



Australian Government  
Australian Transport Safety Bureau

# Engine failures and malfunctions in light aeroplanes

2009 to 2014



Research

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#### **Addendum**

| Page | Change   | Date          |
|------|--|---------------|
| 4    | The number of fatal accidents changed from three to four           | 10 March 2016 |
| 5    | Summary of occurrence 201101002– removal of duplicated information | 10 March 2016 |
| 5    | Summary of AO-2014-149 added                                       | 10 March 2016 |

# Safety summary

## Why the ATSB did this research

Through routine trend monitoring of safety occurrence reporting, the ATSB became aware of a potential issue surrounding the frequency of light aircraft engine failures and malfunctions (both Australian VH and recreationally-registered). To formally and more fully examine the contributing factors behind these statistical observations, the ATSB initiated this Aviation Research investigation (under the provisions of the *Transport Safety Investigation Act 2003*).

## What the ATSB found

Over the 6-year study period between 2009 and 2014, 322 engine failures or malfunctions involving light aircraft were reported to the Australian Transport Safety Bureau (ATSB) and/or Recreational Aviation Australia (RA-Aus). These reports involved single-engine piston aeroplanes up to 800 kg maximum take-off weight. Aircraft powered by Jabiru engines were involved in the most engine failures or malfunctions with 130 reported over the 6 years. This represents about one in ten aircraft powered by Jabiru engines in the study set having reported an engine failure or malfunction. Reports from Rotax powered aircraft were the next most common with 87 (one in 36), followed by aircraft with Lycoming (58 – one in 35) and Continental (28 – one in 35) engines. When factoring in the hours flown for each of these engine manufacturers, aircraft with Jabiru engines had more than double the rate of engine failure or malfunction than any other of the manufacturers in the study set with 3.21 failures per 10,000 hours flown.

Unlike the engines of other engine manufacturers in this study, nearly half of the Jabiru engine failures or malfunctions related to a fractured component. Engine through-bolt failures were the most commonly reported failure mechanism in Jabiru powered aircraft with 21 through-bolt fractures reported between 2009 and 2014. Taking into account the number of aircraft registered in the study period, through-bolt failures occurred in about one in 55 Jabiru powered aircraft. Although originally designed to be replaced after 1,000 hours, 19 through-bolts failed before the 1,000 hour mark, with seven failing before 500 hours. At least four failures involved engines with upgraded 3/8 inch diameter through-bolt nuts. There were no failures reported involving the newer 7/16 inch diameter through-bolts which are used in currently manufactured engines (present in about 20 per cent of Jabiru engines).

## What's been done as a result

Jabiru Aircraft Pty Ltd have designed and tested a modified 3/8 inch diameter through-bolt which incorporates aspects to alleviate the effects of thermal expansion and damp resonant vibrations.

The ATSB has issued recommendations to Jabiru Aircraft Pty Ltd and the Civil Aviation Safety Authority to reduce the risk of engine failure or malfunction in aircraft fitted with Jabiru engines and to assure future reliability of these engines.

## Safety message

Owners and operators of light aircraft with Jabiru engines that have 3/8 inch diameter through-bolt configurations need to be aware of the continued elevated risk of a through-bolt failure leading to an engine failure or malfunction in flight. It appears that Jabiru engine service bulletins, requiring upgraded through-bolts of the same thickness and upgraded nuts to the 12-side ARP nuts, may not have fully addressed this issue. Thicker 7/16 inch through-bolts (installed in newly manufactured engines and recommended as a retro-fit for aircraft conducting flight training), appear to have improved the reliability of Jabiru engines, although future monitoring will provide more definite evidence.

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## Context

When aviation safety incidents and accidents happen, they are reported to the ATSB. The most serious of these are investigated, but most reports are used to help the ATSB build a picture of how prevalent certain types of occurrences are in different types of aviation operations. The ATSB uses this data to proactively look for emerging safety trends. By monitoring trends, issues of concern can be communicated to industry and action taken to prevent accidents.

In 2012, this trend monitoring process identified a significant increase in the number of light aircraft engine failures or malfunctions. This trend was twice communicated to the Civil Aviation Safety Authority and an engine manufacturer. The ATSB also received two REPCONs (confidential safety concern reports) in 2012-2013 about the reliability of light aircraft engines. To formally and more fully examine both the extent of and the contributing factors behind these observations, the ATSB initiated this Aviation Research investigation (under the provisions of the *Transport Safety Investigation (TSI) Act 2003*).

This research investigation aims to assess and compare engine failures and malfunctions in light aircraft. This involves single-engine aeroplanes up to 800 kg maximum take-off weight (MTOW). The weight cut-off of 800 kg encompasses the Light Sport Aircraft (LSA) group of aircraft, which are typically under 600 kg MTOW. Although some of these aeroplanes are registered with the Civil Aviation Safety Authority (CASA) (VH-registered), the majority of these types of aeroplanes are registered with Recreational Aviation Australia (RAAus). Aircraft registered with either body could have either a certified or uncertified aircraft engine, and could be either factory-built or amateur-built. As such, the ATSB has examined occurrences of both VH-registered and RAAus registered aeroplanes reported to the ATSB and/or RAAus between 2009 and 2014 that the ATSB has classified as engine failures or malfunctions. Engine failures or malfunctions are only reportable matters (to the ATSB) under the TSI Act when they happened while the aircraft was boarded for flight. Engine failures or malfunctions found during maintenance would instead be reported as either a defect report to RAAus or a Service Difficulty Report (SDR) to CASA. Neither RAAus defect reports nor CASA SDRs were considered for analysis in this study.

### Reporting of engine failures or malfunctions

The TSI Act requires aircraft accidents and incidents to be reported to the ATSB. Under the TSI Regulations, for aircraft that are not involved in air transport operations, this includes all engine failures or malfunctions (when boarded for flight):

- 2.4 (2)(e) the use of any procedure for overcoming an emergency, and/or
- 2.4 (2)(f)(i) an occurrence the results in difficulty controlling the aircraft including an aircraft system failure.

In addition, any engine failure or malfunction resulting in a fatal or serious injury or serious damage to the aircraft, is immediately reportable to the ATSB.

These reporting requirements apply to all Australian registered aircraft, including those registered with RAAus, and all internationally registered aircraft operating in Australia, and supersede any other organisation's reporting requirements.

All occurrences reported to the ATSB are entered into the ATSB occurrence database. During this process, occurrences are classified by the ATSB occurrence type taxonomy. This taxonomy classifies an engine failure or malfunction as being *an engine malfunction that results in a total engine failure, a loss of engine power or is rough running*. Technical faults that results in an engine failure or malfunction include:

- reports of total power loss of an engine
- a loss of power that limits aircraft performance
- a rough running engine (coughing, spluttering, etc)

- observations of abnormal sights, sounds or vibrations by a crew member
- any mechanical issue that results in an engine shutdown (excluding engine shutdowns based solely on abnormal engine indications).

A loss of engine power due to fuel exhaustion or starvation is not coded an engine failure or malfunction.

**Case Study: Collision with terrain involving Rand Robinson KR-2, near Tumut, NSW on 5 October 2013.**

**ATSB investigation AO-2013-174**

At about 0900 on Saturday 5 October 2013, the pilot of an amateur-built Rand Robinson KR-2, two-seat aeroplane operated in the 'Experimental' category, took off from an airstrip on private property 14 km west of Tumut Airport, New South Wales (NSW). The pilot was reported to have intended to fly the 48 NM (89 km) to Holbrook, NSW, for the weekend.

The ATSB investigation found that shortly after take-off, the number three cylinder upper sparkplug was ejected from the cylinder head hole, resulting in a significant loss of engine power. This failure was the result of an incorrectly installed spark plug thread insert. While positioning the aircraft for a return landing onto the departure airstrip after the power loss, the aircraft probably entered an aerodynamic stall from which the pilot was unable to recover before the aircraft impacted terrain. The pilot was fatally injured and the aircraft destroyed.



Wreckage of the Rand Robinson KR-2

Source: ATSB

# Safety analysis

Occurrence notifications associated with engine failure or malfunctions reported to either Recreational Aviation Australia (RAAus) or the ATSB between 2009 and 2014 were examined.<sup>1</sup> Engine failures or malfunctions were only considered to be occurrences when they happened while the aircraft was boarded for flight. Fuel starvation and fuel exhaustion occurrences were not classified as engine failures or malfunction. Only occurrences involving single (piston) engine aeroplanes were included (helicopters, motorised gliders, gyroplanes, remotely piloted aircraft and weight-shift aircraft were excluded). Although light sport aircraft (LSA) are typically less than 600 kg maximum take-off weight (MTOW), this study was expanded to include single engine aeroplanes up to 800 kg. Doing so facilitated a comparison between engines commonly found in RAAus registered aircraft with comparable engines from VH-registered aircraft. Both RAAus and VH-registered aircraft were considered for analysis.

Between 2009 and 2014 there were 322 engine failure or malfunction occurrences reported to either the ATSB or RAAus involving the set of aircraft described above.

## Higher risk engine failures or malfunctions

An engine failure or malfunction in a single-engine aeroplane can have a variety of safety consequences depending on the extent of the failure or malfunction, phase of flight, pilot response, and availability of suitable landing areas.<sup>2</sup>

The ATSB assesses the probable level of safety risk associated with each reported safety occurrence using the Aviation Risk Management Solutions Event Risk Classification ERC framework.<sup>3</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 aircraft occupants and damage to the aircraft (and does not consider financial loss of the aircraft or engine).

In the set of 322 engine failures or malfunctions described in this report, 80 (25%) were classified as being a low risk rating with a low or no accident outcome. The majority (224 or 69%) were classified as medium risk and 18 (6%) as high risk.

Figure 1 shows the distribution of ERC risk ratings for the 322 engine failures or malfunctions in this study.

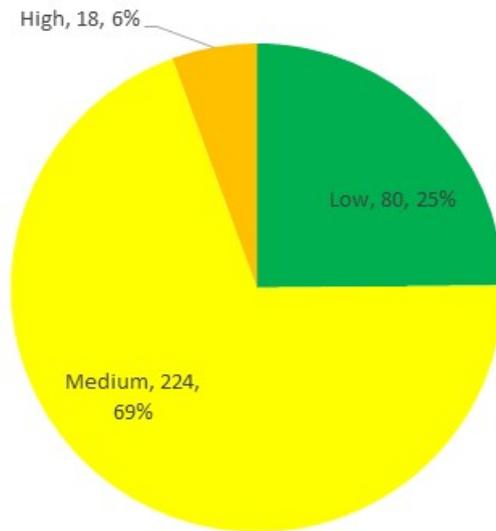
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<sup>1</sup> During the course of this investigation, occurrence notifications were sourced from RAAus and incorporated into the ATSB's aviation occurrence database. These notifications were obtained under the provisions of Section 32 of the TSI Act.

<sup>2</sup> The ERC ratings applied by the ATSB to engine failure and malfunction occurrences do not differentiate within aeroplanes between the crash worthiness of the airframe structure or the aircraft performance at stall speed for each aircraft make and model.

<sup>3</sup> The methodology is from the report *The ARMS Methodology for Operational Risk Assessment in Aviation Organisations* (version 4.1, March 2010).

**Figure 1: The number of low, medium, and high risk engine failure or malfunction occurrences between 2009 and 2014. The majority of engine failure or malfunction occurrences in light aircraft were medium risk, followed by low risk.**



Between 2009 and 2014 there were 18 high risk engine failure or malfunction occurrences, four of which resulted in fatalities.

- During the initial climb from Bankstown NSW on a dual instructional flight, the engine of the Piper PA-38 failed and smoke was observed in the cockpit. The pilot conducted a forced landing at Prospect Reservoir (200903291).
- On a private flight near Julia Creek Aerodrome Qld, the engine of the Tecnam P2004 failed. The aircraft stalled and collided with bushes before coming to rest on the ground. The pilot and passenger sustained no injuries but the aircraft was destroyed (200903356).
- During the initial climb from Bathurst Aerodrome NSW the engine of the amateur-built Lancair lost power. The aircraft subsequently collided with terrain. The aircraft was seriously damaged (200907303).
- While on descent to Serpentine WA, the engine of amateur-built Jabiru failed. During the subsequent forced landing, the aircraft struck trees and collided with terrain. The aircraft was seriously damaged and the pilot suffered serious injuries (201001282).
- An amateur-built Jabiru J400 aircraft with the pilot and three passengers departed Busselton Aerodrome, WA. After the aircraft climbed to about 500 feet and the flaps were raised, the engine then lost power, showing a low RPM reading. The pilot turned back to the aerodrome and conducted a glide approach, landing about two-thirds of the distance down the runway. As the brakes were applied, there was no brake pressure, so the pilot pumped the brakes. The left brake subsequently caught on fire. The aircraft ran off the end of the runway and subsequently impacted a small ditch before rolling into a fence. No one was injured but the aircraft was substantially damaged (201002472).
- During cruise near Goolwa SA, the engine of the amateur-built Pulsar aircraft lost power and subsequently failed. During the forced landing approach onto a nearby paddock, the left wing and nose dropped and the aircraft impacted the ground (201003405).
- During the initial climb from Busselton Aerodrome WA, the Rans S-7 experienced a partial power loss. The aircraft veered right, just cleared a fence and landed in a paddock. The aircraft sustained serious damage and the passenger received a minor injury (201007831).

- On approach to Dubbo NSW, the engine in the amateur-built Van's Aircraft RV-6 failed. The aircraft collided with terrain about 300 m short of the runway threshold. The pilot and passenger were fatally injured and the aeroplane was substantially damaged (AO-2014-149).
- On the approach to Maryborough aerodrome, Vic, the engine of the Vision 600N aircraft failed at 250 ft. While attempting to land, the aircraft stalled at 20 ft and impacted the ground. The sole occupant was not injured, however, the aircraft sustained substantial damage (201101063).
- During cruise near Whyalla Aerodrome SA, the engine of the amateur-built Murphy aircraft failed. During the forced landing into scrub, the main landing gear contacted a tree stump causing the aircraft to cartwheel. The pilot exited the aircraft uninjured but the aircraft was subsequently destroyed by the ensuing fire (201200151).
- During approach at George Town Tas, the engine in the Howard Hughes GR-912 aircraft malfunctioned and the aircraft collided with terrain. The pilot was fatally injured (201300135).
- During cruise near Taree Aerodrome NSW, the engine in the Amateur-built Super Diamond failed and the aircraft collided with terrain. The pilot sustained fatal injuries and the aircraft was destroyed (201303863).
- During the cruise near Wonthaggi Township Vic, the engine in the Skyranger Vmax ran roughly and lost power. The pilot conducted a forced landing and struck a ditch resulting in substantial damage (201306332).
- Shortly after take-off from Tumut NSW the amateur-built Rand aircraft had a significant loss of engine power. While positioning the aircraft for a return landing, the aircraft probably entered an aerodynamic stall and the aircraft collided with terrain. The pilot was fatally injured (AO-2013-174). See case study on page 2.
- During initial climb from The Oaks ALA NSW, the engine of the Jabiru LSA<sup>4</sup> did not develop full power and subsequently failed during the circuit. The pilot attempted to land back on the runway but collided with trees resulting in substantial damage. The pilot received minor injuries and the passenger was seriously injured (201309076).
- During initial climb from Balonne ALA Qld, the engine in the Tecnam P92 lost power and the pilot conducted a forced landing into a cotton field. The nose wheel sank into the soft ground and the aircraft flipped, resulting in substantial damage (201310128).
- The pilot of an amateur-built Pitts S1S conducted an aerobatic flight near Lethbridge ALA, Vic. After successfully completing 987 rolls to the left, at about 2,000 ft above ground level, the pilot elected to return to Lethbridge. About 2 minutes later, when in the cruise, the engine spluttered and lost power. Although the pilot aimed to return to Lethbridge, which was about 1 NM away, the aircraft was rapidly losing altitude and the pilot conducted a forced landing in a field. During the landing roll, the aircraft collided with a rock and nosed over, coming to rest inverted. The aircraft was substantially damaged (AO-2014-036). See case study on page 24.
- During take-off near Montrose Qld, the Aeroprakt A22 did not climb as expected. The aircraft veered left and struck an earth bank resulting in substantial damage (201407244).

## Engine manufacturers

Engines used by light aircraft are:

- mostly horizontally opposed in their cylinder configuration
- typically air cooled (although some have water cooled cylinder heads)
- mostly either four or six cylinder (although some have two cylinders, e.g. Rotax 500 series)
- mostly four stroke (with the exception of the Rotax 500 series of engines)
- typically less than 200 hp engine output.

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<sup>4</sup> Here 'LSA' refers to the aircraft model name rather than the aircraft category.

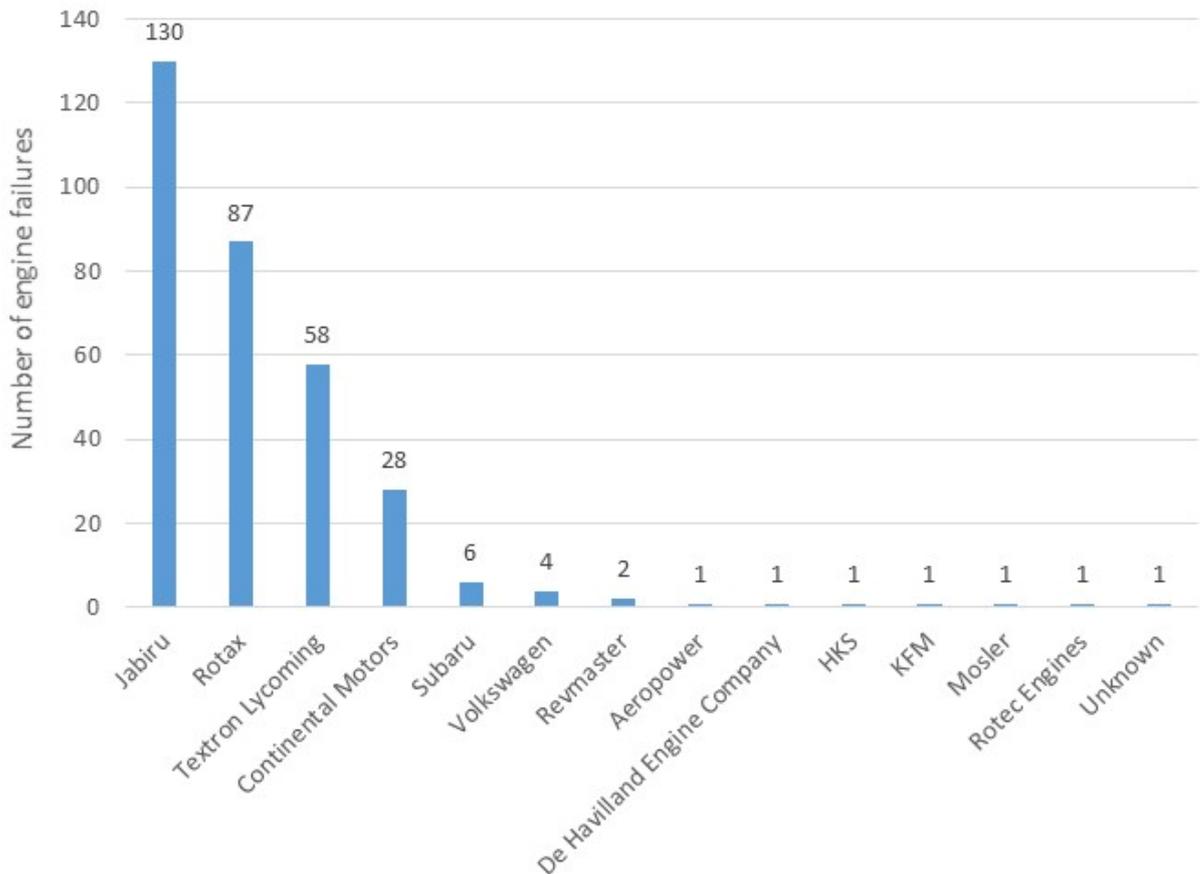
Most aircraft in this set use factory-built engines designed specifically for use in aircraft, however, a small number of aircraft use modified automobile engines.

Thirteen engine manufacturers were represented in the 322 engine failure or malfunction occurrences (see Figure 2). However, just four manufacturers made up 94.1 per cent of the entire set. These were:

- Jabiru (40.4%, 130 occurrences)
- Rotax (27.0%, 87 occurrences)
- Textron Lycoming (18.0%, 58 occurrences)
- Continental Motors (8.7%, 28 occurrences).

The remaining 5.9 per cent (19 occurrences) were made up of nine different engine manufacturers (and one unknown engine manufacturer). The remainder of the analysis will focus on the four aforementioned engine manufacturers.

**Figure 2: The distribution of engine manufacturers represented in the set of light aircraft that had an engine failure or malfunction between 2009 and 2014. Although thirteen engine manufacturers are represented, just four make up the vast majority (94.1 %) of the set.**



Taking into account the number of aircraft on both the CASA and RAAus registers and the number of aircraft involved in the above data, this represents an engine failure or malfunction occurrence in the study period in about:

- one in 10 aircraft with Jabiru engines
- one in 36 aircraft with Rotax engines
- one in 35 aircraft with Continental engines, and
- one in 33 aircraft Lycoming engines.

**Case Study: Engine failure near Amberley Aerodrome, Qld, on 28 October 2013.**

**ATSB occurrence reference number 201312960**

While cruising at 1,000 ft on a flight from Coominya to Emu Gully, Qld, the Skyfox aircraft experienced engine difficulties followed by a total engine failure. The pilot conducted an emergency landing into a paddock. During landing the pilot lost control during a cross-wind. The left wing tip struck the ground after which the aircraft landed heavily and slid along the ground for about 50 metres, resulting in substantial damage. Damage was caused to the landing gear, engine cowling, fuselage, flaps and propeller.



Wreckage of the Skyfox

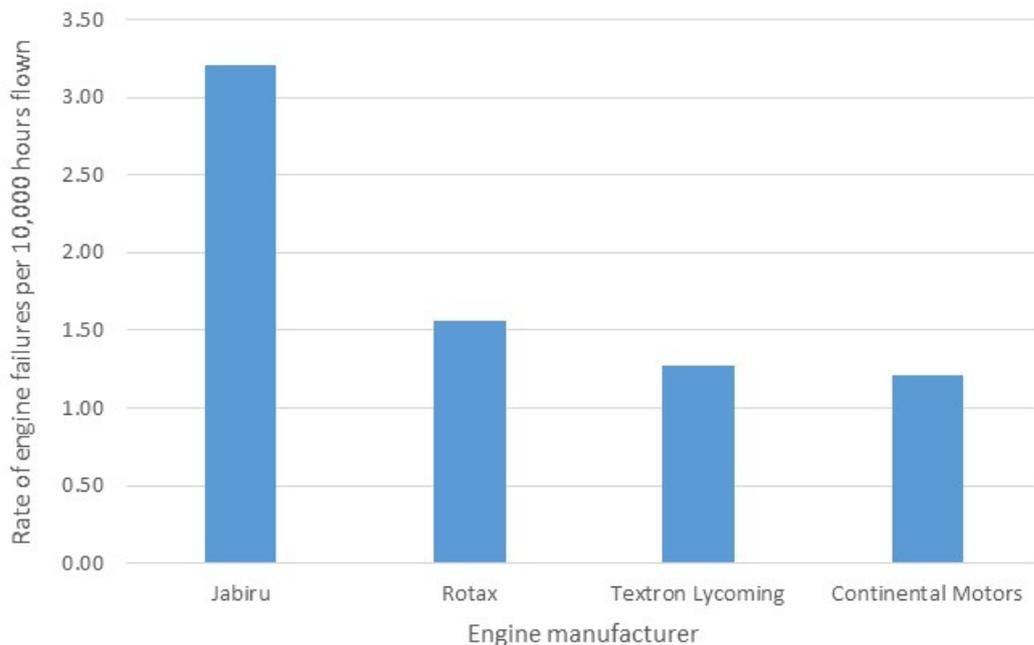
Source: Reporter

## Engine failure or malfunction rates by engine manufacturer

Figure 2 above shows the number of engine failures or malfunctions for each engine manufacturer. To normalise these data, hours flown information was provided by the Bureau of Infrastructure, Transport and Regional Economics (BITRE) for the VH-registered aircraft and RAAUs for the RAAUs registered aircraft. Registration records were examined to account for engine changes in any given year. In cases where an aircraft had an engine change during the year, hours flown data were assigned to engine manufacturers on a pro-rata basis based on the date of the engine change. The number of engine failures or malfunctions presented in Figure 2, for the four main engine manufacturers, were divided by the total hours flown for each engine manufacturer in the 6-year study period between 2009 and 2014 to produce a rate. (Note that neither RAAUs nor BITRE had access to 2014 hours at the time of writing this report. To make use of the 2014 occurrence data, the hours flown for each manufacturer in the preceding 2 years was averaged to obtain an estimate of 2014 hours flown.)

Rates of engine failures or malfunctions per 10,000 hours flown can be seen in Figure 3 for the four major engine manufacturers. Over the 6 years between 2009 and 2014, Jabiru powered aircraft had the highest rate of engine failure or malfunction with 3.21 per 10,000 hours flown, more than double that of any other manufacturer. This was followed by Rotax powered aircraft with 1.56 per 10,000 hours flown. The engine failure or malfunction rates for Textron Lycoming and Continental engines were quite similar with rates of 1.27 and 1.21 per 10,000 hours flown respectively.

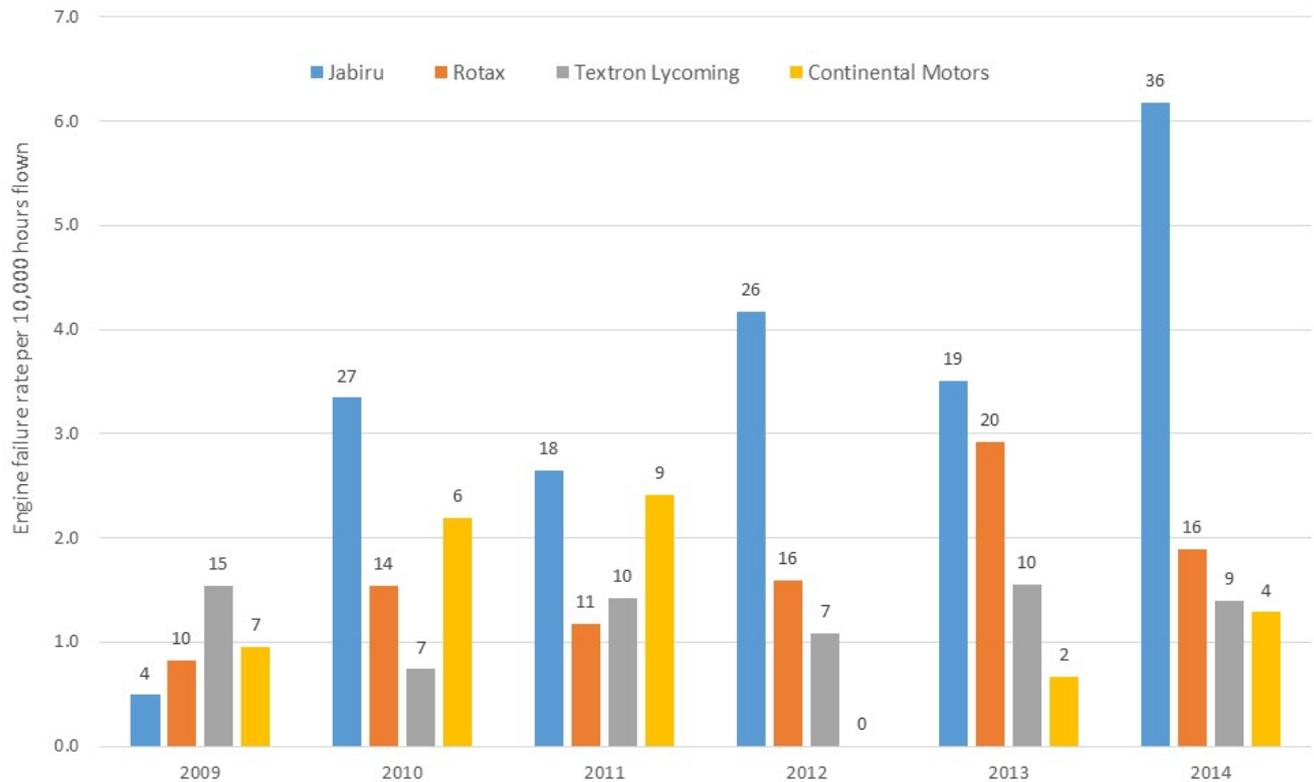
**Figure 3: The rates of engine failure or malfunctions for the four primary engine manufacturers in the light aeroplane set of aircraft between 2009 and 2014. This set includes RAAUs and VH-registered aeroplanes under 800 kg. During the study period Jabiru engines had more than double the rate of engine failure or malfunction than any other manufacturer.**



The engine failure or malfunction rates from Figure 3 are displayed in Figure 4 on a per year basis. Figure 4 shows that the total yearly engine failure or malfunction rates for the four primary engine manufacturers in the set has increased from 36 in 2009 to 65 in 2014. In 2009, reports of engine failures or malfunctions involving Lycoming engines were the most common with 15. However since then, reports from Jabiru powered aircraft have consistently shown the highest yearly rates. The hours flown estimates for 2014 (previously discussed) have to be considered

when comparing 2014 rates. Additionally, changes in reporting culture over the 6 years have the potential to influence such data.<sup>5</sup>

**Figure 4: The rates of engine failure or malfunction per year for the four primary engine manufacturers in the light aeroplane set between 2009 and 2014. This set includes RAAus and VH-registered aeroplanes under 800 kg. The column height shows the rate given by the left-hand axis scale. The numbers above each column are the occurrence counts. During the study period Jabiru engines had the highest rate of failure or malfunction for 5 of the past 6 years.**

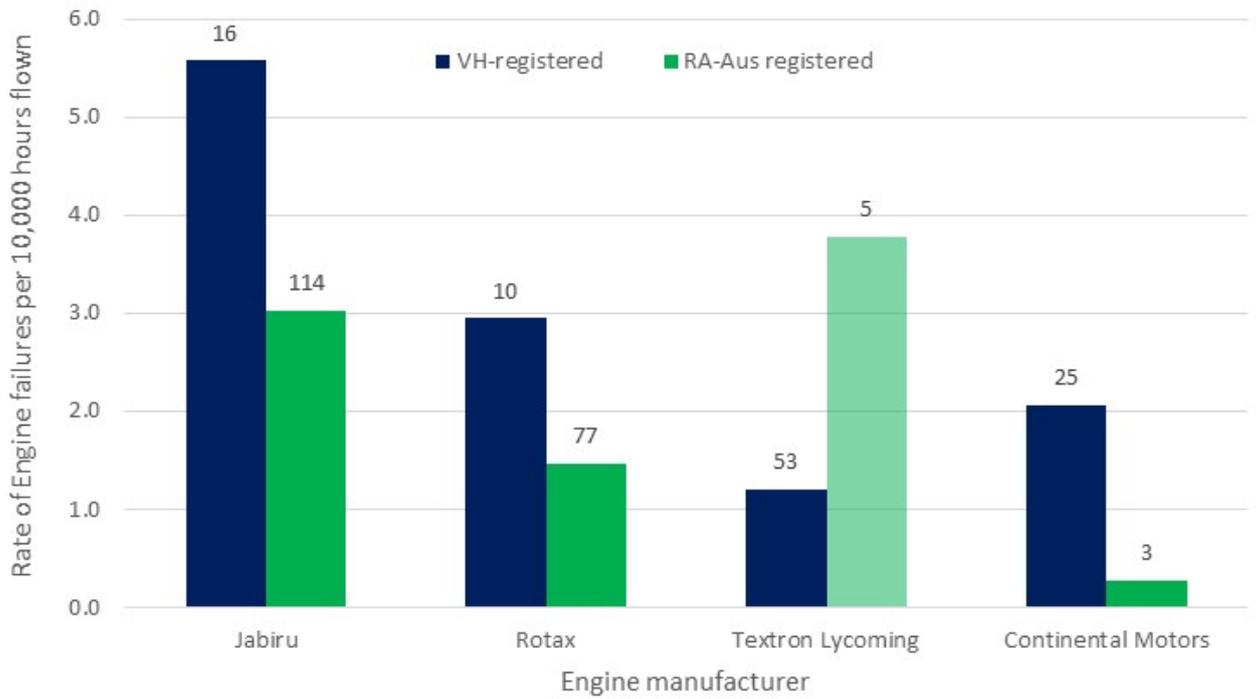


The rates from Figure 3 were further divided into registration type (VH or RAAus), shown in Figure 5. As can be seen in Figure 5, the rates of engine failure or malfunction showed a very similar pattern across the four main engine manufacturers as with Figure 3, with Jabiru powered aircraft having the highest rates for all VH-registered and most RAAus registered aircraft.

For the RAAus registered aircraft, Figure 5 shows Lycoming engines with a relatively high rate of engine failure or malfunction from five occurrences. Further examination shows that four of these five were the same aircraft, experiencing the same failure (magneto failure) in the same year. In addition, RAAus registered aircraft with Lycoming engines had relatively very few hours flown so rate data should be viewed as a less reliable indication, as low hours flown makes the rate very sensitive to small changes in occurrence numbers. It should be noted that when comparing the VH and RAAus occurrences in Figure 5, there is always the possibility that reporting rates for engine failure or malfunction occurrences may differ between VH and RAAus communities. However, it seems unlikely that this would bias any manufacturer in particular.

<sup>5</sup> For example, late in 2014, RAAus placed articles in their member magazine *Sport Pilot* promoting the benefits of reporting occurrences to RAAus and the 2014 changes in RAAus' *open and fair reporting culture policy*. However, any resultant increase in reporting is unlikely to have biased one manufacture in particular.

**Figure 5: The rates (and numbers shown in data labels) of engine failure or malfunction for the four primary engine manufacturers in the light aeroplane set, separated into registration type, between 2009 and 2014. (The transparent column reflects a rate with low hours flown making it very sensitive to small changes in occurrence numbers, and should be treated as a less reliable rate.) Note that the column height shows the rate given by the left-hand axis scale. The numbers above each column are the occurrence counts.**



**Case Study: Engine failure Gloucester, NSW 28 Aug 2013****ATSB Occurrence reference number 201308291**

Following a complete loss of engine power, and a subsequent restart that only produced marginal power, the pilot of the Hornet STOL aircraft conducted a forced landing to a paddock east of Gloucester NSW. The aircraft sustained substantial damage from both the impact and post-impact fire. The sole occupant received minor injuries. Although fuel availability, flow and contamination were ruled out from initial investigation, the cause of the engine failure remains unknown.



Wreckage of the Hornet STOL aircraft

Source: Reporter

Comparative engine failure or malfunction occurrence rates cannot be calculated for certified and uncertified engines due to unknown hours flown for the two groups. A comparison between engine failure or malfunction occurrence rates for factory-built and amateur-built aircraft can be achieved.

Another potential contributor to the likelihood of engine failures or malfunctions is the personnel conducting the maintenance. Maintenance requirements specific to each engine are provided by the manufacturer and would be applicable regardless of whether the engine was in a VH or RAAus registered aircraft. However, there would be differences in who is undertaking this maintenance. For VH-registered aircraft, there are different requirements concerning who can conduct maintenance on aircraft, depending on whether it was factory-built or amateur-built. Factory-built aircraft must be maintained by a licenced aircraft maintenance engineer (LAME). In contrast, amateur-built aircraft that are owned by the builder can be maintained by the owner. Owner-pilots of RAAus registered aircraft can also maintain their own aircraft, provided the aircraft is not used for hire-and-reward (for example flight training). To undertake maintenance on their own aircraft, owners must obtain the Level 1 Maintenance Authority from RAAus. For RAAus aircraft used for hire or reward, persons with Level 2 Maintenance Authority must carry out the

maintenance.<sup>6</sup> Engine failure or malfunction occurrence rates, however, can also not be calculated for different maintenance regimes due to the unknown hours flown (and in many cases occurrences) for RAAus aircraft maintained via Level 1 or Level 2 maintenance authority, nor VH-registered amateur-built aircraft maintained by the owner or a LAME.

An examination of aircraft build-type was conducted for engine manufacturers with sufficient numbers of aircraft hours for each build type within each registration type. For VH-registered aircraft, amateur-built aircraft consistently had a slightly higher rate of occurrences than factory-built (5.84 to 5.18 per 10,000 hours respectively for Jabiru, 3.06 to 2.90 for Rotax, and 1.56 to 1.11 for Textron Lycoming). For RAAus registered aircraft, this was also the case for Rotax powered aircraft (1.61 to 1.42 per 10,000 hours), but the difference was reversed for Jabiru powered aircraft, with a lower rate of occurrences for amateur-built (2.47) than for factory-built (3.20). However, as discussed above, it is difficult to determine whether qualifications of the maintainer contribute to these differences.

## Safety factors associated with engine failures or malfunctions

The ATSB assigns safety factors to occurrences to describe factors that contributed to the occurrence. The ability of the ATSB to assign safety factors to an occurrence is dependent on the information that is reported by the owner or operator, and whether the occurrence was investigated by either RAAus or the ASTB. Information reported to the ATSB varies considerably from one occurrence to another and can depend on:

- the individual reporting the occurrence
- the type of failure mechanism
- whether an engineering inspection was carried out.

Figure 6 shows, by engine manufacturer, the proportion of engine failure or malfunction occurrences where insufficient information was available to the ATSB to determine a contributing safety factor(s) relating to the engine failure or malfunction.<sup>7</sup> The proportions of occurrence without sufficient information to code safety factors relating to the engine failure or malfunctions ranged from 25 per cent for occurrences involving aircraft with Jabiru engines, to 51 per cent for occurrences involving Rotax powered aircraft.<sup>8</sup> The proportions for other manufacturers lay between these values. The average proportion of occurrences across all manufacturers where a safety factor could not be assigned to the engine failure or malfunction was 44 per cent.

Despite being reasonably consistent, there is up to a 26 per cent difference in the proportion of occurrences with safety factors between the manufacturers. These differences in the proportions of safety factors introduce inherent errors in any further comparison and analysis of safety factors. Accordingly, when comparing rates of safety factors, such as in Figure 7, the proportion of occurrences with unknown safety factors are used to generate error bars.

<sup>6</sup> It should be noted prior to December 2012, RAAus L1 maintainers were automatically granted approval to maintain their own aircraft (without formal training or examination). However, in December 2012, CASA enforced that RAAus remove this privilege until such time the person was assessed on the requirements for maintenance.

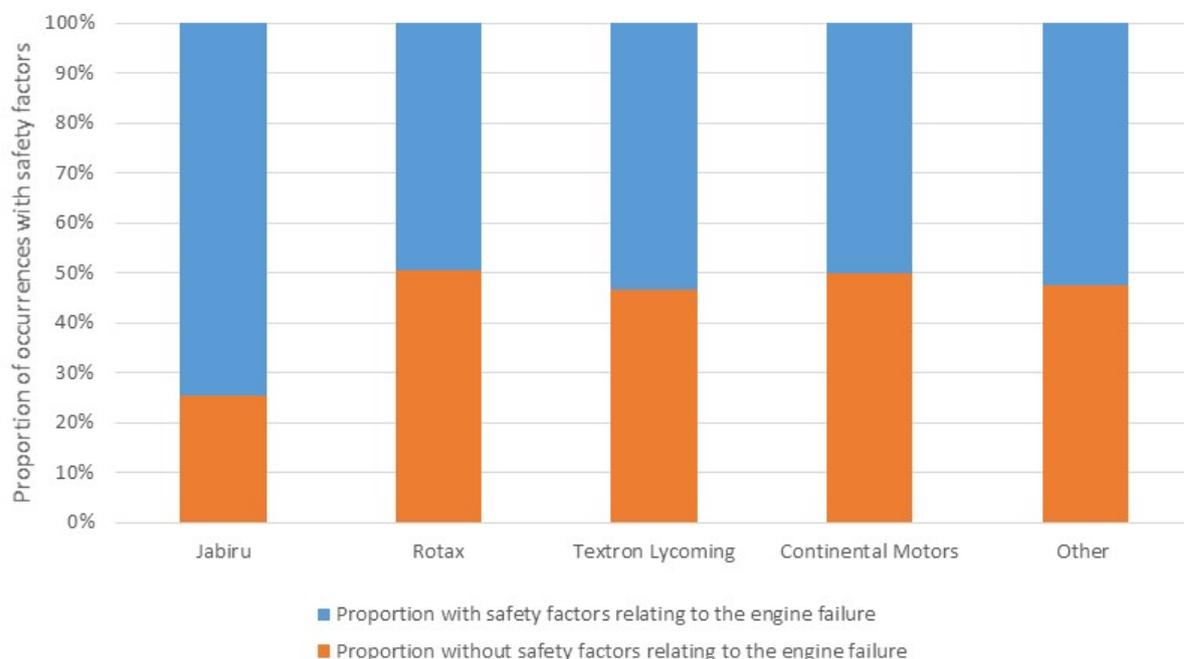
For L2 Maintainers, the RAAus *Technical Manual* requires that the RAAus Technical Manager awards an authority based on the qualifications and experience of each applicant. Once reviewed, a certificate is issued and this is reviewed every two years to ensure currency of the individual in their maintenance role.

For a qualified LAME, the RAAus *Technical Manual* Section 4.1 states that a LAME may only maintain RAAus aircraft if they are: 1. a financial member of RAAus; 2. recommended by the Technical Manager for the person to gain an Amateur Built inspector approval from CASA; and 3. abide by the requirements of the *Technical Manual*.

<sup>7</sup> Some of the occurrences without safety factors relating to the engine failure or malfunction did have information to code other safety factors relating to other aspects of the occurrence, such as factors contributing to any subsequent loss of control or collision with terrain following an engine failure or malfunction.

<sup>8</sup> Initial analysis showed a more consistent range of occurrences without sufficient information to code a safety factor. However, during the draft report review process, additional information was provided by Jabiru Aircraft Pty Ltd regarding some of the occurrences involving Jabiru engines. This additional information substantially increased the proportion of occurrences involving Jabiru engines that had sufficient information to code a safety factor.

**Figure 6: Proportion of engine failure or malfunction occurrences between 2009 and 2014 that had sufficient information provided to assign safety factors regarding the engine failure or malfunction.**



For safety factors relating to engine failure or malfunctions, technical failure mechanisms can include:

- fracture - physical separation of parts of a component. Action of stress created by a single load application or the action of repeated stressing created by alternating loading
- wear - surface interactions involving the removal of material from the surface of a component or transfer of material from one surface to another
- corrosion - loss of material through a chemical action between a component and its environment. May be a localised reaction or a general surface reaction at low or high temperatures
- deformation - physical distortion. Plastic deformation (permanent), elastic deformation (recoverable after force removed)
- electrical discontinuity - disruption of an electrical connection at wiring level, circuit level, integrated circuit level
- mechanical discontinuity - disruption of a physical connection in a mechanical, hydraulic or pneumatic system
- software/firmware anomaly - computer or microprocessor program malfunction
- other technical failure mechanism - any other type of failure mechanism.

Other non-technical issues relating to engine failures or malfunctions (shown in Figure 7 as the non-technical set) include suspected carburettor icing, aircraft maintenance actions (incorrect replacing, repairing or installing), and pre-flight inspecting (such as water in fuel not identified).

Figure 7 shows the rates of technical failure mechanisms safety factors per 10,000 hours flown for the four major engine manufacturers. (Note that this figure is using safety factors, not occurrences, and some occurrences have multiple safety factors.)

***Jabiru***

- Nearly half (45%) of the safety factors associated with Jabiru engine failure or malfunctions (where the safety factor was known) were classified as fractures, leading to a rate of 1.11 fractures per 10,000 hours flown.
- Mechanical discontinuities were the next most common failure mechanism for Jabiru engines (38%, rate 0.94/10,000 hours).
- These were followed by electrical discontinuities (5%, rate 0.12/10,000 hours) and wear (2%, 0.05/10,000 hours).
- Non-technical issues accounted for 11%.

***Rotax***

- Safety factors relating to Rotax engine failure or malfunctions were predominantly due to mechanical discontinuities (46%, rate 0.39/10,000 hours).
- Fractures then made up 13 per cent (0.11/10,000 hours) followed by electrical discontinuities (6%, rate 0.05/10,000 hours) and corrosion issues (4%, rate 0.04/10,000 hours).
- Non-technical issues accounted for 19 per cent of the known Rotax safety factors.

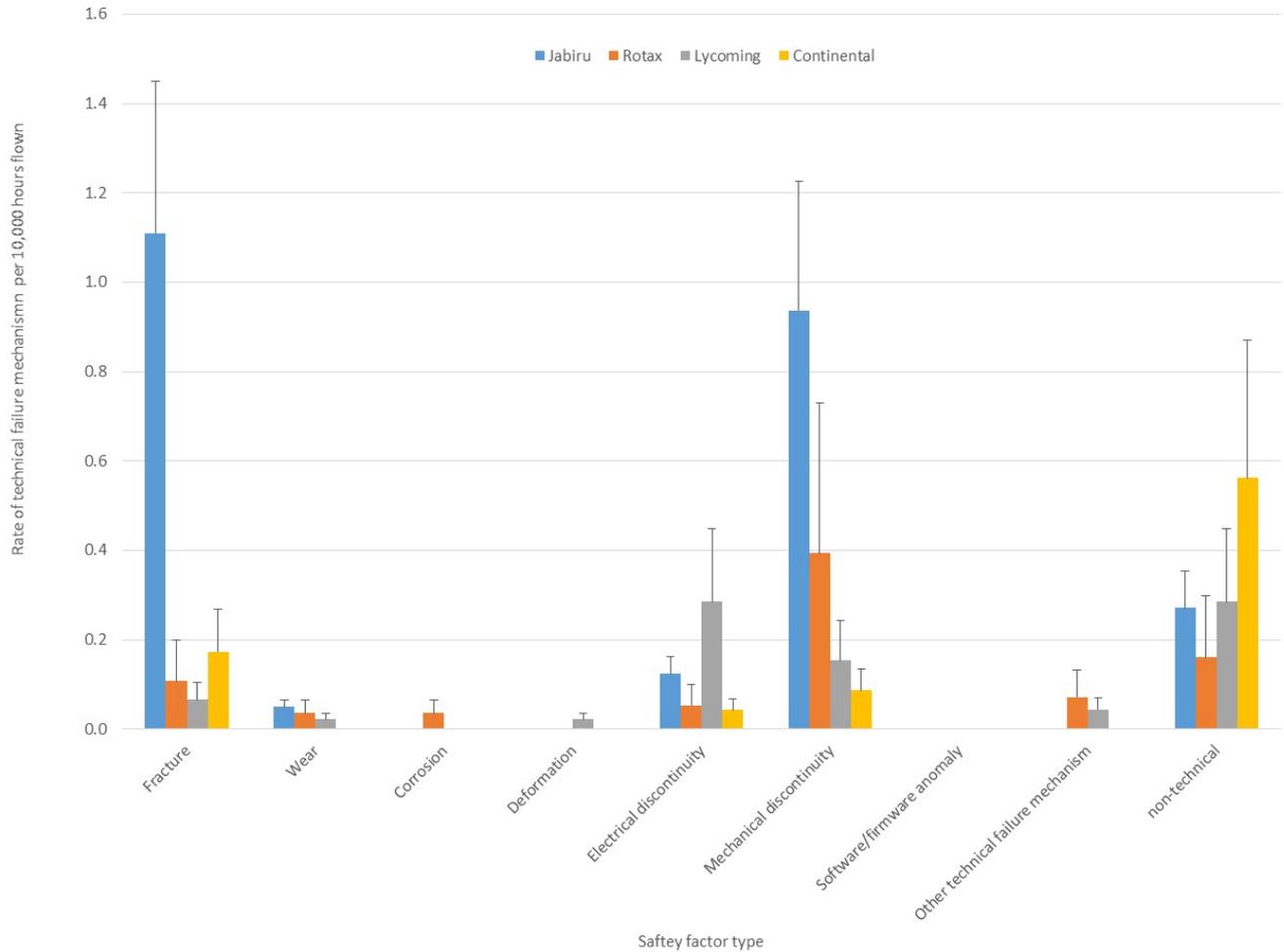
***Lycoming***

- Electrical discontinuities were the most common technical failure mechanism for Lycoming engines with 33 per cent of the known safety factors, leading to a rate of 0.29 per 10,000 hours.

***Continental***

- At a rate of 0.17 per 10,000 hours and accounting for 20 per cent of known safety factors, fractures were the most common technical failure mechanism for Continental engines.
- However, engine failure or malfunction occurrences with Continental engines had by far the highest proportion of non-technical contributing factors (65%, rate 0.56/10,000 hours).

**Figure 7: Technical failure mechanism safety factors for engine failure or malfunctions, as a rate per 10,000 hours flown, for the four primary engine manufacturers in the light aeroplane set, between 2009 and 2014. Error bars show rates extrapolated to occurrences without safety factor information.<sup>9</sup> Jabiru had by far the highest rate of fractures, which also exceed all other rates considerably. Jabiru also had the highest rate of mechanical discontinuities, while Lycoming had the highest rate of electrical discontinuities.**



The most striking observation to be made from Figure 7 is the rate of Jabiru fractures in comparison to both other Jabiru failure mechanisms as well as fractures involving other manufacturers. With a rate of 1.11 per 10,000 flight hours, components in Jabiru engines appear to be fracturing at a rate significantly higher (more than six times) than any other engine manufacturer in the study.

<sup>9</sup> The proportion of unknown safety factors (shown in Figure 3) were used to generate error bars in Figure 4. The number of unknown safety factors were assigned to the error bars of the corresponding safety factors in the same proportions as the known safety factors are distributed. Doing so assumed that the set of unknowns were distributed by the same proportions as the known data. This allows an estimate of what could be reasonably expected to be the upper maximum for each of failure mechanism.

**Case Study: Engine failure near Ballina/Byron Gateway Aerodrome, NSW 30 Apr 2014****ATSB occurrence reference number 201402746**

During the cruise from Broadwater to Mullumbimby, NSW, the engine in the factory-built Brumby aircraft started to run roughly and then failed. During an attempted forced landing on a beach, a wave caught the aircraft, flipping it on its nose. Although the aircraft sustained substantial damage, the pilot received only minor injuries. The cause of the engine failure remains unknown.



Wreckage of the Brumby aircraft

Source: Reporter

**Fractures**

Occurrence records from the 58 engine failure or malfunctions involving a fractured component from the four major manufacturers were examined to determine what engine components had failed. The distribution of components that failed for each of the manufacturers are shown in Figure 9.

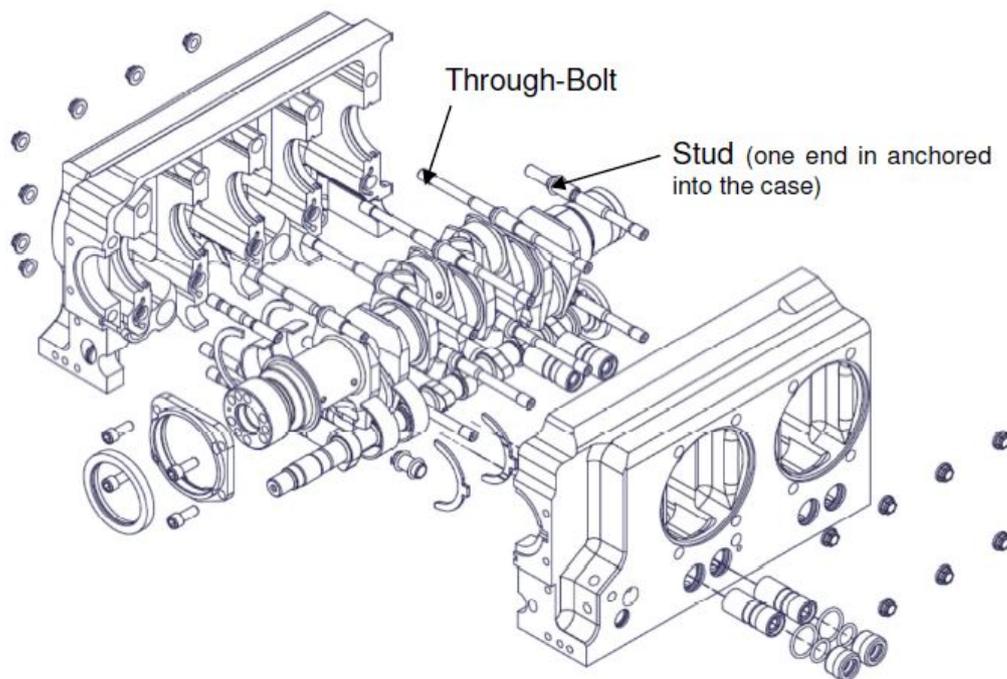
For Rotax, Lycoming and Continental engines, no single component has been reported to have fractured in more than two occurrences in the 6-year study period.

In contrast, for Jabiru engines, about half (47%) of the all Jabiru fractures reported related to engine through-bolt failures, with 21 through-bolt failures reported between 2009 and 2014. There were an additional two occurrences involving engine studs (see figure 8 for details). The combination of stud and through-bolt fractures accounts for 51 per cent of all fractures. However, for the rest of the analysis in this report, they are counted as separate components.

The 21 through-bolt occurrences made up a fifth of all the known Jabiru failure mechanisms and equates to a rate of 0.52 through-bolt failures per 10,000 hours flown. Taking into account the number of aircraft on both the VH and RAAus aircraft registers from this set with Jabiru engines, through-bolt failures occurred in approximately 2 per cent of the Jabiru powered aircraft, or roughly one in 55 aircraft. Given that this analysis relates to the sub-set of engine failure or malfunctions (75%) where the failure mechanism was reported, the actual figure could be higher.

For the set of engines analysed in this investigation, Jabiru engines are somewhat unique in their design. Conventionally, the crankcase is bolted together with separate bolts to those that are used to bolt the cylinders to the crankcase. In contrast, in Jabiru engines the same through-bolts that hold the crankcase together also fasten the cylinders to the block. Figure 8 shows the typical layout of a Jabiru four cylinder engine showing the location of the engine through-bolts.

**Figure 8: Schematic showing the general layout of a Jabiru four cylinder engine**



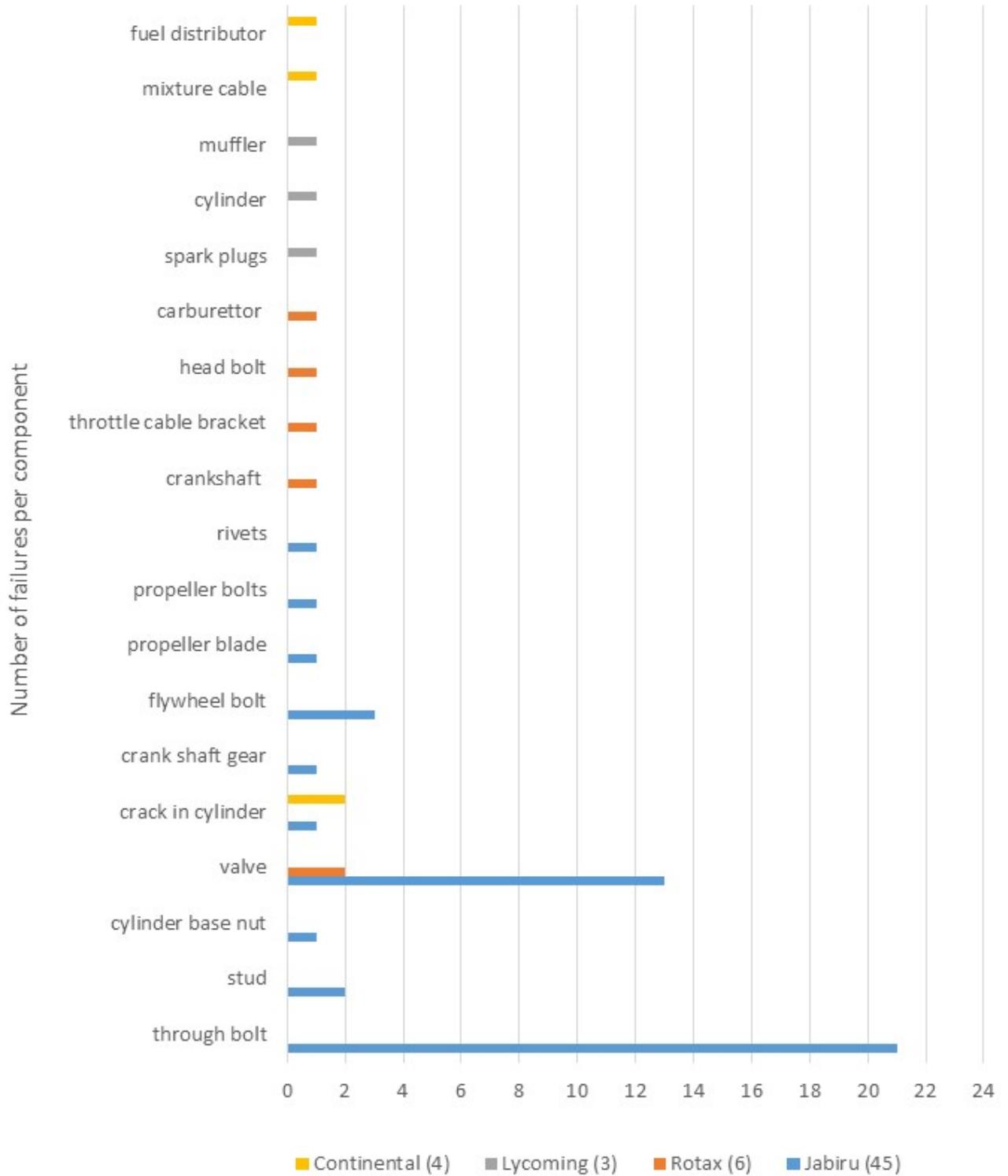
Source: Jabiru Aircraft PTY LTD service bulletin JSB031-3

Fractures relating to valves were the next most common in Jabiru engines, with 13 reported over the 6 years. It should be noted that there were another 15 valve failures coded as mechanical discontinuities. However, the category of valve failures describes failures of one of a number of components in the valve train, not just the valve itself. In the occurrences reported here, these included the valve stem fracturing, the valve head separating from the stem, as well as failures of the valve spring, the valve spring cup, the top spring washer, the tappet adjusting screws, and the valve keepers. Also included were reports of valves ‘dropping’, ‘seizing’ well as general reports of ‘valve failing’. Valve failures are coded as fractures when the reporters specifically mention a component fracturing, breaking or snapping, whereas if the reporter stated the components ‘failed’, ‘seized’, or ‘dropped’, they are coded as a mechanical discontinuity. Conversely, all 21 reports of through-bolts related to the one individual component fracturing.

Through-bolt and valve failures were followed by failures of flywheel bolts (3), studs (2), and one each of crank shaft gear, cracked cylinder, cylinder base nut, propeller bolts, propeller blade, and rivets.

There was a more even distribution of components that failed for the other three manufacturers with the greatest number of fractures for any single components being two.

**Figure 9: The distribution of components that failed within the fracture set of technical failure mechanisms. Nearly half of the Jabiru fractures related to through-bolt failures, and nearly a third relating to fractures of a component in the valve train. There was a more even distribution of components that failed for the other three manufacturers.**



### ***Jabiru valve failures***

In May 2015, Jabiru Aircraft Pty Ltd conducted a root cause analysis of valve train failures from 2013 to 2015.<sup>10</sup> The report identified 25 valve train failures in Jabiru engines between 2013 and 2015. Of these 25 occurrences, 3 were in 2015 (outside the scope of this ATSB investigation). A number were occurrences also reported to the ATSB and are part of the analysis presented here, while others may have been faults found during maintenance and hence not reportable to the ATSB.

The report states that ‘valve failures in Jabiru engines are virtually always exhaust valves’. This is consistent with what has been reported to the ATSB, with ten of the 13 valve fractures identified as being exhaust valve failures. In the other three occurrences it was not reported. The Jabiru report states also that the valve failures fell within three functional groups: the valves, the valve spring top retaining washer, and the valve springs. This is also consistent with what has been reported to the ATSB. Of the 13 fractures, five were described as a fracture of the stem, one fracture of the valve spring cup, one valve spring, while six were simply described as a failed/broken valve.

Jabiru Aircraft Pty Ltd have already taken a number of actions to address these valve train failures, including a complete redesign of the valve train in 2005 to use hydraulic lifters (rather than solid lifters). The engineering report (AVDALSR106-3) states that this design change ‘eliminates valve clearance maintenance requirements’. Other design changes included modifying the valve guide tolerance and the implementation of valve relief pocketed pistons. Additionally, Jabiru Pty Ltd have published a number of service letters and service bulletins to increase awareness of the issues and prescribe correct maintenance practices. These included JSL007 (current issue 6 released August 5 2015), JSL002, which was replaced by JSB018 (issue 3 release October 15 2014), JSL014 (issue 2 released 5 August 2015), and JSL008 (issue 1 released 21 December 2012).

### ***Jabiru through-bolt fractures***

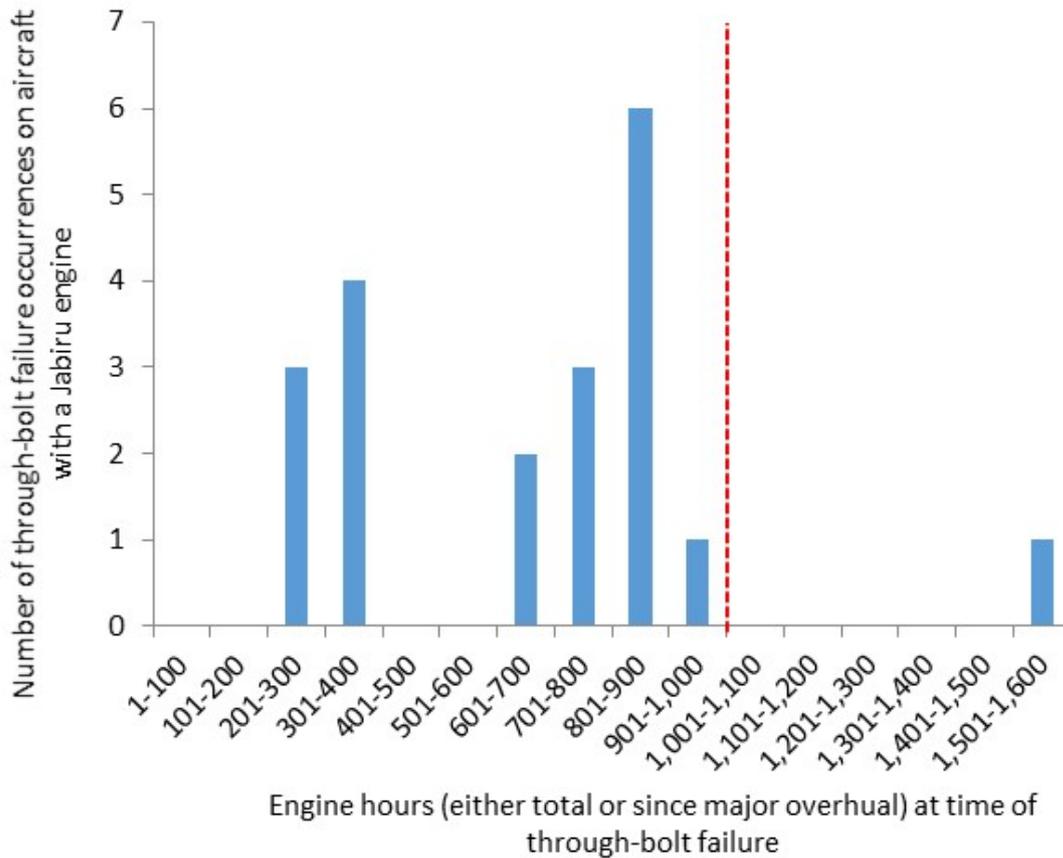
For 20 of the 21 Jabiru through-bolt failures, the total engine hours was reported at the time of the failure. For these 20 occurrences, the average total engine hours was reported to be 672 hours (median 710 hours).<sup>11</sup> The distribution of total engine hours at the time of the through-bolt failure is shown in Figure 10. The two reported failures of studs (data not shown in Figure 10) were reported at 1,183 and 438 hours in service. Jabiru overhaul manuals currently require a top end overhaul after 1,000 hours and a full overhaul after 2,000 hours, with the engine through-bolts and studs being replaced at both overhauls. It can be seen from Figure 10, however, that most of the failed through-bolts (19 of 21) did not make it to the 1,000-hour mark.<sup>12</sup> Furthermore, seven through-bolts (and one stud) failed before 500 hours.

<sup>10</sup> Jabiru Aircraft (14 May 2015) *Jabiru Engine Valve train failure* (Jabiru engineering report AVDALSR106-3),

<sup>11</sup> For two occurrences, total engine hours since the last major engine overhaul (which included through-bolt replacements) were used in the average calculation and in Figure 10.

<sup>12</sup> For the occurrence where the engine hours were greater than 1,000 hours, there was no information available regarding whether the through-bolts had been replaced at 1,000 hours.

**Figure 10: Histogram showing the frequency distribution of total engine hours<sup>11</sup> at the time of the through-bolt failure on aircraft with Jabiru engines. The red dotted line indicates the 1,000 hour mark at which point at which through-bolts were originally required to be replaced**



Throughout the life of the Jabiru 2200 and 3300 engine series, Jabiru has released a number of [service bulletins](#)<sup>13</sup> outlining a number of required and recommended upgrades to components and practices. Three of these bulletins pertain specifically to engine through-bolts and nuts. The first of these bulletins, JSB031-1 released on 14 April 2011, required the upgrading of the through-bolt nuts from six sided nuts to 12-point ARP<sup>14</sup> nuts (see Figure 11 in the Appendix). Other changes included new oversized crankcase dowels and the (non-compulsory) availability of new thicker (7/16 inch) through-bolts. JSB031-1 was superseded on 10 October 2013 with the release of JSB031-2. The second issue required that any engines still fitted with the older style (six sided) nuts have its through-bolts, studs and nuts changed before further flight and the cylinders inspected for cracks. Issue two was in turn superseded by the most current version, [JSB031-3](#), on 31 January 2015. It should be noted that the *requirement* was to replace the 3/8 inch bolts with new 3/8 inch bolts that were slightly longer to accommodate the new 12-point nuts (not with thicker 7/16 inch bolts). Engines made for 3/8 inch through-bolts require modifications to the crankcase to accept the 7/16 inch bolts. Hence the optional upgrade from 3/8 inch to 7/16 inch bolts requires the engine to be sent back to the manufacturer for modifications. A summary of the changes made and engines affected is contained in the Appendix. For further details the links to the original documents are provided throughout this report.

Of the 21 through-bolt failure occurrences, four reports detailed which through-bolts and/or nuts were in use. All four stated that the 12-point ARP through-bolt nuts (as per JSB031-1) were

<sup>13</sup> <http://jabiru.net.au/service/service-bulletins#engine> - . Note that service bulletins JSB031-1 and JSB031-2 are no longer available on this site.

<sup>14</sup> Automotive Racing Products, Inc, Ventura California, US.

installed before the failure. The four failures that occurred with the new nuts installed were at 820, 390, 300 and 840 total engine hours. As it was reported that nuts were changed it is likely that the time in service for the nuts was less than the total engine hours. The report of the failure at 840 hours stated that the through-bolts were also replaced at the same time as the nuts, however, it was unclear what size through-bolts had been installed at the time of the occurrence.

Additionally, in 2014 there were another three through-bolt failures reported on engines that should have been upgraded to the newer 12-point nuts and had their through-bolts and studs replaced in accordance with JSB031-2. These three failures were reported to have occurred at 827, 370, and 376 total engine hours. This gives a total of seven through-bolt failures involving the newer 12-point nuts.

During the course of this investigation a voluntary survey was sent to owners and operators of Jabiru powered aircraft that had reported a through-bolt or valve failure between 2009 and 2014. The aim of the survey was to determine engine hours, and the types of through-bolts and nuts that were in use at the time of the failure. One owner with a through-bolt failure indicated that the original through-bolts and six-sided nuts were in place at the time of the engine failure or malfunction occurrence. Unfortunately, due to low numbers of responses, no further information could be added to the analysis.

The most recent Jabiru service bulletin was released in January 2015, following the publication of preliminary data from this ATSB investigation in December 2014. This service bulletin was published after the data period (2009 to 2014) used for the analysis in this investigation. This through-bolt service bulletin [JSB031 issue 3](#)<sup>15</sup> only applied to aircraft involved in flight training, and recommended changes to 3/8 inch through-bolt replacement time to 500 hours (from 1,000 hours). However, as Figure 10 shows, eight of the through-bolt failures occurred at less than 500 hours' time in service, three of which were reported as being involved in flight training operations.

In the set of 21 through-bolt failures reported to the ASTB between 2009 and 2014 the following operation types were reported as being conducted at the time of the through-bolt failure:

- Flight training – 10 occurrences
- Private – 5 occurrences
- Unknown – 6 occurrences.

Not including the unknown operation types, five of the through-bolt failures occurred when the aircraft was not involved in flight training. Engine hours data is known for four of the five. For these four aircraft the total engine hours before the through-bolt failures were 675.8, 1,600, 390.8 and 782.5.

In addition to these service bulletins, Jabiru Aircraft Pty Ltd have undertaken a recent engineering study into the causes of through-bolt failures.<sup>16</sup> The report was released in February 2015 and notes this is 'a problem noted to occur in some but not all Jabiru 2200 & 3300 engine configurations.'

Specifically, the report states that:

Through bolt failures did not occur in the early engine configurations which featured solid-lifters in the valve train and 3/8" bolts. [However], the report notes that through bolt failures do occur on engine configurations which feature hydraulic lifters in the valve train.

Although the ATSB through-bolt failure data is not inconsistent with this assertion, engines with hydraulic lifters were only identified (from the follow-up survey) in four occurrences. The remaining 18 reported through-bolt related engine failures or malfunctions in the dataset did not identify the type of lifter in use.

<sup>15</sup> [http://jabiru.net.au/images/JSB031-3\\_Through\\_Bolt\\_Replacement\\_and\\_Upgrade.pdf](http://jabiru.net.au/images/JSB031-3_Through_Bolt_Replacement_and_Upgrade.pdf)

<sup>16</sup> Jabiru Aircraft (24 February 2015). *Through bolt vibration study* (Jabiru engineering report AVDALSR105-2).

The report also states:

Jabiru initially considered the failure as a 'classical' bolted joint failure where operating stress levels in the bolts were high. To address this Jabiru intuitively increased the diameter of the through bolts to 7/16" to address the problem by reducing the stress levels.

.....

[However, after subsequent testing Jabiru Aircraft determined that] because the [3/8 inch] bolts are failing and direct tension on the bolts, which is intuitively the primary factor in fatigue, does not predict a failure, the failures must be occurring because of the influence of secondary effects.

This engineering report identified that vibrations in the crankcase could be a plausible 'further effect'. More specifically:

This survey have [sic] identified distinct differences in the vibration signatures of the 'solid lifter' and the 'hydraulic lifter' engines, and have been able to create plausible links between bolt & crankcase resonances to the crankshaft resonance. The vibration survey results show that in the 'solid lifter' engine with the 3/8 through-bolts, individual component resonances were spaced sufficiently that they would not couple together. The survey found individual component resonances in 'hydraulic lifter' engines with some through-bolt configurations were closely spaced and could couple together.

Coupling of resonances is hypothesized to produce a dynamic effect, which would lead to surface movement and fretting, and also to high frequency loading of the through bolts. The high frequency loading is not adequately addressed in the classical fatigue life estimation analysis.

The February 2015 report also states that:

Production records show that 272 production engines have been released into service with the 7/16" diameter through bolts. There have been no reported through bolt failures with these engines. Nine of these engines completed over 1000 hours' time-in-service with flight training schools .....  
[However,] failures continued to occur in engines that are in service with the hydraulic lifters and 3/8" diameter bolts.

The ATSB through-bolt failure set is not inconsistent with this in that there were no through-bolt failures reported with 7/16 inch through-bolts. However, most notifications did not identify the type of through-bolt involved. The approximate Jabiru fleet of 1,300 engines, only about 20 per cent have been produced with 7/16 inch through-bolts (and some engines have been retro-fitted). As the use of thicker bolts is relatively recent, it is probable that all through-bolt failures reported to the ATSB also involved 3/8 inch bolts.

However, the lack of reported failures in 7/16 inch through-bolts may be related to the small proportion of the fleet that have the thicker through-bolts and that most of these engines have relatively low time-in-service (compared to aircraft with engines with 3/8 inch through-bolts). Therefore, it will be important that monitoring of 7/16 inch through-bolt performance is continued into the future.

As for the existing fleet of Jabiru engines, most still have 3/8 inch through-bolt configurations. Although newly manufactured engines use the 7/16 inch configuration, it is likely that most existing engines will continue to use the 3/8 inch bolts into the future. This is because retro-fitting thicker bolts involves modifications to the crank case by the manufacturer, and that the recommendation in January 2015 Service Bulletin JSB031-3 to upgrade to 7/16 inch bolts is only directed at aircraft used for flight-training. As such, given the above results of this ATSB investigation and that the February 2015 Jabiru Aircraft engineering report found that 'engines which are in service with the older configurations are still at risk', a long-term solution for the existing fleet using 3/8 inch through-bolts is required.

### **Actions by CASA**

The aviation regulator, the Civil Aviation Safety Authority (CASA), has independently conducted its own investigation and analysis of engine failures in Jabiru powered aircraft between 2012 and 2014. As a result of their own research, in December 2014 CASA imposed a number of operating limitations on Jabiru powered aircraft. These limitations were imposed by a direction issued by CASA on 22 December 2014 (Instrument Number CASA 292/14), which expired at the end of 30 June 2015. The limitations included:

- Restriction of flights to daytime use under the visual flight rules, or in accordance with an approval by CASA.
- Restrictions to the use of Jabiru-powered aircraft over populated areas such that they are at a height from which they can glide clear of the populated areas to a suitable forced-landing area. Additionally that they are at least 1,000 ft about the ground, except to the minimum extent necessary for take-off and landing.
- Require passengers and trainee pilots flying solo to sign a statement saying they are aware of and accept the risk of an engine failure.
- Require trainee pilots to have recently and successfully completed engine failure exercises before solo flights.

Note that the above are paraphrased from the CASA legislative instrument. For full details of the operating restrictions, see [CASA 292/14 - Conditions and direction concerning certain aircraft fitted with engines manufactured by Jabiru Aircraft Pty Ltd.](#)

CASA has since re-issued the direction with effect from 1 July 2015 (Instrument number CASA 102/15), pending the identification and implementation of effective remedial actions. The operational limitations described above continue to apply under the new instrument with the exception of the relaxing of one the directives as follows:

As from 1 July 2015, the previous requirement that the pilot-in-command of a Jabiru-powered aircraft may only permit a passenger to be carried in the aircraft if a statement (in a form described in the direction) had been signed by a passenger not more than 28 days before a flight, was amended to permit such statements to be signed not more than 3 calendar months before a flight. This change reduces an administrative burden inherent in the previous arrangements, without diminishing the precautionary safety benefits provided by the continuing operational limitations. For the time being, the other terms and conditions of the direction will remain the same.

Further details on CASA's limitations (Instrument number CASA 102/15) can be download from the [ComLaw website](#).

**Case Study: Engine failure involving an amateur-built Pitts S1S****ATSB investigation AO-2014-036**

On 1 March 2014, the pilot of an amateur-built Pitts S1S completed preparations for a world record attempt for the number of continuous rolls, to raise funds for medical research.

Due to low cloud in the area, the pilot elected to delay the initial departure time and to conduct the aerobatic flight in the local training area about 3 NM from Lethbridge approved landing area (ALA), Victoria.

After successfully completing 987 rolls to the left, at about 2,000 ft above ground level (AGL), the pilot elected to return to Lethbridge. About 2 minutes later, when in the cruise, the engine spluttered and lost power. The pilot assumed the aircraft had a partial engine failure, and aimed to return to Lethbridge which was about 1 NM away. He completed the 'trouble' checklist, with no success in restoring engine power.

The aircraft was rapidly losing altitude and the pilot selected a paddock for a forced landing. After turning into wind, the aircraft was sinking quickly and the pilot realised it was unlikely to reach the selected paddock. He revised the aiming point for the landing to a closer field.

During the landing roll, the aircraft collided with a rock and nosed over, coming to rest inverted. The aircraft was substantially damaged.

The pilot reported that the 'flop tube' may have become stuck. It supplies the engine with fuel from the top of the tank when the aircraft is inverted. This may have been resolved by rolling the aircraft inverted. However, this was not a safe option at low altitude, with a partial or complete engine failure. The damage to the aircraft was assessed as being greater than the replacement cost therefore no post-accident engineering inspection was conducted to determine the cause of the engine failure.



Damage to VH-URP

Source: ATSB

## Summary

A review of engine failure or malfunction occurrences reported to the ATSB and/or RAAus showed that there were 322 engine failures or malfunctions (occurring whilst the aircraft was boarded for flight) involving light aircraft (single engine piston aeroplanes up to 800 kg) between 2009 and 2014 (54 per year on average). With a combined total of approximately 1.6 million flight hours for light aeroplanes in this timeframe, this equated to approximately one engine failure or malfunction every 5,000 flight hours.

Aircraft powered by Jabiru engines were involved in the most engine failure or malfunction occurrences with 130 reported over the 6 years. This represents about one in ten aircraft powered by Jabiru engines in the study set having reported an engine failure or malfunction, and equates to about 1 engine failure or malfunction every 3,000 flight hours. Aircraft powered by Jabiru engines had double the rate of reported engine failure or malfunction of aircraft powered by any other engine.

Unlike the engine failures or malfunctions of other engine manufacturers in this study, most Jabiru engine failures or malfunctions (occurring whilst the aircraft was boarded for flight) related to a fractured component. Engine through-bolt fractures were the most common Jabiru failure mechanism, with 21 reported in the study period. Taking into account the number of aircraft registered in Australia, through-bolt failures occurred in about one in 55 Jabiru powered aircraft.

Jabiru has required owners to replace 3/8 inch thick through-bolts with longer bolts and replace nuts with 12-point ARP nuts. Additionally, Jabiru has recommended owners to upgrade to the newer and thicker 7/16 inch through-bolts, and produce new engines with the thick 7/16 inch bolts. Therefore, it is possible that the through-bolt fracture rate may be improved into the future relative to the six years 2009 to 2014. However, there were at least four failures with the upgraded nuts.

Although initially certified to last 1,000 hours, most of the through-bolt failures occurred after less time in service, with the average being about 700 hours. The ATSB acknowledges that Jabiru attempted to address this issue in January 2015 by recommending the replacement of engine through-bolts at 500 hours in service for aircraft involved in flight training operations. However, through-bolt failures were also seen in aircraft not conducting flight training with less than 1,000 hours in service, and seven through-bolt failures occurred under 500 hours.

Jabiru Aircraft engineering analysis suggests that the coupling of resonate frequencies of the crankcase and through-bolt in certain engine configurations is plausibly contributing to the failures. Jabiru engines with older through-bolt combinations (that involve the 3/8 inch through-bolt) continue to be at risk of failure. Jabiru Aircraft state that there have been no through-bolt failures involving 7/16 inch bolts (installed in at least 20 per cent of the engine fleet, mostly more recently manufactured engines). The ATSB is unaware of any failures of 7/16 inch through-bolts, although it should be noted that this is a relatively recent modification. It will therefore be important that the engine failure or malfunction rate of Jabiru engines is closely monitored in the coming years to determine whether these actions by Jabiru sufficiently improves the reliability of Jabiru engines in flight. Moreover, given the results of this ATSB investigation and that the February 2015 Jabiru Aircraft engineering report found that 'engines which are in service with the older configurations are still at risk', a long-term solution for the existing fleet using 3/8 inch through-bolts is required.

Individual reporting practices influence both the scope and effectiveness of occurrence data analysis. With this in mind, the ATSB encourages all operators to continue vigilantly reporting engine failures and malfunctions to the ATSB with, where possible, follow-up engineering inspection reports.

## Findings

From the evidence available, the following findings are made with respect to the analysis of the reliability of engines in light aircraft. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

**Safety issues, or system problems, are highlighted in bold to emphasise their importance.**

A safety issue is an event or condition that increases safety risk and (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

### Other factors that increased risk

- There was a disproportionate rate of engine failure and malfunction occurrences relating to light aeroplanes fitted with Jabiru engines.
- Fractured engine components were the most common technical failure mechanism in Jabiru engines, particularly involving engine through-bolts. Most reported through-bolt failures in Jabiru engines occurred before the 1,000 hour overhaul limit and some before 500 hours.
- **Thicker 7/16 inch diameter through-bolts, fitted to newer Jabiru engines and some retro-fitted engines, have had limited service to date to confirm early indications that they reduce this risk. Retro-fitting engines with thicker through-bolts has only been recommended for aircraft involved in flight training by JSB031 issue 3. Most light aircraft in service with Jabiru engines continue to use 3/8 inch diameter engine through-bolts which, even after upgrades in accordance with Jabiru service bulletins JSB031 issues 1 and 2, remain at an elevated risk of fracturing within the service life of the bolt, leading to an engine failure or malfunction in flight. [Safety issue]**

## Safety issues and actions

The safety issues identified during this investigation are listed in the Findings and Safety issues and actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the directly involved parties were provided with a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

The initial public version of these safety issues and actions are repeated separately on the ATSB website to facilitate monitoring by interested parties. Where relevant the safety issues and actions will be updated on the ATSB website as information comes to hand.

### Through-bolt failures in Jabiru engines

|                     |  |
|---------------------|--|
| Number:             | AR-2013-107-SI-01  |
| Issue owner:        | Jabiru Aircraft Pty Ltd                                    |
| Operation affected: | Aviation: General Aviation                                 |
| Who it affects:     | Owners and operators of aircraft powered by Jabiru engines |

#### **Safety issue description:**

Thicker 7/16 inch diameter through-bolts, fitted to newer Jabiru engines and some retro-fitted engines, have had limited service to date to confirm early indications that they reduce this risk. Retro-fitting engines with thicker through-bolts has only been recommended for aircraft involved in flight training by JSB031 issue 3. Most light aircraft in service with Jabiru engines continue to use 3/8 inch diameter engine through-bolts which, even after upgrades in accordance with Jabiru service bulletins JSB031 issues 1 and 2, remain at an elevated risk of fracturing within the service life of the bolt, leading to an engine failure or malfunction in flight.

#### **Response to safety issue by Jabiru Aircraft Australia**

Jabiru Australia has recently completed an engineering study (*Through bolt strain gauge test*, Jabiru engineering report AVDALSR109-1, 19 November 2015) that has designed and tested a modified 3/8 inch diameter through-bolt which is believed will address the safety issue.

The report states:

..... [the earlier February 2015 Jabiru engineering report AVDALSR105] established that the natural frequency tendencies of the 3/8" through bolt were such that resonance with the engine was likely to occur and this was the probable sources of abnormal (and previously unanticipated) cyclic loads which would cause the bolts to fail.

This report details further work conducted to confirm this hypothesis using an instrumented through bolt installed in a running Jabiru engine. In the course of testing conducted, the nature of loading in the through bolt has been established, vibrational resonance was detected and another aspect of the failure mechanism was uncovered; the previously unanticipated thermal load cycling.

The final tests conducted were on a revised design to the 3/8" through bolt which incorporated aspects to alleviate the effects of thermal expansion and damp resonant vibrations that were found on the standard through bolt.

The revised 3/8" through-bolt was:

designed featuring a more elastic (i.e. less stiff) spring rate and rubber O-rings in the middle to damp resonate transverse vibrations.

- Calculations showed significant reduction in preload tension resulting from a given temperature increase for the new design 3/8" through bolt compared to the standard design.
- Engine test runs were also conducted. The resonant vibration mode identified for the standard 3/8" through bolt had visibly disappeared with the addition of rubber O-rings. This suggests that the addition of rubber O-rings significantly damps the otherwise damaging resonant vibrations.

***ATSB comment/action in response***

The ATSB recognises that Jabiru Aircraft have conducted a number of in-depth analyses of the mechanism of the through-bolt failures. Additionally, the ATSB acknowledges that Jabiru consider that both the implementation of the 7/16 inch through-bolt, and the development of a revised design 3/8 inch though-bolt, have the potential to address this safety issue across the fleet of all Jabiru engines.

As noted in the internal Jabiru engineering report AVDALSR105-2, most Jabiru-powered aircraft remain at risk of a through-bolt failure. This risk exists because most Jabiru engines in use are still using older configurations of through-bolts. At the time of release of this report, about 20 per cent of engines were manufactured with the new 7/16 inch through-bolt configuration. Some older engines have been retro-fitted to accommodate the thicker through-bolts. However, the recommendation in service bulletin JSB031-3 to upgrade through-bolts to the newest available configuration of through-bolts only pertained to aircraft involved in flight training. As the use of the new 7/16 inch configuration through-bolts is relatively recent, on-going monitoring of the reliability of these through-bolts across the fleet is required.

Up to 80 per cent of the Jabiru engines in service, which have the older 3/8 inch configuration through-bolts, are still at risk. Although Jabiru have designed and tested a revised 3/8 inch through-bolt which incorporates aspects to alleviate the effects of thermal expansion and damp resonant vibrations, it can only address the safety issue once these new bolts are made available to Jabiru engine owners and fitted to relevant aircraft.

***ATSB safety recommendation to Jabiru Aircraft Australia***

Action number: AR-2013-107-SR-055

Action status: Released

The Australian Transport Safety Bureau recommends that Jabiru Aircraft Australia takes further safety action to ensure that all owners of Jabiru engines that have not been manufactured with new configuration 7/16 inch diameter through-bolts, or modified in accordance with Jabiru Service Bulletin JSB031-3 have access to, and are encouraged to upgrade to:

- the 7/16 inch diameter through-bolt configuration, or
- any other alternative produced to replace the existing 3/8 inch diameter through-bolt configuration (including newly developed through-bolts incorporating aspects to alleviate the effects of thermal expansion and damp resonant vibrations).

***ATSB safety recommendation to the Civil Aviation Safety Authority***

Action number: AR-2013-107-SR-056

Action status: Released

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority continue to monitor the through-bolt failure rate of Jabiru engines to satisfy themselves of the reliability of the:

- 7/16 inch diameter bolts, and
- any other alternative produced to replace the existing 3/8 inch diameter through-bolt configuration (including newly developed through-bolts incorporating aspects to alleviate the effects of thermal expansion and damp resonant vibrations)

to determine if these modifications have sufficiently reduced the risk of an engine failure or malfunction in Jabiru-powered aircraft.

***Current status of the safety issue***

Issue status: Safety action pending

# 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))
- Recreational Aviation Australia (RAAus) (notifications requested under Section 32 of the *Transport Safety Investigation Act 2003*)
- The Bureau of Infrastructure, Transport and Regional Economics (BITRE)
- Jabiru Aircraft service bulletins, available from <http://jabiru.net.au/service/service-bulletins#engine>

## References

- Aviation Risk Management Solutions (ARMS) (March 2010). *Methodology for Operational Risk Assessment in Aviation Organisations* (version 4.1). <https://easa.europa.eu/essi/documents/Methodology.pdf>
- Jabiru Aircraft (24 February 2015). *Through bolt vibration study* (Jabiru engineering report AVDALSR105-2).
- Jabiru Aircraft (14 May 2015). *Jabiru Engine Valve train failure* (Jabiru engineering report AVDALSR106-3).
- Jabiru Aircraft (19 November 2015). *Through bolt strain gauge test*. (Jabiru engineering report AVDALSR109-1).

## Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the Civil Aviation Safety Authority, Recreational Aviation Australia, Jabiru Aircraft Pty Ltd, Rotax engines, Textron Lycoming, and Continental Motors.

Submissions were received from the Civil Aviation Safety Authority, Recreational Aviation Australia, Jabiru Aircraft Pty. Ltd, and Continental Motors. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

# Appendix

## **Summary of Jabiru service bulletins regarding changes to through-bolts and nuts**

The first of the Jabiru service bulletins regarding through-bolt upgrades (JSB 031-1) was released on 14 April 2011. This bulletin applied to the following Jabiru 2200 and 3300 engines:

- 2200A with serial numbers between 1707 and 3483
- 2200B with serial numbers 001 onwards
- 2200C with serial numbers 001 onwards
- 2200J depending on configuration
- 3300A with serial numbers between 637 and 2391
- 3300L with serial numbers 001 onwards.

The bulletin required the upgrading of the through-bolt nuts (see Figure 11) from 3/8 inch six sided nuts (MS21042 style) to 3/8 inch 12-point nuts. New oversize crankcase dowels were also required to be fitted. The changes were required for any engine (in the above list) at the next overhaul or major maintenance. Additionally, for any engine that had previously suffered a through-bolt failure, new through-bolts, 12-point through-bolt nuts and crankcase dowels were required to be installed within the next 100 hours (TIS) or 12 months, whichever ever came sooner. There were similar requirements for engine with less than 500 hours TTIS or less than 200 hours TSO, as well as engines with 500 – 1000 hours TTIS or more than 200 hours TSO. See JSB 031-1 for further details.

In addition to the above requirements, a number of recommended 'corrective or preventative measures' were also included. These related to fuel use ([JSL007](#)), operating techniques (increasing climb speed to improve engine cooling), the release of a new overhaul manual, shims to reduce compression ratio, crankcase locating dowels and new thicker (7/16") engine through-bolts.

**Figure 11: Jabiru 6-sided and 12-sided through-bolt nuts.**

3/8" MS21042-style nut

3/8" 12-Point nut



Source: Jabiru Aircraft PTY LTD service bulletin JSB031-1

JSB 031-1 was superseded on 10 October 2013 with the release of JSB 031-2. This bulletin applied to the following engines:

- 2200A with serial numbers between 1707 and 3483
- 2200B with serial numbers between 001 and 282
- 2200C with serial numbers between 001 and 018
- 2200J any built or overhauled between 2004 and 2011
- 3300A with serial numbers between 637 and 2391
- 3300L with serial numbers between 001 and 096.

Of the engines above, requirements pertained to any engine meeting the JSB031-1 requirements, any engine at overhaul or major service, and any engine still equipped with the six sided MS21042 style nuts. In Issue 2 of JSB031, any applicable engines that had not complied with Issue 1 were required to be updated and their cylinders inspected. The upgrades related to maintenance practices outlined in the Jabiru engine overhaul manual document JEM0001.

The most recent of these service bulletins, JSB031-3 became effective on 31 January 2015. This bulletin affected the following engines, but only for aircraft involved in flight training operations:

- 2200 engines in the serial number range:
  - 22A2068 to 22A2102
  - 22A2143 to 22A3483
  - (including 22B01 to 22B254)
  - (including 22C001 to 22C018)
- 3300 engines in the serial number range:
  - 33A961 to 33A2574

Required action for engines with 3/8 inch through-bolts (excluding roller cam upgraded engines) included replacing all 3/8 inch through-bolts and studs before reaching 500 hours in service. Or, for aircraft where through-bolts have already exceeded 500 hours in service, they were to be changed at the next 25-hourly service interval.

Additionally, JSB031-3 recommended that all engines to which this service bulletin is applicable and other engines are upgraded to the most current through-bolt configuration, which at the time of writing was the following:

- 7/16" Through-bolts (P/No 4A596A0D)
- 7/16" Stud Bolts (P/No 4A595A0D)
- 7/16" Short Stud Bolts (P/No 4A594A0D)
- 12 point ARP nuts (P/No PH4A062N and PH4A056N)
- Hardened steel washers (P/No 4A625A0D)
- Washers for front stud nuts (P/No AN960716)

All the above must be fitted as per JSB031-3 and the latest Engine Overhaul Manual, JEM0001.

# 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 operations involving the travelling public.

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.

## Australian Transport Safety Bureau

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## Investigation

### **ATSB Transport Safety Report**

Aviation Research Statistics

Engine failures and malfunctions in light aeroplanes 2009 to 2014

AR-2013-107

Final – 9 March 2016