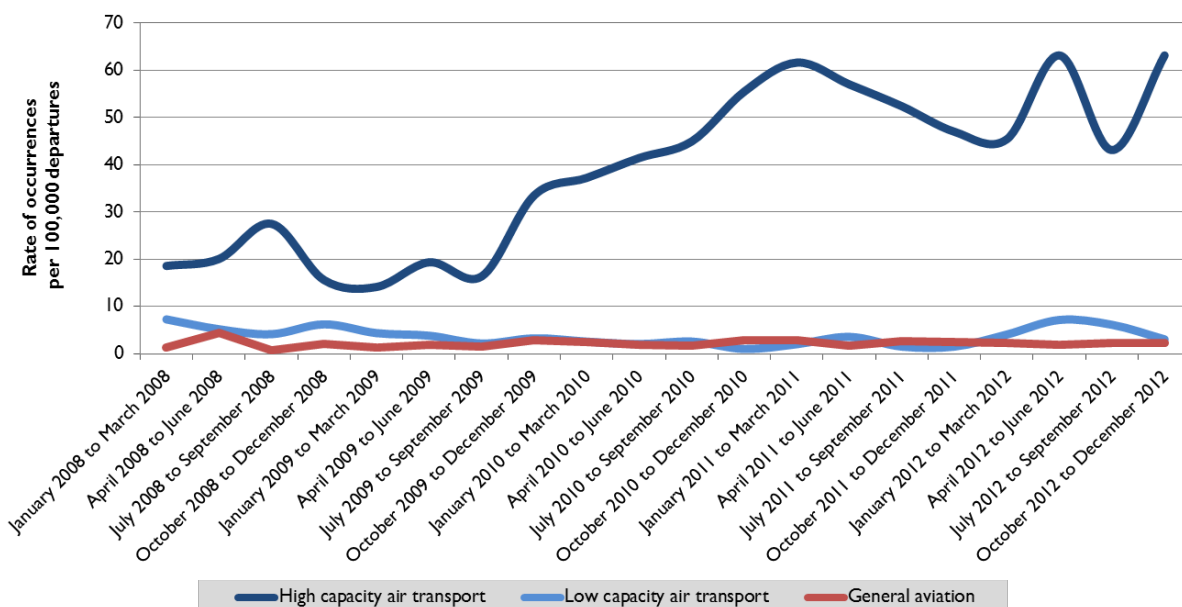


Figure 7 below highlights the increased reporting rate of fumes/smoke events per flight, and furthermore shows that fumes/smoke reporting by high capacity air transport operators has increased significantly over the 2008 to 2012 period when compared to low capacity air transport (including charter) and general aviation.

Figure 7: Fumes/smoke reported to the ATSB by operation type, 2008 to 2012, per 100,000 departures



There are differences in the reporting behaviours of different industry sectors for fumes/smoke events:

- Air transport operators who submitted an SDR were more likely to also submit an ASIR for the same event than vice versa.
- Operators of flying training aircraft were more likely to submit a fumes/smoke-related occurrence report to the ATSB, rather than via the CASA SDR scheme.
- The proportion of smoke/fumes occurrences (relative to all occurrence types) in military aircraft reported to DDAAFS (3 per cent) was the same as the proportion of smoke/fumes occurrence in

civilian aircraft reported to the ATSB (3 per cent) (see Figure 3). This suggests that the reporting rate of smoke and fumes occurrences in the Australian Defence Force is similar to that in civilian aviation.

There were not enough fumes/smoke-related ASORs reported by the Department of Defence to conduct further comparisons between Australian civil and military aircraft operations and fumes/smoke occurrences and reporting.

Types and locations of fumes/smoke

All of the 2,273 fumes/smoke-related notifications identified in the 2008-2012 period that were reported to the ATSB and CASA were reviewed to consider the type and location of fumes/smoke reported. The data collected and coded by each agency varied, considering either the type of fume or likely source of the fumes/smoke, and/or where they were detected in the aircraft.

- Since 1 January 2010, the ATSB classifies fumes and smoke notifications with information on the location of the fume/smoke, the likely source of the fume/smoke, and whether flight crew or cabin oxygen was used. Data prior to 2010 is not categorised.
- CASA does not classify the location or type of fume/smoke in SDR notifications, but categorises the likely source of the fume/smoke through identification of defects, the cause of the defect, and classification by ATA chapter⁵.

This variation in coding practices between agencies has been identified as an area for future improvement, and the ATSB and CASA are taking action to harmonise classification and coding standards for aviation safety data. To establish a comparable dataset for the type and source of fumes/smoke for CASA data, 322 ATSB fumes/smoke notifications submitted in 2011 were reviewed to identify 'types' of fumes (or 'smells') that were detected. The data suggested the following groups represent the majority of occurrences where the reporter described the fume/smoke: *burning, smoke or smoke smell, rubber, plastic, oily, fuel, exhaust, electrical, dusty/musty/damp or toilet, chemical, acrid or hydraulic fluid, and galley-related* (usually food or oven residue by-products). The same groups were applied to both ASIR and SDR data sets.

This review found that information provided to the ATSB in written occurrence summaries was often not specific enough to identify the source, let alone type of fume. No information was provided on the likely source of the fumes/smoke in 50 per cent of the ASIRs of these types reported since 1 January 2010.

As a result, a decision was made to only review SDRs related to fumes/smoke to identify and code what types of 'smells' were identified. Where more than one type of smell was reported, more than one of the categories above was coded against that notification. The location where the fumes/smoke was detected was also coded—cabin, cockpit, both, or neither (generally a fumes/smoke outside of the aircraft, or in a cargo hold separate to the cabin).

The existing coding of fumes/smoke source and location was maintained for ASIRs.

The graphs below (Figure 8 and Figure 9) show the proportions of the types of fumes/smoke (SDRs) and sources of fumes/smoke (ASIRs). The hatched areas indicate the proportion of ASIR-SDR matched notifications for each of those fumes/smoke types and sources. The satellite pie graphs show, for major sources and types of fumes/smoke, where the fume/smoke was detected in the aircraft.

⁵ The classification uses the American Transport Association (ATA) 100 system, which is a standard method used internationally by airlines, aircraft manufacturers and safety regulators to classify aircraft systems, maintenance procedures and components.

Figure 8: Type of fumes/smoke SDRs and ASIRs, by aircraft system/area, 2010 to 2012

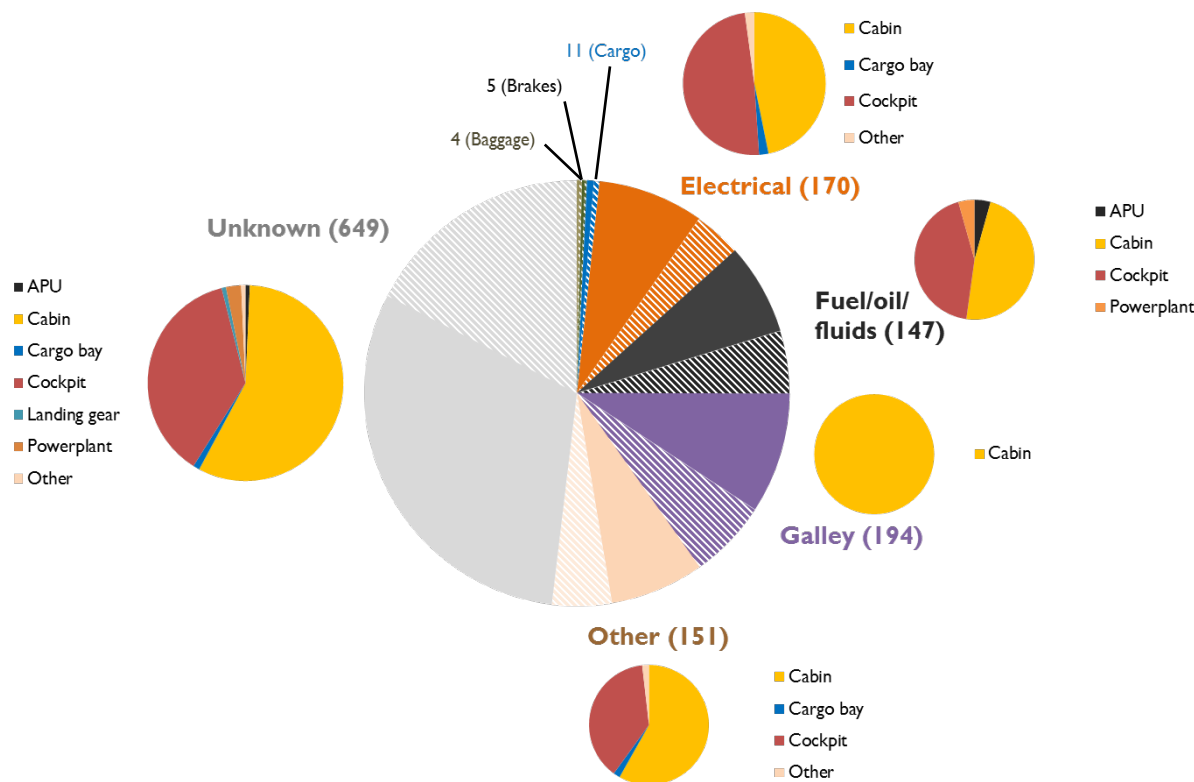


Figure 8 shows that for half of all fumes/smoke events reported to the ATSB between 2010 and 2012, the source was not known or not reported (49 per cent of ASIRs). The galley, fuel/oil/fluids, and electrical systems were found to be the more common sources of fumes/smoke. Most types of fumes/smoke were more likely to be detected in the cabin, though electrical fumes were more likely to be detected in the cockpit due to avionics failures, and fuel/oil/fluids fumes were about equally common in the cockpit and cabin. Fumes and smoke reported outside the aircraft (usually detected by ground personnel) were infrequently reported in ASIRs, limited primarily to fuel and oil fumes/smoke detected in the vicinity of the APU. Fumes or smoke from sources such as brakes, baggage, and cargo were either unlikely to be detected in the aircraft, or were not serious enough to constitute a flight safety risk (and hence were not reported to the ATSB). Fumes or smoke from cargo and baggage were mostly due to leaking fluids from checked passenger baggage, and were detected by ground handlers.

For most of the fumes/smoke sources shown in Figure 8, about 45 to 55 per cent of the ASIR notifications matched to a corresponding maintenance defect (SDR notification). This is comparable to the ASIR-SDR matching rate that was shown in Figure 4. Electrical and galley-related fumes/smoke were more likely to be traced to an identifiable aircraft defect (more than 60 per cent of cases), particularly faulty recirculation fans, air cycle machines, coffee brewers, ovens (most often due to food or oil contamination), avionics and light bulbs.

Where a matching SDR was identified, fuel, oil and fluid fumes/smoke were usually associated with excessive APU oil consumption due to overfilling, and leaking seals between the hot and cold sections of the APU allowing oil or other fluids or gases (such as exhaust or compressor wash) to leak into the air conditioning system.

ASIRs that did not match to an SDR generally related to operational issues usually not related to a major defect with the aircraft:

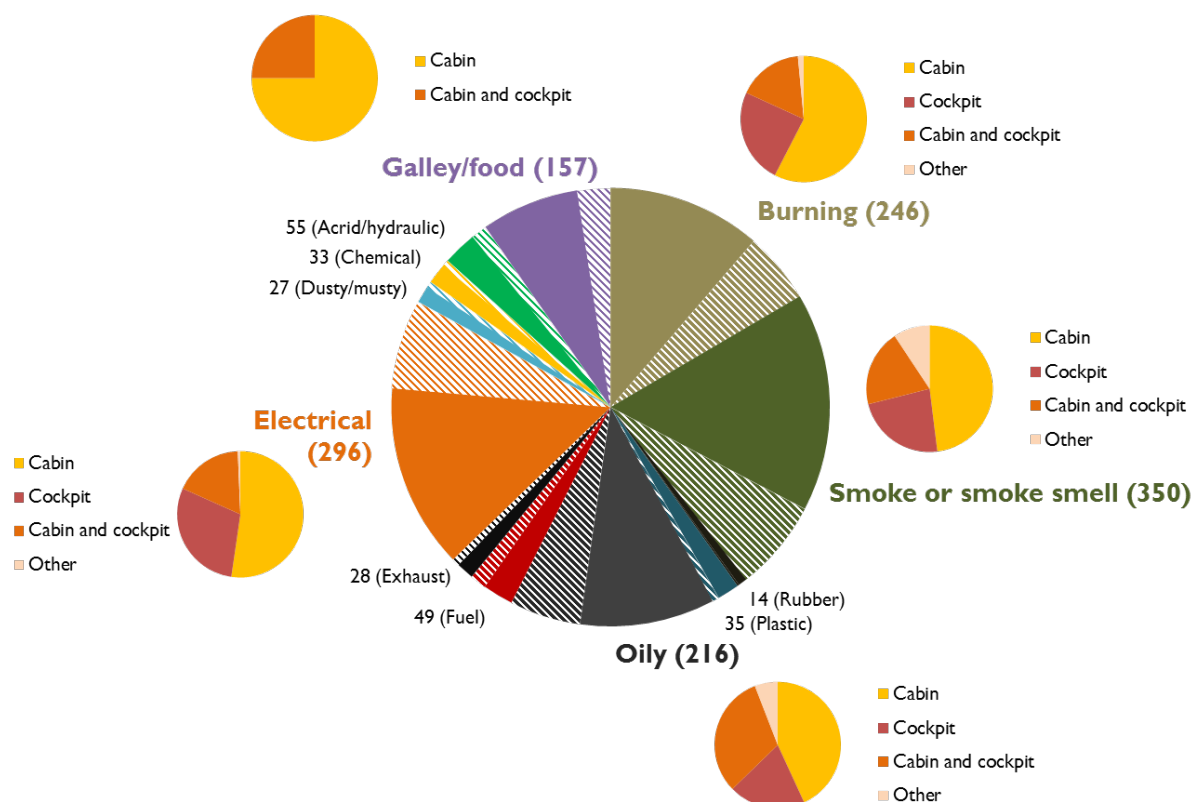
- **Fuel/oil/fluids** – oil or fuel residue due to spillage or refuelling, leaking of passengers' luggage (nail polish remover), exhaust smells from nearby aircraft.
- **Electrical** – fumes/smoke emanating from personal electronic devices, oven inserts, damaged wire insulation, or other situations where the source of the fumes or smoke could not be identified.

- **Galley** – food contamination and build-up burning in ovens or on coffee brewer plates, plastic or metal trays making contact with oven elements.
- **Other fumes/smoke** – smoke entering the aircraft from bushfires or nearby aircraft, burning smells from birdstrikes, spilt or burnt food, dust in air conditioning system.

However, there were many non-matching ASIRs reported by air transport operators that were related to cabin air contamination through the bleed air or air conditioning systems. In most of these ASIRs where an SDR was not submitted as part of the engineering/maintenance follow-up, the source of the fumes or smoke was identified, and similar to commonly reported SDRs (particularly leaking seals in the APU for fuel/oil/fluids fumes, identified equipment problems or damaged plugs for galley fumes, and for electrical fumes, shorted wires in avionics and instrumentation, recirculation fans, or other identified equipment which was electrically isolated for the flight).

Figure 9 shows that the most common types of fumes/smoke reported to CASA (through SDRs) that related to aircraft defects were similar to those reported to the ATSB through ASIRs – galley-related smells (usually burnt food), oil smells through APU or bleed air system contamination of the air conditioning system, and electrical smells.

Figure 9: Type of fumes/smoke reported by SDR, by aircraft system/area, 2008 to 2012



A higher proportion of SDRs reported to CASA relating to fumes/smoke matched ASIRs than vice versa (about 65-70 per cent for most fume/smoke types).

Defects reported via SDRs that did not have an accompanying ASIR included failures of aircraft systems where there was a potential for the failure to have led to a fumes and a smoke event (such as evidence of electrical arcing or burning during teardown of avionics units or radios, or heavy contamination of ovens by food residue and grease noted during normal maintenance).

Some of the more common types of defects reported to CASA but not to the ATSB were:

- **Smoke or smoke smell** – electrical failure of windscreen wiper motor, navigation system/avionics, oil leaks from air cycle machines (ACM)s or turbocharger units, seized APU, seized recirculating fans, internal electrical shorts in oven, oven fan rubbing on oven insert, failed electric motors with burnt brushes (engine starters/generators, landing gear).

- **Burning** – failed or overheating lighting ballasts, contaminated ovens, electrical smells from coffee or water brewers, faulty avionics and inverters, seized recirculation and gasper fans, failed windscreen heater elements.
- **Oily** – leaking seals in APU load compressor, ACM failure or leaking seals, engine bearing seal pack leaks, coalescer bag contamination.
- **Galley/food** – internal electrical faults in ovens or brewers, food residue/grease contamination of ovens.
- **Acrid/hydraulic** – seized recirculation fans, seized ACM, hydraulic fluid leaks, undeclared dangerous goods contamination of cargo hold.
- **Fuel** – deteriorated O-rings in fuel heater lines, fuel line corrosion.
- **Plastic** – plastic items/trays left in ovens, electrical arcing, and exhaust contact with firewall due to fractured tailpipe.
- **Chemical** – spill or leakage of undeclared dangerous goods, cleaning fluid residue in galley.
- **Exhaust** – incorrectly adjusted door seals, seized APU, fracture in exhaust tailpipe (primarily non-air transport aircraft).
- **Dusty/musty/damp/toilet** – contaminated coalescer bags, leaking seals in APU.
- **Rubber** – inappropriate packaging used on meals heated in oven.

Some types of fumes were more likely to occur with other types of fumes. Matched ASIRs and SDRs found that smoke and smoke smells were heavily associated with oily and electrical-type fumes. Burning smells were normally non-specific, but in many cases were also associated with electrical or galley smells.

Defects (ATA chapters)

Defects reported during maintenance or engineering inspections are generally identified by part number, serial number, and the aircraft system they are associated with. A broadly standardised system (ATA 100⁶) is used by aircraft manufacturers, component manufacturers, airlines and maintenance and repair organisations (MROs) worldwide to classify aircraft systems across all types of aircraft. This includes air transport, general aviation, and military aircraft.

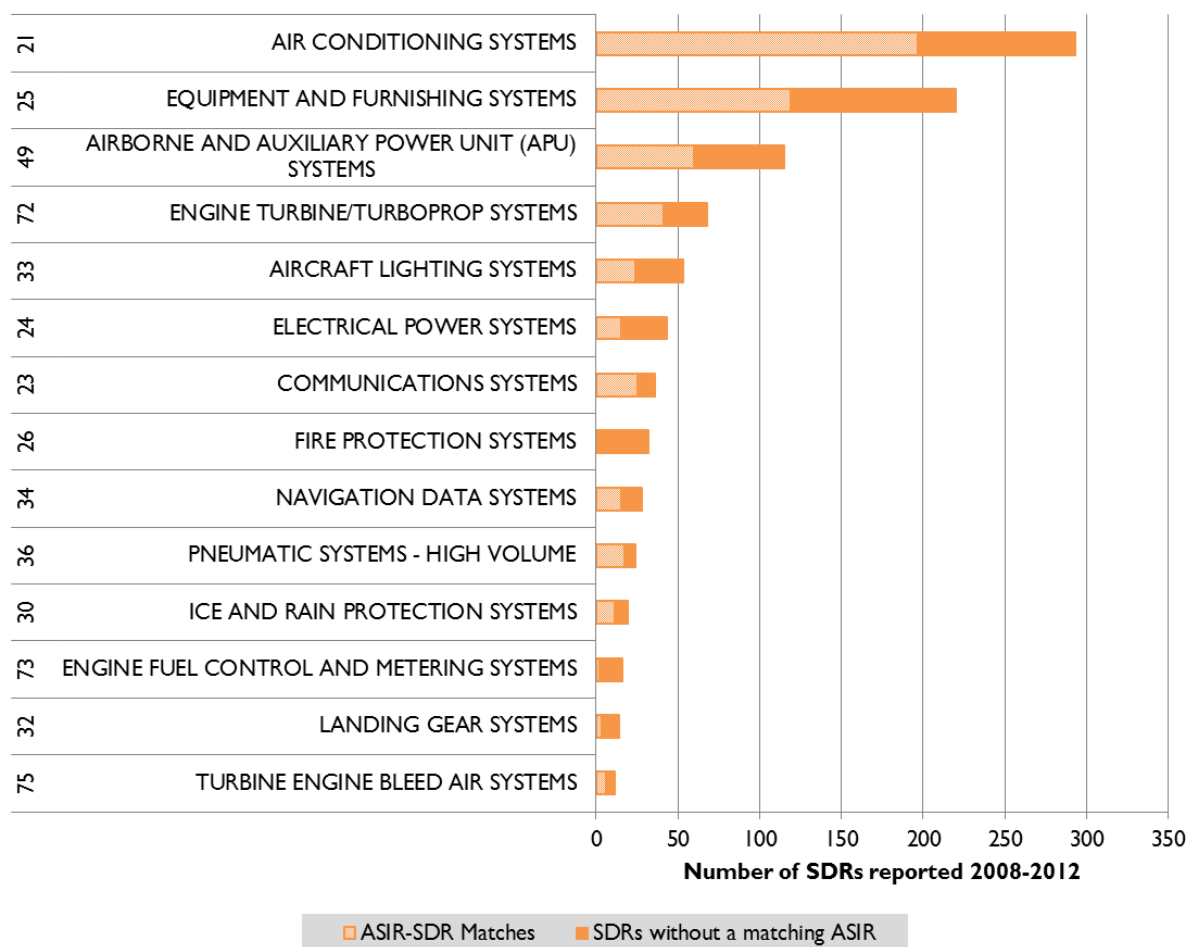
The ATA system breaks an aircraft down into a series of chapters, each associated with a different aircraft system (such as wings, air conditioning, electrical power, fittings and furnishings, flight controls, landing gear, bleed air system). Chapters may then be further broken down into assemblies and subassemblies — for example, an air conditioning system can be broken down into a ducting system, ram air system, avionics and control systems, pressurisation control, and air conditioning packs.

When SDRs are reported to CASA, the affected part and ATA chapter are provided by the reporter along with specific details of the aircraft, defect and remedial actions.

Figure 10 below looks at the most common fumes/smoke-related defects reported via SDR by ATA chapter, and the proportion of those defects that were also reported to the ATSB. As some defects generally do not pose a risk to flight safety (such as contamination of ovens), SDRs reported in some ATA chapters are not likely to have associated ASIRs (such as ATA Chapter 25 – Equipment and furnishings). Other SDRs indicate defects that did not result in a fumes or smoke event but had the potential to (such as many in ATA Chapter 73 – Engine fuel control and metering systems, and Chapter 32 – Landing gear systems), or the defect meant that a defence that prevented or helped to detect fumes or smoke was not available (ATA Chapter 26 – Fire protection systems).

⁶ Originally from the Air Transport Association.

Figure 10: Fumes/smoke SDRs reported to CASA, by ATA chapter, 2008 to 2012



Defects relating to air conditioning systems (ATA Chapter 21), equipment and furnishings (ATA Chapter 25) (such as galley equipment), and those related to the APU and the APU bleed air system (ATA Chapter 49) were the most common defects that were associated with fumes/smoke, and also the most common defects that had a potential safety of flight impact (or led to a fumes/smoke event).

Approximately two-thirds (67 per cent) of ATA Chapter 21 (Air conditioning systems)-related SDRs were associated with an ASIR. The most common parts affected where there was a matching ASIR-SDR were:

- Air conditioning (98 defects) – primarily other ‘smells’ transmitted through the air conditioning system. Most were transient electrical, damp, or oily/exhaust smells which did not have an identified source, but which were probably associated with contaminated coalescer bags, or APU bleed air contamination from oil or smells external to the aircraft.
- Air cycle machine (17 defects) – primarily seized (lack of oil).
- Recirculation fan (15 defects) – primarily seized (bearing failure).

Most air conditioning SDRs not associated with an ASIR were limited to particular operators, but involved the same kind of defects (contaminated coalescer bags, non-identifiable air conditioning fumes) as ASIR-SDR matches.

Equipment and furnishing (ATA Chapter 25) defects associated with fumes/smoke (where there was an ASIR-SDR match) were largely related to:

- Oven (49 defects) – smoke or sparks emanating from oven, due to burnt food residue or internal electrical failure
- Other galley equipment (21 defects) – food spillage or items in appropriately locations (on brewer plates, in ovens).

- Cabin power supply (7 defects) – power supply failures at individual seats, primarily in first class cabins.
- Coffee maker/brewer failures (6 defects) – electrical short often associated with burning smells, sparks and electric shocks.

Most equipment and furnishing SDRs not associated with an ASIR were related to oven contamination or incorrect positioning of oven inserts. Other sources of fumes/smoke were cleaning chemical spills, discarded cigarettes in toilet wastepaper bins, or non-identifiable transient burning smells in the galley.

Auxiliary power unit failures (ATA Chapter 49) defects were the third most common SDR reported relating to fumes/smoke. The most common parts affected where an ASIR was also reported were:

- APU core engine (25 defects) - primarily related to seal failures and oil leaks which were likely to have happened (associated blue haze or oil smell was observed in many cases), but were not able to be confirmed through an engineering inspection.
- Seal failures (8 defects) – oil leaks through APU load compressor seal, often detected through high APU oil consumption.

APU defects for which there was no ASIR-SDR match were limited to particular operators, and were largely related to load compressor seal failures resulting in oil contamination of cabin or cockpit air, or cases where oily fumes were detected but no APU fault was found.

Operator reporting

All fumes/smoke events and related defects reported to the ATSB and CASA were reviewed to identify air transport and general aviation operators that were most likely to report these types of events.

The graphs below show how reporting of fumes and smoke-related events by airlines has changed over the 2008 to 2012 period. Airlines have been de-identified in this analysis, but can be grouped as follows:

- Airlines B, D, F, and H are domestic and/or international airlines operating on trunk routes
- Airlines E, G, L, I, and M are domestic airlines operating primarily on regional routes
- Airlines A, C, J, and K are primarily large domestic charter airlines, with some scheduled passenger services
- Airlines N, O, P, Q are charter or aerial work operators.

Not all airlines are shown in all graphs.

Figure 11: Fumes/smoke ASIRs reported to ATSB by operator, 2008 to 2012

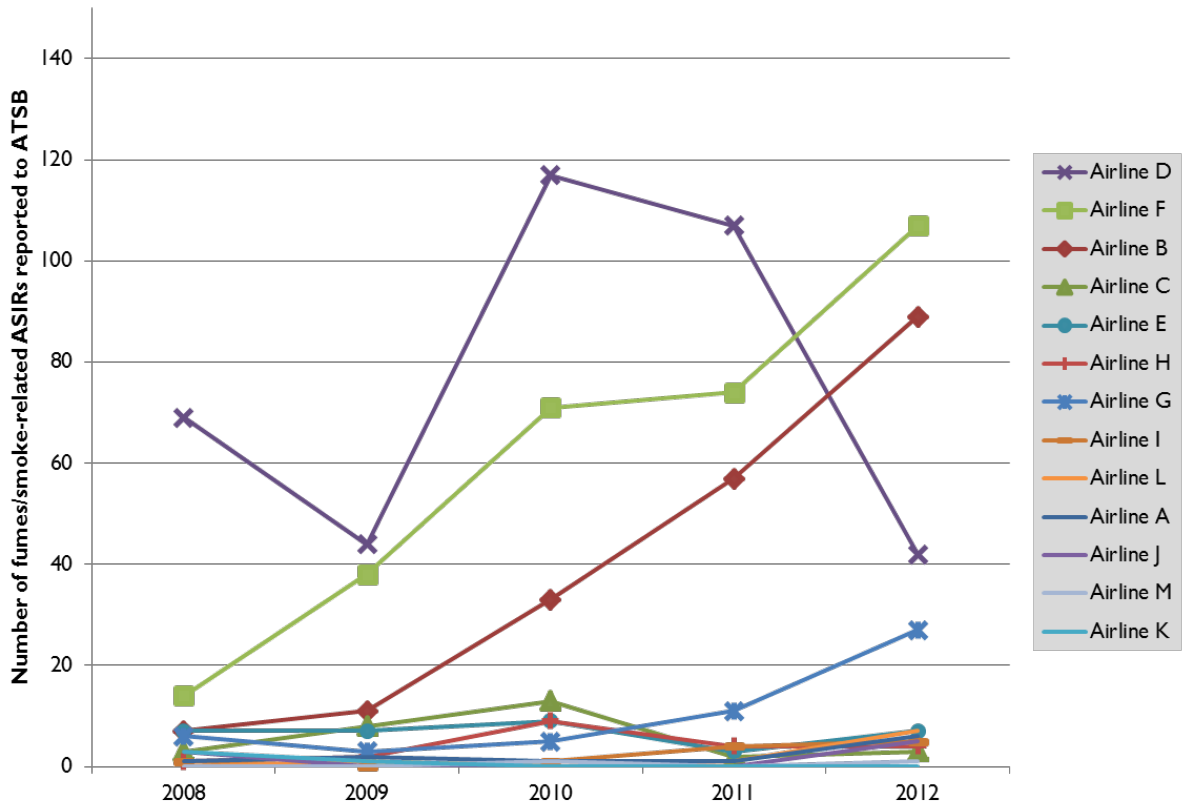
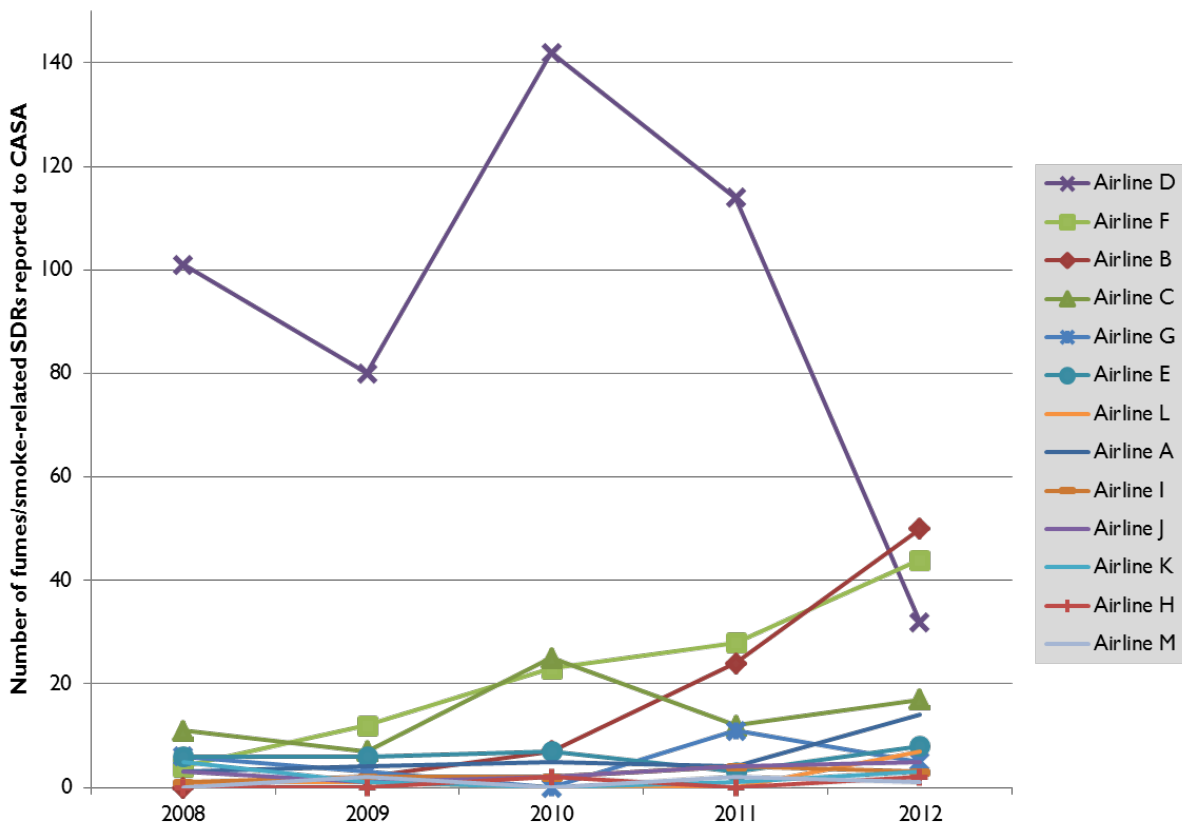


Figure 12: Fumes/smoke SDRs reported to CASA by operator, 2008 to 2012



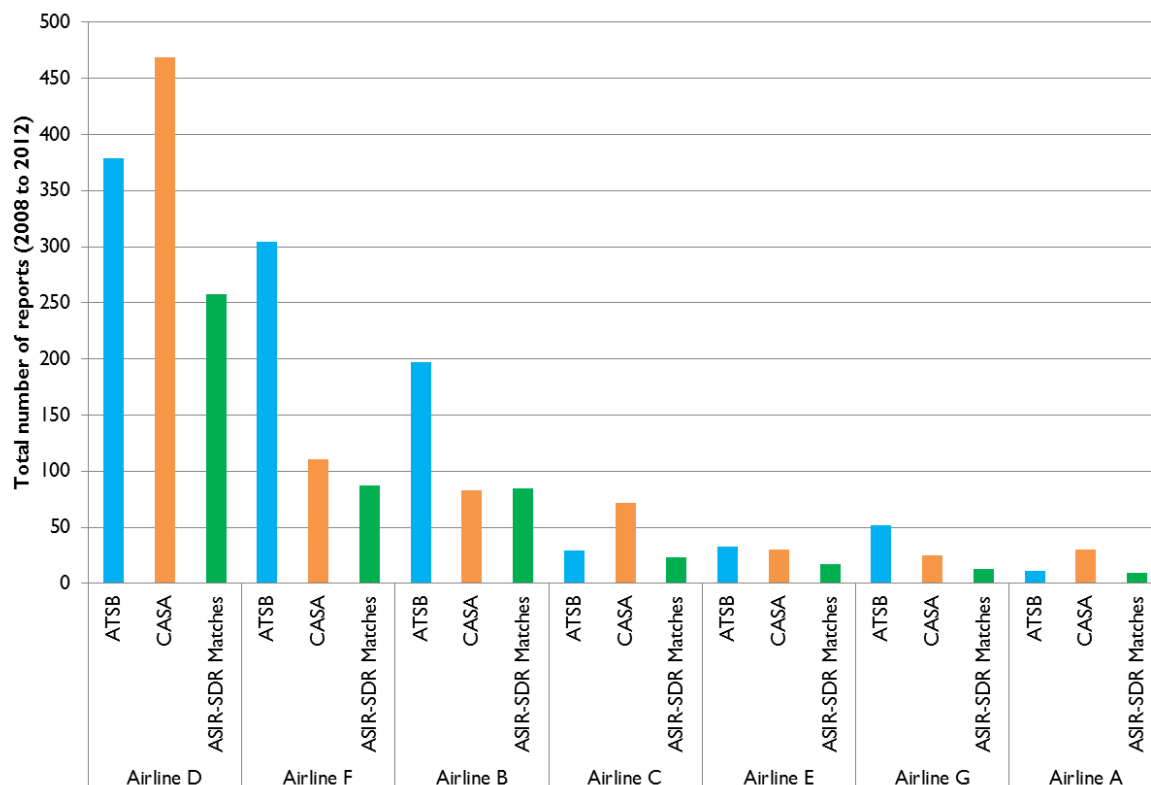
Airline D was by far the largest reporter of fumes/smoke events for most of the 5 year study period, with the exception of a large and unexplainable drop in reporting in 2012 of both ASIRs and SDRs. Airline B

and Airline F were the next most frequent reporting, and the number of reported events increased year on year for both operators.

While fumes/smoke event notifications by all operators to the ATSB increased year on year from 2008 to 2012, reporting to CASA peaked in 2010 and declined slightly in 2011 and 2012. The figures above show clearly that Airline D's ASIR and SDR reporting patterns were similar, and that this increase in reporting was due to better reporting by Airline B and Airline F (at a much larger rate of increase for ASIRs than for SDRs).

Figure 13 below looks only at ASIR-SDR matches for operators that reported at least 25 fumes/smoke-related events to either the ATSB or CASA over that period. Operators are ordered from left to right by the highest number of ASR-SDR matches.

Figure 13: Fumes/smoke reporting to ATSB (ASIRs) and CASA (SDRs) and to both agencies, by operator, 2008 to 2012



A detailed review of reporting rates (per flying hour) by operator was not able to be performed, as CASA Air Operator's Certificate (AOC) survey data was not available for the entire 2008 to 2012 period. An estimated rate of fumes/smoke-related notifications submitted by larger operators per 100,000 hours flown was calculated using 2011 AOC survey data supplied by CASA (Figure 14 to Figure 16). The graphs below show that Airline B reported a large proportion of fumes/smoke events to the ATSB, while Airline C reported mostly through the SDR system. Smaller operators not shown in the graphs in this section (including some regional airlines, some charter operators, and most aerial work operators⁷) had similar fumes/smoke event reporting rates to Airlines A, E, H, I, and L (in the range of 5 to 10 reports per 100,000 hours flown).

⁷ No activity data was submitted by Airline I or Airline K in the 2011 AOC survey.

Figure 14: Fumes/smoke ASIRs reported to ATSB, by operator, per 100,000 hours flown (estimated)

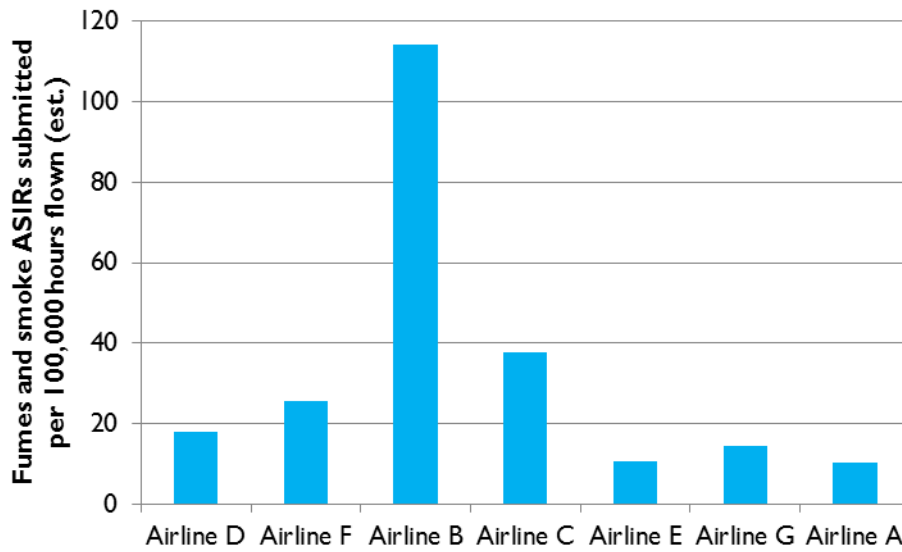


Figure 15: Fumes/smoke SDRs reported to CASA, by operator, per 100,000 hours flown (estimated)

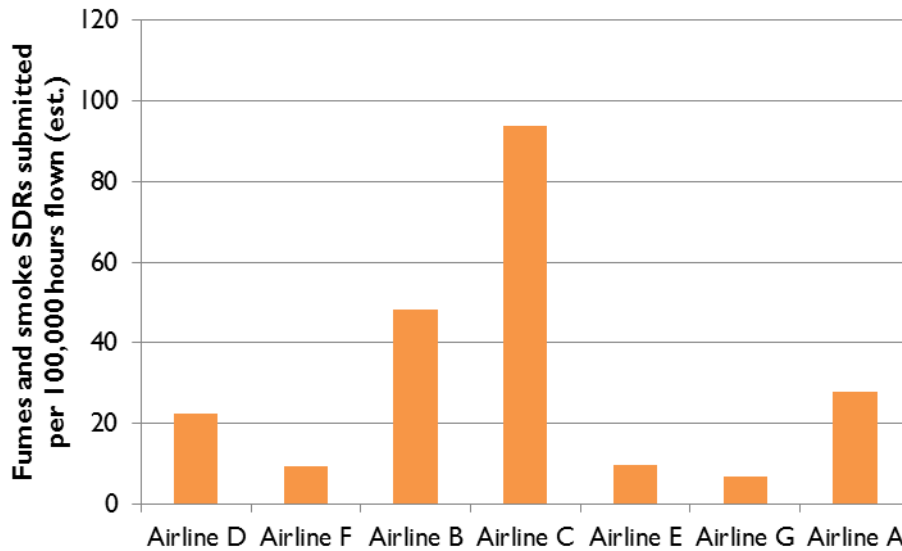
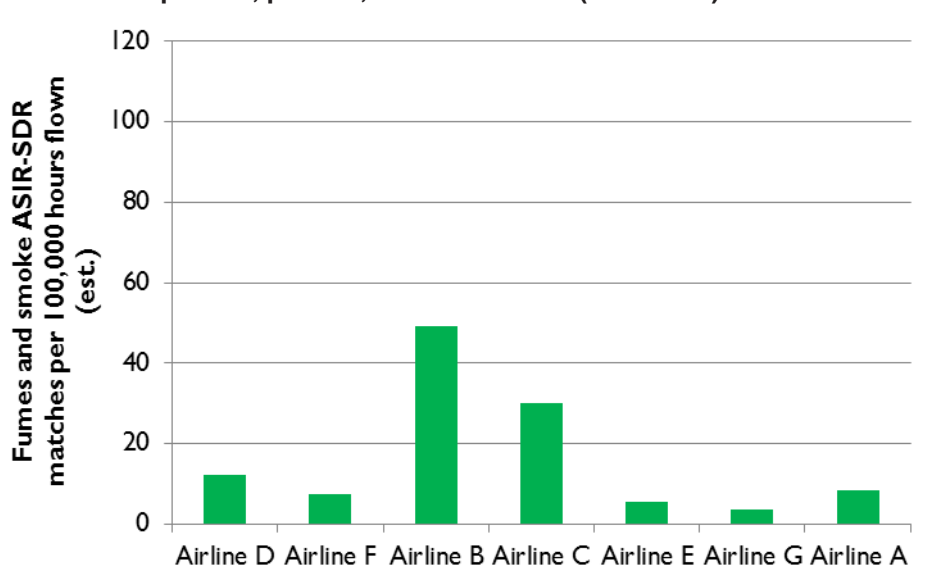


Figure 16: Fumes/smoke SDRs reported to both ATSB and CASA (ASIR-SDR matches), by operator, per 100,000 hours flown (estimated)



Some operators were more likely to report fumes/smoke events to the ATSB, and some were more likely to notify CASA:

- Airline A reported most events via SDR. Most of these notifications were not matched with ASIRs, and were due to avionics failures or transient fuel smells in the cabin. The small number of ASIR-SDR matches identified related to seized air cycle machines.
- Airline B reported most events via ASIRs, most being transient cabin fumes, electrical equipment fumes, or fumes from passenger luggage. While fewer fumes/smoke events were reported via SDRs, almost all matched with ASIRs.
- Airline C reported most events via SDR. Most of these reported related to oil smells in the cabin from the APU or engine bleed air system, and included almost all of the air conditioning (ATA Chapter 21) and APU (ATA Chapter 49)-related SDRs that did not have an ASIR match. The few ASIR-SDR matches identified were related mostly to electrical system or avionics issues, with only a few relating to oily or damp air conditioning smells.
- Airline D reporting showed an expected mix of ASIR and SDR reporting, and ASIR-SDR matches. While the number of fume and smoke-related ASIRs and SDRs declined in 2011 and 2012, the number of ASIR-SDR matches increased during these years. Most of the unmatched ASIRs were related to transient cabin fumes, fumes from passenger luggage, or fumes/smoke from outside the aircraft. Most unmatched SDRs were related to electrical fumes in the galley or lavatory area, and oil smells on the flight deck.
- Airline E tended to report fumes/smoke events via both ASIR and SDR, but only about 50 per cent matched. Identified ASIR-SDR matches were mostly fumes or smoke emanating from avionics and electrical systems. Most unmatched ASIRs were related to fuel and oil leaks in engine compressors. Most unmatched SDRs were related to faulty smoke detectors, and faulty cabin light fittings.
- Airline F reported primarily via ASIR, and more than 70 per cent of ASIRs and SDRs reported did not match (though most SDRs reported since 2010 had a matching ASIR). Most of the unmatched ASIRs reported were related to transient cabin fumes, galley-related fumes, or smoke/exhaust smells from outside the aircraft. Most unmatched SDRs related to galley-related fumes and APU oil leaks.
- Airline G reported most events via ASIRs. Most ASIRs related to air conditioning system problems (faulty recirculation fans, faulty air cycle machines) or electrical equipment problems. The few ASIR-SDR matches identified related to fumes or smoke from bleed air or air conditioning, or electrical fumes. All of the SDRs reported by this airline that did not have a matching ASIR primarily related to O-ring failures in the fuel/oil heat exchanger of a particular aircraft type.

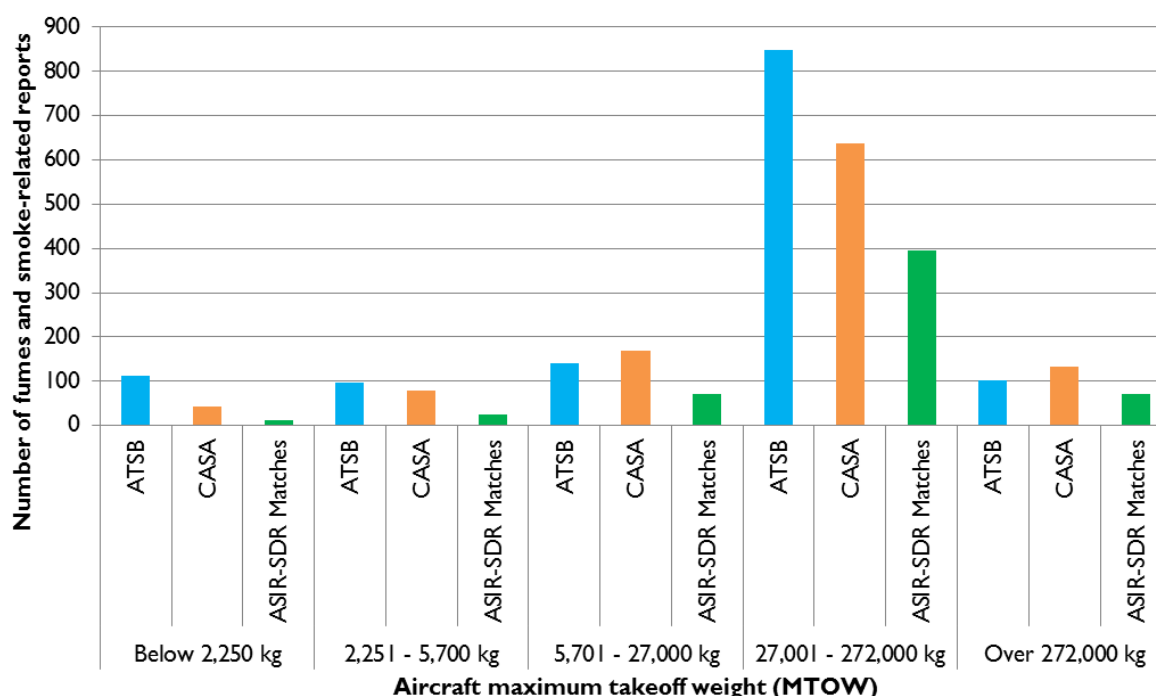
Patterns noticed for some smaller operators were:

- Airline J (a large charter operator) reported fumes/smoke events almost exclusively via SDR, with very few ASIR notifications submitted for these types of events.
- Airline N (an onshore/offshore helicopter operator) reported fumes regularly to the ATSB prior to 2008, but had not reported any occurrences between 2008 and 2012.
- Airline O (a medical evacuation operator) generally reported all events via both ASIR and SDR, and matching notifications could be identified for almost all occurrences.
- Airline P (an onshore/offshore helicopter operator) reported fumes events almost exclusively via SDR, with very few notifications of any occurrence type reported to the ATSB.
- Airline Q (a medical evacuation operator) reported fumes events via SDR, but generally not through ASIRs.

Aircraft grouping

Figure 17 shows the number of fumes/smoke events reported via ASIRs and SDRs over the 2008 to 2012 period, by aircraft size. Aircraft are grouped into size categories based on their maximum take-off weight (MTOW).

Figure 17: Fumes/smoke reporting to ATSB (ASIRs) and CASA (SDRs) and to both agencies, by aircraft size, 2008 to 2012



Aircraft above 5,700 kg MTOW (generally indicating low and high capacity air transport aircraft) were the most likely to be involved in reported fumes/smoke events. This could be expected based on the frequent flying activity of air transport aircraft, and their being more sources for fumes and smoke events in air transport aircraft (galleys, baggage and cargo carriage, air conditioning and bleed air systems).

Aircraft in the 27,001 – 272,000 kg weight range accounted for by far the most notifications. Typical aircraft in this weight range include most of the Australian domestic airline fleet — Airbus A320/A330, Boeing 717/737/767, BAe 146/Avro RJ, Fokker F100, Bombardier Q400, and Embraer E-170/190. More notifications of fumes/smoke were submitted to the ATSB than to CASA — most of the unmatched ASIRs related to galley-related smells, fumes from passenger baggage, or fumes/smoke entering the aircraft from outside (from the landing gear, from exhaust, or from other smoke). The majority of ASIR-SDR matches related to transient air conditioning smells, burnt food residue in ovens, galley equipment defects, and APU oil wetting. Unmatched SDRs showed similar types of defects to ASIR-SDR matches.

Low capacity air transport aircraft were the next most commonly involved in reported fumes/smoke events. Saab 340 (overheating cabin lighting), Embraer EMB-120 Brasilia (overfilled oil, and air

conditioning contamination from APU oil wetting or a leaking engine air pressure valve guide), and Bombardier DHC-8-200/300 aircraft (electrical equipment and avionics failure) were most commonly involved in events where an ASIR-SDR match was found. Most unmatched ASIRs and SDRs showed similar types of defects (particularly oil smells in air conditioning) associated with fumes/smoke events.

Very large aircraft above 272,000 kg MTOW (Boeing 747/777 and Airbus A380) were the third largest source of fumes/smoke events; however, most notifications were made via an SDR. There were more events where both an ASIR and SDR were submitted when compared to fumes/smoke events on smaller aircraft. Identified ASIR-SDR matches mostly involved faulty cabin lighting, air conditioning recirculation fans, and electrical problems with galley equipment. Unmatched ASIRs were almost exclusively fumes or smoke from burnt food residue. Unmatched SDRs were due to electrical failures of passenger service and power supply units, and overheating/contaminated ovens (these accounted for almost all fumes/smoke events on Boeing 777 aircraft).

Fumes/smoke events in smaller general aviation aircraft (below 5,700 kg MTOW) were more likely to be reported via ASIRs. Electrical problems (shorting, alternator or starter motor failure, faulty switches) were the most common sources of fumes or smoke that were reported via ASIRs. SDR notifications were largely similar, but also included exhaust and fuel supply system problems. The low level of SDR reporting compared to ASIRs may reflect a lower level of awareness in this section of industry (particularly pilots of aircraft below 2,250 kg MTOW) of the CASA SDR scheme and its reporting requirements. The few ASIR-SDR matches identified tended to be reported by flying training schools, and by twin-engine aircraft aerial work or charter operators who also operated larger aircraft above 5,700 kg.

Aircraft types and registrations

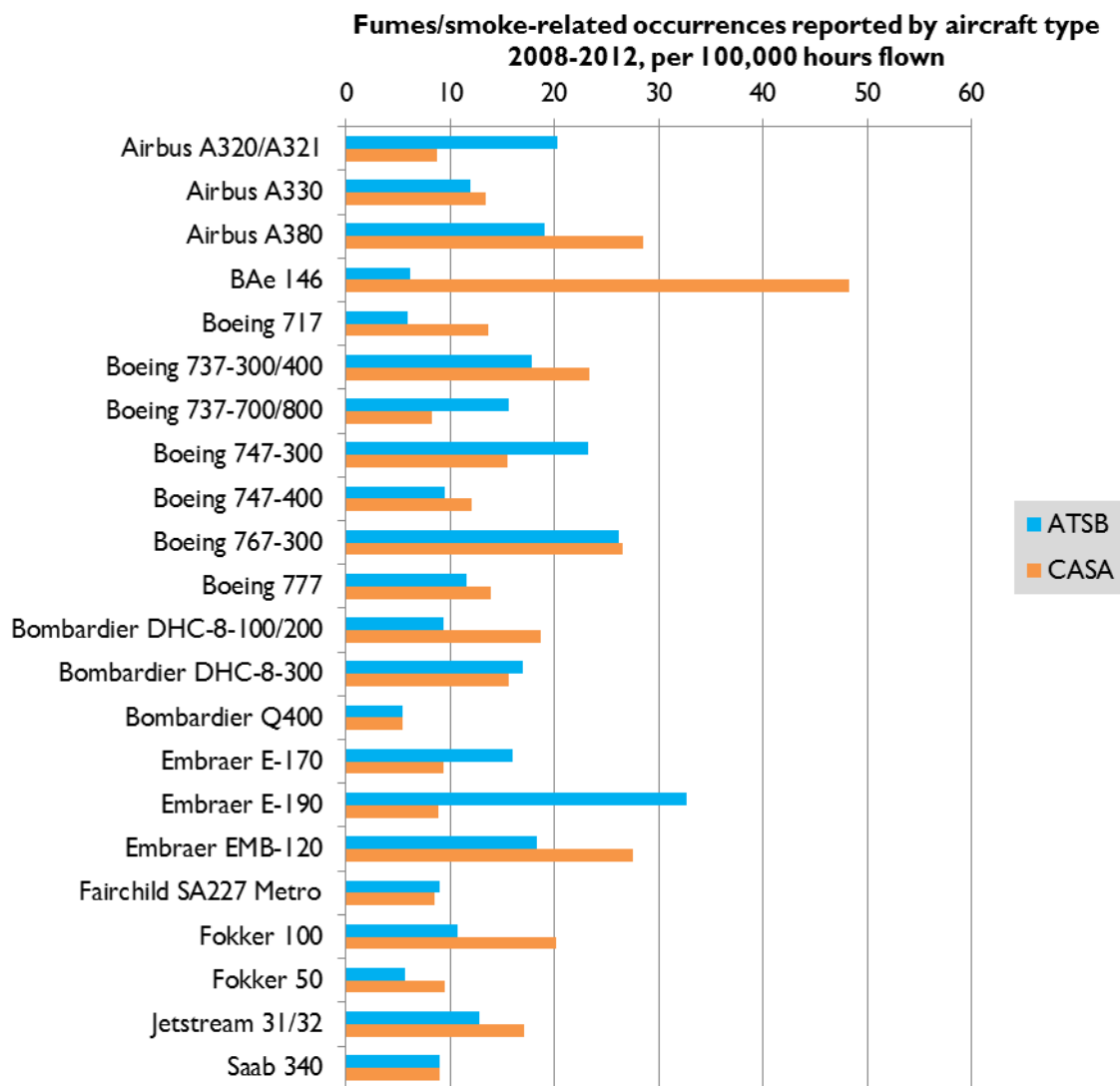
Fumes/smoke events were more likely to be reported on some individual aircraft than others. There were 23 aircraft with more than five SDR and 33 aircraft with more than five ASIR notifications relating to fumes or smoke over the 2008 to 2012 period. There were five aircraft with more than 15 ASIR or SDR fume/smoke-related notifications.

Generally, the number of notifications submitted to either the ATSB or CASA for individual aircraft was reflective of the regularity of reporting of that operator. For example, most aircraft with a large number of reported fumes/smoke events were operated by Airline B and Airline D, because these airlines were the primary reporters of fumes/smoke events via both the ASIR and SDR schemes in most years between 2008 and 2012.

When considering the rate of fumes/smoke notifications to both the ATSB and CASA as a proportion of total flying activity between 2008 and 2012, some aircraft makes and models were overrepresented when considering their flying activity⁸ as a proportion of the Australian air transport fleet (Figure 18). In particular, the British Aerospace BAe 146 had far more fumes/smoke events reported per 100,000 hours flown than other air transport aircraft operating in Australia during this period. Ageing aircraft issues may have contributed to the increased number fumes/smoke-related notifications (particularly SDRs) involving these aircraft.

⁸ Flying activity by aircraft type from 2008 to 2012 provided by the Bureau of Infrastructure, Transport and Regional Economics (BITRE). An update to this report in October 2014 has corrected flying activity data provided by the BITRE to include all charter hours flown by these aircraft types.

Figure 18: Fumes/smoke reporting to ATSB (ASIRs) and CASA (SDRs) by aircraft type, 2008 to 2012, per 100,000 hours flown^{8, 9, 10}



Aircraft types with an ASIR or SDR fumes/smoke reporting rate of more than 20 notifications per 100,000 hours flown are discussed below.

- British Aerospace BAe 146** - over 75 per cent of SDRs related to oil contamination of cabin air, generally via leaking bearing seals in the APU. The majority of SDRs were in response to flight crew reports of fumes during engine start-up, standing/pushback, take-off and during descent (such occurrences would normally be considered to be also reportable matters to the ATSB.) Very few of these SDRs (less than five) involved events that occurred when the aircraft was undergoing maintenance, check flights, or was not boarded for a commercial air transport service. Only a very small number of ASIRs (five) were reported involving fumes/smoke on this aircraft type, and most of these related to transient cabin fumes which dissipated when the flight crew selected the air conditioning packs to off.

⁹ Only commercial air transport aircraft types with more than five or more fume/smoke-related ASIRs or SDRs reported between 2008 and 2012 are shown.

¹⁰ The rates of fume/smoke-related SDRs reported involving BAe 146, Fokker 100, Embraer EMB-120 aircraft and other types of aircraft used by charter operators in Australia were overrepresented in the initial release of this report due to incomplete BITRE activity data. This data has been corrected in October 2014 to include all charter hours flown by these aircraft types, in addition to scheduled passenger and GA hours flown.

- **Embraer EMB-120 Brasilia** – ASIRs mostly related to failed air conditioning packs. Sources of fumes/smoke most commonly identified in SDRs were overfilled engine oil reservoirs and faulty lighting ballasts, as well as oil fumes.
- **Fokker 100** – SDRs related to numerous issues, including seized air cycle machines, windscreen wiper motor failures, and internal faults in avionics. ASIRs mostly due to air cycle machine failures and split air conditioning distribution ducts.
- **Bombardier DHC-8-100/200** – ASIRs and SDRs were related to range of avionics and mission equipment failures, and to a lesser extent lighting failures.
- **Embraer E-190** – due to numerous issues, though APU and galley fumes featured in several SDRs. ASIRs were most commonly associated with burnt food in ovens. In many cases the source of the fumes was unable to be identified.
- **Airbus A380** – passenger power supply unit failures and oven failures accounted for almost all fumes/smoke ASIRs and SDRs.
- **Boeing 767-300** – recirculation fan failures and galley equipment failures accounted for over 70 per cent of SDRs. Many ASIRs reported did not identify the source of the fumes/smoke, though where the source was known, galley-related fumes were most common.
- **Fairchild SA227 Metro** – ASIRs were reported for a range of issues, including landing gear-related fumes and smoke (often associated with hot brakes or a deflated tyre) and electrical fumes in the cockpit. A review of SDRs found most of these electrical fumes were due to moisture under console panels, or poor terminal connections allowing arcing to occur.
- **Fokker 50** – ASIRs and SDRs were mostly associated with fumes from oil residue from engine maintenance, and air cycle machine failures.
- **Boeing 747-300** – only a small number of ASIRs and SDRs were reported, with a range of fumes/smoke-related events occurring. The higher rate of occurrences involving this aircraft type was due to low flying activity (13,234 hours between 2008 and 2012) leading up to a withdrawal from airline service in Australia.
- **Airbus A320 and A321** - fumes/smoke-related ASIRs were mostly minor in nature, most commonly transient cabin fumes, galley-related smells and smoke, electrical equipment fumes, or fumes from passenger luggage. SDRs primarily related to APU oil seal or O-ring failures.
- **Boeing 737-300/400** – Most ASIRs and SDRs related to burnt smells from ovens, oil contamination of air conditioning, and failed recirculation fans.

Engine makes and models

Fumes/smoke-related SDRs where 'oily' or 'exhaust' fumes were reported were reviewed to identify the makes and models of engine and APU fitted to the aircraft at the time that the defect occurred. The intention of this analysis was to explore whether certain types of aircraft, APUs, air conditioning equipment or engines were more likely to be involved in a fumes/smoke event where there was cabin air contamination by combustion products.

Between 2008 and 2012, there were 225 fumes/smoke-related SDRs identified where the type of fume reported was 'oily' or 'exhaust', and where the issue was not galley-related (such as from burning cooking oil residue in ovens). This accounted for slightly less than one-quarter of all SDRs related to smoke or fumes submitted to CASA over this period, and about 55 per cent of these defect notifications had a matching ASIR.

The most common defects reported related to smoke, odours and fumes from the air conditioning system (34 notifications) and the APU (27 notifications), leaking seals not specific to an aircraft component (17 notifications), and oil leaks in the engine (8 notifications) and APU (7 notifications).

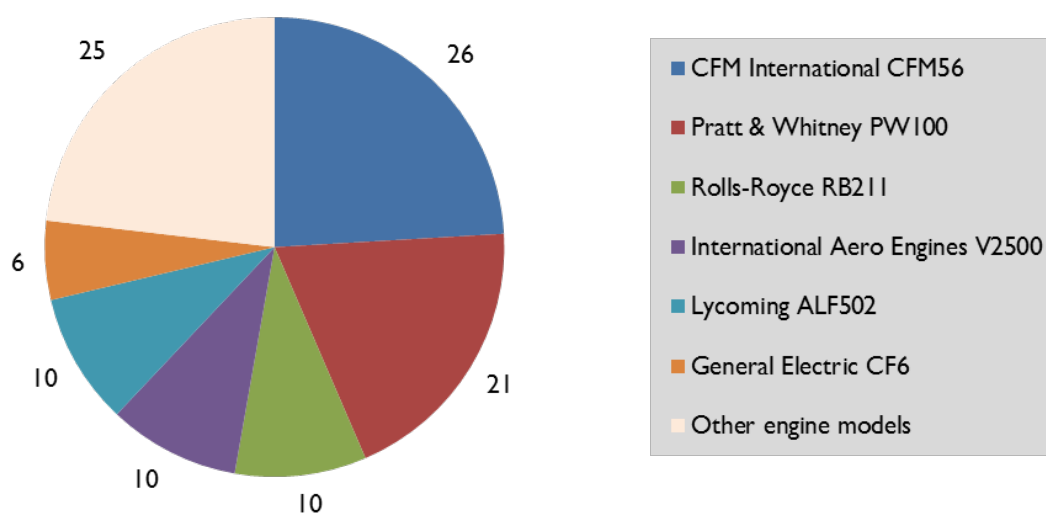
Most notification submitters did not provide a component make, model and serial number for most of these defects (including those relating to an APU or air cycle machine), so it was not possible to look for any patterns with particular components or systems.

Aircraft types involved where more than 10 SDRs were submitted in regards to oily or exhaust fumes over this 5 year period were:

- Boeing 737 (40 defects)
- Airbus A320 (25 defects)
- British Aerospace BAe 146 (24 defects)
- Bombardier DHC-8 (24 defects)
- Boeing 767 (21 defects)
- Airbus A330 (16 defects)

Only a subset of the 225 oily and exhaust fumes/smoke-related SDRs were associated with an engine (ATA Chapter 72), pneumatic (ATA Chapter 36), or bleed air system (ATA Chapter 75) problem. Figure 19 below shows how these 65 SDRs were associated with different engine makes and models.

Figure 19: Fumes/smoke SDRs reported to CASA related to engine and bleed air systems, by engine model, 2008 to 2012



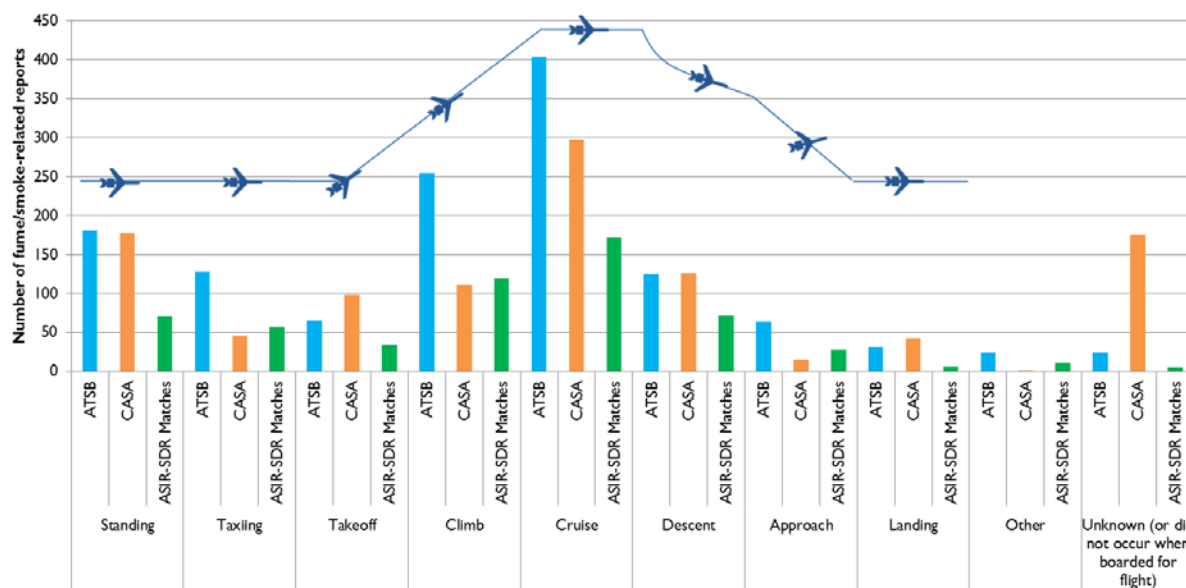
The proportions of engine models shown reflects those typically fitted to the aircraft types that were most frequently having reports of oily and exhaust-related fumes/smoke (for example, the CFM56 is fitted to the Boeing 737, the V2500 is fitted to the Airbus A320, the CF6 is fitted to the Airbus A330 and Boeing 767, and the PW100 is fitted to the Bombardier DHC-8). The BAe 146 had less reported defects than expected where exhaust or oily smoke or fumes were due to the operation of the Lycoming ALF502 engines and the aircraft's bleed air system (10 associated with engine or bleed air system operation, 14 associated with the APU and air conditioning system).

Phase of flight

All fumes/smoke-related ASIR and SDR notifications between 2008 and 2012 were reviewed to look at what phase of flight the event occurred in.

Figure 20 below shows that by far, most fumes/smoke events happened when the aircraft was in cruise. The large number of 'unknown' phase of flight occurrences reported via SDR is indicative of that fact that many SDRs are submitted during aircraft maintenance, or at other times when the aircraft is not boarded for flight (ASIRs only consider incidents that occur when the aircraft is boarded for flight).

Figure 20: Fumes/smoke reported to ATSB (ASIRs) and CASA (SDRs) and to both agencies, by phase of flight, 2008 to 2012



Typical fumes/smoke events reported in each phase of flight (where there was both an ASIR and an SDR submitted for the fumes or smoke) were:

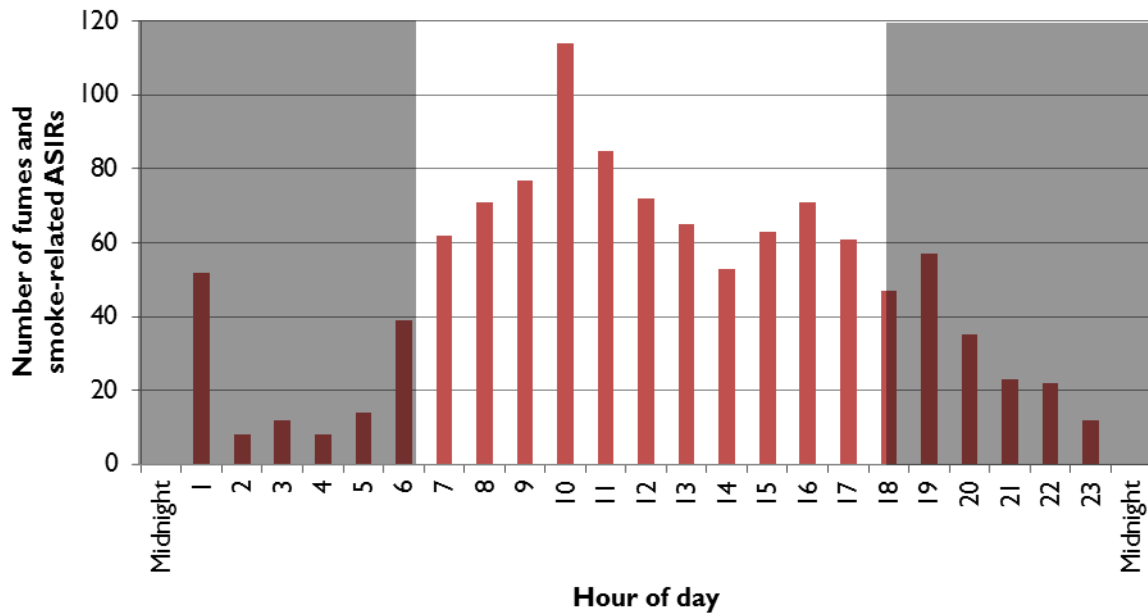
- **Standing** – fumes relating to cargo and ground handling operations, electrical failure of lighting and avionics, oil fumes on APU start.
- **Taxiing** – transient air conditioning fumes in cabin, fumes or smoke from outside of the aircraft, electrical failure of passenger service units/in-flight entertainment units.
- **Take-off** – burnt rubber fumes in the cockpit, transient air conditioning fumes in the cabin.
- **Climb** – transient air conditioning fumes in cabin, air conditioning system failures, electrical failure of avionics, oily or exhaust smells from bleed air, failed recirculation fans.
- **Cruise** – galley-related smells, electrical failure of passenger service units/in-flight entertainment units and lighting and galley equipment, recirculating fan failure.
- **Descent** - oily smells from air cycle machine or APU, transient air conditioning fumes in the cabin.
- **Approach** – transient burning or electrical smells, oily or burning smells from air cycle machine or APU.
- **Landing** - oily or exhaust smells from bleed air system or APU, electrical failure of avionics.

In most phases of flight, the number of ASIRs and SDRs, as well as the number of ASIR-SDR matches identified was relatively constant. In taxiing and approach, there were notably more fumes/smoke events reported via ASIRs.

Time of day

The local time of day at which fumes/smoke events occurred was only available for events reported through ASIRs to the ATSB. Figure 21 below shows that the most common times for fumes/smoke events to occur was mid to late morning, with a smaller peak in the late afternoon, though events were reported regularly across most hours of the day. Fumes/smoke events did not specifically correlate to typical meal service times (7-8 am, 12-2 pm, 5-8 pm) when heating of meals or use of ovens contaminated with food residue might be more likely to result in galley-related fumes.

Figure 21: Fumes/smoke ASIRs reported to ATSB by time of event, 2008 to 2012



Data from 12 am to 1 am was excluded as it was suspected to be erroneous (if no occurrence time is submitted by the reporter of the ASIR, the default occurrence time is recorded as 12 am). Some of the occurrences shown in the early hours of the morning (1 to 5 am) involved international flights or repositioning flights, but many appeared to have erroneous data.

Risk analysis – event risk classification

There are limitations in how well counting the number of occurrences reported can flag areas of significant safety concern. The frequency of occurrences of a certain type is not necessarily indicative of the risk that those types of occurrences pose. As a result, all occurrences reported to the ATSB, including all fumes and smoke occurrences, are risk rated using the event risk classification (ERC) framework.

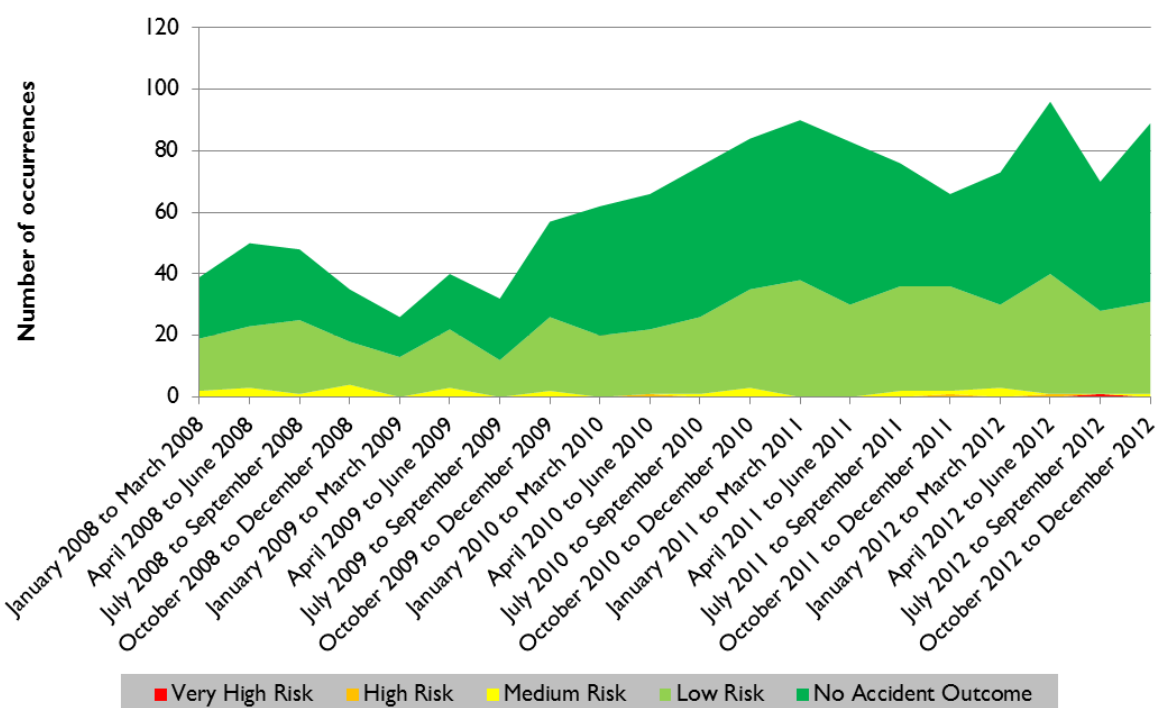
The ERC framework is used to determine whether an occurrence could pose a low, medium, high, or very high risk to the safety of people, property and aircraft. It is not necessarily based on the actual outcome of the reported incident, but rather, what could have happened. The risk that is credibly posed by an occurrence is determined by answering two questions:

- If this event had escalated into an accident, what would have been the most credible accident outcome?
- What was the effectiveness of the remaining barriers between this event and the most credible accident outcome?)

Most fumes/smoke occurrences are low risk in nature, and there is no potential for an accident outcome. In fact, there are generally many good defences in place (such as isolating the source of the fumes/smoke and conducting a diversion) that keep the safety of flight risk associated with these occurrences low. However, some smoke occurrences could have had the potential to develop into an in-flight fire, which are reflective of a potential for injury and aircraft damage, and there are fewer defences available to the crew to prevent this outcome.

Very few of the 1,263 fumes/smoke occurrences reported to the ATSB between 2008 and 2012 posed any likely injury risk. About 40 per cent of fumes/smoke occurrences posed a low risk of injury to aircraft occupants, with only 2.3 per cent being assessed using the ERC framework as posing a medium or higher safety risk (Figure 22). There were also fewer of these occurrences reported in the more recent years of the study.

Figure 22: Event risk classification (ERC) of fumes/smoke ASIRs, 2008 to 2012



The increased risk associated with these occurrences was generally because of a fire, or the fumes/smoke being detected in association with another issue which affected flight safety (such as a power loss). Some examples are provided below.

- **Forced/precautionary landing** – seven occurrences involving general aviation aircraft where smoke was detected in the cockpit. In all but one case, the smoke or burning smell was associated with an engine malfunction (the remaining case involved smoke emanating from the pilot’s approach plate holder light assembly). In three cases, the pilot elected to conduct a precautionary landing, or an on-aerodrome forced landing. In four cases, the pilot made a forced landing with minimal damage to the aircraft and no injuries to aircraft occupants.
- **Engine malfunction** – five occurrences involving single-engine general aviation aircraft while the pilot observed smoke outside the aircraft after the engine lost power in a critical phase of flight (climb, take-off, or during a go-around). In two occurrences, smoke reportedly entered the cockpit. In all cases, the pilot made an air return (or rejected the take-off).
- **Crew incapacitation** – one occurrence involving a small piston-engine air transport aircraft where the pilot noticed fumes in the cockpit during the cruise, causing some dizziness. The pilot opened the cockpit windows to ensure fresh air flow, and air traffic control and nearby pilots provided assistance for her to conduct an air return. This occurrence was discussed below in *Injury and Incapacitation*.
- **Fire** – two occurrences where the pilot of a general aviation aircraft detected smoke in the cockpit at the start or end of a flight, and made an air return to diagnose the problem. Upon landing, the pilot detected a fire and extinguished it. One fire was due to a battery line arcing with a brake line, and another was an engine fire caused by a loose carburettor bowl.
- **Aircraft system failure** – three occurrences, two involving general aviation aircraft (smoke detected in cockpit due to an electrical motor failure or a hydraulic leak) and one involving a large air transport aircraft (main static inverter failure during pre-flight checks, resulting in a small fire that was extinguished).
- **Foreign object damage** – one occurrence involved cabin crew on a large air transport aircraft observing smoke emanating from a galley oven. The smoke was due to a battery that had been left under a meal trolley, and had melted during the heating of the meals.
- **Cargo / baggage (including passenger actions)** – eight occurrences (all involving scheduled air transport operations), five of which involved cigarette fumes being detected in an aircraft lavatory. In two of these occurrences, a small fire started due to a cigarette being disposed in a wastepaper bin. The other three occurrences were related to spilled items in passenger baggage or food-related fume complaints.

In each of these cases, there were still numerous effective defences in place to prevent an injury outcome (crew or passenger injury or incapacitation, or aircraft systems degradation). These included portable oxygen supplies and/or protective equipment (such as flight crew hoods), use of fire extinguishers or aircraft fire suppression systems, conducting a diversion or return, and electrical isolation of faulty systems.

Only four occurrences associated with fumes/smoke were reported over this period where the ATSB assessed that there was a high or very high risk to safety using the ERC framework. One involved a near collision between two aircraft, and the other three were in-flight fires that were not able to be extinguished:

- During an aerial survey near Litchfield Station, NT, the pilot of the Hughes 269C helicopter noticed smoke in the cockpit and conducted a precautionary landing in an open area with long grass. The helicopter caught fire and was seriously damaged (201003903).
- While inbound to Derby, WA, the Cessna 208 crew detected rubber-like fumes in the cockpit. The crew conducted an emergency descent with the intention of an expedited landing at the non-controlled aerodrome. As the aircraft joined downwind, the flight crew observed an aircraft joining crosswind below them, and there was a near collision between the two aircraft. The crew then noticed that they had inadvertently switched the radio frequency when broadcasting their intentions. The source of the fumes was traced to an air conditioning belt (201108884).
- A Eurocopter AS.350 helicopter was en route from Ceduna to Border Village, SA carrying a cargo of dangerous goods when abnormal fuel fumes were detected in the cockpit. The pilot conducted an emergency landing. Once on the ground, the passenger exited the aircraft and noticed smoke and

fire emanating from the engine area and aft cargo compartment. The passenger attempted to extinguish the fire with a portable fire extinguisher but the fire erupted. The pilot and passenger attempted to remove cargo from the aircraft, but evacuated the area and the helicopter was destroyed by fire (201205776).

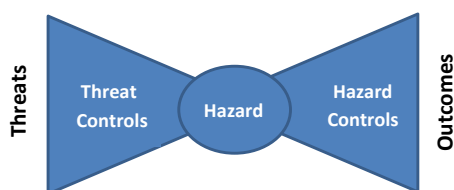
- During the approach into Princess Alexandra Hospital in Brisbane, a piece of medical equipment on board the MBB BK117 medical evacuation helicopter caught fire and the patient sustained a minor burn. Attempts to extinguish the fire were unsuccessful. The pilot attempted to conduct a precautionary landing at a nearby football field but was unable to, and it was not possible to discharge the portable fire extinguisher. Upon landing, the aircraft doors were opened to evacuate the smoke, and the burning equipment was thrown out on to the helipad (201208876).

Risk analysis – bow tie method

To understand the nature of fumes/smoke events and the risk they pose to flight safety, the Bowtie risk model¹¹ was applied to the fumes context. The Bowtie model is commonly used in a number of high complexity industries (including aviation) to model systems as a means of understanding organisational hazards and risks. As shown in Figure 23, the hazard under review is represented as the centre of the bowtie. The Bowtie model provides a means of mapping the possible causes of a hazard ('threats'), the defences in place to stop that from happening ('controls'), and the possible outcomes the hazard may generate and the controls in place to prevent or reduce the scale of that outcome. On a basic level, this fosters an understanding of the potential scenarios that may lead to adverse safety outcomes.

Note that the Bowtie model is in itself a descriptive tool, and is not intended to assess the quality of controls or the likelihood of the hazard or its outcomes developing. This can be done using the information gained from the Bowtie at a later stage as desired.

Figure 23: The Bowtie model of organisational hazards and risks

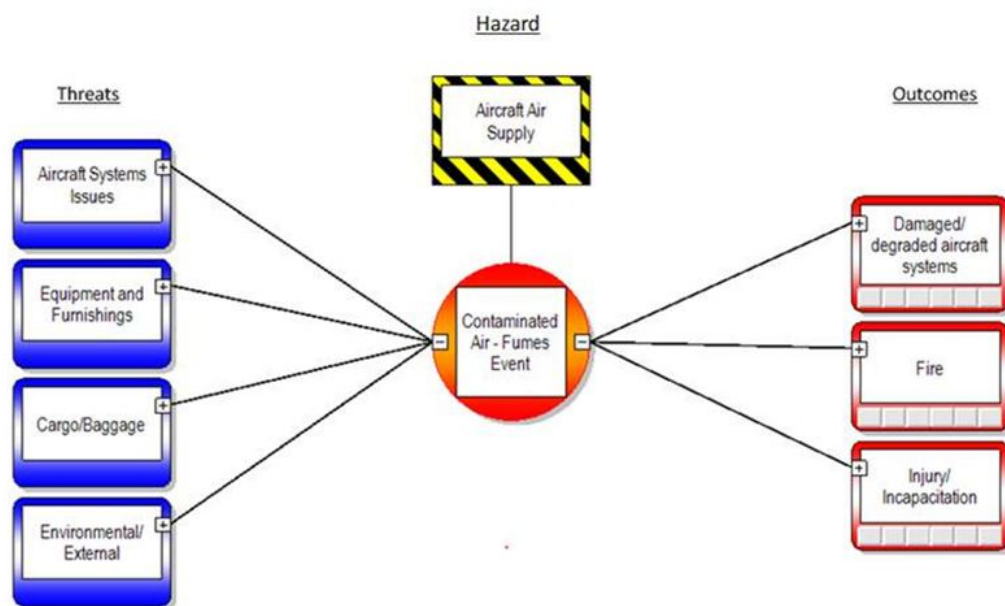


Using the fumes and smoke related occurrences reported to the ATSB as the hazard under analysis, the probable threats and outcomes of these events can be seen in Figure 24 below. The lines between the threats and outcomes represent the controls in place that may be effective in avoiding or reducing the hazard or outcomes. The controls are included in the complete version of the Bowtie model created for fumes/smoke events, which is presented in Appendix D, along with an explanatory table of the elements identified in the diagram (Appendix E). The threats identified have been categorised into high level groupings due to the similarity of controls within each group. A detailed discussion of each of these threat groups follows.

It is important to note that not all possible eventualities are captured within this Bowtie model. In order to gain maximum benefit from the Bowtie model approach, the scope of the Bowtie has been limited to consider only those threats and outcomes that are probable in a fumes/smoke event. When considering outcomes in the Bowtie model, the outcomes identified can be the final outcome of the hazard in themselves. They can also be seen as new hazards with their own sets of threats and controls. Only the former will be considered in detail within the scope of this report.

¹¹ The Bowtie risk analysis methodology was first used by Imperial Chemical Industries (ICI) in the late 1970s, and further refined by Royal Dutch Shell in the early 1990s in the wake of the Piper Alpha offshore platform disaster. It allows modelling and evaluating risks where quantification is not possible or desirable.

Figure 24: Summary of the Fumes/smoke hazard Bowtie



Threats leading to fumes/smoke events, and the outcomes of these events, were identified through both service difficulty reports (SDRs) submitted to CASA, aviation safety incident reports (ASIRs) submitted to the ATSB, and for military aircraft, aviation safety occurrence reports (ASORs) collected by the Department of Defence. In many cases there were crossovers between the information about threats provided in each type of notification.

All ASIRs indicated a fumes/smoke outcome by their nature as reports of operational safety incidents, whereas not all SDRs were related to an outcome. Most ASORs that related to operational events also indicated outcomes of fumes/smoke events.

Threats

The focus of the data analysis provided in this section was to look at threats that led to outcomes. As a result, this section primarily provides an analysis of ASIR data to describe the types of threats that existed in those situations where a fumes/smoke threat actually led to a fumes/smoke outcome. As described above, only about half of ASIR occurrences had enough reported information to determine the fume/smoke source. Service difficulty reporting data was used to provide greater context to some types of threats (such as aircraft systems and equipment/furnishings issues) where failure or malfunction of an individual aircraft component and system may have been reported.

For other types of threats (cargo/baggage and environmental/external), it was not likely that an SDR would have been raised if a fumes/smoke event occurred. In these cases, an ASIR would likely be the only source of information that indicated that one of these threats led to a fumes/smoke outcome.

Aircraft systems issues

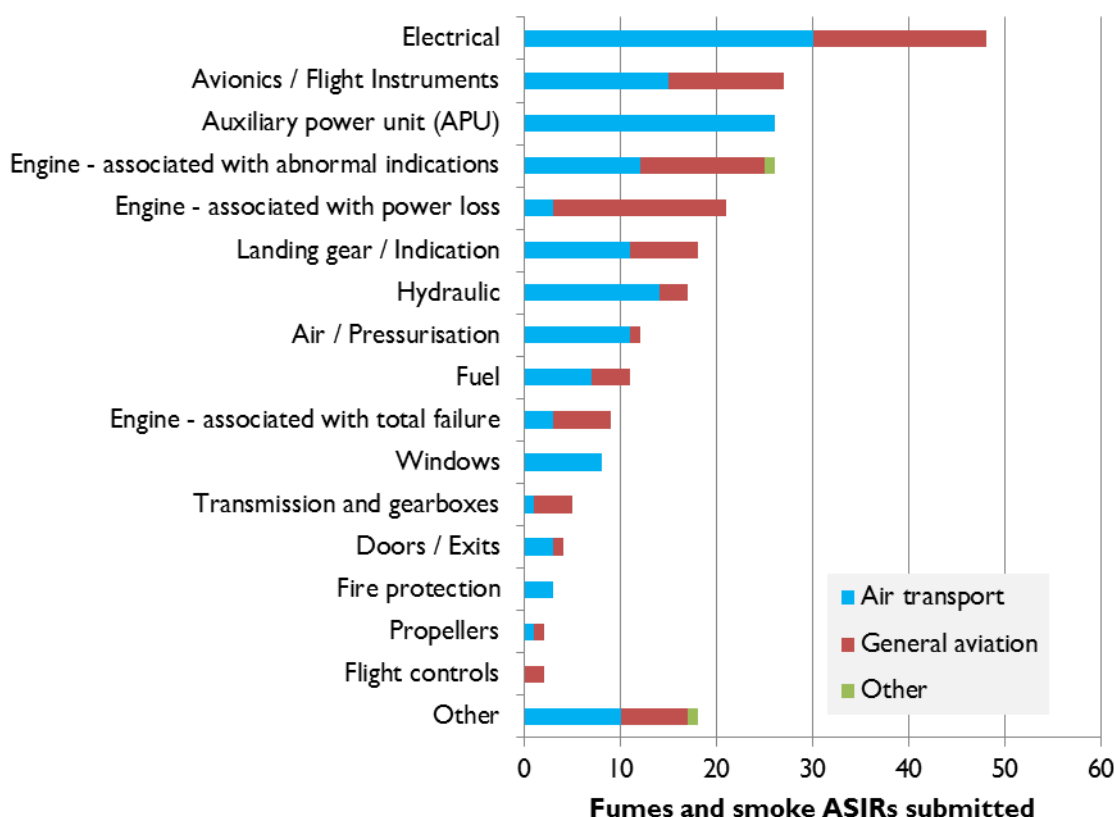
This category of threat covers fumes/smoke generated from any aircraft system issue – be it mechanical or electrical – that affected one or more aircraft systems or components used for aircraft operation. Although systems/components are required for aircraft operation in some way, safe flight does not necessarily rely on all of them functioning. Examples of aircraft operational systems that may generate fumes/smoke include engines, bleed air or pressurisation systems, electrical systems, flight controls, avionics, or the auxiliary power unit (APU) to name but a few. Aircraft systems issues may involve failure of any of these systems to operate appropriately due to electrical or mechanical failure, malfunction or misuse.

Defences used to prevent, or limit the operational and safety impact of aircraft systems issues, include a network of rules and regulations, procedures and checks (such as audits, investigations and issue reporting), and appropriate training and education initiatives.

Of the 1,263 fumes/smoke occurrences reported to the ATSB over the 2008 to 2012 period, 19 per cent (239) were associated with an identified aircraft system issue. These covered a diverse range of issues (airframe, powerplant, and systems such as avionics and flight instruments, bleed air and pressurisation, electrical, fire protection, flight controls, fuel, and hydraulic). About 57 per cent of those ASIRs associated with an identified aircraft system issue (136 ASIRs) had a matching SDR which detailed the likely source of the fumes/smoke. In a small fraction of cases, multiple systems issues resulted in the fumes/smoke, or multiple SDRs were submitted to CASA for the same event.

Figure 25 below shows what systems were most likely to be involved in reported fumes/smoke events for different types of operations.

Figure 25: Fumes/smoke ASIRs associated with aircraft system issues, 2008 to 2012



Electrical issues causing fumes or smoke were varied in nature, with the most common being shorts due to chafing of wires in non-essential avionics (global positioning system (GPS) equipment, navigational beacon) or systems (air circulation fan, instrument backlighting). In the majority of these cases, the flight crew were able to use their training and knowledge of the aircraft systems to identify the problem themselves by electrically isolating systems, and eliminate the source of the fumes/smoke by pulling circuit breakers. In 11 of 48 occurrences, a more serious electrical system failure occurred during flight (alternator failure, primary battery or inverter failure, avionics master switch failure) which prevented most or all electrical systems from operating. All of these occurrences involved general aviation aircraft, and in almost all occurrences, the pilot decided to make a precautionary return or diversion. In these cases, design and crew defences effectively mitigated the potential for the fumes/smoke to result in a more serious outcome. The most serious occurrences were due to lightning strikes, where multiple electrical and engine system failures resulted as well as fumes. In these situations, pilots were able to isolate the affected electrical systems to prevent further fumes/smoke or fire, regain sufficient power from the engine, and divert to a nearby aerodrome.

Example notifications:

201002461: During climb out from Sunshine Coast Airport, the pilot of the Mooney received a landing gear unsafe indication from one of the aircraft's gear position indicators. A short time later the instrument lighting circuit breaker tripped and a burning odour was noted for about 10 seconds. On arrival at Rockhampton a flyby inspection was done and the tower confirmed that the gear appeared to be retracted correctly. The subsequent engineering inspection found no problems with the landing gear and the burning odour was likely caused by a wiring short.

200805224: At the top of climb after take-off from Ceduna, SA, a flight attendant of a Saab 340 noticed smoke emanating from the overhead light above seat 6A. The light was switched off and the smoke ceased. A strong odour remained throughout the cabin and the crew elected to divert to Port Lincoln as a precaution.

Avionics and flight instrument failures that resulted in fumes/smoke were also largely due to internal electrical faults. About one-third of these occurrences involved air transport aircraft of several types and operators. Failures of multi-function displays and control panels were the most common sources of localised fumes/smoke in the cockpit. As for other electrical issues, electrical isolation of the likely source of the fumes/smoke was an effective control and mitigated the need for other defences such as crew oxygen use, or conducting a flight diversion. The remaining two-thirds of occurrences involved a variety of general aviation aircraft types. Most of these occurrences happened in cruise, when the aircraft's electrical system was under maximum load. The most common failures involved high frequency (HF) radios, and to a lesser extent, transponders, flight management computers and weather radars. These avionics tend to draw more current from the aircraft's electrical system than other avionics or systems (such as lighting).

Auxiliary power units (APU) were the third most common aircraft system associated with fumes and smoke events, and second most common involving air transport aircraft. Fumes or smoke associated with APU problems were most commonly oil leaks from both O-rings and the load compressor carbon seals. All involved air transport aircraft. Half of the 26 occurrences involved Airbus A320 aircraft operated by one airline. The ATSB believes this reflects good reporting of fumes/smoke events by this operator compared to other Australian air transport operators.

Fumes/smoke from APU oil leaks were generally first detected in the aft cabin or galley, and about half were detected while the aircraft was still on the ground (after engine start or during boarding). Most APU and bleed air fumes detected during flight were during descent. The remainder of occurrences were mostly fuel and oil leaks in the engine, which affected bleed air quality. About 10 of these occurrences involved high or low capacity RPT air transport aircraft, with the remainder involving general aviation and charter aircraft. When APU or bleed air fumes were detected during flight, effective actions taken by the crew to mitigate any impact of the fumes/smoke on safety were to either cancel the flight or ask for an engineering inspection (when the aircraft was on the ground). No reported occurrences resulted in a more serious outcome such as a fire, engine failure, or crew or passenger incapacitation.

Example notifications:

201107164: During cruise on a flight from Brisbane to Newcastle, the crew of the Airbus A320 detected fumes in the cockpit. The engineering inspection revealed that the external APU bleed leak system was faulty (APU starter O-ring cut and leaking).

201102144: The Embraer E-190 returned to the bay due to an APU failure on pushback at Brisbane Airport. While the engineers were investigating the problem, fumes from a pneumatic cart entered the aircraft. The passengers were disembarked as a precaution. The engineering inspection found no fault with the APU.

201102944: After engine start, the Fokker 100 crew received an APU fault warning. An engineer restarted the APU which produced black smoke. The crew shut the APU down and cancelled the flight. The APU was removed and sent to the APU repair and overhaul vendor for engineering investigation.

Abnormal engine indications and vibrations associated with fumes/smoke most commonly affected general aviation and charter aircraft, particularly twin-engine piston aircraft. Most fumes/smoke occurrences were related to low or decreasing oil pressure indications, due to ruptured oil lines. Occurrences involving air transport aircraft (nine of 26) were mostly reports of smoke observed from the engine, but not entering the cabin. These occurrences involved a range of aircraft types and operators, and were due to oil leaks or mechanical damage from turbine failures or liberated compressor blades. In all cases, a precautionary shutdown of the affected engine, and a diversion or air return were effective defences taken by the flight crew to prevent further fumes/smoke and engine damage.

Engine issues resulting in a reported loss of power were only associated with fumes/smoke in piston-engine general aviation aircraft. Fuel control unit failures were the most common source of the fumes, followed by failed cylinders. Very few occurrences reported to the ATSB had a corresponding SDR submitted to CASA.

Landing gear issues most commonly resulted in fumes or smoke when a tyre burst on landing (accounted for almost all reported issues with air transport aircraft), or when the landing gear motor failed. Other sources of fumes/smoke were hydraulic leaks, and salt/sand contamination on brake discs burning off when the brakes were applied.

Hydraulic problems associated with fumes/smoke most commonly affected the landing gear – hydraulic fluid leaking on to hot brakes due to chafed flexible hoses. Leaking drain tubes/valves and seized hydraulic pumps were other sources of fumes/smoke (acidic and electrical smells respectively).

Example notifications:

200807059: When the landing gear was selected up after take-off from Darwin, the pilot of the Cessna 402 received an unsafe landing gear indication. The pilot recycled the landing gear and continued the flight. During the cruise, the unsafe landing gear indication reappeared, followed by a hydraulic pressure light warning. The smell of burning hydraulic fluid permeated through the cabin. The pilot selected landing gear down and continued the flight to Snake Bay, NT. An engineering inspection revealed a hydraulic fluid leak from the reservoir in baggage area. During the return flight to Darwin, the airspeed indicator became unserviceable.

200803010: On lowering the landing gear on approach to Darwin Airport, the pilot of the Cessna 210 noticed a smell and, subsequently on touchdown on runway 11, the aircraft's exhaust fell off. The exhaust was retrieved from the centreline of the runway intersections.

'Other' occurrences related to both non-essential airframe and powerplant systems. There was an upward trend in reporting of these types of systems associated with fumes/smoke over the 2008 to 2012 period, which may be due to increased awareness by airline operators and staff of the increased public attention being given to fumes and smoke events on board aircraft.

Example notifications:

201005067: During descent, the Airbus A320 crew noticed a smell emanating from the air conditioning system. The flight crew reported this on landing, and identifying the source of the smell was initially accepted as a deferred defect by engineers. On a later flight on the same day, the smell recurred, being strongest at top of descent. Engineers carried out a borescope inspection of stages 3 and 4 of the left engine high pressure compressor which revealed evidence of oil contamination. The engine was changed.

Equipment and furnishings

Fumes/smoke may be generated from the failure, malfunction or misuse of aircraft equipment and/or furnishings. In this report, equipment and furnishings refers to those parts of the aircraft that are provided for the comfort of passengers or crew and are not required for the operation of the aircraft. This includes items such as in-flight entertainment systems, galley equipment, air conditioning and air filtration systems, and toilets.

Eleven per cent (140) of the 1,263 fumes/smoke occurrences reported to the ATSB over the 2008 to 2012 period were associated with an identified equipment or furnishings issue. Air conditioning system issues were by far the most commonly reported sources of fumes/smoke, followed by cabin and galley equipment. Over 80 per cent had a matching SDR which detailed the likely source of the fumes/smoke.

Very few fumes/smoke occurrences due to equipment or furnishings issues required an operational change (flight diversion or cancellation) to prevent the fumes/smoke event from escalating to a more serious outcome). Flight crews were normally able to effectively dissipate the fumes/smoke by electrically isolating affected systems, and the flight continued as normal without any health or safety impact on flight crew or passengers. Sometimes, portable crew oxygen was used by flight or cabin crew in isolated areas of the aircraft (generally very close to the source of the fumes/smoke) until that crew member was able to isolate the source (visually or through execution of a non-normal checklist), or leave the area affected. In situations where the source was not able to be identified and the fumes were associated with smoke, the flight crew donned oxygen masks and conducted a precautionary descent and air return or diversion. Even in these occurrences, no flight/cabin crew or passengers reported feeling unwell.

Air conditioning issues accounted for 54 reported fumes/smoke occurrences over this period. Almost all involved air transport aircraft, but of varying types and operators. Fumes emanating from the air conditioning system were most often identified in the first instance by cabin crew. Recirculation and blower fan failures were the most common cause of fumes/smoke (almost half of these occurrences), usually through mechanical failure (bearing failure, fan rubbing against housing). Air conditioning pack (also known as air cycle machine) failures were also a common source of fumes/smoke. While it was often not reported (either through ASIRs or SDRs) why the pack failed, reported reasons included split rubber bellows/riser ducting allowing non-filtered air to enter the air conditioning system, and faulty compressor motors. There were also several occurrences reported to the ATSB where dust and water-contaminated air conditioning filters caused fumes or unpleasant smells in the cabin air supply. Reporting to the ATSB of air conditioning problems resulting in fumes/smoke increased in 2011 and 2012, particularly by major charter and regional airline operators.

Example reports:

201103433: During cruise on an international flight, fumes were smelled throughout the Boeing 747-400. The flight crew switched the air conditioning fans and chillers plus power to passenger services off, and the smell dissipated. Services were reactivated until the source of the fumes was identified as two chillers. During the maintenance inspection, a recirculation fan was replaced.

200907394: During descent into Learmonth, WA, a flight attendant smelled fumes in the galley area and shortly afterward, donned an oxygen mask. Engineering inspection revealed a split in the main riser air distribution duct of the Fokker 100 coupled with a blank separating the air conditioning bay from the avionics bay that had become dislodged, allowing hot air to enter the avionics bay and be drawn through the galley ventilation system.

200903380: During the approach into Sydney, fumes were detected in the cabin and the cockpit and a passenger reported a grinding metal on metal sound. The crew of the Saab 340 donned oxygen masks, actioned the non-normal checklist and the fumes dissipated. An engineering inspection revealed that the left air conditioning pack had seized.

Cabin and galley equipment and fittings failures resulted in 84 reported fumes/smoke occurrences. While the sources of the fumes/smoke were varied, oven failures, burnt food or improper items placed in ovens, in-flight entertainment units, lighting ballasts, exhaust fans, and water pumps were more

common sources of fumes. Most occurred in cruise on air transport aircraft corresponding with cabin service periods, the heating of meals, and the use of in-flight entertainment systems.

Example notifications:

201104979: During the cruise, the crew of the Boeing 737 detected slight burning fumes from the front toilet. The aircraft was diverted to Alice Springs. An engineering inspection revealed a faulty toilet light and water heater.

201103433: During cruise, fumes were smelt throughout the aircraft. The crew of the Boeing 747 switched the air conditioning fans and chillers plus power to passenger services off, and the smell dissipated. Services were reactivated until the source of the fumes was identified as two chillers. During the maintenance inspection, a recirculation fan was replaced.

200801932: During a flight from Melbourne to Brisbane, fumes were reported from the galley ovens causing the cabin crew to feel nauseous. The Boeing 737 had just returned from maintenance, where the galley ovens had been sprayed with the incorrect cleaning agent.

200901639: Shortly after the cabin crew switched the ovens on for heating meals, they noticed an unusual odour. Investigation revealed that the catering provider had loaded the crew meals on the Boeing 737 flight using polystyrene trays instead of the oven-proof cardboard trays.

In only four of these 83 occurrences did a cabin crew member report feeling unwell or nauseous, or was reported to have seen a doctor:

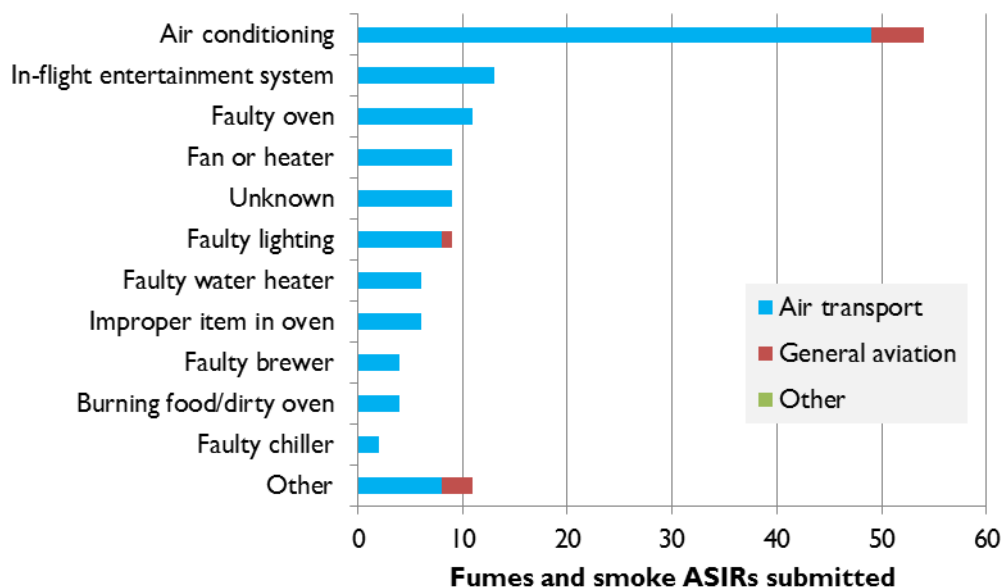
- 200801932 – fumes were reported from the galley ovens of the Boeing 737, causing the cabin crew to feel nauseous. The source of the fumes was found to be cleaning agent residue inside the ovens.
- 201002376 – cabin crew noticed a chemical smell in the cabin of the Airbus A320 during descent, one crew member reported feeling unwell. An engineering inspection found no fault with the aircraft.
- 201103947 – fumes were detected throughout the Airbus A320 during descent. Cabin crew members reported feeling unwell. An engineering inspection did not reveal the source of the fumes.
- 201203620 – cabin crew reported a strong oily smell in the cabin of the Embraer E-190 during turnaround. While trying to identify the source of the fumes with engineers, a cabin crew member became ill and had to be offloaded. The source of the fumes could not be confirmed, however, the aircraft had undergone a compressor wash the night before.

Only one fumes/smoke events resulting from equipment or furnishings was associated with a report of passengers feeling unwell:

- 201204298 – prior to departure, pungent fumes emanated from a forward galley oven on the Airbus A320. A passenger and some cabin crew members became nauseous due to the fumes. A thorough overnight clean of the ovens was conducted following the fumes event.

Figure 26 below shows the cabin and galley equipment and fittings involved in these reported occurrences. Note that many minor fumes occurrences that do not have a safety of flight impact (such as burnt food smells) are not reported to the ATSB.

Figure 26: Fumes/smoke ASIRs associated with equipment and furnishings issues, 2008 to 2012



- **In-flight entertainment system** – power supply unit and cooling fan failures led to individual in-flight entertainment system units overheating, and emitting fumes. These failures probably occurred due to manufacturing controls being ineffective, as these systems are normally sealed units that are replaced on an on-condition basis. Electrical isolation of the individual unit during flight, followed by an engineering inspection after the flight were the normal controls used by flight crews to prevent escalation or recurrence of the fumes or smoke event.
- **Faulty oven** – most of these failures appeared to be electrical in nature, but the SDR investigation could not definitively identify the cause of the failure in most cases. Anecdotal evidence from SDRs suggests that many oven failures are due to a build-up of food residue and grease on the heating element, and dust in the cooling fans due to the ovens not being cleaned regularly (discussed later in the report). Maintenance controls and crew inaction are the two major ineffective controls that result in these types of fumes/smoke occurrences, as well as design or manufacturing controls in cases where an electrical fault caused the oven failure. Electrical isolation of the individual unit during flight, followed by an engineering inspection after the flight were the normal controls to prevent escalation or recurrence of the fumes or smoke event.
- **Fan or heater** – included blower heater fan, exhaust fan, and galley floor heating panel failures. Very few SDRs were submitted for these fumes/smoke occurrences (so the mode of failure was generally not known), but the typical defence employed to prevent escalation was electrical isolation of the affected system. In one occurrence involving a galley floor heater failure, the flight crew and cabin crew used portable oxygen and conducted a diversion. The galley floor heater was made unserviceable until it was able to be replaced.
- **Lighting** – a range of lighting systems (in the cockpit and cabin) were affected. In almost all cases, a faulty bulb was the source of the failure, resulting in the light ballast overheating and emitting fumes or smoke.
- **Other equipment and furnishings issues** – improper items in ovens are a situation where controls to prevent a fumes/smoke event are not effective due to unintended interactions. When ovens are used for storage of non-food items (such as plastic cutlery), or are cleaned with inappropriate agents, the risk of a fire or toxic smoke and resulting injuries or incapacitation of crew and passengers is increased. In one occurrence reported to the ATSB, the remains of an electronic point-of-sale machine battery were found inside of an oven after cabin crew detected smoke.

Cargo and baggage

Cargo or baggage carried by an aircraft (either in the cabin or in the cargo holds) can be a source of fumes/smoke if handled or stored improperly, or if it is not suitable for carriage on an aircraft. This includes freight and passenger luggage carried in the cargo area of the aircraft, as well as the contents of passenger luggage carried on board. While some types of cargo/baggage that are potential fumes or smoke sources are permitted for carriage on aircraft, others are prohibited. Those that are allowed to be carried require certain containment measures to be taken, such as specific packaging materials, orientation, and temperature control.

The term 'dangerous goods' is used to describe many of the types of cargo/baggage that have the potential to produce fumes or smoke. Dangerous goods requirements, guidelines and resulting procedures are the primary control for managing the carriage of dangerous goods on aircraft, and minimising the risk of a fumes/smoke event or other safety incident. Information is provided to passengers, freight personnel and crew at different levels to guide their behaviour regarding the carriage of dangerous goods. This extends to loading practices, packaging and identification of items, knowledge of prohibited items, and deterrents/penalties for their improper or prohibited carriage. To encourage these requirements to be followed, there are a range of education and training initiatives and requirements specific to dangerous goods targeting each of these parties, and other participants in the aviation industry (such as freight forwarders).

Another control for avoiding the carriage of items on board aircraft that have a potential to generate fumes or smoke is the operational crew. This applies to designated dangerous goods items as well as those not covered under those requirements. Flight and cabin crew, in addition to ground crew, are responsible for the oversight and management of passengers and their baggage/cargo in relation to safety. Should such an item make it on board an aircraft, the flight and cabin crew serve as a defence to detect and address the fumes/smoke risk that the item might pose. The role of crew in controlling for cargo/baggage safety risks is generally driven by procedures and standards. There are a number of assurance measures to encourage these standards and procedures are followed and are effective in detecting and managing cargo/baggage safety risks, including training and performance monitoring.

Example notifications:

200707464: While en route from Sydney to Christchurch, the crew requested to return to Sydney for a landing due to smoke and fumes in the cockpit. The foreign-registered Boeing 767 aircraft was carrying dangerous cargo containing dry ice and frozen cultures in the cargo hold.

200807363: During the cruise, the flight crew of the Boeing 747 received a smoke in lavatory EICAS warning. Cabin crew subsequently extinguished a fire located in a rubbish bin in the number R5 bar toilet. The smoke detector had been blocked by a passenger who could not be identified. A cigarette butt was found in the burning bin.

Only 17 of the 1,263 fumes/smoke occurrences reported to the ATSB over the 2008 to 2012 period involved cargo or passenger baggage. As fumes/smoke from cargo and baggage are operational safety of flight issues not related to the function of the aircraft or its systems, these occurrences did not have matching SDRs reported to CASA.

Half of these were due to dangerous goods being packed improperly, and the other half were due to passenger actions (such as smoking in the lavatory, or placing cigarette butts in a waste bin) or carry-on baggage contents. Almost all occurrences were reported by Airline D and Airline G, due to more consistent reporting of aircraft loading-related events by these operators over the 2008 to 2012 period.

Spilled or improperly packed dangerous goods causing detectable fumes/smoke included a damaged package solvent-based glue detected when the cargo hold was opened, a bottle of methyl methacrylate leaking from a passenger's bag in the overhead locker, spilt nail polish remover, paint, and mineral turpentine.

Almost all passenger-related fumes/smoke occurrences were due to smoking on board the aircraft. In two cases, a fire started because of hot ash placed in a waste paper bin. Cabin crew monitoring and

actions, as well as lavatory smoke alarms were effective controls to prevent escalation of the fire (even when they had been interfered with by the passenger).

Environmental and external sources

Fumes/smoke may enter an aircraft from an external source, either in flight or while on the ground. This could be from environmental conditions such as volcanic ash or bushfires, or other external sources such as exhaust from nearby aircraft or industries.

Operational standards and procedures are one of the key defences available to avoid environmental-related fumes or smoke from entering an aircraft. There are a number of tools available to flight crew, such as weather report services, which enable them to identify and subsequently avoid unfavourable or risky weather conditions. The decision making and action of the flight crew with respect to weather is supported and defined in many cases by standard procedures and responses.

There are also operational standards in place to avoid other sources of external fumes/smoke (such as aircraft exhaust) from entering an aircraft. These may relate to, for example, the avoidance of congestion, appropriate airport movements and boarding practices. As for environmental-related threats, there are operational standards in place to support positive action by flight crews to avoid external fumes/smoke sources. Additional resources, such as air traffic services, may also be available to keep aircraft separated from these fumes/smoke sources.

Design standards of aircraft and airports also serve to reduce the possibility of external fumes/smoke sources impacting on normal operations. These help to reduce exposure to external sources through, for example, providing suitable aircraft parking and movement space; or prevent or mitigate the entry of fumes or smoke into the aircraft cabin through the design of aircraft filtration or ventilation systems. Both aircraft and airport design are influenced by regulations and requirements, as well as quality assurance controls to avoid safety issues – including fumes/smoke events.

Example notifications:

201009080: During the take-off roll at Queenstown, New Zealand, the cabin crew detected smoke and fumes in the cabin. The engineering inspection revealed burnt insects in the auxiliary power unit of the Airbus A320.

200902510: During pushback at Melbourne Airport, cabin crew reported a strong smell of fumes in the aft cabin of the Boeing 737. The smell subsequently dissipated. The crew believed that wind on the tarmac was blowing fumes back onto the aircraft.

201102144: The Embraer E-190 aircraft returned to the bay at Brisbane Airport due to an auxiliary power unit (APU) failure. While the engineers were investigating the problem, fumes from a pneumatic cart entered the aircraft. The passengers were disembarked as a precaution. The engineering inspection found no fault with the APU.

200902009: During cruise, the Boeing 737 was struck twice by lightning. When the aircraft was returning to Melbourne, it was struck by lightning a third time and the crew reported electrical fumes in the cockpit.

Very few fumes/smoke occurrences caused by external or environmental factors are reported to the ATSB. As fumes/smoke from external sources is not related to the function of the aircraft or its systems, those occurrences that are reported are unlikely to have a matching SDR reported to CASA.

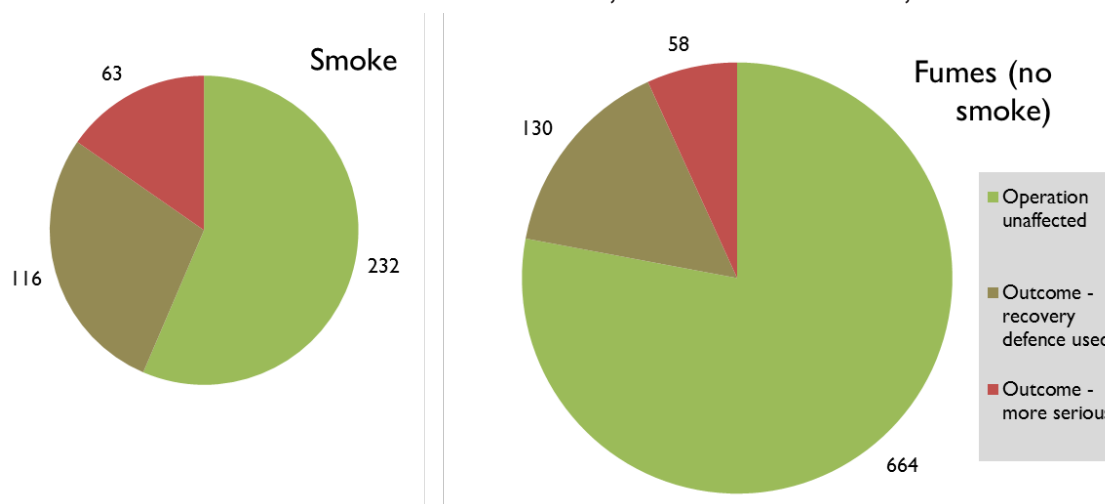
Eight fumes/smoke occurrences were reported to the ATSB between 2008 and 2012 that emanated from an environmental/external source. These involved fumes due to lightning strike, and fumes entering the aircraft from ground support equipment. In most cases the source of the fumes was not identified or the effect of the external influence was not known, so crew-based controls were the most effective means of preventing the fumes/smoke event from escalating (such as a precautionary diversion or air return, or if the aircraft was on the ground, a precautionary disembarkation).

Potential outcomes

As fumes/smoke events that may have posed a risk to the safety of flight are operational safety of flight issues, ATSB aviation safety incident reports were reviewed to identify typical outcomes from these events and what effect they had on the flight, passengers or crew.

Figure 27 shows the proportion of the 1,263 fumes/smoke occurrences reported to the ATSB between 2008 and 2012 that resulted in an outcome versus those where there was no operational effect. Occurrences involving smoke were more likely to result in an outcome.

Figure 27: Outcomes associated with smoke ASIRs, and with fumes ASIRs, 2008 to 2012



Very few led to a serious consequential event (such as a forced landing) or outcome such as a fire or crew incapacitation. This is because:

- the fumes/smoke were minor in nature and did not pose a risk to the safety of flight
- neither normal operations, the aircraft, nor the health of any persons on board were impacted upon
- the source of the fumes/smoke was identified, and an effective defence was available in the moment for the flight or cabin crew to adequately mitigate the threat (such as extinguishing a rubbish bin fire, removing burning food from an oven, activation of a warning device, or electrical isolation of a malfunctioning radio)

In cases where there was an operational impact due to the fumes/smoke, the flight crew were often able to utilise recovery defences to minimise the risk of a more serious outcome from occurring.

Use of recovery defences

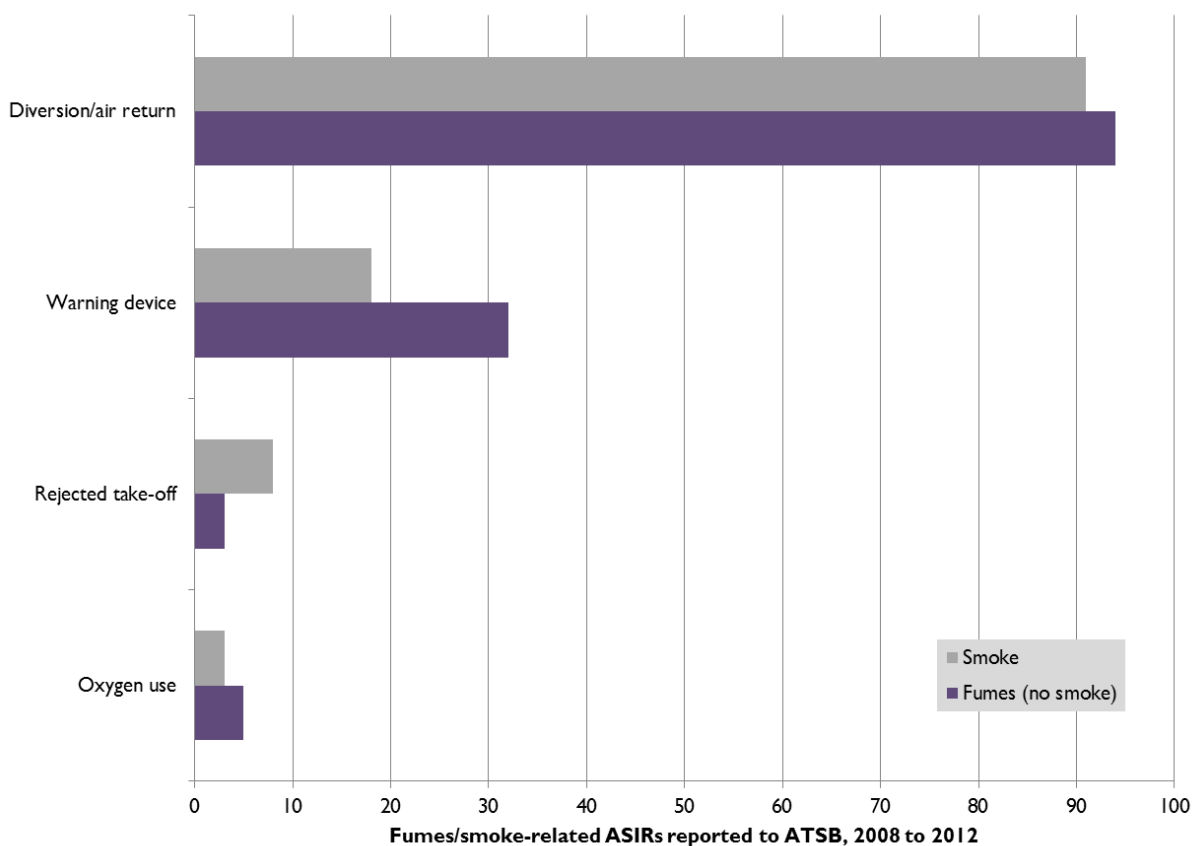
While fumes/smoke events have the potential to result in more serious outcomes (damaged or degraded aircraft systems, fires, and injury or incapacitation), these outcomes (described in the next section) are relatively rare. This is because in almost all cases, the source of the fumes/smoke (whether they be systems, environmental, equipment, or cargo related) is effectively managed by recovery defences to prevent more serious outcomes. Depending on the type or source of fumes/smoke, these defences may include electrical isolation, crew intervention or operational diversions.

Recovery defences are still outcomes (and sit on the right-hand side of the bowtie model), but they act as barriers to prevent more serious outcomes from occurring.

Where the fumes or smoke may have represented a safety of flight risk, diversions or air returns were the typical response, sometimes in response to a warning device activating indicating a technical fault (see Figure 28 below). This outcome is reflective of the effectiveness of crew training and operational procedures (such as non-normal checklists) as a defence to prevent the escalation of fumes/smoke events. Oxygen was used by the flight crew when fumes or smoke were detected in 65 occurrences (about five per cent of all fumes/smoke occurrences reported to the ATSB between 2008 and 2012). In only 25 of these did the flight crew don oxygen masks as a precaution against a real perceived threat of incapacitation. In most of the other cases, the flight crew donned oxygen masks as a precautionary

defence (usually as part of actioning the non-normal checklist), even if the fumes/smoke did not affect normal flight operations.

Figure 28: Recovery defence use associated with smoke ASIRs, and with fumes ASIRs, 2008 to 2012¹²



Example notifications:

200801282: During final approach to Christchurch Airport, New Zealand, various EICAS messages momentarily displayed on the flight deck of the Boeing 767, and at the same time the crew noticed a burning electrical smell in the cabin. As a precautionary measure, the pilot in command's oxygen mask was donned and the co-pilot continued to a normal landing. An engineering inspection revealed two circuit breakers had tripped.

201103859: During the initial climb out of Cairns, the flight crew of the Boeing 737-800 detected oily fumes. The copilot donned an oxygen mask. Engineers confirmed a recent compressor wash was the source of the fumes.

201107783: During the climb, the flight crew of the Boeing 737-800 detected fumes in the cockpit and returned to Brisbane. The engineering inspection determined the likely cause of the fumes was an engineer entering the cockpit with fuel-soaked clothing.

In only a handful of fumes/smoke occurrences did cabin crew use portable oxygen, or were administered oxygen after the flight due to a fumes/smoke event. There was only one smoke occurrence reported to the ATSB between 2008 and 2012 where the flight crew deployed oxygen masks for passengers. The following four occurrences involved air transport operations:

¹² Warning device indicates a crew action in response to a non-normal cockpit indication (such as an EICAS message, or a failure light). Crew actions might include electrical isolation of the affected aircraft system or equipment, use of an auxiliary system, use of another recovery defence (such as a diversion or rejected take-off), or troubleshooting of the warning device activation.

- While on climb from Gladstone to Brisbane, a flight attendant detected an electrical burning smell in the cockpit and slight smoke in the cabin. The crew donned oxygen masks, actioned the non-normal checklist, advised the cabin crew to use portable oxygen masks, and diverted to Bundaberg where the aircraft was landed safely. A precautionary evacuation was conducted, though the passenger oxygen masks were not deployed. Emergency services attended but were unable to detect the smoke source. An engineering inspection revealed a failure in the aft air cycle machine.
- During a flight between Melbourne and the Gold Coast, the flight crew detected a strong intermittent smell in the rear of the cabin. An inspection by the cabin crew did not detect the source of the smell. On descent prior to landing, cabin crew presented various symptoms. Two of the cabin crew used oxygen before recovering sufficiently to resume their duties. No passengers were affected. The airport rescue and fire fighting service attended the aircraft at the arrival gate. Paramedics conducted medical checks on the cabin crew. Both the cabin crew and flight crew were taken to the local hospital for further examination and later released. The cargo holds were opened prior to a precautionary inspection for the source of the fumes. The source and nature of the fumes was not identified.
- During descent into Learmonth, a flight attendant smelled plastic fumes in the galley area and shortly afterward, donned an oxygen mask. Engineering inspection revealed a split in the main riser air distribution duct coupled with a blank separating the air conditioning bay from the avionics bay that had become dislodged, allowing hot air to enter the avionics bay and be drawn through the galley ventilation system.
- During a flight from Clermont to Brisbane, the cabin crew noticed smoke in the cabin emanating from an overhead locker. The crew and passengers donned oxygen masks and a fire extinguisher was discharged towards the likely source of the smoke. The flight crew declared a PAN and the aircraft diverted to Thangool. An engineering inspection revealed the source of the smoke to be a charred lamp holder.

The remaining occurrences affected aeromedical evacuation services.

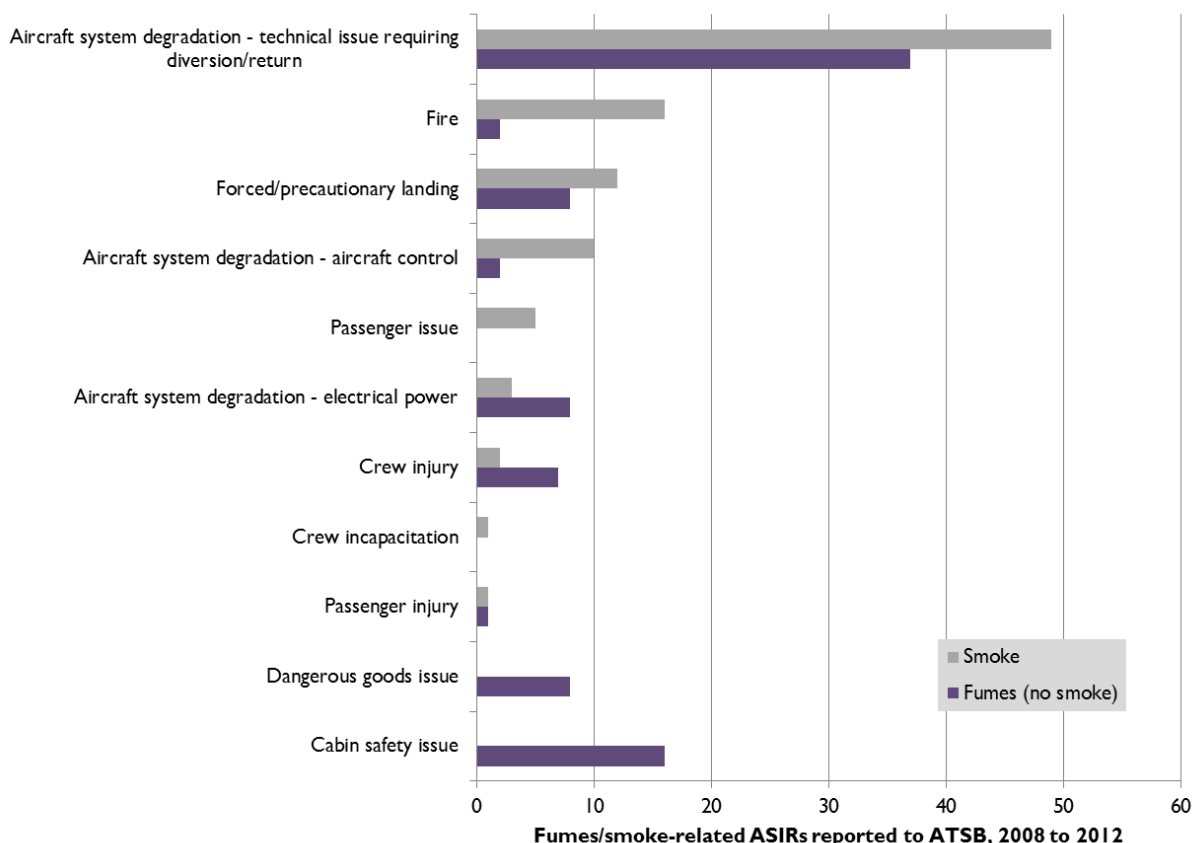
In each of these cases, defences were in place (oxygen, cabin crew training, diversion/return, precautionary evacuation) that prevented the fire/smoke event from escalating. Fumes/smoke events associated with fires, injuries, and crew incapacitation are discussed in detail in the next section.

More serious outcomes

In only a very small number of occurrences did a fumes/smoke event escalate to a more serious outcome (fire) or a more hazardous consequential event, such as a forced landing or crew incapacitation. Many of these occurrences involved a fumes/smoke on a single-engine general aviation aircraft, where the fumes and smoke were associated with an engine failure or rough running.

Figure 29 below shows the most common serious outcomes associated with both fumes and smoke events. Varying levels of aircraft system degradation were the most common outcome, though the majority of these were less serious technical issues that resulted in the flight crew conducting a precautionary diversion or air return. Aircraft-wide electrical system failures and aircraft control problems occurred less frequently. Fires, forced landings, and passenger issues (usually related to smoking in aircraft lavatories) were more likely to be outcomes from smoke events. Cabin safety and dangerous goods issues (spilled liquids in passenger baggage, incorrect carriage or packing of cargo) were more likely to be associated with a fumes event, and have been described earlier in this report.

Figure 29: More serious outcomes associated with smoke ASIRs, and with fumes ASIRs, 2008 to 2012



All ASIRs indicated a fumes/smoke outcome by their nature as notifications of operational safety incidents. As a result, the analysis of potential fumes/smoke outcomes in this section is based on ASIRs only.

Injury and incapacitation

This outcome encompasses two related issues: injury and incapacitation. Injury refers to circumstances where passengers or crew experienced any adverse health effects at the time of the fumes/smoke event, or within 30 days of the event occurring. These health effects may have been mild, such as the case of irritation responses (e.g. itchy eyes, headaches), or more serious such as where normal breathing is inhibited or consciousness is lost (see EPAAQ (2011) for more complete effects). Secondary injuries may also result, such as physical injury resulting from a fall due to loss of consciousness.

There were 11 occurrences reported to the ATSB between 2008 and 2012 where a minor injury was associated with a fumes/smoke event, eight of which involved air transport aircraft, and three involved aerial work/general aviation:

- At the top of decent into Melbourne, cabin crew on the Boeing 767 were affected by fumes emanating from the food storage area in the aircraft's forward galley. Two cabin crew members reported red eyes and difficulty breathing on oxygen. The flight crew did not require oxygen, and turned off power to the galley as a precaution. The cabin crew were able to return to normal duties. During the subsequent engineering inspection, one oven filter was found clogged with grease (201003876).
- During an Airbus A320 flight from Ballina to Sydney, a passenger spilt acetone in the cabin, resulting in fumes. The flight crew diverted the aircraft to the Gold Coast as a precaution (201004999).
- During a flight from Adelaide to Perth, fumes were detected in the cabin of the Boeing 737-400. A cabin crew member reported becoming light headed and developed a headache. The fumes were

described as being a chemical 'mild chlorine, alkaline' smell, however, the subsequent engineering inspection found no fault with the aircraft that could have generated the fumes (201005541).

- During descent into Brisbane, cabin crew and passengers on the Airbus A320 detected fumes in the cabin. The fumes were described as a sulphur-like. Several cabin crew members reported feeling light headed with laboured breathing, but the fumes were hardly noticeable in the cockpit. After landing, the airline's base manager took the affected crew to see a doctor. An engineering inspection failed to locate the source of the fumes, though similar fumes had occurred during descent on the previous flight involving this aircraft (201103946).
- After take-off from Melbourne, the cabin crew stationed at the L2/R2 doors of the Airbus A320 detected musty, dusty fumes in the cabin. One of the cabin crew felt light headed and nauseous and was not able to carry out her duties. The fume dissipated slightly during the flight, but increased against during descent. The first officer also came back to the cabin to try and locate the fume source. Upon landing at the Gold Coast, the affected crew member was offloaded. An engineering inspection traced the smell to wet insulation blankets at the L2 door (201202823).
- On take-off from Melbourne, the captain of the Boeing 737-700 reported a burning smell in the cockpit that dissipated at the top of climb. Shortly afterwards, the cabin supervisor advised the flight crew of a very unusual smell in the front and rear of the passenger cabin. The cabin supervisor and one other cabin crew reported a headache and nausea from the fumes. Another cabin crew was unable to continue with his duties due to nausea and vomiting. As there was an extra cabin crew member on the flight, the supervisor assessed that his inability to continue with his duties did not pose a risk to flight safety. After landing and following a review of the maintenance log, a company engineer advised that the fumes may have been the result of a recent engine wash. No passengers reported feeling unwell during or following the flight, though some passengers in the front of the cabin were coughing during the flight. The captain at no time felt unwell and the first officer did not smell anything unusual throughout the flight. After landing, two of the cabin crew were later deemed by a doctor to be unfit for work (201203572).
- During the take-off and climb from the Gold Coast, a cabin crew member detected transient fumes from the aft galley of the Airbus A320. An engineering inspection of the APU and air conditioning system did not reveal the source of the fumes, and they were not detected by the flight crew. The cabin crew member reported having a strong headache due to the fumes (201205822).
- On push-back at Melbourne while starting the number 2 engine, the cabin crew at the R4 door of the Airbus A321 reported a nauseating chemical smell, felt radiant heat, and heard what sounded like drilling under the floor below the galley service carts. The aircraft returned to the gate and a precautionary disembarkation was conducted. No passengers reported smelling fumes. Two cabin crew were examined by a doctor for a 'burning throat' feeling but were later cleared. The aircraft was grounded overnight for an engineering examination, however, the fumes or heat were not detected again. The operator reported that the likely source of the fumes was ingestion of exhaust from another aircraft through the APU air intake during engine start, due to the position of the aircraft at Melbourne and a south-easterly wind (201211212).
- During cruise over Sydney, the pilot noticed arcing behind the NAV/COM 1 radio, and a significant volume of smoke began to emanate from behind the instrument panel of the Aero Commander 500. The pilot shut down the electrical system, including the battery master switch. Smoke continued to emanate from behind the panel, so the pilot discharged a portable fire extinguisher and pulled the circuit breakers for the NAV/COM radios. After the smoke began to dissipate, the pilot began switching on the electrical system, isolating a problem with the left alternator field. After being out of communication with air traffic control (ATC) for over a minute, the pilot re-established contact and advised ATC of the situation. Due to the large amount of acrid smoke remaining in the cockpit, the pilot was unsure if there was still a fire, and make a precautionary landing at Bankstown Airport. The pilot suffered nausea and vomiting after the flight due to smoke inhalation (201102635).
- During the approach into Princess Alexandra Hospital, Brisbane, a piece of medical equipment on board the MBB/Kawasaki BK-117 aeromedical evacuation helicopter caught fire when one of its batteries exploded. The battery fell onto an intubated patient, causing a third degree burn on their right knee. The intensive care paramedic and doctor informed the pilot, and attempted to extinguish

the fire without success. Due to the close proximity of the landing point, the pilot continued the landing, at which point all of the aircraft doors were opened to expel the smoke, and the burning equipment was thrown clear of the helicopter and on to the helipad (201208876).

- During an aerial work flight near Dili, Timor-Leste, the transmission low oil pressure warning light on the Bell 212 helicopter illuminated and the pressure gauge indicated low oil pressure. Approximately 10 seconds later the transmission chip light illuminated. The pilot completed an emergency landing, and the helicopter was evacuated during which the crewman sprained his back. After shutdown, the crewman reported smoke emanating from the rear of the helicopter and was unable to move the main rotor in either direction (200808151).

Incapacitation relates to those same injuries whereby flight crew no longer have the ability to carry out their operational duties. Only one occurrence was reported to the ATSB in the 2008 to 2012 period where fumes/smoke was associated with crew incapacitation:

- After departure from Port Hedland, the pilot of the Piper Navajo noticed fumes in the cockpit which caused some dizziness. ATC received a badly broken call from the pilot advising that she had visible smoke in the cockpit and was opening a window. ATC advised the pilot of possible alternate landing sites, but communication was lost with the aircraft. Communications were re-established by relaying through a nearby aircraft, and the pilot advised that she was returning to Port Hedland. The pilot then advised that there was no smoke, but carbon monoxide in the cockpit and that operations were now normal and no services were required. ATC confirmed that the pilot had fresh air entering the cockpit, specifically fresh air on to her face. The pilot replied that she had, but was feeling dizzy. Both ATC and the relay aircraft remained in contact with the pilot throughout the remainder of the flight, ensuring that the pilot was spoken to at regular intervals to attempt to assess the pilot's wellbeing. The pilot's responses were appropriate, and she made all expected broadcasts on approach and landing (200801318).

A complete exploration of crew incapacitation as a hazard and potential adverse safety outcomes are outside the scope of this report, however, it should be noted that fumes/smoke events are not unique as a potential incapacitation threat. The issue of incapacitation is well-known to the aviation industry and, like fumes/smoke events, there are a wide range of controls and defences in place to mitigate the safety risks associated with the onset of incapacitation and its outcomes. Information regarding the possible health effects of fumes on operational crew performance is widely available, particularly as it relates to fumes/smoke generated from bleed air. The 2011 report by the Expert Panel on Aircraft Air Quality (EPAAQ) provides a comprehensive summary of the evidence and literature surrounding this issue to date (EPAAQ 2011). While the EPAAQ noted that there were significant concerns relating to the potential for fumes events to compromise pilot performance, both the EPAAQ report and fumes/smoke occurrence data analysed in this study both found that cases of crew incapacitation were rare (EPAAQ 2011, p.ix).

Controls in place to minimise the risk of injury or incapacitation outcomes resulting from a fumes/smoke event generally fall into the categories of personal protective equipment (PPE), source clean-up or isolation, ventilation, and operational responses (diversion). The controls are not mutually exclusive, and in most fumes/smoke events, multiple controls are used.

Personal protective equipment serves to protect individuals from exposure to fumes and smoke, and other related outcomes (such as fire). The most effective PPE for fumes/smoke events are oxygen masks, the use of which is supported by standard response procedures to the detection of fumes or smoke for both crew and passengers. The emergency oxygen system on aircraft is regularly tested for operability and is required to meet certain quality standards.

The isolation and/or clean-up of the source of fumes/smoke may be a manual task (such as the case of spillages) or an operational response (such as the shut-down of affected equipment) depending upon the nature of the fumes/smoke event. Source clean-up or isolation is supported by tools (spill kits, redundancy systems, response checklists) as well as standardised operational processes relating to the identification and diagnosis of problems.

In some cases, the fumes or smoke may be able to be dispersed via ventilation. The effectiveness of this control relies on adequate ventilation systems being available, operable and utilised. In some cases,

the nature of an aircraft's operation may preclude the use of ventilation as a fumes/smoke control (such as a commercial airliner operating at high altitude). Like many other controls discussed here, ventilation systems or methods are supported by regulation/policies, training and education and performance assurance activities (testing, audits, investigations etc.)

In cases where a fumes/smoke event cannot be controlled or isolated, there are operational responses available to the crew to prevent the fumes/smoke leading to an undesirable outcome (the primary one being diversion of the aircraft to a nearby aerodrome). This essentially serves to minimise the duration of exposure and possibly to reduce the extent of aircraft problems associated with their source (e.g. equipment failure).

Fire

Fumes/smoke events are sometimes linked with fire. Prior to developing into a fire, heated materials or chemicals may emit fumes or smoke, which can travel throughout the aircraft. The presence of some types of fumes/smoke in the aircraft (such as those from electrical or galley equipment) can serve as an indicator of a fire risk, as they are generally produced by something overheating or smouldering. Alternatively, fumes/smoke may be an indicator of uncontained, volatile chemicals which could be flammable if subjected to an ignition source.

Like incapacitation, fire (particularly fire in flight) is both a potential outcome of a fumes/smoke event, and a safety of flight hazard in itself. The nature of fire as a hazard, and the possible threats leading up to it will not be explored in this report beyond the fumes/smoke context. There are a number of resources available addressing the risk and controls associated with this issue available.¹³

There are a number of operational and technical controls aimed at avoiding the escalation of fumes/smoke events into fire events. Isolation and removal of the fumes/smoke and/or their source avoids any opportunity for ignition. Mechanisms for doing so may take the form of ventilation, sectioning off affected areas or increasing separation from potential ignition sources (such as electrical equipment or cargo/baggage). For sources, cleaning up spills or shutting down affected equipment may reduce the likelihood of a fire occurring. Operational responses to avoid the time of exposure may also be used, such as diverting the aircraft to reduce flight time or returning to the gate if still on the ground.

The above controls, like those that exist for other fumes/smoke threat areas, are supported by a range of policies/regulations, procedures and standards, training and education, and assurance measures.

Fires are infrequent occurrences on board aircraft, especially those fires that pose a credible safety of flight risk. Most of the 18 fires reported to the ATSB between 2008 and 2012 that were associated with a fumes/smoke event were engine fires detected when the aircraft was on the ground, which were extinguished by fire protection systems in the engine or by ground personnel with fire extinguishers.

Example notifications:

201205836: During the start at Adelaide Airport, sparks and smoke emanated from the right engine of the Boeing 737-800, and the start was discontinued. Engineers found the starter had failed.

201210090: During the landing roll at Biloela, Qld, smoke and a small fire was observed emanating from the left main landing gear of the Bombardier DHC-8-200. An engineering inspection did not find any faults with the landing gear and it was determined that the smoke was the result of residue fluid from the overnight maintenance.

201105282: During the attempted engine start at Mangalore, Vic., the pilot of the Piper PA-28 detected smoke in the cockpit. Once the emergency drill was completed and the cockpit was evacuated, the pilot noticed flames coming from the carburettor. During the engineering inspection, a fuel primer line was found to be broken.

¹³ See http://www.skybrary.aero/index.php/Fire_in_the_Air.

Of the nine fires associated with fumes/smoke that occurred in flight, effective controls used by the crew to prevent the fire from causing injury or aircraft damage were isolation of the affected system (or engine), the use of portable fire extinguishers to suppress the fire, actioning emergency checklists, and declaration of an emergency with ATC followed by a precautionary landing or diversion.

Example notifications:

201000003: While on descent to Tamworth, NSW, the crew of the Convair 580 noticed smoke emanating from below the instrument panel. Shortly after, the smoke intensified and flames appeared. The flight crew declared an emergency and suppressed the flames using a portable fire extinguisher. The crew continued the descent and the aircraft landed without further incident. A subsequent engineering inspection revealed that a small amount of insulation material had become detached and fallen onto the right red instrument panel light rheostat and surrounding wires. The rheostat had developed a 'hot spot' and consequently, the insulation absorbed the heat and transferred it to the wires, which produced smoke and flames.

The operator advised the ATSB that, as a result of this occurrence, it had taken a number of safety actions:

- all of the organisation's aircraft have been examined to ensure that there is sufficient clearance between the rheostats, insulation material and wires
- any insulation material located in close proximity to a rheostat has been removed
- a notice to crew was issued to emphasise the importance of recording defects in the maintenance log.

Most fires associated with fumes/smoke on air transport aircraft were due to passenger actions (such as placing cigarette ash in a wastepaper basket) or associated with meal preparation (oven fires).

As was shown in Figure 28, smoke is often not an indicator of fire. Out of the 411 smoke occurrences reported to the ATSB between 2008 and 2012, only 16 (less than four per cent) resulted in a fire¹⁴. In most cases where a fire was not reported, the smoke was transient, or was effectively managed by the flight crew (usually through electrically isolating the suspected source of the smoke).

It is not possible to measure how many fumes/smoke events on aircraft have the potential to develop into fires. Given the non-safety of flight nature of most fumes/smoke events and the effective defences in place to isolate and control their likely source, the number is certainly very small.

Aircraft system degradation

Fumes/smoke events are often associated with damaged aircraft systems. It is unlikely that fumes/smoke in itself would cause damage to aircraft systems, rather, the source of the fumes/smoke event may result in damage (e.g. overheated components, an engine fire, or shorted electrical circuits).

Detection of a fumes/smoke event may provide an opportunity to address any underlying aircraft system problems before equipment is damaged, or a loss of aircraft system functionality occurs that may pose a risk to the safety of flight. Controls in place aimed at achieving this include aircraft diversion, and isolation of the fumes/smoke source. Diversion encompasses in-flight redirections as well as decisions not to operate if fumes or smoke are detected on the ground before departure. Isolating the fumes/smoke source typically involves cutting electrical power to affected equipment and related systems. Both of these controls essentially serve to reduce the time in which a flight is exposed to a degraded aircraft system, and to reduce the risk that the damage may spread to other systems or cause a safety of flight issue.

Of the 1,263 fumes/smoke occurrences that were reported via ASIRs, nearly 15 per cent (185) also involved a diversion or an air return. Most of these were examples of precautionary defences being used effectively by flight crews to prevent possible or perceived fumes/smoke outcomes from eventuating (discussed in the previous section). Eighty-six of these diversions/returns were associated with a

¹⁴ Of the 18 fires reported to the ATSB between 2008 and 2012 that were associated with a fumes/smoke event, smoke was not reported in two cases.

technical problem with the aircraft's systems or equipment/furnishings, and the largest proportion of these occurrences involved charter or aerial work aircraft. Compared to most fumes/smoke events (which are reported by high capacity air transport operators), those associated with a mechanical problem in smaller aircraft were more likely to result in a diversion because those aircraft have less redundant systems in the event of failure or malfunction which will allow operations to be continued safely. Abnormal alternator readings, avionics failures, fuel leaks, and abnormal engine indications were the most common types of aircraft systems and equipment issues that were associated with fumes/smoke and a diversion/return in smaller aircraft.

In most of these situations, the fumes or smoke were able to be controlled by switching off the affected system. As discussed previously, 11 fumes/smoke occurrences were identified where a more serious electrical system failure occurred during flight (alternator failure, primary battery or inverter failure, or avionics master switch failure) which prevented most or all electrical systems from operating. All of these occurrences involved general aviation aircraft, and in almost all occurrences, the pilot decided to make a precautionary return or diversion. In multi-engine aircraft where the fumes or smoke were associated with engine malfunction or fuel system issues, the crew conducted a precautionary in-flight shutdown of the engine.

Example notifications:

200908222: During the initial climb, the crew of the Cessna 210 detected slight fumes in the cockpit. The crew then realised that the alternator had failed. The alternator was switched off and the fumes dissipated. The aircraft returned to Darwin.

201100535: During the initial climb, the crew of the Pilatus PC-12 heard a loud noise and noticed a strong smell of fumes. The crew donned oxygen masks and returned the aircraft to Adelaide. Post flight inspection revealed a hole burned through the left side of the cowl by hot gases escaping from the combustion chamber through the mounting for the left spark igniter plug that had separated from the engine.

201107988: During the climb, the crew of the Cessna 402 detected fumes and smoke in the cockpit and returned the aircraft to Jandakot Airport, WA. The pilot observed that the hydraulic pump had not stopped after the landing gear was retracted and the overheated hydraulic fluid was the source of the fumes and the smoke. The landing gear was extended manually. The engineering inspection revealed faulty wiring in the landing gear system.

Twelve occurrences (less than 0.1 per cent of all fumes/smoke occurrences reported between 2008 and 2012) involved degraded aircraft control – almost all due to a total power loss (only two were associated with an aircraft control problem. Most involved private general aviation aircraft and occurred when the aircraft was already on final approach and the pilot was able to continue the landing, conduct a rejected take-off, or make an air return to the departure aerodrome. In only three of these occurrences was a warning available to the flight crew (via fumes/smoke, a warning system, abnormal engine indications, or engine rough running) that would have given the flight crew time to take action to prevent a total power loss. In the remaining occurrences, the engine failed, which was then followed by fumes/smoke.

There were another three occurrences where a fumes/smoke event was associated with degraded aircraft control, and involved a passenger aerial work, charter, or air transport aircraft:

- During the initial climb from Laura, SA, the pilot of the Cessna 402 detected smoke entering the cabin and noted a hydraulic failure indication for the right landing gear. The landing gear would not lock and the pilot retracted the landing gear and returned to the runway for a successful wheels-up landing at Laura. The pilot and eight passengers were not injured, but the aircraft was substantially damaged (200802192).
- During the final approach into Mildura Airport, the flight crew of the Saab 340 received multiple warnings and abnormal left-hand engine indications (including an over temperature and chip detector warning), and the cabin crew detected smoke and oil smells in the cabin. At this point, the flight crew were committed to landing, and the engine subsequently failed during the landing. During the post-flight inspection, a significant quantity of oil was found in the engine tailpipe, and the engine was replaced (201001404).

- During the flare to land at Hobart Airport, the left engine of the Jetstream 31 began to shut down (flameout) without crew input. The aircraft landed safely and the engine appeared to the flight crew to shutdown normally. During subsequent taxiing, smoke and flames were observed coming from the left engine nacelle, and the flight crew released both fire bottles into the engine. Subsequent engineering inspections were unable to reproduce the problem, and the aircraft was released back into service with no further reported issues (200906362).

The effectiveness of actions to prevent further damage or degradation of aircraft systems to a point where aircraft control might be affected relies on correct and rapid diagnosis and identification of affected systems. Crew action in these situations is assisted by the extensive training and education they receive. In turn, these initiatives are supported and reinforced through legislation, regulation and assurance processes (including auditing/testing).

Summary and recommendations

This report provided an analysis of fume and smoke-related events in Australian aviation that have the potential to impact the safe operation of aircraft. By using datasets held by the ATSB, CASA, and the Department of Defence (reported via DDAAFS), this report was able to consider both operational and maintenance aspects of fumes and smoke notifications. A threat and outcome-based framework was developed to allow analysis of fumes and smoke events in terms of their typical sources, likelihood, and operational risk in order to better understand their potential risk to flight safety.

Fumes/smoke notifications and sources

- The increased reporting of fumes/smoke events identified by both CASA and the ATSB in internal trend monitoring of aviation safety incidents is at least partially due to improved reporting of these types of occurrences. This may be due to increased awareness of possible health issues associated with fumes events, as has previously been identified in the EPAAQ report.
- Fumes/smoke events constitute a relatively low proportion of operational occurrences; approximately 10 per cent of all SDR notifications and only 3 per cent of ASIR notifications.
- The most common source of fumes/smoke was aircraft systems issues, primarily relating to failure or malfunction of electrical and auxiliary power unit (APU) systems. Equipment and furnishing systems also featured highly as a source of fumes and smoke. Within this category, air conditioning and galley equipment were the most common sources of fumes/smoke. External sources of fumes/smoke and cargo/baggage related events were relatively rare.

Reporting

- Approximately half of all fumes/smoke ASIRs were able to be matched to a corresponding SDR notification. Matching ASIRs and SDRs provided greater insight and detail about the engineering issues that were associated with safety occurrences.
- While ASIR reporting of fumes/smoke events has been increasing steadily over the 2008 to 2012 period, SDR reporting has been declining slightly from 2010.
- Operators of smaller general aviation aircraft were far more likely to report fumes/smoke related events to the ATSB through the ASIR system than to CASA through the SDR system.
- Commercial operators tended to report fumes/smoke occurrences more heavily to one agency over another. For example, Airline A and Airline C were more likely to notify CASA of a fumes/smoke occurrence, while Airlines B, F and G reported more often to the ATSB. It could not be established why this was the case.

Safety

- An analysis of the safety of flight risk associated with fumes/smoke occurrences showed that it was very rare that the risk of a credible accident outcome occurring was higher than 'low'. In the small number of higher risk events identified in the 2008 to 2012 period, recovery defences were effective, with diversions being the most commonly used to avoid escalation of a fumes/smoke event.
- Most fumes/smoke events did not result in an operational deviation of an aircraft (such as an air or ground return, flight cancellation, or a diversion). A review of these infrequent adverse safety outcomes of fumes/smoke events found that they were mostly minor over the 2008 to 2012 period.
- In relation to injury or crew incapacitation, there was a single incapacitation event where, due to pilot action and ATC assistance, the aircraft was able to land safely. There were a further 11 minor injury events involving cabin or flight crew.
- In relation to the possible outcome of fire, only 18 (approximately 4 per cent of all reported fumes/smoke events) resulted in a minor fire over the 5-year period under review. Many of these occurred on the ground, and were extinguished by fire protection systems in the engine or by ground personnel with fire extinguishers.

- In relation to aircraft system degradation, 80 per cent of diversions/returns due to fumes/smoke were associated with a technical problem with the aircraft's systems or equipment/furnishings. There were 11 fumes/smoke occurrences identified where a more serious failure occurred during flight which prevented most or all of the aircraft's electrical systems from operating. However, effects to the aircraft's controllability were identified in less than 0.1 per cent of fumes/smoke occurrences.
- Large commercial aircraft (those with an MTOW above 5,700 kg) accounted for the majority of fumes/smoke notifications. Within this group, most notifications involved aircraft between 27,001 and 272,000 kg (typically domestic RPT aircraft).
- The aircraft type most commonly involved in fumes/smoke events reported between 2008 and 2012 was the British Aerospace BAe 146, when considering this type's flying activity over this period. Other aircraft models that had more than 20 fumes/smoke occurrences reported per 100,000 hours flown (a higher than average rate) via the ASIR or SDR reporting schemes were the Airbus A380, Boeing 737-300/400, Boeing 747-300, Boeing 767-300, Embraer E-190, Embraer EMB-120, and Fokker 100.
- The British Aerospace BAe 146, Embraer EMB-120 Brasilia, and the Fokker 100 were the aircraft types most commonly connected with oily or exhaust fumes that were not galley related. In relation to the engines involved, the number of engine or bleed air-related fumes/smoke occurrences generally accorded with the popularity of the engine type in the Australian fleet.
- In most years since 2008, Airline D was by far the largest reporter of fumes/smoke events via both the ASIR and SDR reporting schemes. Since 2010, this airline has shown a large, inexplicable decline in reporting of both fumes/smoke-related ASIRs and SDRs, and in 2012 was only the third most frequent reporter of these types of events. In 2012, Airline B and Airline F were the largest reporters of fumes/smoke events in both schemes.

Data availability and quality

Based on the research presented here, the quality and volume of data regarding fumes/smoke occurrences that is currently available can be seen to be generally adequate for building a picture of the nature of the risks associated with these events as they occur in the Australian environment. However, a few issues were identified in this report:

- There are reporting rate differences between operators, sectors, and the types of notifications being made when comparing reporting of fumes/smoke events to the ATSB and CASA. Although the discrepancies noted in this report may be partially due to actual differences in incidence, it is likely that reporting practices between sectors and operators play a significant role. These differences are already known across sectors/operators outside the fumes/smoke context. However, differences between SDR and ASIR reporting rates have not been specifically compared prior to this research.
- Details of the source (location) or the type of fume/smoke (smell) detected were only categorised by the ATSB in half of the fumes/smoke events reported to the ATSB between 2008 and 2012. This information is valuable in understanding the nature of fumes/smoke events from a safety perspective.
- A high proportion of fumes/smoke events reported to CASA via the SDR system did not include information on affected components. This limited the scope for the identification of sources/problem areas when reviewing the threat areas associated with fumes/smoke.
- Reporting of aviation fumes/smoke events in Australian Defence Force transport operations does not provide a useful comparison with fumes/smoke events involving Australian civil aircraft when analysis is conducted at an aggregate level. This is due to the low number of notifications involving comparable Defence transport aircraft.
- Comparative international data on fumes/smoke, and other low risk, high volume aviation safety occurrences, are not available at the present time.

Safety actions

Based on the above findings, this report recommends continuation of fumes/smoke surveillance by all relevant agencies and operators mentioned in this report.

Australian Transport Safety Bureau and Civil Aviation Safety Authority

Trend monitoring activities

The ATSB and CASA will continue to conduct quarterly trend monitoring of safety incident reporting for all types of incidents, including fumes and smoke. Where the number of fumes/smoke occurrences increases or decreases significantly, the reasons for the change will be reviewed and communicated to agency decision makers and to other aviation safety agencies by means of the JAASACG.

Data sharing between agencies

Both CASA and the ATSB continue to share and match (where possible) SDR and ASIR data for the purposes of safety research. In the spirit of the memorandum of understanding between the two agencies, CASA and the ATSB commit to sharing safety-related data wherever possible to improve safety outcomes for both agencies. With respect to matching data, issues relating to privacy and identification of individuals will continue to be carefully considered before any data is shared between the agencies.

Australian Transport Safety Bureau

Record smell type in occurrence records

The ATSB has recently reviewed its classification taxonomy for aviation safety occurrences. Changes stemming from this review include future collection and coding of smell type and fume source for fumes occurrences. This information will also be retrospectively coded for all fumes occurrences reported to the ATSB since 1 July 2003.

Safety occurrences reporting education

Aviation industry awareness of the ATSB, its functions, and mandatory reporting requirements is a continuing challenge for the ATSB, especially among smaller operators and in general aviation and recreational aviation. The ATSB is currently undertaking a roadshow to promote its *SafetyWatch* priorities, one of which specifically deals with reducing underreporting of transport safety matters.

The ATSB will also approach individual operators who appear to be under-reporting fumes/smoke related safety occurrences based on the disproportionate number of SDRs reported.

Civil Aviation Safety Authority

Review of SDR reporting

This study represents the first time that SDR reporting rates and notification types have been compared across a range of operators. Patterns identified in this report in SDR reporting between commercial air transport operators will help to inform future reviews of SDR underreporting. CASA will undertake a review to ascertain whether patterns in SDR reporting extend beyond the limited subset of fumes/smoke data and seek to improve reporting where there appears to be underreporting.

References

- Expert Panel on Aircraft Air Quality (EPAAQ) (2011). *Contamination of aircraft cabin air by bleed air – a review of the evidence*. http://www.casa.gov.au/wcmswr/_assets/main/cabin/epaaq/epaaq-entire-report.pdf
- CASA. *Civil Aviation Safety Authority response to the Expert Panel on Aircraft Air Quality report: Contamination of aircraft cabin air by bleed air – a review of the evidence*. http://www.casa.gov.au/wcmswr/_assets/main/cabin/epaaq/epaaq-response.pdf
- Senate Rural and Regional Affairs and Transport References Committee (2000). *Air Safety and Cabin Air Quality in the BAe 146 Aircraft*. Canberra: Parliament of the Commonwealth of Australia. http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Rural_and_Regional_Affairs_and_Transport/Completed_inquiries/1999-02/bae/~media/wopapub/senate/committee/rrat_ctte/completed_inquiries/1999_02/bae/report/report_pdf.ashx

Appendix A - EPAAQ data and analysis recommendations

- 8. That CASA utilise ATSB data together with any other available data to maintain an ongoing comprehensive study of cabin air contamination incidents using available data collected in Australia by operators collating all relevant information including, but not limited to, numbers of incidents, types of incidents, aircraft types involved, engine types involved, flight phases involved, companies involved, dates and times, witness statements, to create and maintain a solid base of consolidated cabin air contamination incidents data to enable analysis of trends and common features.
- 10. That CASA collate and follow up information collected both through the proposed Internet database and from any other cabin air contamination recording systems submitted to the regulators (NAAs) and safety boards (NTSB, ATSB, BSTB etc.) for reporting to the Minister.
- 11. That CASA negotiate with ATSB for ATSB to undertake an in-depth analysis of all aircraft air contamination incidents at regular intervals and over a set period of time, to document trends over time, changes in the incidence of categories of cabin air contamination, identify common features and provide de-identified overall results and conclusions which could be used to design measures to eliminate cabin air contamination risks to aircrew and passengers.

Appendix B – Associating threats and outcomes via ASIR/SDR matching

To draw a link between operational notifications of fumes/smoke, and aircraft defects indicating their source, ASIR and SDR fumes/smoke notifications were matched where possible.

The purpose of this matching exercise was to consider the likelihood and nature of normally reported aircraft defects that developed into a potential safety of flight issue (i.e. those that had an effect on operations that was reportable to the ATSB). The matched data was used to look at how often different precursors of fumes/smoke events ('threats') led to an undesired outcome in the bowtie-model risk analysis (presented further on in this report, and in Appendix B).

The match was performed on aircraft registration, and on the reported date of the occurrence. Given the possibility for differences in the occurrence date in notifications submitted to CASA and the ATSB for the same fumes or smoke event, and the different persons who normally submit these notifications (maintenance and operational roles respectively), the matching process considered an error of +/- 5 days in the reported occurrence dates. This margin was found to be favourable compared to matches performed using both smaller margins (1–3 days) and larger margins (10 days).

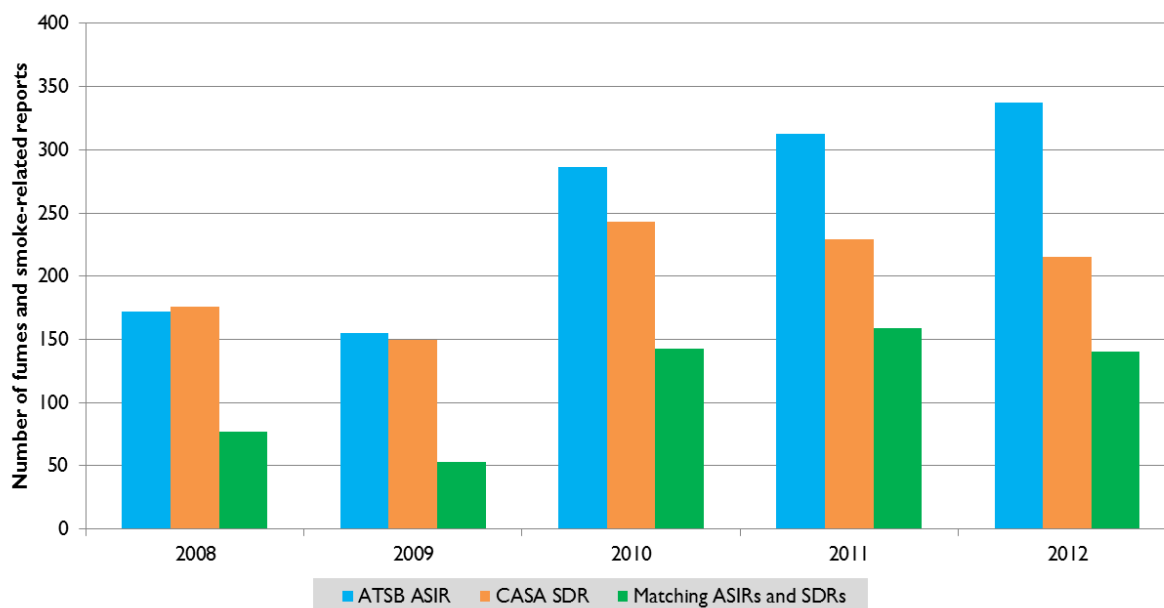
Matching was only performed using notifications where an Australian civil (VH-) registered aircraft was involved in the fumes or smoke event.

Data analysis in this study focuses primarily on those fumes/smoke events for which both ASIRs and SDRs were submitted and matched. ASOR notifications for military aircraft were not able to be matched, as these considered a combination of operational and maintenance notifications of fumes/smoke and their sources. They were also small in number (shown in Figure 3), and not reliably reported to the ATSB over the 2008 to 2012 period¹⁵. As a result, a decision was made to exclude ASORs from most aspects of the analysis. A review of this data found that the types of fumes and smoke occurrences were similar in nature to those involving civil aircraft over this period, with slightly more occurrences involving fumes/smoke from a cargo source.

The matching exercise found that across the whole study period, about half of fumes and smoke-related ASIRs could be matched with SDRs which found the source of the fumes/smoke. There was some variation from year to year in the proportion of fumes/smoke ASIRs and SDRs that could be matched. Figure 30 below shows the number of occurrences matched over the 5 year study period.

¹⁵ Fumes and smoke events involving Defence aircraft, other than those registered under the *Civil Aviation Act 1988* (VH-registered aircraft) are exempt from reporting transport safety matters to the ATSB.

Figure 30: Fumes/smoke reporting to ATSB (ASIRs) and CASA (SDRs) and to both agencies, 2008 to 2012



There are some very good reasons why all ASIRs do not have an equivalent SDR, and vice versa. Many fumes/smoke notifications to the ATSB are followed up by a maintenance inspection that does not find a potential source or defect causing the fume/smoke, in which case an SDR would not be submitted to CASA. There are also other fumes/smoke detected that do not relate to an aircraft or equipment problem (such as fumes from cabin baggage or cargo, or smells from food) that are regularly reported to the ATSB, and would not have an accompanying SDR. Conversely, SDRs are raised for all aircraft defects that have the potential to impact safety, not just those that have resulted in an operational problem that has increased the risk of a safe flight. For example, unmatched SDRs include defects related to smoke detectors, or smoke occurrences that did not contaminate cabin air (such as excessive APU exhaust observed by ground personnel). These sorts of defects, which are often identified in routine maintenance tasks, are not normally reported to the ATSB, nor are they required to be unless the aircraft is boarded for flight. Some level of error is also expected in the data due to underreporting of fumes and smoke events.

While not the focus of this study, occurrences that were not matched can provide an insight into fumes/smoke events that are unlikely to have a mechanical source (in cases where an ASIR is not matched with an SDR), as well as sources of fumes/smoke that are not likely to have an impact on the safety of flight (in cases where an SDR does not have a matching ASIR).

Appendix C – Notification requirements and data sources

Notification requirements

Even though each reporting scheme has a different purpose, notification requirements for fumes and smoke events are similar across the ATSB, CASA, and the Department of Defence in that any situation or event that may constitute a credible risk to the safety of a flight is required to be reported.

ATSB

All transport safety matters that occur in Australia, or involve an Australian transport vehicle, must be reported to the ATSB. Transport safety matters are defined by the *Transport Safety Investigation Act 2003* ('TSI Act') as:

- the transport vehicle being destroyed or damaged
- the transport vehicle being abandoned, disabled, stranded or missing in operation
- a person dying as a result of an occurrence associated with the operation of a transport vehicle
- a person injured or incapacitated as a result of an occurrence associated with the operation of the transport vehicle
- the transport vehicle being involved in a near-accident
- any property damaged as a result of an occurrence associated with the operation of the transport vehicle
- the transport vehicle being involved in an occurrence that affected, or could have affected, the safety of the operation of the transport vehicle
- something occurring that affected, is affecting, or might affect transport safety.

For the purposes of the TSI Act, transport vehicles exclude Australian defence aircraft, or a foreign-registered aircraft used in the military, customs, or police services of that country.

An immediately reportable matter (IRM) is a serious transport safety matter that covers occurrences such as accidents involving death, serious injury, destruction of, or serious damage to vehicles or property or when an accident nearly occurred. Under section 18 of the TSI Act, immediately reportable matters must be reported to a nominated official by a responsible person as soon as is reasonably practical. These are the matters that are the subject of most investigations conducted by the ATSB. Immediately reportable matters include the death or serious injury to any person on board an aircraft. For air transport operations, IRMs relating to fumes/smoke events also include:

- a fire (even if subsequently extinguished), smoke, fumes or an explosion on or in any part of the aircraft
- an event requiring the use of oxygen by a flight crew member
- a flight crew member becoming incapacitated during flight
- the use of any procedure for overcoming an emergency
- a mechanical failure resulting in the shutdown of an engine
- The failure of two or more related redundant systems for flight guidance and navigation.

A routine reportable matter (RRM) is a transport safety matter that has not had a serious outcome and does not require an immediate notification but transport safety was affected or could have been affected. Under section 19 of the TSI Act, a responsible person who has knowledge of a routine reportable matter must notify the ATSB within 72 hours with a written report to a nominated official. The list of routine reportable matters is contained in the TSI Regulations. Although fumes and smoke events are IRMs in air transport operations, they are mostly a RRM for general aviation. Routine reportable matters would include a non-serious injury or the aircraft suffering minor damage or structural failure that

does not significantly affect the structural integrity, performance or flight characteristics of the aircraft and does not require major repair or replacement of the affected components.

CASA

Part 4B of the *Civil Aviation Regulations 1988* ('CAR 1988') requires reporting of major defects to CASA. A major defect is defined in the Dictionary of the Civil Aviation Safety Regulations 1998 as being:

- in relation to an aeronautical product that is not fitted to an aircraft — a defect of such a kind that the aeronautical product, if fitted to an aircraft, may affect the safety of the aircraft or cause the aircraft to become a danger to persons or property
- in relation to an aircraft — a defect of such a kind that it may affect the safety of the aircraft or cause the aircraft to become a danger to persons or property.

Appendix A of CAAP 51-1(2) gives examples of major defects, which includes fumes and smoke. Major defects can be found at any time and must be reported to CASA through the Service Difficulty Reporting (SDR) system. Part 4B of CAR 1988 requires that SDRs can be reported by maintenance organisations, licensed aircraft maintenance engineers (LAMEs), Air Operator's Certificate holders or by pilots.

Defence

The Australian Defence Organisation defines an aviation safety occurrence in the Defence Aviation Safety Manual as an occurrence that: *affects or could adversely affect the safety or airworthiness of an Aviation System, or safety of third parties.*

Almost all fumes and smoke occurrences reported via aviation safety occurrence reports (ASORs) are incidents. Incidents are aviation safety occurrences *where system defences were adequate to limit the severity of the occurrence such that the consequences to safety or airworthiness were less than major, or were inadequate/absent to limit the severity of the occurrence (but system tolerance limited the consequences to safety or airworthiness to less than major).*

An incident can be thought of as an occurrence that did affect or could affect safety or airworthiness, but the outcome was not serious (i.e. injuries, if any, were not serious, and damage, if any, was repairable in less than 14 days).

Fumes and smoke occurrences (as well as all other aviation safety occurrences) can be reported by any Australian Defence Organisation member or contractor involved in aviation operations, and are then reviewed by the chain of command of the reporting member. Notifications of these occurrences are entered into an occurrence database, and are investigated at a level appropriate to the occurrence classification (Unit, Wing, Group, or Directorate of Defence Aviation and Air Force Safety (DDAAFS)) to identify factors that contributed to the occurrence and to implement safety actions to prevent reoccurrence. Further research and analysis on aviation safety occurrences are conducted by DDAAFS and other safety elements within the Australian Defence Organisation.

Data sources

Fumes and smoke notifications reviewed in this study were taken from the ATSB SIIMS database, the CASA SDR system, and the Department of Defence DAHRTS database. Records considered for the study were all events that occurred between 1 January 2008 and 31 December 2012, even if the notification was submitted outside of these dates. Events involving transport category aircraft were considered, irrespective of whether they were conducting passenger transport operations.

Relevant ASIRs were identified by selecting all IRMs, RRM, and non-TSI Act reportable 'events' coded with the *Fume* and *Smoke* occurrence types in the ATSB Safety Investigation Information Management System (SIIMS). This selection excluded fume and smoke occurrences related to security issues, such as passengers found smoking in toilets, and smoke warnings received by the flight crew that were not associated with any detectable fumes or smoke. A total of 1,263 fumes/smoke-related ASIRs were identified over this 5 year period.

Relevant SDRs were identified by an initial selection of notifications coded with the *Smoke, fumes or odour (internal)* nature of condition type in the CASA SDR database. As many fumes and smoke

occurrences were identified in other nature of condition types (such as *Avionics, Engine, Air conditioning, Arcing or sparking, and Passenger entertainment*), a secondary pass of all SDRs was made to select those where the following keywords appeared in both the submitted description of the event, and the description of the event coded by CASA: *smoke, fumes, smell, odour, odor*. This allowed capture of not just defects resulting in fumes and smoke events in the cabin or cockpit, but failures of smoke detection systems, and notifications of smoke outside the aircraft that could have affected air quality through the bleed air system. A total of 1,010 SDRs related to fumes and smoke incidents, or defects that had the potential to results in smoke and fumes were identified over this 5 year period.

Relevant ASOR notifications were identified by an initial selection of all ASORs coded with the *Smoke and fumes* occurrence type in the DDAFFS DAHRTS database. A secondary pass of all ASORs was made to select those where the following keywords appeared in the occurrence summary or the investigation findings of the ASO: *fume, burning, odour, electrical*. These occurrences were then filtered to identify only those which were actually related to a fumes or smoke event. All notifications of interest were then filtered to select only those involving transport category military aircraft operated by the Australian Defence Force in the 2008 to 2012 period. These included the Airbus A330 MRTT, de Havilland Canada DHC-4 Caribou, Lockheed C-130 Hercules and P-3 Orion, Bombardier Challenger, Boeing C-17 Globemaster III, 707, 737 BBJ, and Wedgetail. A total of 48 fumes and smoke ASORs were identified over this 5 year period.

After notifications of interest were identified in each dataset, those that were maintenance notifications of aircraft defects which were linked to fumes or smoke events (SDRs and ASIRs only) were categorised into aircraft system groups based on information provided by agency investigations, the submitted description of the event or in the case of SDRs, the aircraft part affected. The intent of this process was to identify areas of the aircraft which were the source of the fumes or smoke. The classification used was the American Transport Association (ATA) 100 system, which is a standard method used internationally by airlines, aircraft manufacturers and safety regulators to classify aircraft systems, maintenance procedures and components.

Appendix D – Fumes Bowtie model

Threats

Figure 31: Threat - Aircraft Systems Issues

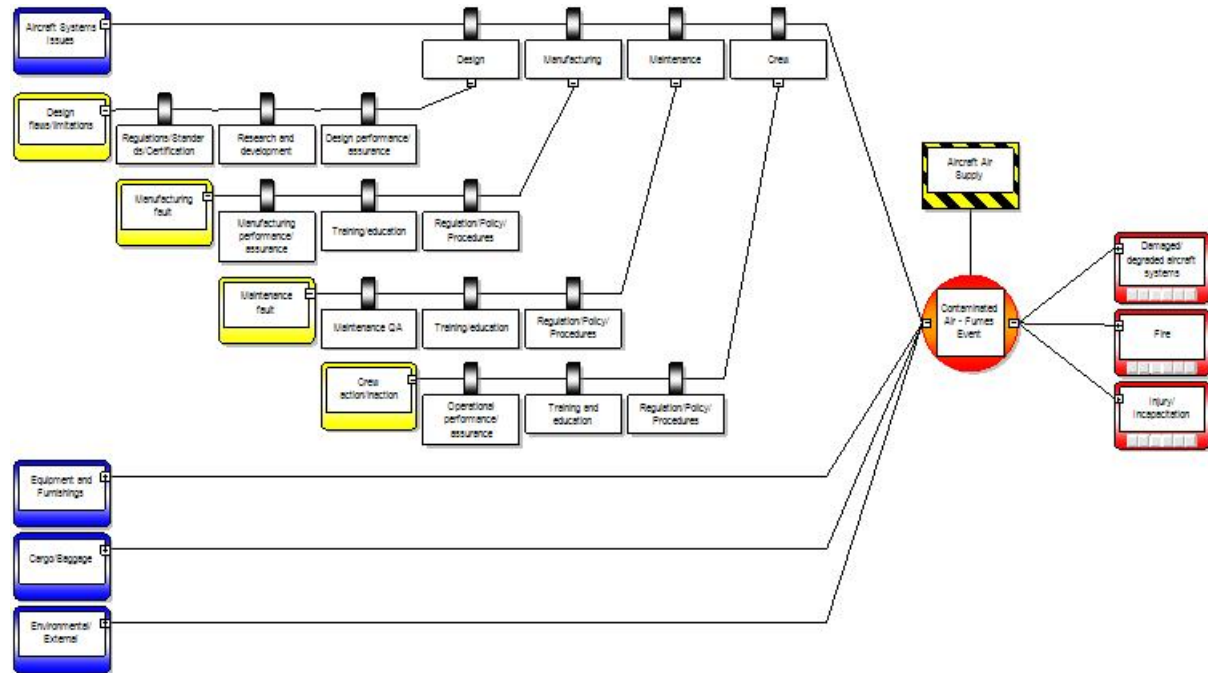


Figure 32: Threat - Equipment/Furnishings

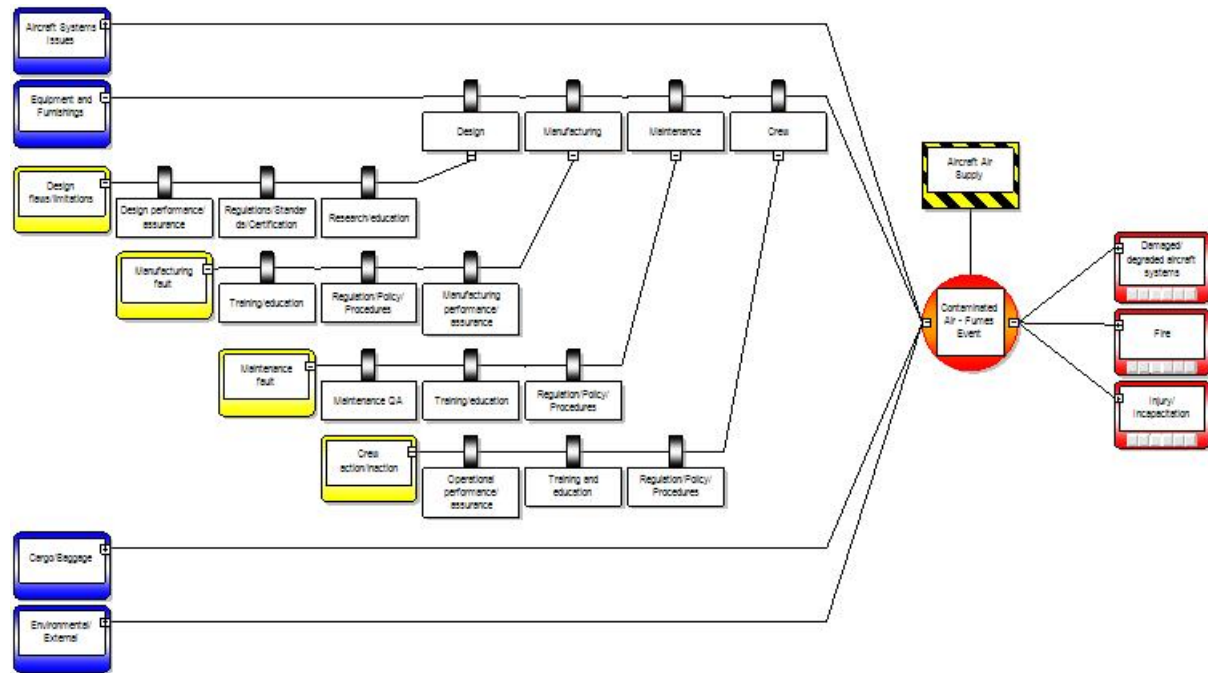


Figure 33: Threat - Cargo/Baggage

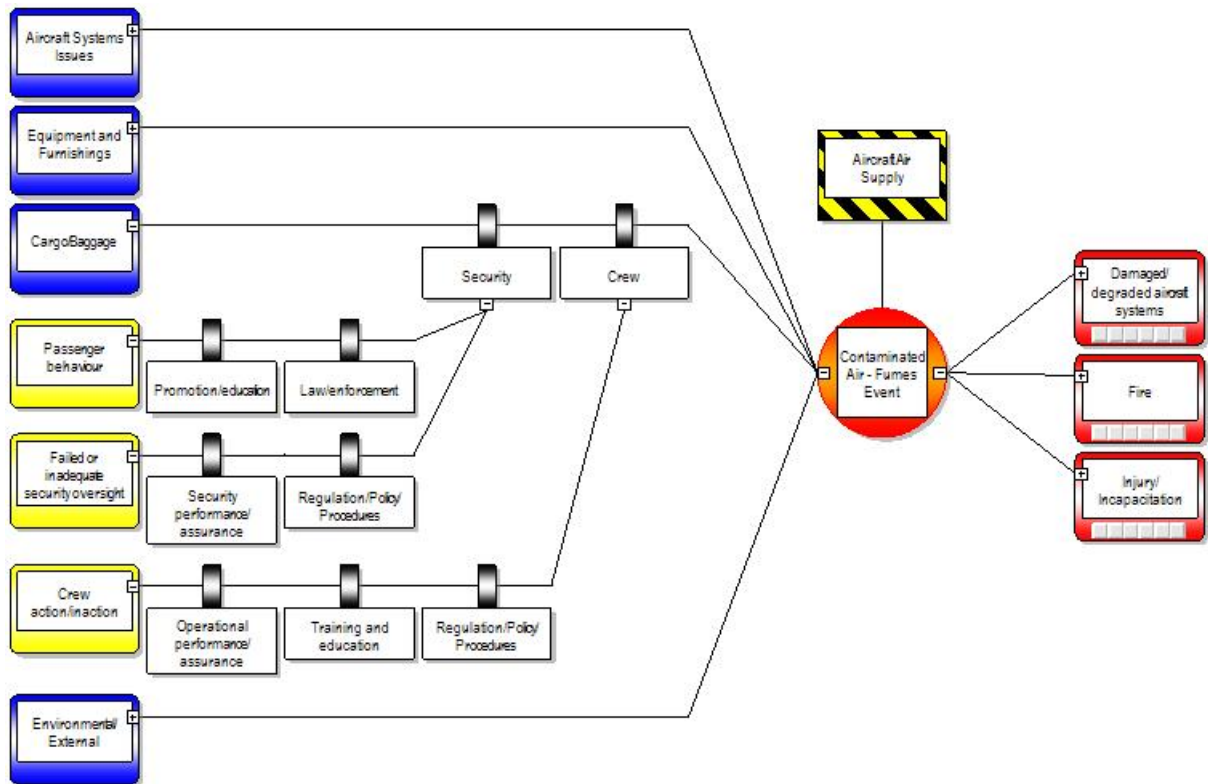
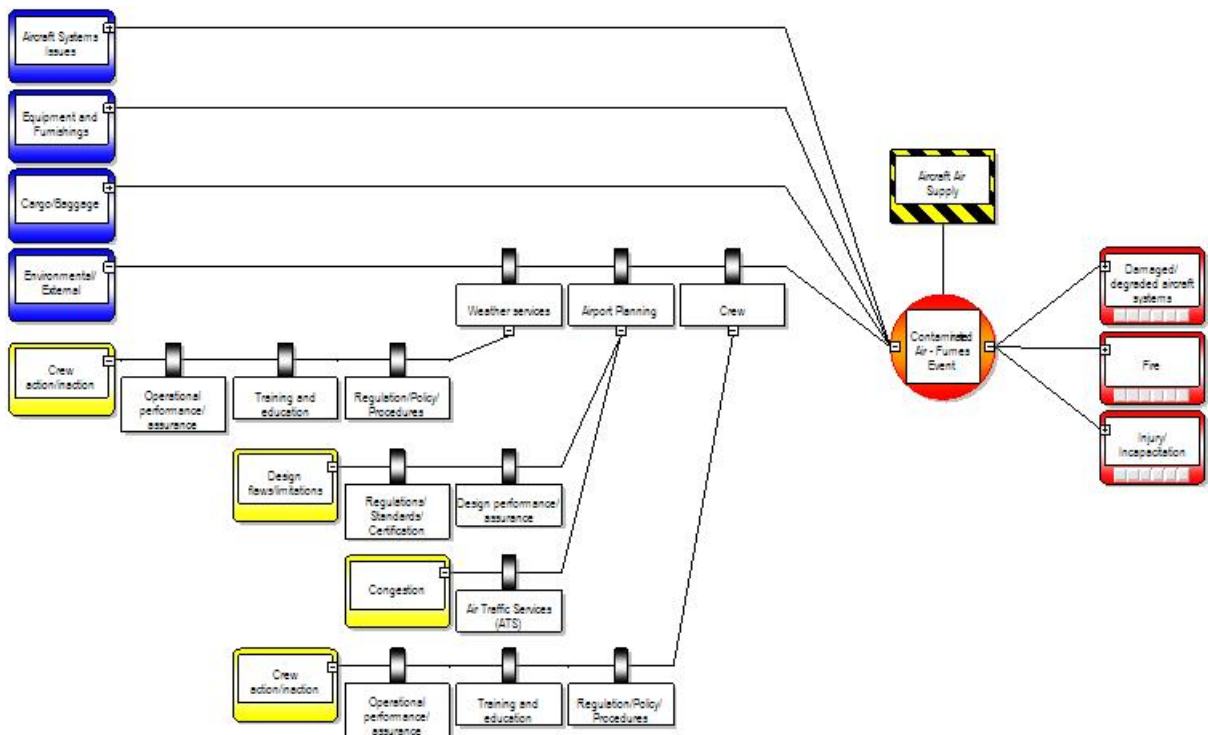


Figure 34: Threat - External/Environmental



Outcomes

Figure 35: Outcome – Damaged/Degraded Aircraft Systems

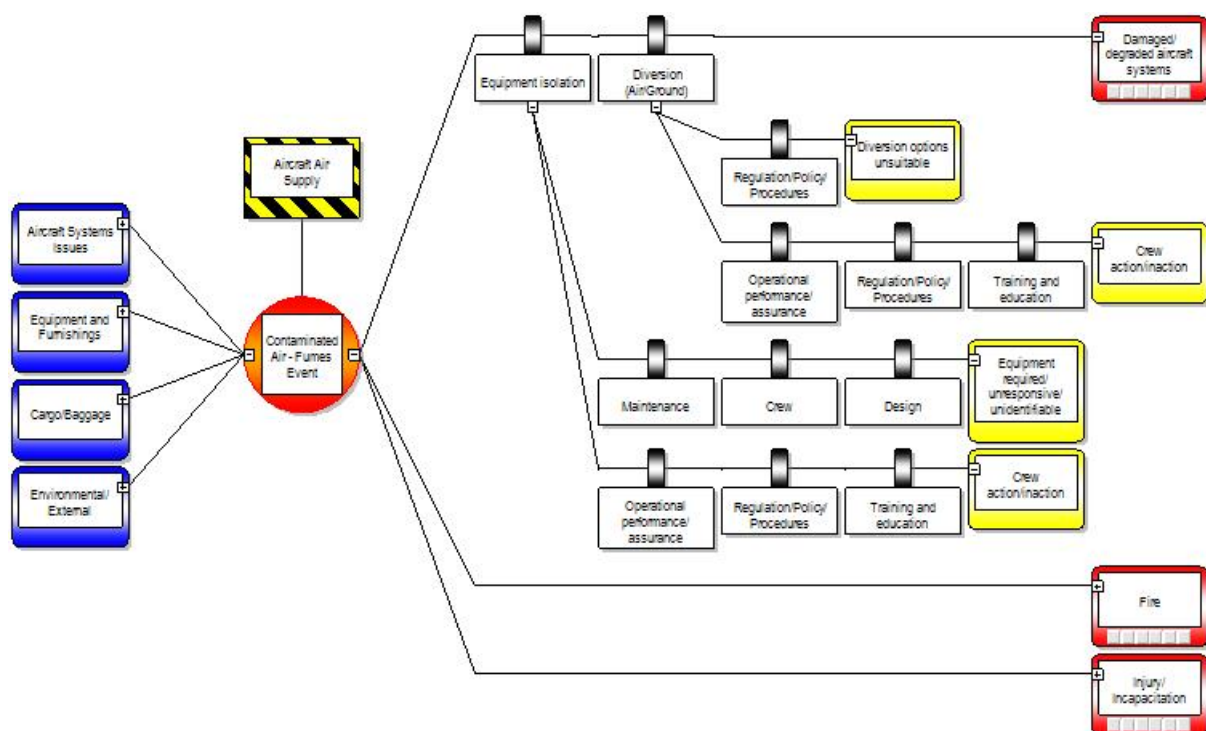


Figure 36: Outcome – Fire

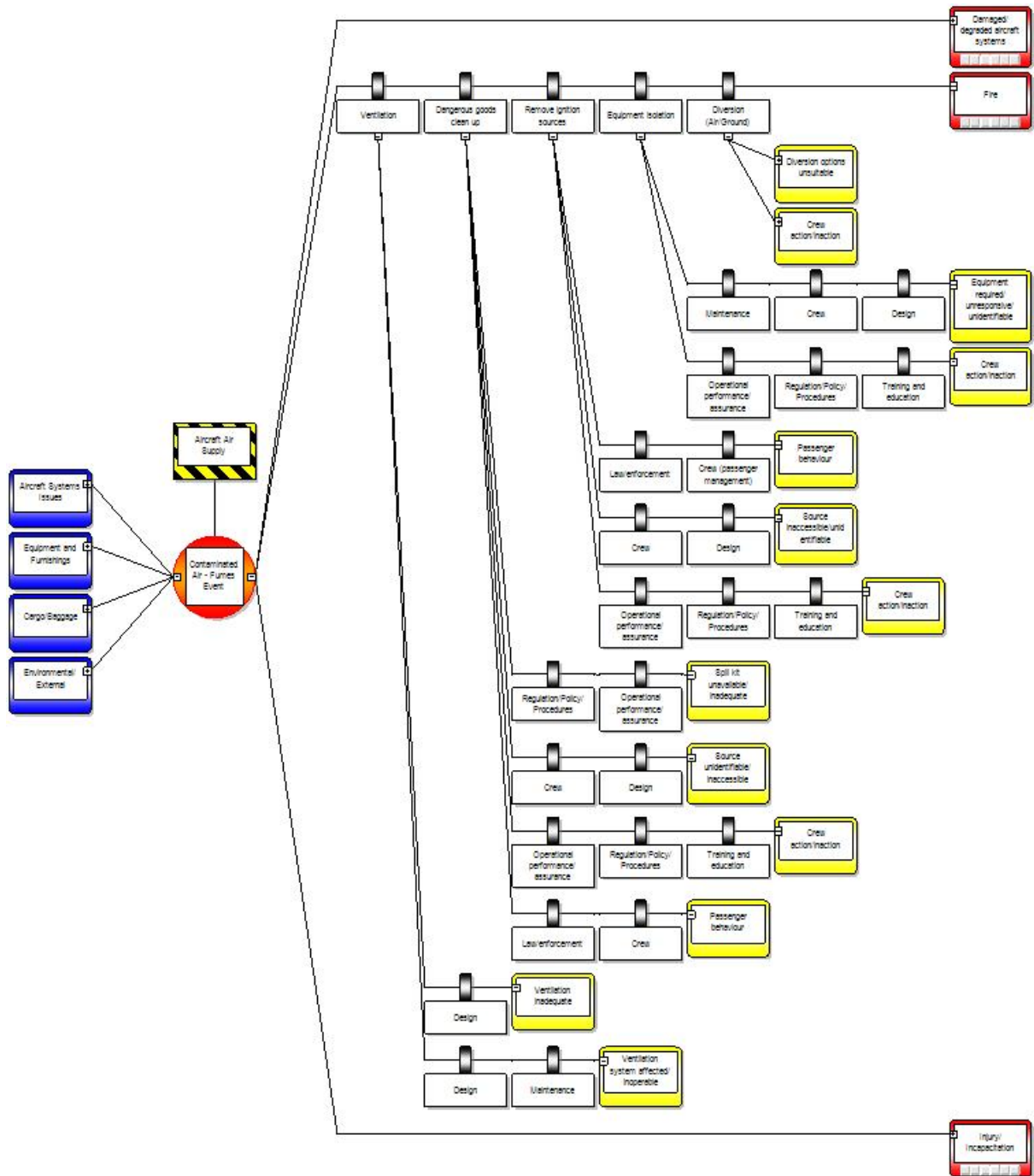
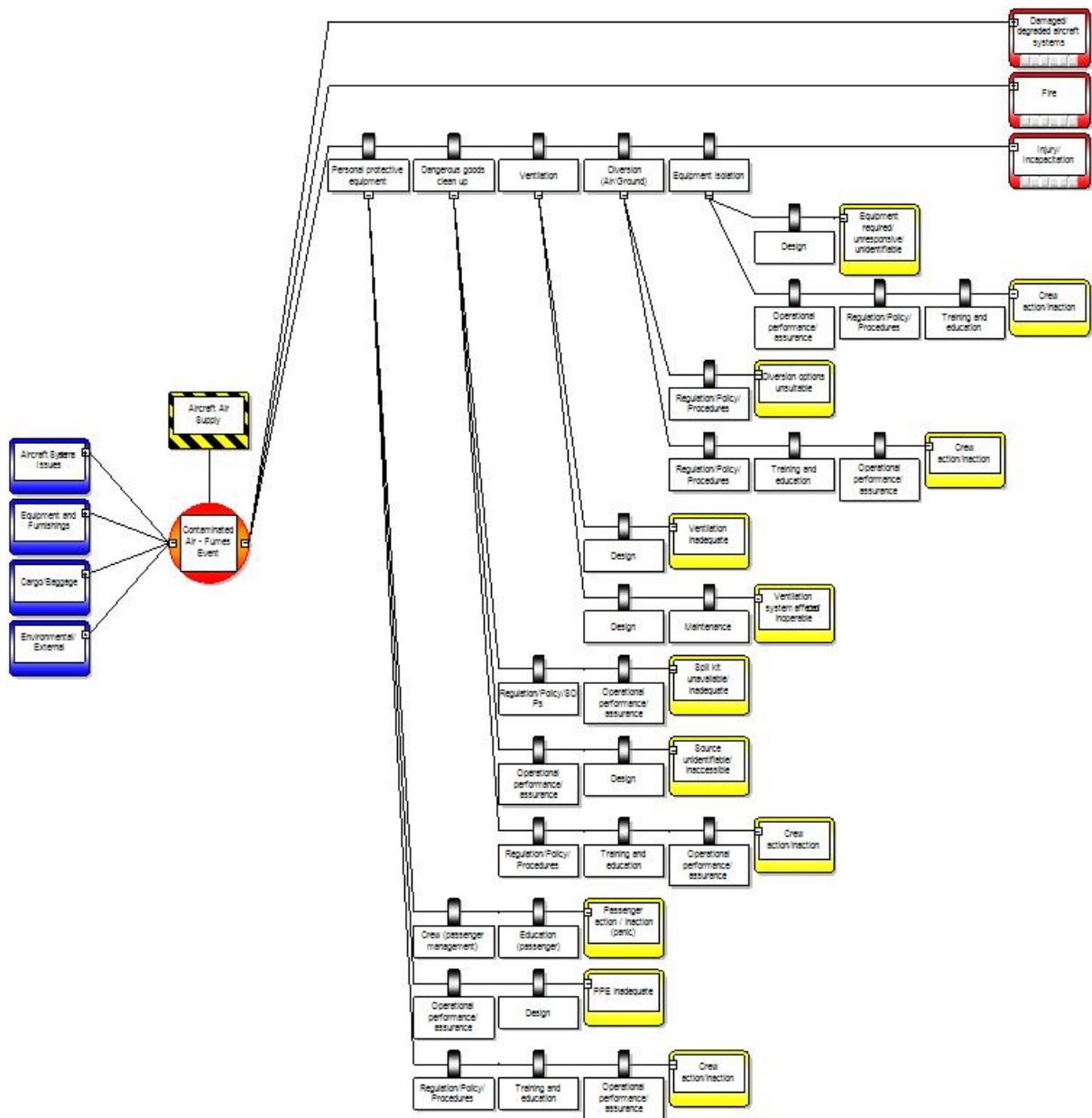


Figure 37: Outcome – Injury/Incapacitation



Appendix E – Description of fumes/smoke bowtie elements

Threats

Level 1 - Threats	Description	Examples
Aircraft systems issue(s)	Aircraft operational systems, including electrical/mechanical.	<ul style="list-style-type: none"> • APU • Flight controls/computers • Engines • Filtration systems
Equipment and furnishings	Relates to all cabin furnishings and equipment.	<ul style="list-style-type: none"> • Air conditioning • Ovens, coffee makers • Inflight entertainment • Toilets • Chemicals present in plastics and fabrics
Cargo/baggage	Non-operational goods carried on board the aircraft via passengers or crew. This extends to cargo hold and cabin baggage.	<ul style="list-style-type: none"> • Freight • Baggage • Dangerous goods • Cigarette smoke
Environmental/external	Fumes entering the aircraft from a source external to the aircraft and its systems.	<ul style="list-style-type: none"> • Bushfires nearby result in fumes ingestion by aircraft. • Airport is located near industrial, fumes producing infrastructure such that fumes are able to enter aircraft through ventilation systems. • Airport congestion such that aircraft are too close and exhaust from one enters another.
Level 2 - Threat Controls	Description	Examples
Design	Encompasses design aspects of materials, composition, and its interactions (including with other materials/systems and users).	<ul style="list-style-type: none"> • Placement of smoke detectors • Capacity of filtration mechanisms • Safety defences built in to galley equipment (auto-off)
Manufacturing	Aircraft components/systems manufactured in accordance with design.	<ul style="list-style-type: none"> • Construction of aircraft parts • Use of appropriate materials
Maintenance	Maintenance of all of aircraft -scheduled and unscheduled.	<ul style="list-style-type: none"> • Aircraft maintained at suitable intervals
Crew	Appropriate use of equipment and monitoring of aircraft state.	<ul style="list-style-type: none"> • Operating aircraft within limitations • Equipment used in accordance with purpose
Security	Security services that work to prevent dangerous goods from entering the aircraft (cargo or cabin).	<ul style="list-style-type: none"> • Screening of bags • Passenger dangerous goods waiver
Weather services	Resources facilitating knowledge of weather conditions.	<ul style="list-style-type: none"> • Weather forecasting • Radar • ATS • ACARS/SATCOM
Airport design	Airport planning to support the type of operations serviced.	<ul style="list-style-type: none"> • Parking/taxi space • Airport positioning/location • Surroundings

Level 3 - Defeating Factors	Description	Examples
Design flaws/limitations	Equipment/systems/component: <ul style="list-style-type: none"> • Fails to achieve what it is intended to do, either completely or partially, or • Achieves what it is intended to do, but with unanticipated effects. 	<ul style="list-style-type: none"> • Fails to disperse fumes/channels them onto the aircraft • Sensors fail to detect/locate/alert presence of fumes • Positioning of components/systems causing over-heating and subsequent fumes
Manufacturing fault	A fault that occurs during manufacturing of aircraft parts. This may be a result of human, procedural, organisational or other factors.	<ul style="list-style-type: none"> • Imperfections in parts/components • Use of incorrect, unsuitable materials
Maintenance fault	A fault that occurs during aircraft maintenance activities. This may be a result of human, procedural, organisational or other factors.	<ul style="list-style-type: none"> • Undetected equipment issues (e.g. part fatigue) • Inadequate intervals leaving parts unchecked • Maintenance carried out incorrectly, fails to address issue adequately
Crew action/inaction	Irrespective of intention, crew behave in a way that poses a safety threat to some aspect of the flight. This includes both actions and failed/absent actions.	<ul style="list-style-type: none"> • Catering/cabin misuse of equipment/furnishings. • Failing to respond to/communicate observed aircraft issues. • Delayed/absent/inappropriate responses to fumes sources (including weather).
Passenger behaviour	Irrespective of intention, passengers behave in a way that poses a safety threat to some aspect of the flight.	<ul style="list-style-type: none"> • Carrying dangerous goods on-board • Smoking • Use of fumes producing, though allowable carry-on items (e.g. nail polish, deodorant). • Misuse of on-board furnishings/equipment (e.g. interfering with IFE equipment)
Inadequate/failure in security oversight	Deficiencies in security oversight, including human, procedural and equipment inadequacies/failures.	<ul style="list-style-type: none"> • Screening personnel miss dangerous goods in baggage. • Screening material is unable to detect particular materials.
Weather/forecast change	Environmental changes are encountered en-route	<ul style="list-style-type: none"> • Volcanic ash, fires, lightning etc.
Congestion	Traffic congestion due to increased traffic into aerodrome(s).	<ul style="list-style-type: none"> • Aircraft parking distances compromised
Level 4 - Defeating Factor Controls	Description	Examples
Maintenance performance/assurance	Monitoring of performance and outputs, includes operator or external agency driven activities such as: <ul style="list-style-type: none"> • scheduled checks • defect reporting 	<ul style="list-style-type: none"> • Phased checks • Service difficulty (defect) reporting • CASA AMO audits • Internal auditing of processes and performance
Design performance/assurance	<ul style="list-style-type: none"> • auditing • testing • investigations 	<ul style="list-style-type: none"> • Testing throughout development • Investigation of failures to improve design
Operational performance/assurance	<ul style="list-style-type: none"> • feedback (reporting) 	<ul style="list-style-type: none"> • Crew recurrency training and testing of knowledge, skills and adherence to SOPs • Safety audits • Incident reporting and investigations
Manufacturing		<ul style="list-style-type: none"> • Checks throughout process

performance/assurance		<ul style="list-style-type: none"> • Training/auditing of manufacturing processes and personnel
SOPs/Policy/Regulation	<p>This extends to operational and maintenance activities</p> <ul style="list-style-type: none"> • CASA Regulation • Operator policy/procedures (including checklist support) • Safety management systems 	<ul style="list-style-type: none"> • AFM (Aircraft design limitations) • Maintenance schedules/manuals • Airworthiness directives • Go/no go policies (weather, aircraft state) • Diversion procedures (weather, aircraft state) • Aircraft parking distances and taxi procedures • Weather monitoring
Training/education (Staff)	<p>Training in operational policy/ procedures/ regulations/ Non-technical skills (human factors, safety management etc.)/ Technical skills</p>	<ul style="list-style-type: none"> • Dangerous goods • Galley equipment operation • Aircraft operation (pilots)
Promotion/education (Passengers)	<p>Promotional and educational strategies targeting passenger behaviour in regard to dangerous goods.</p>	<ul style="list-style-type: none"> • Public articles (e.g. flight safety, operator magazines) • Displays/posters in airports
Regulation/enforcement	<p>Legislated consequences for breaching security requirements.</p>	<ul style="list-style-type: none"> • Penalties for smoking on board • Penalties for carriage of dangerous goods

Outcomes

Level 1 - Consequences	Description	Examples
Damaged/degraded aircraft systems	Aircraft systems degraded due to the source of the fumes (e.g. overheating components)	<ul style="list-style-type: none"> • Flight control systems • Landing gear
Smoke/Fire	Smoke or fire caused by ignition of either the fumes source, or ignition of the fumes themselves.	<ul style="list-style-type: none"> • Stray material in galley oven ignites <p>Electrical malfunction resulting in fire</p>
Injury/Incapacitation	Injury/incapacitation to passengers or crew directly resulting from fumes (not associated fire, accident etc.)	<ul style="list-style-type: none"> • Fumes inhalation • Injury due to effects of fumes inhalation (e.g. fall from light-headedness)
Level 2 – Consequence Controls	Description	Examples
Diversion (Air/Ground)	Diversion of aircraft to avoid or minimise damage to affected aircraft parts.	<ul style="list-style-type: none"> - Diverting around/out of volcanic ash - Diverting to alternate aerodrome in case of aircraft damage
Equipment Isolation	Controlling the affected areas/systems to isolate the problem area(s) – includes both manual and automated controls.	<ul style="list-style-type: none"> - Circuit breakers - Zoned aircraft systems - Isolating or depowering electrical buses
Remove ignition sources	Addressing ignition sources to avoid ignition of fumes or fumes source.	<ul style="list-style-type: none"> - Turning off electrical equipment - Removing/preventing any flames from passengers belongings (e.g. cigarette lighters)
Dangerous goods clean up	Removing or isolating dangerous goods (fumes source).	<ul style="list-style-type: none"> - Dangerous goods spill kit
Ventilation	Ventilating fumes to disperse or exhaust.	<ul style="list-style-type: none"> - Fans - Air-conditioning - Reducing cabin pressure differential and increasing bleed air flow rates
Personal protective equipment	Equipment designed to protect individuals from fumes inhalation.	<ul style="list-style-type: none"> - Oxygen masks (may or may not be recommended practice)

Level 3 - Defeating Factors	Description	Examples
Crew action/inaction	Irrespective of intention, crew behave in a way that poses a safety threat to some aspect of the flight. This includes both actions and failed/absent actions.	<ul style="list-style-type: none"> • Fail to isolate fumes • Use of ignition sources in fumes event • Failing to address identification of dangerous goods or passenger misbehaviour • Poor decision-making regarding actions – e.g. diversion options.
Diversion options unsuitable	Options for diversion are unsuitable either because they are unachievable or will increase safety risk.	<ul style="list-style-type: none"> • Proximity to aerodromes • Serviceability of aircraft • Weather conditions • Traffic conditions
Equipment required/ unresponsive/ unidentifiable	Equipment is required for the operations and will be detrimental to safety if shutdown, or is damaged to the point that it is no longer responding, and the crew are unable to identify the problem area.	<ul style="list-style-type: none"> • Landing gear • Flight controls • Power plants
Passenger behaviour	Irrespective of intention, passengers behave in a way that affects the crews' ability to address the situation, or are the cause of the situation (e.g. ignition source).	<ul style="list-style-type: none"> • Passengers using cigarette lighters or faulty (sparking) electrical equipment • Passengers and/or their belongings conceal dangerous goods source • Panic leads to misuse or failed use of PPE
Source inaccessible/unidentifiable	Location of the source is either unable to be identified and/or accessed by crew in order to manage.	<ul style="list-style-type: none"> • Cargo hold • Internal to appliances (e.g. oven) • In passenger baggage • Fumes can't be traced with specificity required to address
Spill kit unavailable/inadequate	The dangerous goods spill kit for clean-up is, for whatever reason, unavailable or inadequate for the purpose.	<ul style="list-style-type: none"> • Kit not maintained • Contents not adequate for likely situations
Level 4 - Defeating Factor Controls	Description	Examples
Operational performance/assurance	Monitoring of performance and outputs, includes operator or external agency driven activities such as: <ul style="list-style-type: none"> • scheduled checks • defect reporting • auditing • testing • investigations • feedback (reporting) 	<ul style="list-style-type: none"> • Crew recurrency training and testing of knowledge, skills and adherence to SOPs • Safety audits • Incident reporting and investigations
Training and education (crew)	Training in operational policy/ procedures/ regulations/ non-technical skills (human factors, safety management etc.)/ Technical skills.	<ul style="list-style-type: none"> • Dangerous goods • Fumes/fire response • Passenger management • Aircraft operation (AFM-design limitations)
Regulation/policy/procedures	All areas (maintenance, manufacturing, operations, design) <ul style="list-style-type: none"> • CASA Regulation 	<ul style="list-style-type: none"> • The Civil Aviation Act, CARs, CASRs, CAOs e.g. Parts: 119, 121, 42, 145, 21 • Ops manual suite

	<ul style="list-style-type: none"> • Operator policy/procedures (including checklist support) • Safety management systems 	
Passenger education	Educating passengers as to safety issues associated and associated legal obligations.	<ul style="list-style-type: none"> • Safety briefing • On-board flight magazines • Airport promotional materials
Design	Encompasses design aspects of materials, composition, and its interactions (including with other materials/systems and users).	<ul style="list-style-type: none"> • Ventilation systems designed to appropriate capacity • Placement of ventilation systems • Redundancy systems • Zoned systems
Maintenance	Maintenance of all of aircraft -scheduled and unscheduled.	<ul style="list-style-type: none"> • Ventilation systems • Operational components
Crew	Crew actions/presence during the operation.	<ul style="list-style-type: none"> • Passenger management in case of panic • Co-ordination of response • Actioning response checklists/procedures

Research

ATSB Transport Safety Report Aviation Research Report

A Joint initiative of Australian aviation safety agencies
An analysis of fumes and smoke events in Australian aviation
2008 to 2012

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Final – 20 May 2014

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