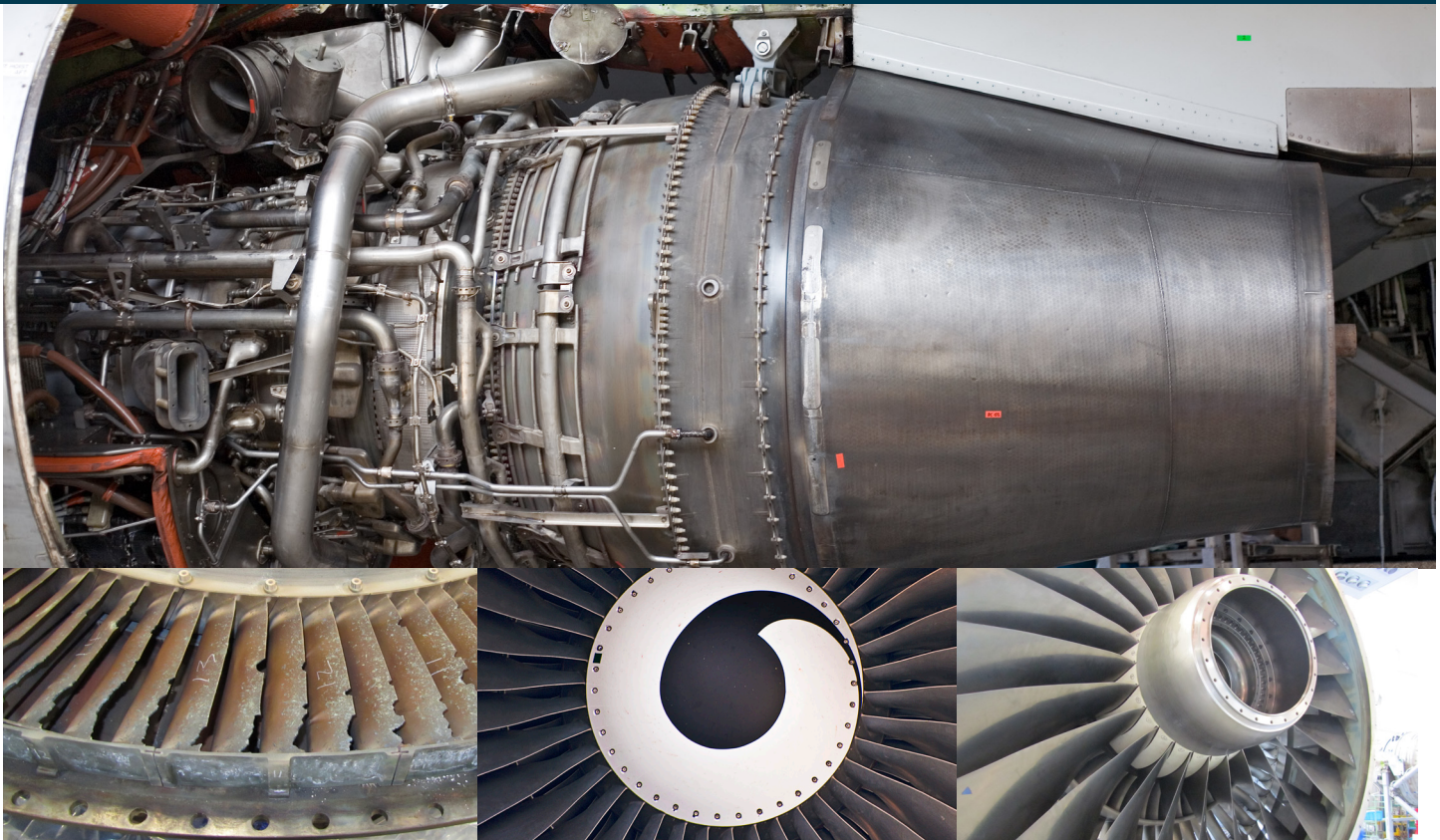




Australian Government  
Australian Transport Safety Bureau

# Power plant failures in turbofan-powered aircraft

2008 to 2012



Research

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### Addendum

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# Safety summary

## Why the ATSB did this research

This is the first in a series of research investigations looking at technical failures reported to the ATSB between 2008 and 2012. This report reviews power plant problems reported to the ATSB affecting turbofan-powered aircraft, and the types of incidents they are associated with.

By summarising power plant-related occurrences across all operators, this report provides an opportunity for operators to compare their own experiences with others flying the same or similar aircraft types, or aircraft using the same engines. By doing so, the ATSB hopes that the wider aviation industry will be able to learn from the experience of others.

## What the ATSB found

Despite the complexity of modern turbofan engines, their reliability is evidenced by the remarkably low rate of power plant occurrences. With a combined total of over five and a half million flight hours for turbofan engine aircraft between 2008 and 2012, there were only 280 occurrences relating specifically to the power plant systems (or approximately one occurrence every 20,000 flight hours). Additionally, the vast majority of these (98%) were classified as being a low risk rating occurrence with a low or no accident outcome. Only four were classified as medium risk, two as high risk and one as very high risk. None resulted in injury to passengers or crew.

Although the rates were low for the turbofan engine aircraft group as a whole, there were large differences between individual aircraft models. Three aircraft types in particular, the Boeing 747 classic, the Fokker F28/F100 and the British Aerospace BAE 146/Avro RJ, had far greater rates of power plant occurrences between 2008 and 2012 than any other aircraft in this study. Although these three aircraft types represented some of the older fleets, there were other fleets of aircraft of similar ages with far lower rates of occurrences.

## Safety message

The small number of high and very high risk power plant occurrences between 2008 and 2012 remind us that even highly sophisticated modern power plants can, and do, fail. Timely and vigilant reporting of all technical problems is therefore strongly encouraged to ensure as much information as possible is collected to better understand these problems. Of particular importance in technical occurrences are the follow-up reports from engineering inspections. These are often the only way that the root cause of the problem can be determined. The more comprehensively these are reported to the ATSB, the more insightful and useful reports like this become.

# Contents

<b>Context</b> .....	<b>1</b>
Reporting of technical failures	1
<b>Safety analysis</b> .....	<b>3</b>
Review of occurrences reported to the ATSB	3
Operations and aircraft involved	4
Common occurrence events	5
Abnormal engine indications	6
Auxiliary power units	6
Partial power loss	7
Oil loss	7
Engine controls	7
Total power loss / engine failures	7
Precautionary in-flight shut downs	8
Engine systems	8
Transmission and gearboxes	8
Compressor stalls	8
Other	8
Occurrences by engine model	10
CFM-56	12
CF-6	12
V2500	13
Rates of occurrences by aircraft model	15
BAE 146/Avro RJ	18
Boeing 747 classic	18
Fokker F28/F100	19
Occurrences by aircraft year of manufacture	21
Higher risk technical failures	22
<b>Summary</b> .....	<b>26</b>
<b>Sources and submissions</b> .....	<b>27</b>
Sources of information	27
References	27
<b>Australian Transport Safety Bureau</b> .....	<b>28</b>
Purpose of safety investigations	28
Developing safety action	28
<b>Glossary</b> .....	<b>29</b>

## Context

When aviation safety incidents and accidents happen in Australia, or involve Australian-registered aircraft operating overseas, they are reported to the Australian Transport Safety Bureau (ATSB). Accidents, as well as those incidents that pose a serious risk to safe aviation operations are investigated. Most reports, however, are used to help the ATSB build a picture of where trends exist, if they are indicative of safety issues, and how these could affect different types of aviation operations.

Proactively reviewing all occurrences reported to the ATSB provides the opportunity to monitor the health of aviation across Australia over many types of operations and before emerging safety issues manifest into accidents. By doing so, it is hoped that the wider aviation industry will be able to learn from the experience of others.

This report is the first in a series of research investigations looking at technical failures reported to the ATSB. This report will review power plant problems reported to the ATSB affecting turbofan-powered aircraft, and the types of incidents they are associated with. Other reports in this series will look at airframe and systems issues affecting turbofan-powered aircraft, and technical failures involving other aircraft types such as turboprops, piston-engine fixed-wing aircraft, and piston and turboshaft powered helicopters.

### Reporting of technical failures

Under the *Transport Safety Investigation Act and Regulations (2003)*, technical issues must be reported to the ATSB if they constitute a transport safety matter. While a transport safety matter can include anything that has, or has the potential to, affect the safety of an aircraft, power plant related technical issues that occur from when the aircraft is being prepared for flight until all crew and passengers have disembarked after flight, must be reported to the ATSB when they include:

- a failure that has prevented an aircraft from achieving predicted performance during take-off or climb
- an uncontained or contained engine failure
- a mechanical failure resulting in the shutdown of an engine (precautionary or otherwise)
- any malfunction that affects the operation of the aircraft
- any technical failure that has caused death or serious injury, led to aircraft control difficulties, or that has seriously affected operation of the aircraft.
- items that have become detached from an aircraft
- a failure that has caused fumes, smoke, or fire, or has led to crew incapacitation

Many of these technical issues would be considered major or other defects by the Civil Aviation Safety Authority (CASA), and should also be reported to CASA via the Service Defect Report (SDR) system.

**Case Study: In-flight engine malfunction 100 km south-east of Bali International Airport, Indonesia – 9 May 2011 Boeing 747-400**

**ATSB investigation AO-2011-062**

On 9 May 2011, a Boeing 747-400 aircraft was en route from Sydney to Singapore. Approximately 100 km south-east of Bali, all engine thrust levers were advanced and the aircraft began a climb from flight level<sup>1</sup> (FL) 360 to FL 380. Following initiation of the climb, the flight crew noticed that the No. 4 engine exhaust gas temperature (EGT) had increased rapidly to 850 °C. The thrust lever for the No. 4 engine (Rolls-Royce RB211-524G2-T) was then retarded, until the EGT was brought within the normal limits. Subsequently, the flight crew noted that the N2<sup>2</sup> vibrations for that engine remained at approximately 3.5 units, well above normal operating level, and as such, they elected to shut the engine down. Air Traffic Control (ATC) was informed and the aircraft was descended to FL 340. The flight continued to Singapore without further incident.

The increase in the exhaust gas temperature and vibration from the No. 4 engine was a direct result of the failure and separation of a single intermediate-pressure turbine blade. The turbine blade had fractured following the initiation and growth of a fatigue crack from an origin area near the blade inner root platform. Detailed modelling and analysis was undertaken by the engine manufacturer, Rolls-Royce, following the occurrence, and while the root cause for the intermediate pressure turbine blade failure was not fully identified at the time of this report, it was considered that the wear and loss of material from the turbine blade outer interlocking shrouds had reduced the rigidity and damping effects of the shroud and may have contributed to the high-cycle fatigue cracking and failure. The engine manufacturer has advised that they are continuing work to understand the underlying mechanism of the failure and will advise the ATSB if any further information is obtained.



Turbine blades from the damaged Rolls-Royce RB211-524G2-T

Source: ATSB

<sup>1</sup> At altitudes above 10,000 ft in Australia, an aircraft's height above mean sea level is referred to as a flight level (FL). FL 380 equates to 38,000 ft.

<sup>2</sup> In a 3-spool turbine engine, N1 refers to the low pressure (LP) shaft speed, expressed as a percentage of the maximum rated speed. N2 refers to the intermediate pressure (IP) shaft speed.

# Safety analysis

## Review of occurrences reported to the ATSB

As the ATSB and industry work closely to continually improve the level and quality of reporting, there has been a gradual increase in the number of all reported safety occurrences over time that is independent of growth in flying activity. A review of the ATSB occurrence database shows that between 2008 and 2012 approximately 1,930 occurrences relating to technical failures<sup>3</sup> were reported to the ATSB by flight crews and operators of Australian civil (VH-) registered turbofan-powered aircraft. In contrast, there were about 20,500 safety occurrences of all types that were reported to the ATSB over the same period involving the same types of aircraft. Within the technical failures occurrences, 280 were classified as being power plant occurrences.

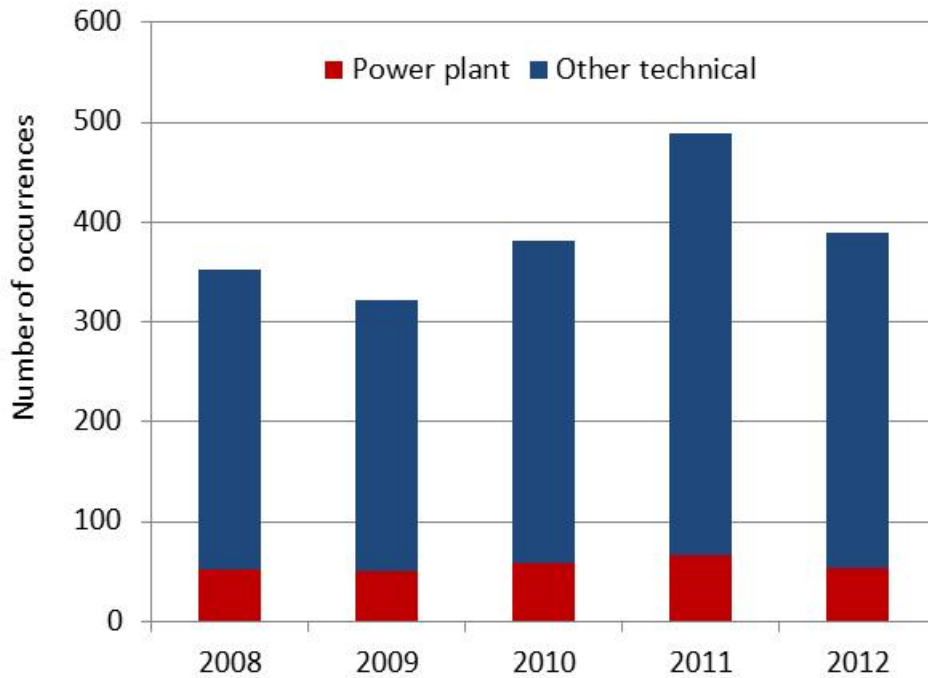
Each of these occurrences are characterised by one or more specific occurrence events. For example, a single occurrence may involve an abnormal engine indication followed by a partial power loss, followed by a precautionary in-flight shut-down, followed by a diversion/return. Thus, from the 280 power plant occurrences, there derive 363 occurrence events. Each event has been coded using the ATSB occurrence type classification.

Although the total number of all reported safety matters to the ATSB has been generally increasing, Figure 1 shows that the number of reported occurrences relating to technical failures in turbofan aircraft has fluctuated between 321 and 489 occurrences per year. In contrast, the power plant sub-set (shown in red) has remained fairly consistent over the past five years with between 52 and 66 occurrences per year, or 13 to 15 per cent of the annual total of technical occurrences.

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<sup>3</sup> This does not include approximately 70 reports submitted to the ATSB over this period relating to technical issues that were considered as non-reportable 'events' under the Transport Safety Investigation Regulations 2003.

Figure 1: The number of technical occurrences involving turbofan aircraft, 2008 to 2012



## Operations and aircraft involved

These power plant-related occurrences originate from six different operational groups; air transport high capacity<sup>4</sup>, air transport low capacity<sup>5</sup> and charter<sup>6</sup> (which collectively make up the commercial air transport operation group), as well as, aerial work, flying training and private.

Figure 2 shows the distribution of the power plant occurrences for each operation type. As this report is focused on turbofan engine aircraft is not surprising to see that the vast majority, 256 of 280 (91.4%), of the occurrences originated from high capacity aircraft. The aircraft in this group are exactly what would be expect for civilian aircraft greater than 4,200 kg payload with turbofan engines and range from Embraer ERJ-170's to Airbus A380's.

Specifically, the aircraft (and their counts in parenthesis) are as follows: Boeing 717 (6), Boeing 737 classics (300 and 400 series) (21), Boeing 737 Next Generation (NG, 700,800, series) (39), Boeing 747 classic (300 series) (4), Boeing 747-400 (37), Boeing 767 (22), Boeing 777 (3), Airbus A320 (44), Airbus A321 (9), Airbus A330 (21), Airbus A380 (12), British Aerospace BAE 146/Avro RJ (17), Embraer ERJ 170 (7), Embraer ERJ 190 (3), Fokker F28/F100 (11).

The 12 (4.3%) occurrences from charter aircraft came from eight F28-100s, and one each of LearJet 45s, Raytheon 400As, Cessna 525 and a LearJet 35A.

The seven (2.5%) aerial work occurrence were on emergency and medical services, and defence support flights, and involved one LearJet 35A, three LearJet 45s, two Israel Aircraft Industries (IAI) 1124 and one LearJet 36.

4 High capacity aircraft are certified as having a maximum capacity exceeding 38 seats, or having a maximum payload capability that exceeds 4,200 kg.

5 Low capacity operations are conducted in aircraft other than high capacity aircraft, that is, aircraft with a maximum capacity of 38 seats or less, or having a maximum payload capability of 4,200 kg or below.

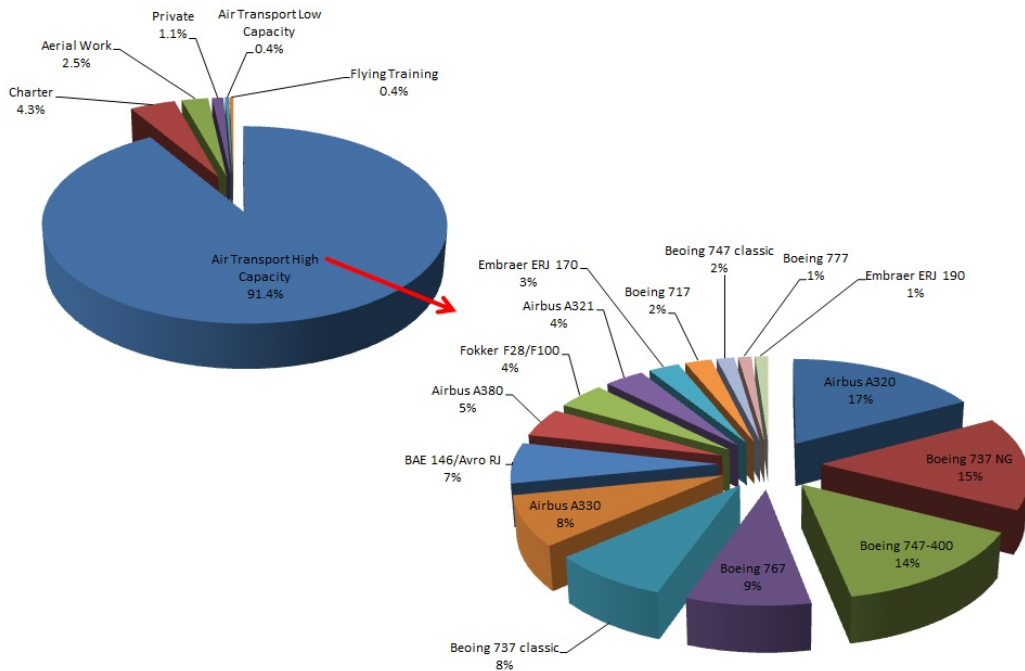
6 Charter operations involve the carriage of passengers and/or cargo on non-scheduled flights by the aircraft operator, or by the operator's employees, for trade or commerce.



Private/business operations accounted for three occurrences which came from a Canadair CL-604s, a Cessna 560 and a Hawker 900XP.

The single occurrence from a low capacity RPT aircraft involved an IAI 1124 (operating freight).

**Figure 2: The proportion of power plant occurrences from each operation type between 2008 and 2012.**



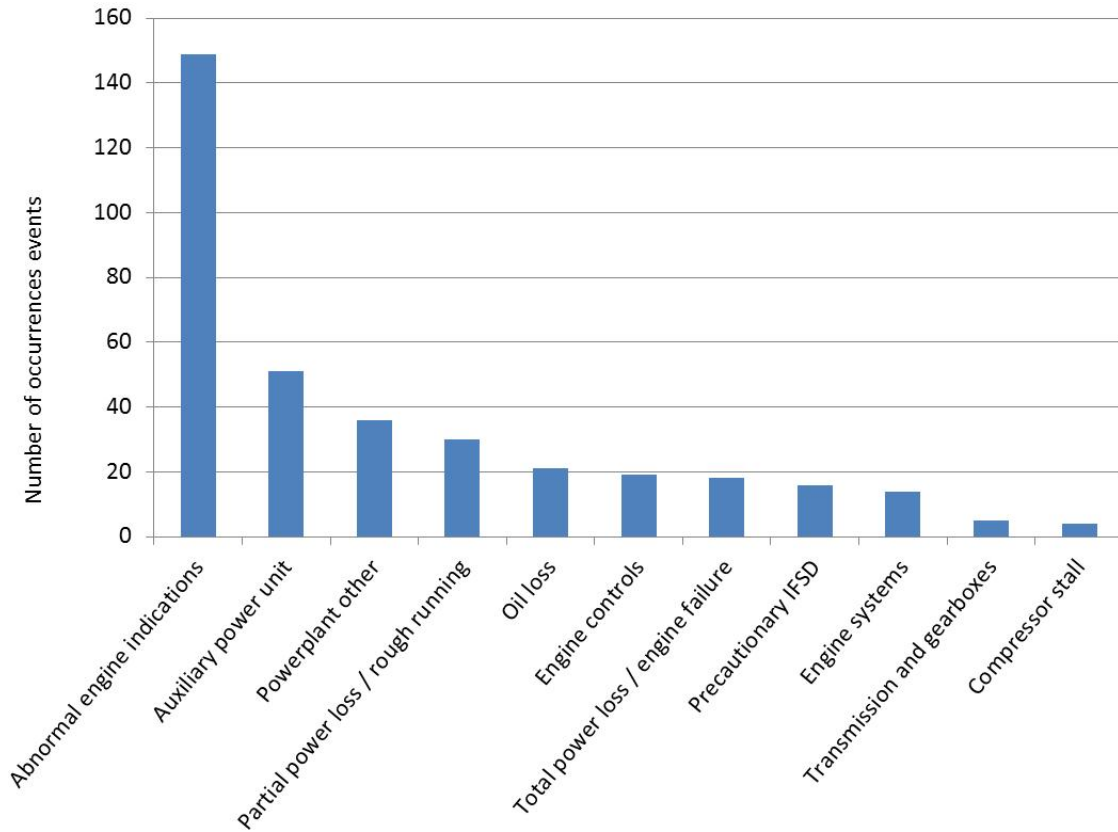
### Common occurrence events

For the purposes of this study, power plant related technical failures have been categorised as one or more of the following:

- Abnormal engine indications
- Auxiliary power unit
- Compressor Stall
- Engine controls
- Engine systems
- Oil loss
- Partial power loss
- Power plant other
- Precautionary in flight shut down (IFSD)
- Total power loss or engine failure (of a single engine)
- Transmission and gearboxes

The power plant occurrences were each coded into one or more of the 11 previously described occurrence types; the five year totals for each occurrence type are displayed individually in Figure 3.

**Figure 3: The number power plant related occurrence events between 2008 and 2012.**



***Abnormal engine indications***

The most common type of power plant events related to abnormal engine indications, which were one of the occurrence events in 149 (53%) of the 280 occurrences. Of these occurrences, 55 involved other occurrence events as well. Reported abnormal engine indications related to any abnormal engine instrument readings, such as engine power output or temperature, as well as engine over-speed or over-torque warnings. Additionally, abnormal engine indications included any general reports of engine problems or observations of abnormal sights or sounds by a crew member, such as smoke or fumes in the cabin/cockpit or excessive engine vibration (further detail regarding common abnormal engine indications are provided below in an analysis by aircraft and engine type).

Although many abnormal engine indications can be insignificant or even spurious, 36 did result in air-returns, with 34 of these necessitating a shutdown of the affected engine. A further 38 abnormal indications occurred at some point in the take-off with 30 of these resulting in the take-off being rejected, while five of the eight abnormal engine indications that occurred during taxi resulted in a return to the gate.

***Auxiliary power units***

Following from abnormal engine indications, failures relating specifically to auxiliary power units (APUs) were the next most prevalent (51 occurrences, 18%). Although APUs are not technically part of the propulsion system, they are a turbine in themselves with similar components, operating temperatures/pressures and failure mechanisms to the turbines used for propulsion. Indeed, some of the main engines in some smaller business jets are based on the core of the APU units from large commercial airliners. Thus, in the context of technical failures, they have been included in this report.

By far the most common fault associated with the APUs were events of smoke and/or fumes in either the cabin or cockpit, typically as a result of a contamination of the air-conditioning as a

result of an APU oil leak. These kind of events accounted for 29 (57%) of the 51 APU events, two of which resulted in air-returns.

Nine of the APU events were a result of a failure of the APU to start, either in cruise (1), climb (1), on descent (2) and five at start-up (one of which resulted in a flight cancellation). Another six events described an auto-shutdown of the APU in cruise, four of which resulted in air-returns. Seven events were unspecified APU warnings or faults after landing (3) on taxi (2), or in cruise (2), however, only one of these resulting in a ground return. Intriguingly, one of these events describes an APU warning that was a result of a dog in the cargo hold escaping its cage and chewing through a wiring loom.

### ***Partial power loss***

In the 30 occurrences involving partial power loss events, only two related specifically to rough running engines (one engine surging and another producing excessive vibrations). The remaining 28 occurrences involved a partial power loss, seven of which went on to require a precautionary in-flight shut down on the affected engine. Ten of the 28 partial power losses occurred on take-off and resulted in rejected take-offs, while the remaining 18 occurred in flight with ten resulting in an air-return. Where the failure mechanism was reported, fuel flow regulators and pump failures (4) and variable incidence guide vanes<sup>7</sup> (3) were the only reoccurring failure types. Other one-off examples include pressure/temperature probe failures, governor failures and metal particles in the chip detectors.

### ***Oil loss***

More than half (11 of 21) of the occurrences with oil loss events related to APU oil leaks, which were usually detected as fumes or smoke in either the cabin or cockpit transported by the air-conditioning system. Of these, most (7) occurred on the ground during APU start-up or shut down. The remaining APU related oil loss events happening during flight, two of which resulted in a return to the departure aerodrome. The remaining 10 oil loss occurrences were as a result of engine oil leaks; two of these necessitated an in-flight shut down of the affect engine, two necessitated diversions to alternate aerodrome and there was one occurrence resulting in an air-return.

### ***Engine controls***

Of the problems that related to engine control issues, nearly half (9 of 19) were a failure of the autothrottle systems, five of which occurred during take-off and resulted in rejected take-offs. Four more of the engine control events described thrust modulation system (TMS) failures, three of which led to air-returns and the fourth to a rejected take-off. All four of these events involved the same aircraft (a BAE 146) in a four month period. The remaining six events described one-off failures of the following; throttle lever fault, a failure of the engine computer, an uncommanded thrust increase, a problem shutting down an engine, a reverse thrust fault and a failure of engine firewires, none of which pertained to any particular aircraft or aircraft models.

### ***Total power loss / engine failures<sup>8</sup>***

Two of the 18 engine failures were a result of fuel starvation, whereby there was sufficient fuel on board the aircraft but it didn't reach the engine. Both of these cases were a result of an inadvertent switching of the fuel controls, in one case resulting in an air-return, in the other the fault was realised and the engine was able to be restarted and the flight continued.

Of the remaining 16 engine failures, four occurred at start-up, two during take-off with both resulting in rejected take-offs, while ten engine failure occurred in-flight. Four of the in-flight shutdowns resulted in air-returns and three in diversions. Of particular concern, two occurrences

<sup>7</sup> Variable incident guide vanes are located in front of the first compressor rotor and vary the angle of incidence of inlet air to the first compressor rotor to keep it in the stall-free operating range.

<sup>8</sup> Note: total power loss refers to the loss of power to a single engine only, not all engines on the aircraft.

were uncontained engine failures whereby a failed component of the engine was ejected beyond the protective casing of the engine cowling.

### ***Precautionary in-flight shut downs***

All 16 precautionary in-flight shut downs were associated with (or in response to) some form of abnormal engine indication. These indications ranged from low oil pressure warnings, high temperature warnings, engine surge/stalls, smoke and/or visible fire, leaking de-icing fluid and a dis-bonded acoustic liner that fowled outlet guide vanes. Nine of these precautionary in-flight shut downs resulted in returns (eight air-returns and one ground-return) and two necessitated diversions to alternate aerodromes. One occurrence involved shutting down an engine during landing. In the four remaining occurrences, the flights continued to the intended destination with one engine shut down.

### ***Engine systems***

There were 14 occurrences that involved one or more of the engine ancillary systems; starter motors or thrust reversers, for example. Nearly half of these engine system occurrences (6 of 14) described a stater motor failing on start-up. The remaining eight occurrences were an assortment of the following; trust modulating systems (TMS) warning, integrated drive generator failure (2), spar valve motor failure, electronic engine control (EEC) failure, thrust reverser fault, high jet pipe temperature warning and a variable-incidence guide vane air flow control unit failure.

### ***Transmission and gearboxes***

Of the five transmission and gearboxes occurrences, two related to the APU gearbox. In one, the gearbox magnetic chip detector leaked oil and in the other, metal particles were detected by the APU gearbox chip detector. The other three occurrences were of engine gearbox faults, one during taxi leading to a ground return, one in-flight shutdown due to a low oil pressure warning leading to an air-return and one high speed gearbox failure that led to an in-flight shutdown and an air-return.

### ***Compressor stalls***

There were four occurrences recorded as being compressor stalls in this period; two involved compressor stalls on the initial climb resulting in air-returns while the two others occurred on final approach and did not alter the remainder of the flight.

### ***Other***

There were 36 occurrences with a technical failure event that did not fit into one of the above groups. Often, these 'power plant other' occurrence events were associated with another occurrence type and the other describes a part of that occurrence which did not fit within the context of the primary occurrence type.

This group of occurrences contained 29 occurrences that included an abnormal engine indication; two on start-up, two in-flight where the flight continued unaffected, three that resulted in a diversion, ten that occurred during take-off and resulted in rejected take-offs, and 11 that resulted in returns (10 air-returns and one ground-return). Of these 11, three were associated with partial power losses and another three necessitated an in-flight shut down of an engine. An additional seven events described thrust reverser faults, two of fumes events and one an autothrottle fault.

The failure mechanisms that led to these events were as varied as the events themselves. As an example, looking at the causes of the ten rejected take-offs, the only recurring fault was failures of a variable incidence guide vane on three occasions. Other faults leading to rejected take-offs included; high-pressure bleed valve faults, compressor vane faults, high stage valve faults, pressure/temperature sensor probe faults, high pressure compressor damage, pitot probe faults and a fuel flow regulator fault.

**Case Study: In-flight engine malfunction and air turn-back 120 km SW of Brisbane Airport 10 November 2009**

**ATSB investigation AO-2009-069**

On 10 November 2009, a Boeing 737-400 departed Brisbane on a scheduled passenger service to Melbourne. As the aircraft was climbing through 24,000 ft, the crew reported hearing a loud thump from the right side of the aircraft, accompanied by a rise in exhaust gas temperature (EGT) and engine vibrations outside of normal limits.

The crew retarded the right engine thrust lever and the engine indications returned to normal levels. At this time, a non-normal checklist for engine limit / surge / stall was also completed. The aircraft was returned to Brisbane and landed without further incident. As a precaution, the right engine was shut-down during taxi.

A preliminary inspection by the operator's engineering staff revealed significant damage to the low pressure turbine (LPT) assembly. The CFM56-3C-1 engine was subsequently returned to an overhaul facility for disassembly and inspection, overseen by ATSB investigators.

Creep rupture was identified as the likely failure mechanism in previous stage-1 LPT blade failures in this engine type investigated by the ATSB and the engine manufacturer. As a result of this occurrence, the engine manufacturer revised service bulletin SB 72-1113 to expand the range of blade manufacturing batch numbers that had previously been identified as being predisposed to creep-related failure. Blades in the identified batches were to be withdrawn from service as soon as they are next removed from the engine.



LPT stage 1 blades on the damaged CFM56

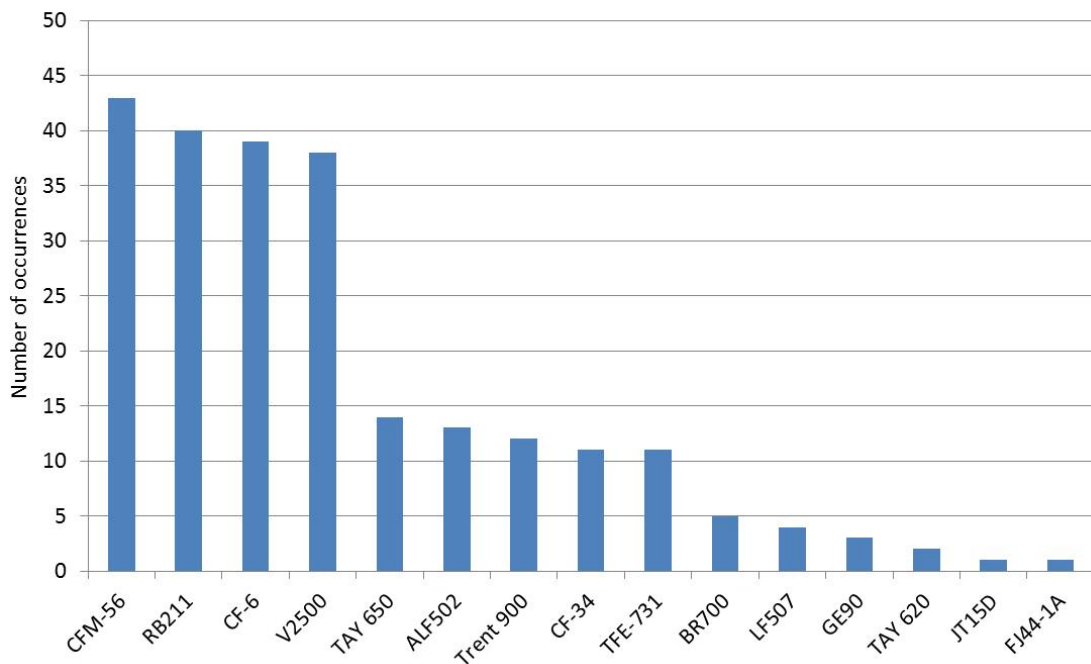
source: ATSB

## Occurrences by engine model

Figure 4 shows the number of power plant occurrences between 2008 and 2012 for each engine model. For this review by engine model, the APU occurrences have been removed as the APUs are a completely separate system and there is no correlation between the APU and engine manufactures. Also note that data in this section are non-normalised counts (which do not take into account either fleet size or hours flown) and thus do not represent a rate of occurrences.

The CFM International CFM<sup>9</sup>-56 were associated with the most power plant occurrences (43), followed by the Rolls Royce RB211 (40), the General Electric (GE) CF-6 (39), and the International Aero Engines (IAE)<sup>10</sup> V2500 (38). The remaining 11 models all had less than 15 occurrences each.

**Figure 4: Power plant occurrences by engine model, 2008 - 2012**



Many of these engine models are used in a number of different aircraft, and conversely, many aircraft can be specified with a number of different engine types. Table 1 outlines the different engine/airframe combinations that are found for the occurrences in this report (note that other combinations are possible but are not contained in this report so have been omitted from the table).

<sup>9</sup> CFM International is a joint-owned company of SNECMA and GE Aviation.

<sup>10</sup> International Aero Engines is a consortium backed by four aero-engine manufactures, Rolls-Royce, Pratt & Whitney, Japanese Aero Engine Corporation and MTU Aero Engines.

**Table 1: List of possible engine / airframe combinations in Australian registered aircraft.**

Engine manufacturer	Engine Model	Aircraft
Textron Lycoming	ALF502	British Aerospace BAE 146, Canadair CL-604
Textron Lycoming	LF507	Avro RJ
BMW Rolls Royce Aero Engines	BR700	Boeing 717
General Electric Company	CF-34	Embraer ERJ-170, Embraer ERJ-190
General Electric Company	CF-6	Airbus A330, Boeing 747, Boeing 767
CFM International, S.A.	CFM-56	Boeing 737
Williams International	FJ44-1A	Cessna Citation Jet
General Electric Company	GE90	Boeing 777
Pratt & Whitney Canada	JT15D	Cessna Citation I, V
Rolls Royce Ltd	RB211 <sup>11</sup>	Boeing 747, Boeing 767
Rolls Royce Ltd	TAY 620	Fokker F28/F100
Rolls Royce Ltd	TAY 650	Fokker F28/F100
Rolls Royce Ltd	Trent 900	Airbus A380
Honeywell International Inc.	TFE-731	Learjet 31, Cessna Citation III
International Aero Engines	V2500	Airbus A320, Airbus A321

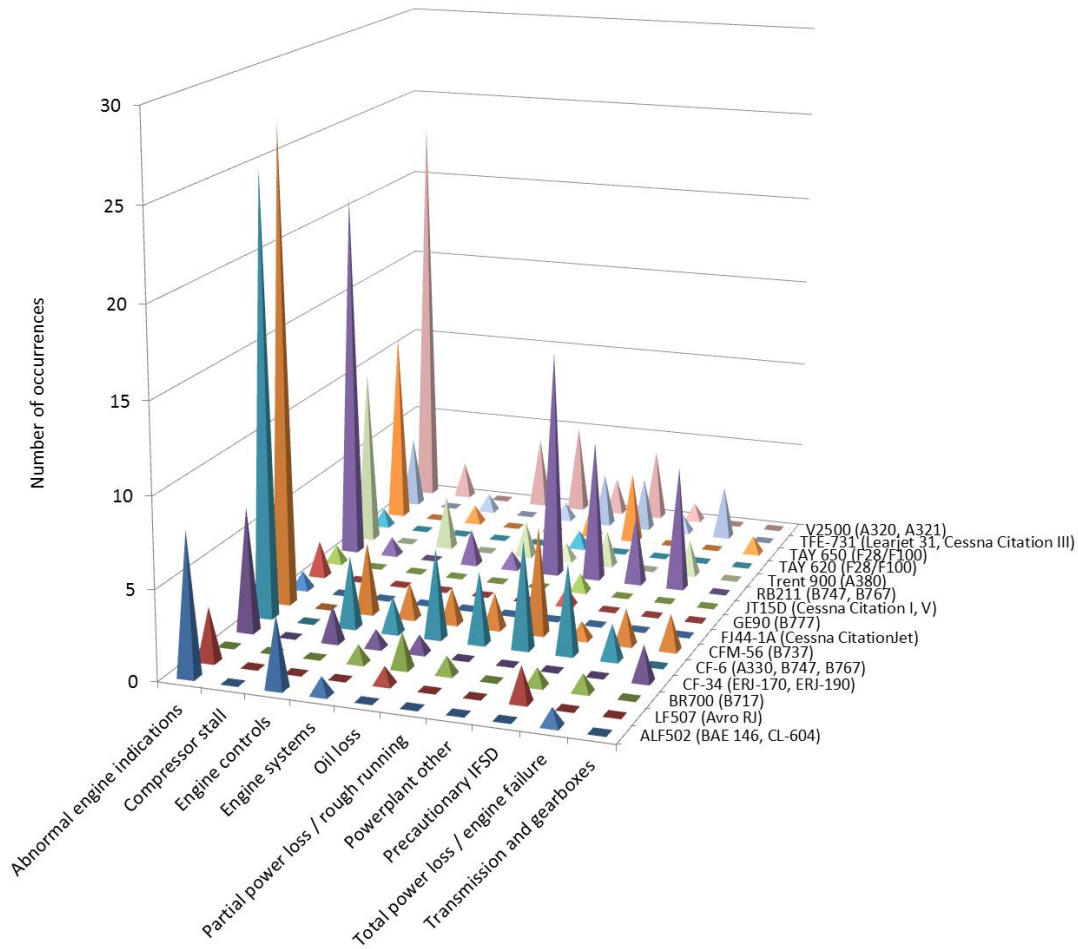
To get further insight as to whether certain types of occurrences are affecting particular engine models, the occurrence types are graphed individually in Figure 5. As in Figure 3, most occurrences involve abnormal engine indications. However, Figure 5 shows that the majority of these occurrences derive from only four different engine models; the CFM-56 (27), the CF-6 (25), the V2500 (23) and the RB211<sup>11</sup> (21).

The difficulty in making any meaningful conclusions from the data in either Figure 4 or Figure 5 is that there are a number of different possible airframe / engine combinations (see Table 1). Additionally, these data do not take into account either the number of these engines in the fleet or the hours that they have flown. In order to make any useful comparisons, occurrence data must be normalised by the number of hours flown. However, as the hours flown data pertain only to aircraft model, and due to the various airframe/engine combinations, there is currently no practical way of discerning actual engine hours. Thus no quantitative conclusions can be made regarding the reliability of any particular engine model and these figures serve only as a qualitative insight into the types of issues associated with each engine model.

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<sup>11</sup> The Rolls Royce RB211 describes a family of engines manufactured from the early 1970's through to the late 1980's. In this report there are three RB211 models used on three different aircraft, they are the RB211-524 D4 (Boeing 747-300), RB211-524 G2 (Boeing 747-400), and RB211-524H36 (Boeing 767-300). In this report, the Trent 900 engines are included in their own category.

**Figure 5: Power plant related occurrences by engine model, 2008 – 2012.**



**CFM-56**

All 27 abnormal engine indications from the CFM-56 (dark orange bars in Figure 5) were associated with Boeing 737 aircraft, 11 classics and 16 NG. Nine of the 27 occurrences involved an indication of an engine overheating (including engine gas temperature (EGT) warnings), resulting in one rejected take-off, one diversion and one return (with six unknown outcomes). A variable by-pass valve, a low pressure turbine blade failure and an engine spar valve were each responsible for EGT warnings while the cause of the other six remain unknown.

Indications of low oil were the next most common with four events; compared to overheating events, the consequences were consistently more severe with three of the four events resulting in an in-flight shut-down (two of which were followed by a diversion), with the fourth resulting in an air-return. An inspection showed this to be a result of a spurious low oil pressure warning caused by a faulty test switch, while one of the other indications was attributed to a scavenge oil filter and oil indicator. The only other recurring indication was that of an engine thrust reversal problem. The remaining indications included N1 indicators, engine control warning, fuel imbalance, duct pressures and a master caution-engine.

**CF-6**

Recurrent indications from the CF-6 (green bars in Figure 5) engine include oil warnings (6), excessive vibrations (3), and full authority digital engine control (FADEC) warnings (2). Other one-off indications included abnormal thrust and/or low power, digital engine control unit fault, amber engine caution, N1 and N2 fluctuations, engine pneumatic systems warnings, EGT warnings, engine valve lights and reverse thrust warnings. In the events where the cause of the fault is



known; two of the oil warnings were a result of integrated-drive generator faults which both lead to diversions, another oil warning resulted from a faulty temperature sensor and one from a faulty oil seal which lead to an in-flight shut-down followed by an air return. A leaking de-icing unit led to a digital engine control unit fault which resulted in an in-flight shut-down. One of the engine vibration indications lead to an air return, an engineering inspection found that the engine had seized with LPT stages 1-5 damaged with stage 3 nozzle segment found with broken and cracked airfoils.

### **V2500**

For the 23 abnormal indication events involving the V2500 engine (pink bars in Figure 5), 18 were in A320-200's and five in A321-200. Three of the four abnormal engine indications that occurred en route resulted in diversions. One of these indications was known to be a compressor valve indication. The fourth that occurred during en route involved numerous electronic centralised aircraft monitor (ECAM) warnings but had no bearing on the rest of the flight. An engineering inspection traced the indication to an engine pylon connector not being installed correctly. Four indications were received at start-up, with one involving sparks emanating from the engine and other fumes in the cabin. A faulty starter unit and a faulty indicator were responsible for the two others.

### **Rolls-Royce RB211<sup>11</sup>**

Of the 21 abnormal engine indications generated by the Rolls-Royce RB211 (purple bars), there were five occurrences of excessive engine gas temperatures (EGT), two of which were also accompanied by engine vibrations while another three involved vibrations alone. Low oil pressures, engine surges, engine thrust problems and fuel system warnings each accounted for two of the indications. The remainder were made up of an overpressure warning, an engine overspeed, an electronic engine control (EEC) warning and an engine bleed air warning. There was one occurrence where the indication type was not reported.

Determining the cause of the abnormal engine indications for non-investigated occurrences usually relies on the ATSB receiving a follow-up notification after an engineering inspection. For the Rolls-Royce RB211 occurrences, only 11 of the 21 occurrences had follow-up reports. Where they were reported, there was little repetition of any particular fault, with the causes being just as varied as the indications. A de-bonding of an acoustic liner resulted in one of the noise and vibration indications; a compressor blade release from the high pressure compressor and a failure and separation of a single intermediate-pressure turbine blade both resulted in vibration and EGT warnings; a loose bolt in the low pressure fuel filter resulted in a fuel leak indication; metal in the tail pipe and in the magnetic chip detector resulted in an engine surge, while a fuel metering unit and variable inlet guide vane were found responsible for another engine surge and oil level indications; metal chips found in the gearbox and oil filter lead to a low oil pressure and temperature indication; an engine electronic control fault lead to a low thrust indication and an autothrottle warning; the engine bleed air warning was found to result from an engine fan air modulating valve tubes; an open circuit in the engine heat probe and a fuel valve actuator lead to throttle issues.

The RB211 generated the most occurrences of partial power loss with 13 occurrences, all of which were associated with Boeing 747-400 aircraft. Interestingly, over half of all these occurrences related to insufficient thrust on take-off, all seven of which resulted in rejected take-offs. In three of these rejected take-offs the fault was traced to the variable inlet guide vanes (VIGV); the control unit, the return spring and the ram actuators were all found to be the sources of problems. Two others were fuel related with a faulty fuel flow regulator from a faulty fuel management unit. The final two rejected take-offs were a result of a faulty pressure/temperature probe and a damaged high pressure compressor.

Other partial power losses involving RB211s included; severe vibrations (1) that lead to a precautionary in-flight shut-down due to a failure and separation of an intermediate-pressure turbine blade; an engine surge (1) with visible flames emanating from the engine resulted in a

precautionary in-flight shut-down and a return, although the cause was unknown metal fragments were found in the chip detector and tail pipe; reduced thrust and fuel pressure warning (1) as a result of a faulty engine fuel governor; an acoustic liner de-bonding caused a partial power loss resulting in an in-flight shut-down; and two temporary partial power losses where the cause was unknown and had no impact on the rest of the flight.

In addition to partial power loss, the RB211 was also associated with the largest number of total power losses / engine failures<sup>12</sup>, with 7 occurrences. Six of these involved 747-400 aircraft and one involved a 767-300. One of these occurrences was classified as being uncontained engine failure; a potentially serious occurrence. In this case, a Boeing 747-400 sustained an engine failure on climb as a result of a fatigue fracture of a single stage-2 low pressure turbine (LPT) blade. This occurrence was investigated by the ATSB (AO-2010-066). The other six total power losses were all contained and generally much lower risk occurrences. Two occurred during the engine start, with both involving automatic engine shutdowns; one of these was traced to burnt pins in an electrical connection. The one that happened on take-off resulted in the take-off being rejected. A subsequent engineering inspection revealed damage to the high pressure compressor and the engine was replaced. One occurred en route and involved an engine failure due to the fuel metering unit. Finally, two total power losses occurred on climb, both necessitating precautionary in-flight shut-downs and returns. One of these cases a subsequent examination confirmed that the engine had sustained serious damage as the result of a compressor blade release from the stage 1 high pressure compressor (HPC 1).

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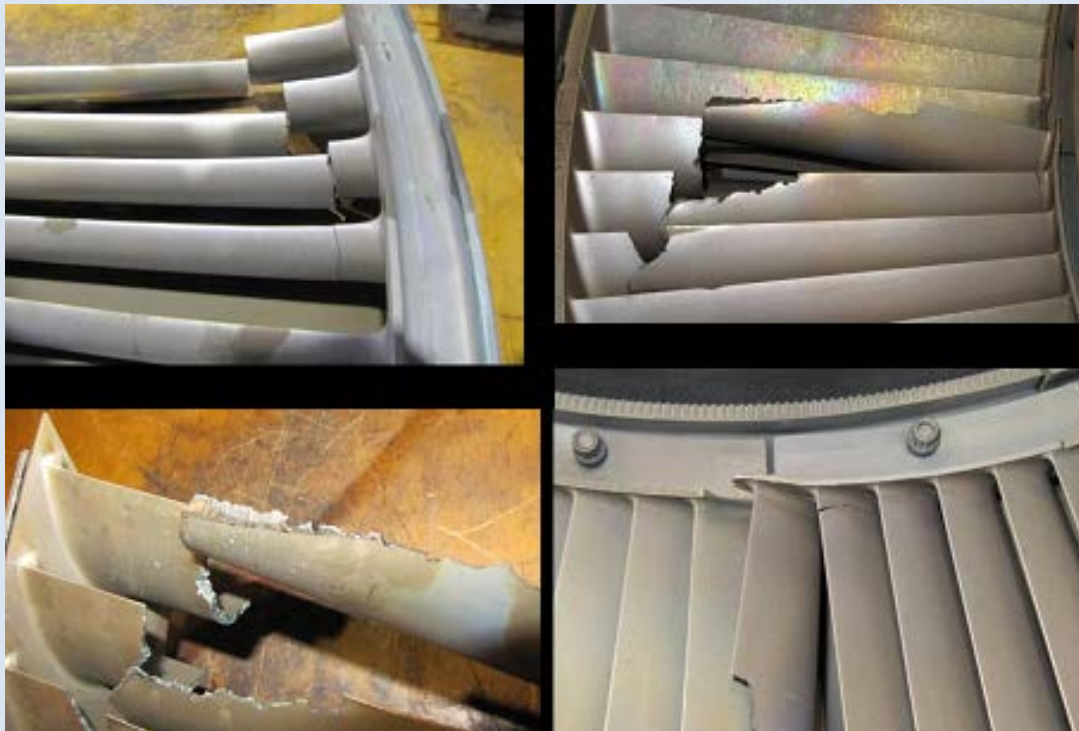
<sup>12</sup> Note: total power loss refers to the loss of power to a single engine only, not all engines on the aircraft.

**Case Study: Abnormal engine indications - Boeing 767-300, near Perth Airport WA, 12 November 2010**

**ATSB investigation AO-2010-093**

On 12 November 2010, a Boeing 767-300 aircraft departed Perth on a scheduled passenger flight to Melbourne. During the climb through 7,000 ft, the flight crew heard a popping sound followed by vibration coming from the left engine. Engine vibration gradually increased to a peak value of about 4 units while all other engine parameters were noted as normal. The vibration decreased when the crew retarded the engine power lever to the flight idle position. Shortly thereafter the crew declared a PAN<sup>13</sup> and requested a return to Perth, then notified all passengers of the situation. The turn back and subsequent single-engine landing were uneventful.

The aircraft operator carried out an initial examination of the aircraft and engine. The engine was found to have seized and metal pieces were found in the tail pipe. The engine was replaced and the aircraft returned to service. The engine manufacturer conducted an investigation into the failure of the LPT stage 3 nozzle segments. The investigation identified that the most probable reason for the failure was a transient mean stress of the segments during take-off, coupled with other operational stress and mechanical factors.



The damaged General Electric CF6-80C2 engine

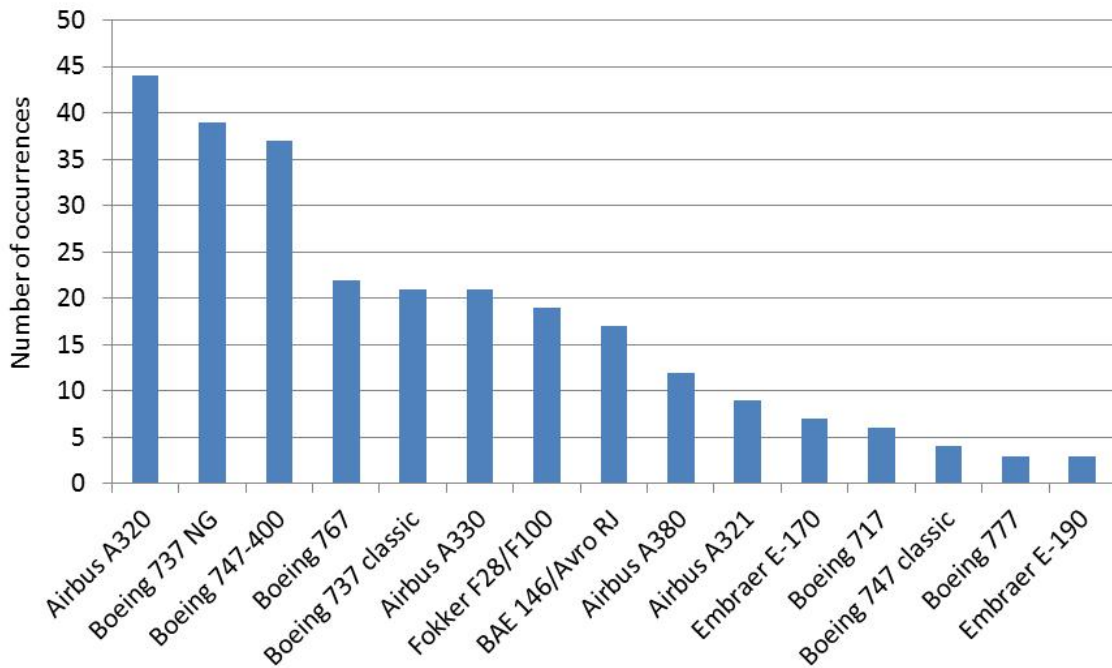
source: ATSB

**Rates of occurrences by aircraft model**

Figure 6 shows the number (non-normalised) of power plant occurrences for each type aircraft. To normalise these data, hours flown per aircraft information was provided by the Bureau of Infrastructure, Transport and Regional Economic (BITRE). Unfortunately, the hours flown data were not available for aircraft undertaking charter operations, this includes the Learjet 45, 36 and 35A, Israel Aircraft Industries 1124, Canadair CL-604, Raytheon 400A, Cessna 560 and 525 and Hawker 900XP. This leaves the aircraft shown in Figure 7 for further analysis.

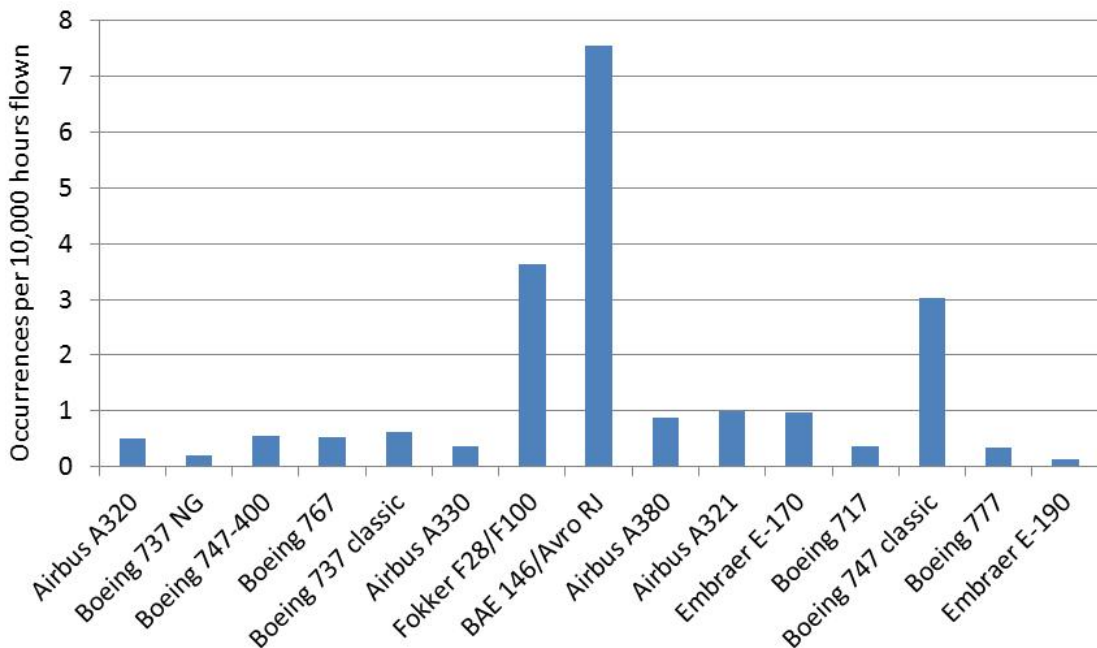
13 A PAN radio broadcast is an international urgency call indicating uncertainty or alert to the safety of an aircraft or its passengers.

**Figure 6: Number of power plant occurrences for all occurrence aircraft where hours flown is known.**



Data from Figure 6 are divided by the total hours flown for each aircraft model in the five year period between 2008 and 2012. This is displayed as the rate of power plant occurrences per 10,000 hours flown in Figure 7. The contrast between the two figures shows the importance of normalising this type of data by hours flown. Note that the data in Figure 7 are normalised by airframe flight hours, not engine hours, and thus do not take into account the number of engines per aircraft. In Figure 7, the 747 classic, 747-400, A380 and BAE 146/Avro RJ all have four engines whereas the remaining aircraft models all have two.

**Figure 7: Rate of power plant occurrences by aircraft model per 10,000 hours flown.**

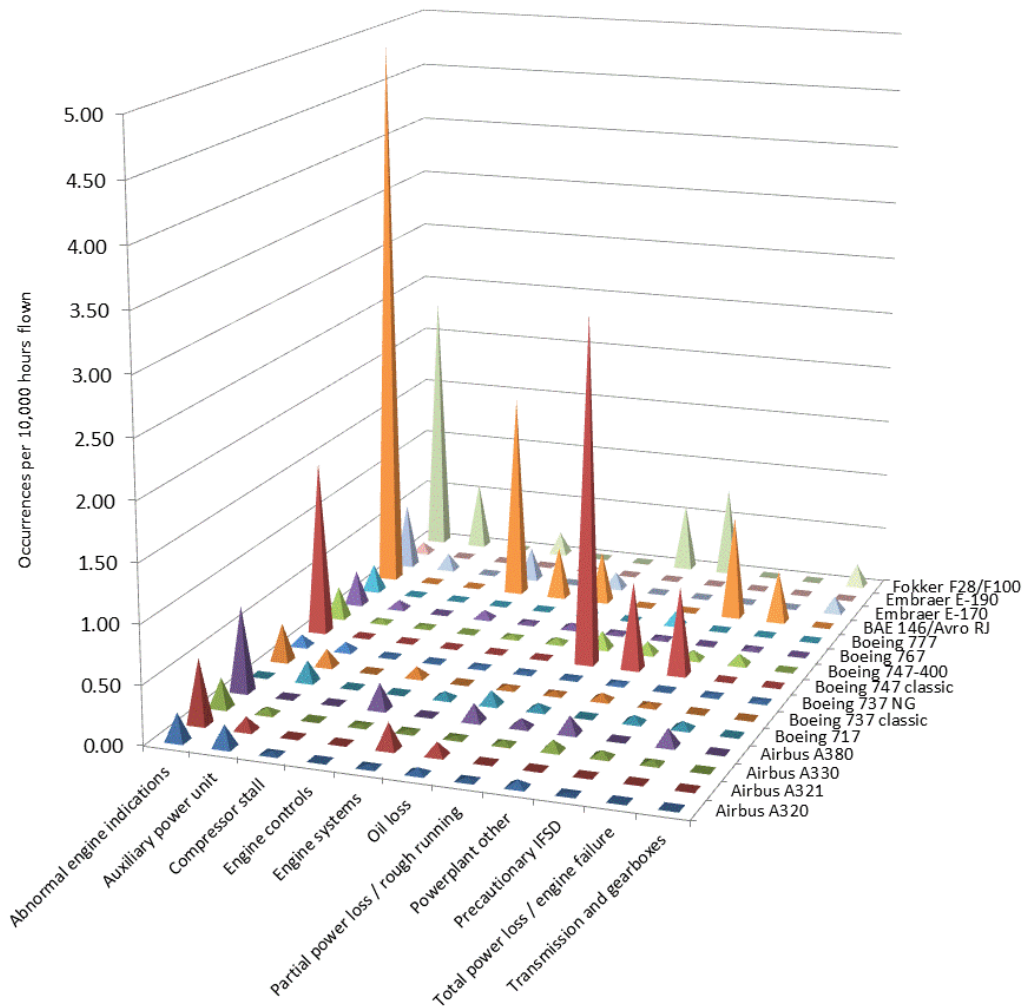


In Figure 7 it can be clearly seen that over the this five year period the BAE-146/Avro RJ have had a rate of occurrences more than twice as high as any other aircraft model in this data set, with a

rate of 7.55 occurrences per 10,000 hours flown. The next closest was the Fokker F28/F100 with a rate of 3.63 occurrences per 10,000 hours flown, followed by 747 classics with a rate of 3.02 occurrences per 10,000 hours flown. When taking into account the different number of engines per airframe the BAE-146/Avro RJ and F28/F100 have rates (per engine) more than double any other airframe, including the 747 classics. The remaining 12 aircraft models have comparatively lower rates ranging between 0.13 and 1.00 occurrences per 10,000 hours flown (by airframe). When reviewing rates of occurrences like those in Figure 7, it is important to consider that different aircraft models are operated by different airline operators and that higher rates of occurrences could simply be a result of a better reporting culture in particular operations.

Figure 7 shows the rate of all power plant occurrences while in Figure 8 the rate of occurrences are displayed individually for each of the 11 occurrence types in the power plant group. As we are now looking at the airframe as a whole, all occurrences in the power plant set including auxiliary power unit are included in both Figure 7 and Figure 8.

**Figure 8: Rate of power plant occurrences by aircraft model by occurrence type.**



Abnormal engine indications accounted for the highest rate for most aircraft models. In fact, the only aircraft model where abnormal engine indications were not the most prevalent type of occurrence rate was the 747 classics, which had a greater rate of reported partial power loss occurrences (with the abnormal engine indications being the next highest rate). The 747 classics actually had the highest overall rate of partial power loss, which was also reflected in Figure 5

which showed most of the partial power losses attributable to the two engines used by the 747 classic (CF-6 and RB211).

Within the abnormal engine indications set of occurrences, by at least a factor of two, the BAE-146/Avro RJ has the highest rate, with just under five occurrences per 10,000 hours flown. These aircraft also have the highest rates of engine control, engine systems, oil loss, precautionary in flight shut down and (a single engine) total power loss / engine failure reports.

### ***BAE 146/Avro RJ***

There were 11 abnormal engine indications involving BAE 146/Avro RJ aircraft between 2008 and 2012. Although this was by no means the highest number of occurrences for an individual aircraft model, when taking into account the hours flown, the rate becomes increasingly significant. These 11 indications included one indication of a compressor stall (although the stall itself was unconfirmed), an engine fire warning indication, a thrust modulation system warning, three indications of excessive vibrations (one was accompanied by a low oil warning), two exhaust gas temperature warnings (one high temperature and one failed sensor), a high turbine gas temperature warning and two indications of low oil. Seven of these abnormal engine indications led to inflight shutdowns, five of which resulted in air returns, one return to gate, and one rejected take-off.

There were only four engine control issues with BAE 146/Avro RJ's, however, this was not only the highest rate but also the highest number of occurrences for any aircraft model. As previously described in the Control Issues section, these four occurrences involved thrust modulation issues on the same aircraft within a four month period. A brief summary of the sequence of events is outlined below:

- Nov 2011. During cruise, the crew received a Thrust Modulation System (TMS) warning and returned to Adelaide. Engineers replaced the TMS computer.
- Jan 2012. During the climb, the Thrust Modulation System (TMS) fault light illuminated and the crew returned the aircraft to Adelaide. An engineering inspection revealed a faulty actuator.
- Feb 2012. During cruise, the Thrust Modulation System (TMS) failed. After burning off fuel, the aircraft returned to Adelaide. Engineers replaced the number 4 TMS actuator.
- Feb 2012. During the take-off run, the crew received a Thrust Modulation System (TMS) fault warning and rejected the take-off. Engineers replaced the TMS computer.

The two precautionary in flight shut downs also occurred in the same aircraft, albeit seven months apart and on different engines. In the first occurrence the number four engine was shutdown due to smoke being detected in the cabin. The flight was diverted. An engineering inspection revealed that a bearing seal had failed resulting in an oil leak that contaminated the air-conditioning. The other occurrence involved a shutdown of the number two engine due to excessive vibration. After burning off fuel for approximately 90 minutes, the flight was return to the departure airport. The cause of the vibration remains unknown.

### ***Boeing 747 classic***

The 747 classics had only four occurrences of partial power loss occurrences but this equated to a rate of 3.02 occurrences per 10,000 flight hours, more than five times the next closest rate of 0.57 from the Fokker F28/F100s. Three of these occurrences involved the same aircraft within a six month period. The first of these occurrences, previously described, was caused by the de-bonding of an acoustic liner which impinged the outlet guide vanes causing disrupted airflow. The crew were alerted by unsafe number two engine indications and a loud rumbling noise. The engine was shut down as a precaution and the aircraft was returned and landed safely. Approximately a month later the same aircraft experienced insufficient thrust from the number three engine on

take-off. At 80 knots, the take-off was rejected and the aircraft was returned to the gate without further incident. The power loss was attributed to a fuel flow regulator which was subsequently replaced. Five months later while on approach, the number four engine failed to respond to throttle inputs. The engine was shut down and then restarted. The engine then performed normally and the aircraft continued to an uneventful landing. During the subsequent engineering inspection, the fuel flow regulator was replaced. The fourth partial power loss occurrence involved a different aircraft in which the number two engine surged during the landing when reverse thrust was selected. There were no further consequences and the cause was not known.

### ***Fokker F28/F100***

For the Fokker F28/F100, abnormal engine indications were the highest rate of occurrences, and the second highest rate of abnormal engine indications overall. Of the 11 of these type of occurrence involving the F28/F100, five occurred on take-off which all resulted in rejected take-offs. One of these was attributed to a sticky high pressure bleed valve and another to a faulty fuel flow regulator; the causes of the remaining three were unknown. Another four of the 11 happened on climb; one was a faulty engine pressure ratio reading which was manually reset and the flight continued; another resulted in an in-flight shut down and an air return and was attributed to a faulty oil pressure transmitter; another was an indication of low oil pressure which also resulted in an in-flight shut down and an air-return, an engineering inspection revealed metal particles in the engine which were suspected to have originated from a failed starter idler gear in the high speed gear box. In the remaining occurrence on climb, a hole in the combustion chamber lead to a reduction in thrust and an air-return.

The two abnormal indications that occurred en route both resulted in precautionary in-flight shut downs; one led to a diversion and was found to be due to a loss of air sealant to the number three bearing, while for the other, the oil pressure indicator failed and resulted in an air-return; the oil pressure transmitter was later replaced.

The one abnormal engine indication that occurred on descent was due to a lack of lubrication on the fan blades which resulted in excessive vibration and a grinding noise. The engine was reduced to idle and the flight continued.

**Case Study: Engine failure involving Airbus A380, A6-EDA<sup>14</sup>**

**ATSB investigation AO-2012-150**

On 11 November 2012 an Airbus A380 aircraft departed Sydney for Dubai, United Arab Emirates. While climbing through an altitude of approximately 9,000 ft, the flight crew reported hearing a loud bang, which was accompanied by an engine exhaust gas temperature over-limit warning. This was followed by an uncommanded shutdown of the No 3 engine (right inboard). The flight crew jettisoned excess fuel and returned the aircraft.

A witness to the event reported hearing a distant bang on the night of the occurrence, followed by impact noises on the tile roof of their property in NSW. Pieces of suspected engine debris were later collected by the NSW police service.



Pieces of engine debris recovered from Riverstone, NSW. Source: NSW Police

The investigation found that the increase in the exhaust gas temperature and subsequent engine shut down was a result of significant internal damage that had initiated within the high pressure turbine (HPT) module. The damage had resulted from the effects of HPT stage-2 nozzle distress, likely caused by exposure to hotter than expected operating temperatures. The nozzle distress led to eventual failure and separation into the gas flow path. Over the preceding weeks there were two other engines within the operator’s fleet that had experienced a similar problem, and a number of steps had been taken by the manufacturer to address the issue, including the increased monitoring of distress development. During the previous flight, the engine health and trend monitoring program had identified a performance trend shift with this particular engine, and it was due to be inspected upon return to the main base in Dubai.



The damaged Engine Alliance<sup>15</sup> GP7200. Clockwise from left; HPT stage-2 nozzle distress, HPT stage-1 nozzles (forward looking aft), Hole in HPT case and missing stage-2 nozzles

<sup>14</sup> Note: As this occurrence involved an overseas operator it is not part of the data set for this report.

<sup>15</sup> Engine Alliance is a joint venture between General Electric and Pratt and Whitney

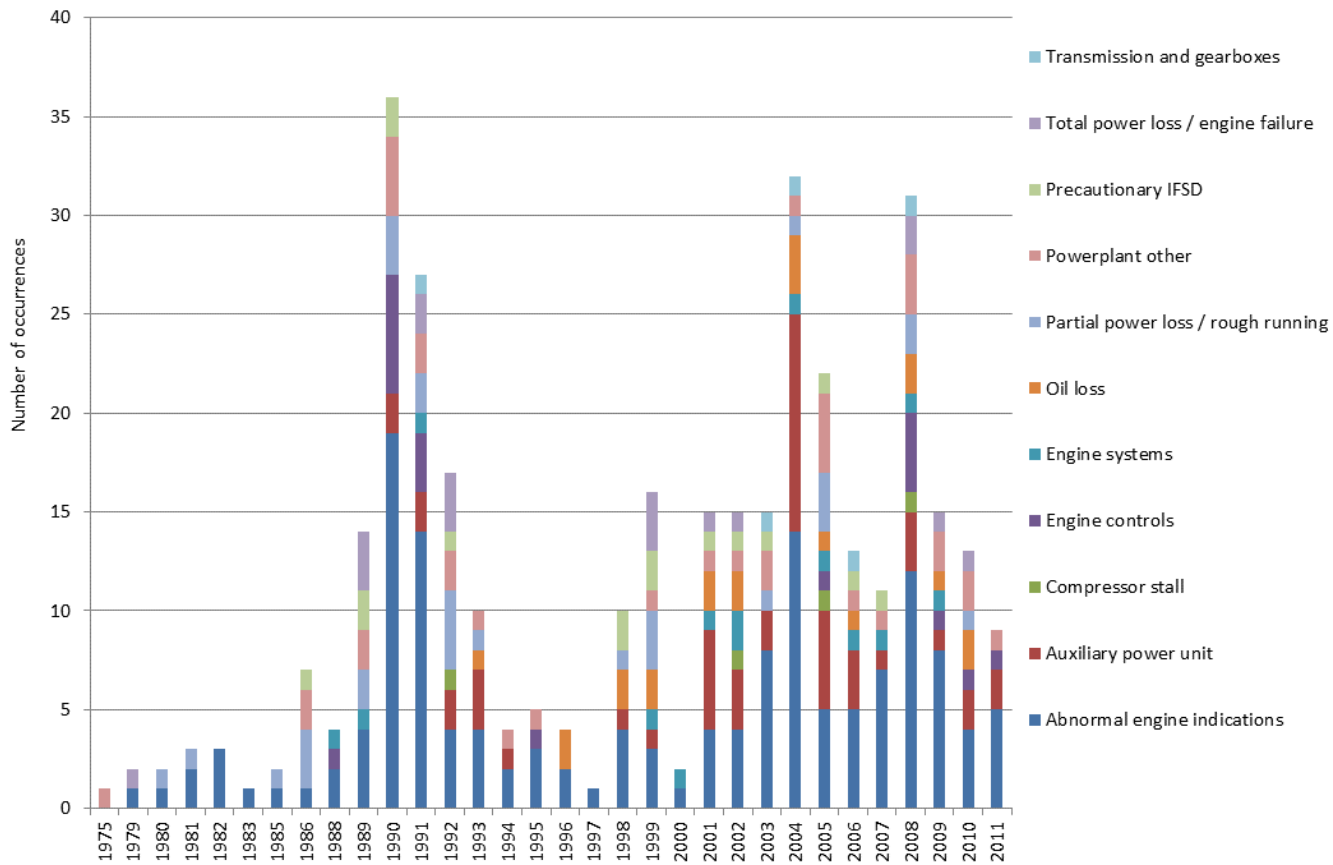


## Occurrences by aircraft year of manufacture

In reviewing power plant occurrences that have occurred in the five years between 2008 and 2012, one of the potential risk factors could be aircraft age. Although individual aircraft may have engines replaced in their lifetime, data was not available to the ATSB for an analysis by engine age. It can be assumed, however, that there is a positive correlation between aircraft age and engine age.

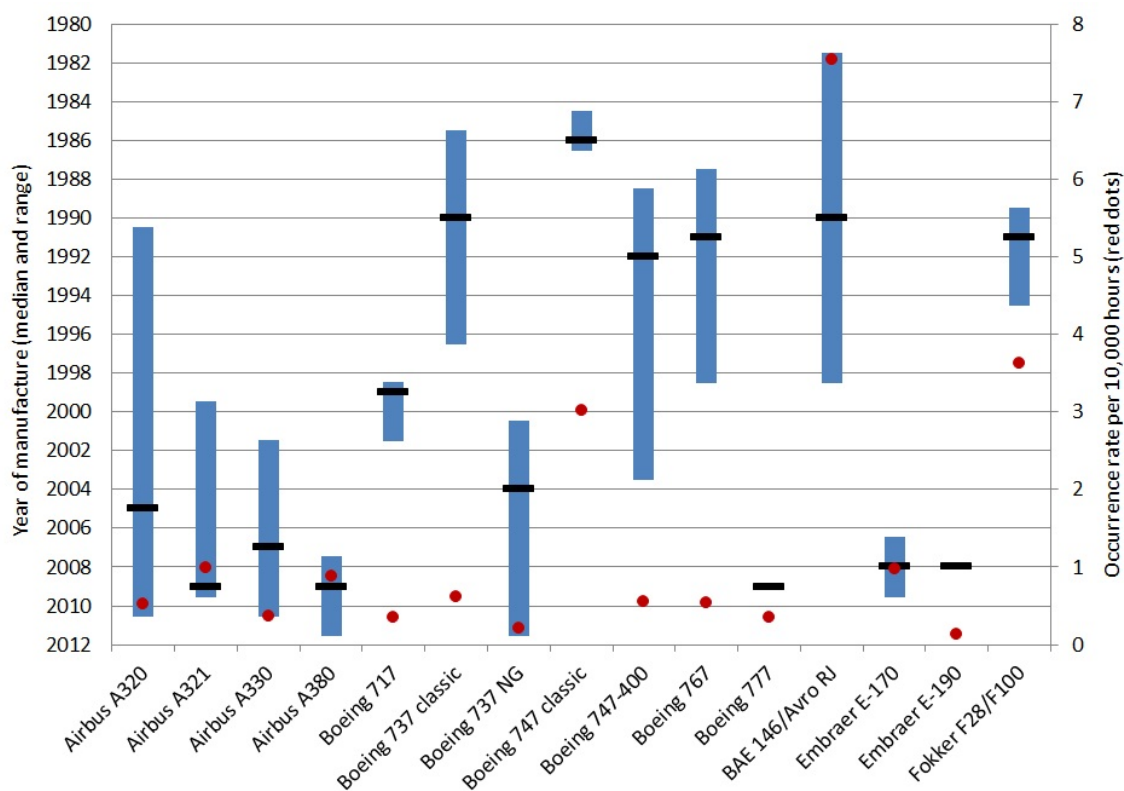
To get an overview of the general age of the aircraft in the 2008-2012 power plant occurrence dataset, the number of power plant occurrences per year of manufacture is plotted in Figure 9. Also shown, represented by the different colours, are the occurrence types that occurred for each year of manufacture. It is clear from this figure that aircraft age is not necessarily in itself an indicator of likelihood of experiencing a power plant occurrence, with more aircraft manufactured after 2000 involved in power plant occurrences between 2008 and 2012 than those manufactured before 2000. However, these results cannot be normalised for hours flown so reflect the frequency aircraft in each year of manufacture are still used in Australia.

**Figure 9: Number of power plant occurrences per year of manufacture for aircraft involved in power plant occurrence between 2008 and 2012.**



Potentially more relevant is the age of each fleet of aircraft models having power plant occurrences. Figure 10 shows the range in the year of manufacture for each aircraft model, for aircraft involved in power plant occurrences between 2008 and 2012. Note that these years of manufacture relate to the actual aircraft involved in occurrences and do not represent the entire year range over which these models were manufactured. For each aircraft model, the blue bars represent the range of years in which the occurrence aircraft were manufactured and the small black horizontal bars represent the median (middle value) of the range. The year values are given on the left side vertical axis. To compare aircraft model age with occurrence rate, on the right vertical axis, and shown by the red markers, is the rate of occurrences per 10,000 hours flown for each aircraft model (the same data shown in Figure 7).

**Figure 10: Range of manufacture years and occurrence rates for the aircraft involved in power plant related occurrences between 2008 and 2012**



The median values (black horizontal bars) in this figure give an indication to age of the aircraft which were most affected within each model fleet. For example, in the BAE-146/Avro RJ, Boeing 737 classic and Embraer 170 groups, the median age lies in the middle of the age range indicating that aircraft across the entire range of ages were more-or-less affected in equal numbers. Whereas in groups like the Airbus 321 where the median lies at one extreme of the age range, this shows that the distribution of aircraft ages was skewed to the younger end of the fleet; i.e. more newer aircraft in the A321 fleet were having power plant occurrences than the older aircraft. The opposite applies to the Boeing 717 and Fokker F28/F100 groups for example, where a greater proportion of older aircraft were affected.

It can also be seen in this graph that the prevalence, or likelihood, of a power plant occurrences is not necessarily associated with aging aircraft. For example, the Boeing 737 classic (0.62), Boeing 747 classic (3.02), Boeing 747-400 (0.55), Boeing 767 (0.53), BAE-146/Avro RJ (7.55) and Fokker F28/F100 (3.63) all have similar aircraft ages, however, three of these models have much higher rates of occurrences (BAE-146/Avro RJ, Boeing 747 classic and Fokker F28/F100).

### Higher risk technical failures

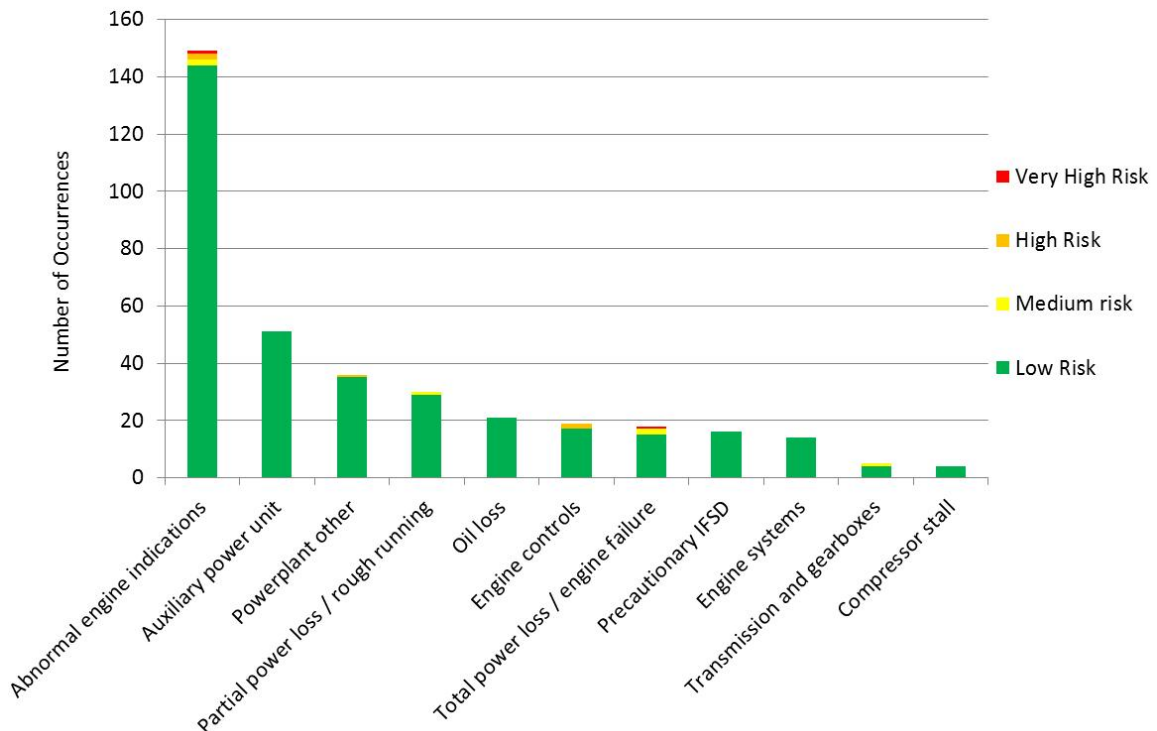
There are limitations in how well occurrence frequency-based analysis can flag areas of significant safety concern. The frequency of occurrences of a certain type is not necessarily indicative of the risk that those types of occurrences pose. As a result, all occurrences reported to the ATSB are risk rated using the Event Risk Classification (ERC) framework.

The ATSB assesses the probable level of safety risk associated with each reported safety occurrence, considering the circumstances of the occurrence at the time it happened<sup>16</sup>. The safety risk of occurrences is assessed using a modified version of the Aviation Risk Management Solutions (ARMS) ERC framework<sup>17</sup>. This framework bases the safety risk on the most credible potential accident outcome that could have eventuated, and the effectiveness of the remaining defences that stood between the occurrence and that outcome. The intention of this assessment is to determine if there was a credible risk of injury to passengers, crew, and the public or damage to the aircraft.

Most occurrences reported to the ATSB are unlikely to conceivably result in any type of accident because there were numerous defences in place including pilot skills and training, standard operating procedures, aircraft systems and design, air traffic management, airspace and aerodrome infrastructure, and components of an operator’s safety management system (SMS) to prevent an accident outcome from developing.

In the set of 280 occurrences described in this report, 273 (98%) were classified as being a low risk rating with a low or no accident outcome. Only four were classified as medium risk, two as high risk and one as very high risk. Figure 11 shows how the low, medium, high and very high risk occurrences are distributed across the 11 occurrence types. It can be seen clearly from Figure 11 that the vast majority of all occurrence types are low risk occurrences and that no one type of occurrence has resulted in more very high, high, or even medium risk occurrences.

**Figure 11: The number of low, medium, high and very high risk occurrence events per occurrence type for power plant related occurrences between 2008 and 2012.**



<sup>16</sup> The Event Risk Classification (ERC) methodology is used by the ATSB to make assessments of the safety risk associated with occurrences. For more information on how the ATSB uses occurrence and investigation data to drive proactive safety improvements, see Godley, 2012.

<sup>17</sup> The methodology is from the report *The ARMS Methodology for Operational Risk Assessment in Aviation Organisations* (version 4.1, March 2010). ARMS is an industry working group set up 2007 in order to develop a new and better methodology for Operational Risk Assessments. It is a non-political, non-profit working group, with a mission to produce a good risk assessment methodology for the industry. The results are freely available to the whole industry and to anyone else interested in the concept.

The single very high risk occurrence, which involved abnormal engine indications and a (single engine) total power loss / engine failure, is summarised below. It should be noted that very high risk occurrences, particularly power plant ones, are very rare.

- On 4 November 2010 during climb through 7,000 ft, the Airbus A380's No. 2 engine (a Rolls-Royce Trent 900) sustained an uncontained engine rotor failure of the intermediate pressure turbine disc. The engine failure was the result of a fatigue crack in the oil feed stub pipe; that allowed the release of oil into the engine and resulted in an internal oil fire. This fire led to the separation of the engine's intermediate pressure turbine disc from the drive shaft. The disc rapidly accelerated and burst; with sufficient force that the engine structure could not contain it, releasing high-energy fragments and debris. Multiple impacts were sustained by the aircraft resulting in significant structural and systems damage. The ATSB found that a number of Trent 900 engines were manufactured with non-conforming oil feed pipes that did not conform to the design specifications. The non-conformance led to a thin wall section that significantly reduced the fatigue endurance of the affected oil feed stub pipes, increasing the risk of premature, in-service failure. This accident was investigated by the ATSB (AO-2010-086).

The two high risk occurrences both involved abnormal engine indications as well as engine control issues. These two occurrences are summarised below:

- On 18 April 2012, an Airbus A330 was conducting a passenger service between Sydney and Jakarta when, during the initial climb passing FL 300, the crew received abnormal engine indications for the left engine. The indications included significant N1 fluctuations accompanied with vibrations through the airframe. After levelling off at FL 360 all engine parameters stabilised and the aircraft returned to Sydney. On the descent the left throttle reduced uncommanded to idle and the speed dropped 20 knots before the pilot intervened. During the subsequent engineering inspection, the hydro-mechanical unit was replaced.
- On 29 March 2011, while on approach to Singapore after a flight from Melbourne, the crew of an Airbus A380 reported an uncommanded thrust increase on the number 1 engine. The thrust lever was closed and the landing proceeded without further incident.

The four medium risk occurrences involved six different occurrence events; abnormal engine indications (2), partial power loss (1), total power loss (2) and transmission / gearboxes (1).

Summaries of the four medium risk occurrences are provided below:

- On 22 December 2012, a Gates Learjet 35A was being used for an emergency medical service operation from Sydney to Darwin. During the cruise, the crew received a chip light indication for the left engine. Approximately 20 minutes later the left engine failed. After actioning the checklist a PAN call was made and the aircraft diverted to Mount Isa. An engineering inspection revealed that the engine failure was caused by a failure of a bearing in the left engine tower shaft.
- On 26 June 2011, during climb the crew of a Fokker F28/F100 on a scheduled passenger flight from Brisbane to Rockhampton noticed that the left engine oil pressure had reduced. The engine was shut down and a PAN call made. The aircraft returned to Brisbane. The engineering inspection found metal particles and the engine was removed from the airframe. It was suspected that the starter idler gear in the high speed gearbox failed.
- On 13 May 2009, a Boeing 737-400 on a passenger flight from Brisbane to Townsville struck a bird on departure. The bird was ingested into the left engine resulting in engine vibration and broken fan blades. The aircraft was returned to Brisbane for a landing.
- On 30 August 2010 a Boeing 747-400 aircraft departed San Francisco, US. As the aircraft passed through 25,000 ft, the aircraft's number-4 engine failed, resulting in the puncturing of the engine casing and nacelle and the release of debris. The engine was shut down and the flight crew returned the aircraft to San Francisco. There were no injuries. An investigation conducted by the engine manufacturer found that the engine failure was initiated by the fatigue

fracture of a single stage-2 low pressure (LP) turbine blade. The ensuing rotor imbalance caused the LP turbine bearing to fail, which ultimately resulted in the uncontained release of debris. As a result of this occurrence, the engine manufacturer released non-modification service bulletins NMSB72-AG729 and NMSB72-AG800; instructing operators of RB211-524 engine variants to fit a more robust LP turbine bearing, so as to reduce the likelihood of catastrophic engine failure resulting from rotor imbalance. This serious incident was investigated by the ATSB (AO-2010-066).

## Summary

A review of power plant occurrences reported to the ATSB showed that there were 280 power plant related occurrences involving turbofan engine aircraft between 2008 and 2012 (36 per year on average). With a combined total of over five and a half million flight hours for turbofan engine aircraft in this timeframe, this equates to approximately one occurrence every 20,000 flight hours. The vast majority of these (98%) were classified as being low risk rating occurrences with a low or no accident outcome, however, there were four classified as medium risk, two as high risk and one as very high risk, although none of these resulted in injury to passengers or crew.

Although the rates of power plant occurrences (by hours flown) were low, there were large differences between individual aircraft models. In particular, the British Aerospace BAE 146/Avro RJ had a rate of power plant occurrences more than double any other aircraft in this study. They were followed by the Fokker F28/F100 and the Boeing 747 classic, with the rest of the aircraft in the study all having comparatively low rates of occurrences. These three aircraft types were some of the older fleets in the study, however, there were several other aircraft types with similar median airframe age with far lower rates of occurrences. This may suggest that other operating conditions may need to be considered with estimating engine reliability. These could include the operating environments, flight cycle number (as opposed to total engine hours) or maintenance procedures.

As always, the individual reporting practices of each operator could also potentially influence the final data. With this in mind, the ATSB encourages all operators to continue vigilantly reporting all technical problems with, where possible, follow up engineering inspection reports.

# Sources and submissions

## Sources of information

The sources of information during the investigation included the:

- the ATSB aviation occurrence database
- ATSB investigation reports (investigation reports can be downloaded from [www.atsb.gov.au](http://www.atsb.gov.au))
- the Civil Aviation Safety Authority (CASA)
- The Bureau of Infrastructure, Transport and Regional Economics (BITRE)

## References

Civil Aviation Safety Authority (CASA) (2012, November). Civil Aviation Advisory Publication (CAAP) 51-1(2): Defect Reporting.

[http://www.casa.gov.au/wcmswr/\\_assets/main/download/caaps/airworth/51\\_1.pdf](http://www.casa.gov.au/wcmswr/_assets/main/download/caaps/airworth/51_1.pdf)

Godley, S. T. (2012, September). *Proactively monitoring emerging risks through the analysis of occurrence and investigation data: Techniques used by the Australian Investigator*. Paper presented at the 2012 annual meeting of the International Society of Air Safety Investigators (ISASI), Baltimore, MD.

Aviation Risk Management Solutions (ARMS) Methodology for Operational Risk Assessment in Aviation Organisations (version 4.1, March 2010).

<https://easa.europa.eu/essi/documents/Methodology.pdf>

# Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

## Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

## Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.



# Glossary

**Occurrence:** accident or incident.

**Transport safety matter:** Defined in section 23 of the *Transport Safety Investigation Act 2003* (TSI Act) as an event where:

- a transport vehicle (an aircraft, ship, or rail vehicle) is destroyed
- a transport vehicle is damaged
- a transport vehicle is abandoned, disabled, stranded or missing in operation
- a person dies as a result of an occurrences associated with the operation of a transport vehicle
- a person is injured or incapacitated as a result of an occurrence associated with the operation of a transport vehicle
- any property is damaged as a result of an occurrence associated with the operation of a transport vehicle
- a transport vehicle is involved in a near-accident
- a transport vehicle is involved in an occurrence that affected, or could have affected, the safety of the operation of the transport vehicle

A transport safety matter also includes something that occurred that affected, is affecting, or might affect transport safety.

## Australian Transport Safety Bureau

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## Research

### **ATSB Transport Safety Report** Aviation Research Report

Power plant failures in turbofan-powered aircraft  
2008 to 2012

AR-2013-002  
Final – 19 June 2014