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ATSB TRANSPORT SAFETY REPORT

Aviation Occurrence Investigation AO-2009-006

Final

Main landing gear wheel failure Sydney Airport, NSW 6 February 2009 VH-KDQ Saab 340B

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Sydney Airport, NSW
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VH-KDQ
Saab 340B

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Abstract

During the post-flight inspection of a Saab 340B passenger aircraft, the number-two outboard main landing gear wheel was observed to have sustained noticeable damage. The flight crew reported that there was no prior indication of the failure, as the aircraft had handled normally during the landing and taxiing phase of the flight.

Subsequent examination found that the wheel inner rim had fractured away from the hub for approximately one-half of the total circumference. A circumferential fatigue crack had initiated at a location at the bead seat radius, and had propagated until a final ductile overload failure caused a section of the wheel rim to separate.

During the course of the investigation, it was found that the particular wheel design was being phased out due to recognised fatigue problems identified at the bead seat area.

Both the manufacturer and operator were aware of the increased fatigue susceptibility of the earlier wheel design, and had established increased inspection regimes for those wheels remaining in service.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau 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 safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

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.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (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 operational environment at a specific point in time.

Risk level: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

FACTUAL INFORMATION

History of the flight

On 6 February 2009 at approximately 1435 Australian Eastern Daylight-saving Time[1], a Saab 340B aircraft, registered VH-KDQ, landed at Sydney Airport following a scheduled passenger service from Orange, New South Wales. The flight crew reported to the Australian Transport Safety Bureau (ATSB) that during post-flight inspection, the aircraft's left outboard (number-two) main landing gear tyre was found to have deflated and the wheel assembly had sustained noticeable damage. The crew reported that there had been no prior indication of any problems with the aircraft, with normal handling during the landing and taxiing phase of the flight.

Damage to the aircraft

Failure of the rim had resulted in deflation of the tyre. Further examination by the operator's maintenance staff found that a section of the bead seat had fractured, but was still attached to the outboard left main wheel assembly. Both the brake assembly and the wheel axle had also been damaged as a result of the failure. The operator advised that to enable the aircraft to be returned to service, the entire main landing gear assembly was replaced. No other damage was sustained by the aircraft.

Aircraft information

Table 1: Aircraft details

Manufacturer	Saab Aircraft Company
Model	340B
Serial number	340B-525
Registration	VH-KDQ
Year of manufacture	1992
Date first registered in Australia	13 March 1996
Maximum take-off weight	13,155 kg
Take-off weight at occurrence	12,299 kg

1 The 24-hour clock is used in this report to describe the local time of day, Australian Eastern Daylight-saving Time (AEDT), as particular events occurred. At the time of the event AEDT was Coordinated Universal Time (UTC) + 11 hours.

Wheel information

General

The Saab 340B aircraft incorporated a tricycle landing gear arrangement, with twin wheels on each of the main and nose gear legs.

Component history

Maintenance records stated that the failed wheel (serial number SEP92-0621) had accumulated 251.8 hours and 293 cycles since last overhaul. The records indicated that the wheel had been installed on two Saab aircraft since overhaul; VH-ZLF and the occurrence aircraft, VH-KDQ. The wheel assembly, including a new tyre, was fitted to VH-KDQ on 24 January 2009. Subsequently, the wheel had operated for a further 34 hours and 40 flight cycles, until the failure occurred on 6 February. A summary of the wheel rim service and maintenance history is shown in Table 2.

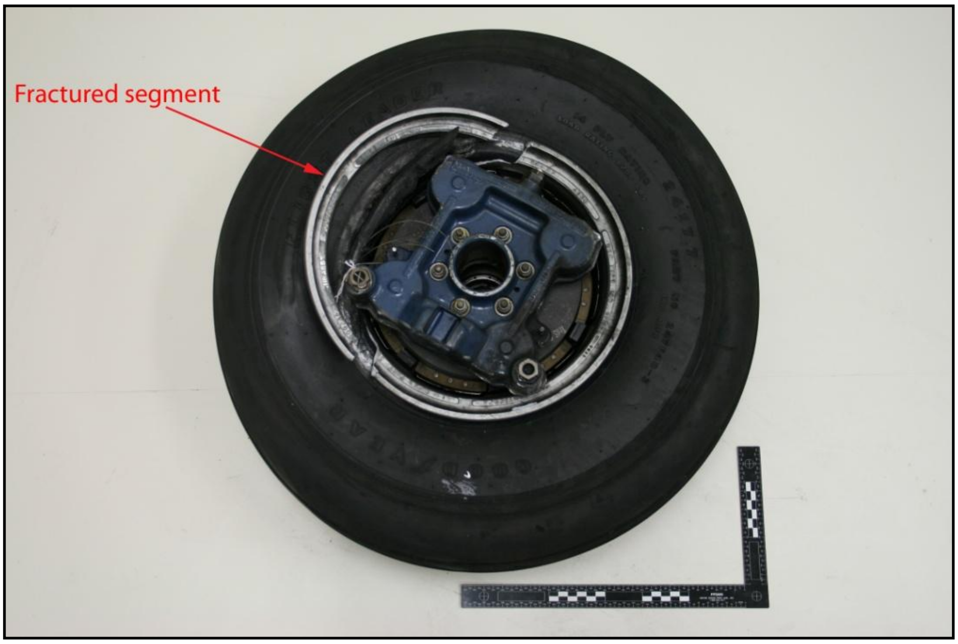
Table 2: Number-two main landing gear wheel detail

Wheel part number	5010488 REV A (Subassembly 5009237-1)
Wheel serial number	SEP 92-0621
Tyre brand and size (fitted)	Goodyear Flight Leader, 24x7.7-in tubeless
Tyre part number (fitted)	247F48-3
Total hours / cycles since overhaul	251.8 hrs / 293 cycles
Total tyre changes since new	26
Date of fitment to VH-KDQ	24 January 2009

Examination of the failed component

The failed wheel assembly was removed from the aircraft and sent to the ATSB’s Canberra laboratories for further examination. Initial inspection revealed that a section of the rim had broken away, with the fracture path extending through the bead seat area (Figure 1). The broken section represented just less than one half of the entire circumference of the wheel rim. The tyre had been damaged in the area of the fracture, with evidence of exposed steel reinforcement. The tyre had moved over the fractured segment and was caught on the fractured edges of the rim.

Figure 1: Left outboard main wheel assembly as received



The fracture had followed a radial path through the wheel rim bead seat area. Features consistent with fatigue crack progression (beach-marks) were evident across the fracture surfaces. Those features extended radially from the internal bead seat radius surface, towards the centre of the exposed fracture face (Figures 2 and 3). The beach-marks extended circumferentially around the rim for approximately 100 mm, with several other crack initiation sites identified around the internal bead seat radius.

The outer sections of the fracture face were observed to be dull grey in colour, and were rough and fibrous in appearance, consistent with a ductile overstress failure in a heat treated aluminium alloy.

Evidence of a black discolouration, most likely rubber or grease, was observed on the fatigue area of the fracture face.

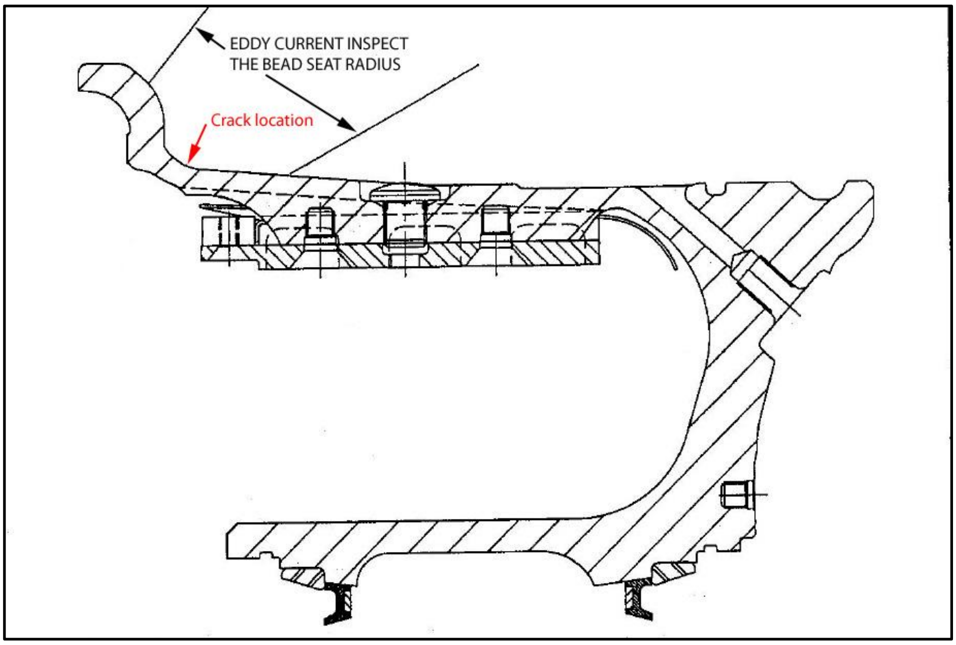
Figure 2: Inside surface of the fractured wheel rim section

Figure 3: Magnified view of fracture face showing the crack progression (beach-marks) extending from the bead seat radius origin area (arrowed)

Disassembly of the wheel rim and removal of the tyre allowed inspection of the hub side of the fracture face (Figure 4). This surface exhibited similar features to those observed on the smaller section that had been excised from the wheel, and showed a clearer indication of the location of the fracture (as shown on the engineering drawing of the wheel, Figure 5). The primary crack origin was located at the transition radius between the bead seat and the rim area.

Figure 4: Overview of the wheel assembly following removal of the tyre

Figure 5: Cross section diagram of main wheel hub[2] showing the location of the fracture



Scanning electron microscopy of the fracture surfaces revealed a relatively smooth fracture face, with evidence of step-wise crack formation, again indicative of a fatigue crack propagation mechanism.

Microstructural examination of a cross section taken through the fracture face revealed a relatively smooth, transgranular fracture path, also typical of fatigue.

2 Image source: 'SAAB 340 Main Wheel Subassembly 5009237 and 5009237-1 Bead Seat Inspection', SF340-32-24 Rev 1, Apr 28/94, pg 2

Corrosion was not evident at any of the locations examined, nor was there any evidence of pre-existing material or manufacturing defects throughout the sections examined.

Externally, there was no evidence of any significant surface mechanical damage (such as indentations, scratches or bruises) in the vicinity of the fractured rim section.

Hardness testing of the bulk wheel alloy returned values around 150 BHN (Brinell hardness number) - consistent with a high-strength aluminium alloy typically used in this application.

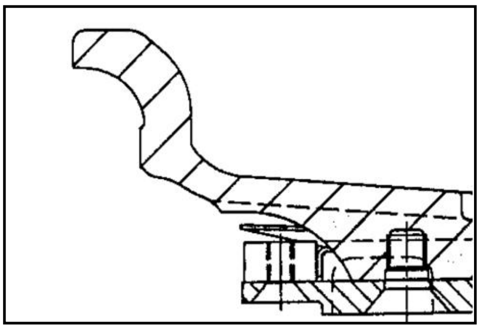
Manufacturer’s response to previous wheel failures

In April 1994, following a number of other in-service wheel failures world-wide, the wheel manufacturer published a service bulletin, *SF340-32-24*, ‘SAAB 340 Main Wheel Subassembly 5009237 and 5009237-1 Bead Seat Inspection’. The bulletin provided inspection techniques and inspection frequencies for the detection of fatigue cracking in the bead seat region.

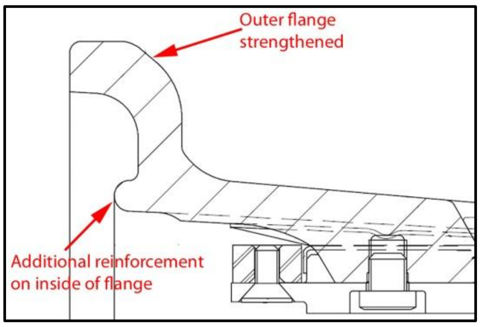
Subsequent to *SF340-32-24*, a revised main wheel assembly (part number 5010488-1) was introduced by the wheel manufacturer in December 1995. The service bulletin, *Saab 340-32-41*, detailed the introduction of the revised design and advised that the earlier main wheel assembly (part number 5010488), would no longer be supplied. The bulletin also stated that operators could continue to use the earlier assembly (serial numbers OCT95-1606 and earlier) until stock depletion. The serial number SEP92-0621 identified on the failed wheel indicated that it was the earlier (pre SB Saab 340-32-41) wheel design.

To reduce the probability of fatigue crack initiation, the revised design incorporated measures to reduce bulk stress levels in the rim region. This was achieved by an increase in the outer flange area and the use of additional reinforcement on the inside of the flange, opposite the tyre bead seat area (Figure 6).

Figure 6: Diagrams showing the difference in the original and revised wheel designs



Bead seat of the subject original wheel design, part number 5010488, image from SF340-32-24 Rev 1



Bead seat of the revised design, part number 5010488-1, image from Saab 340-32-41

Wheel maintenance

The wheel manufacturer had published instructions for examination of the subject wheel assembly in the Component Maintenance Manual (CMM)[3]. The testing required at a tyre change involved the non-destructive inspection of the bead seat area using eddy-current or ultrasonic crack detection techniques. At overhaul, it was recommended that the bead seat area be inspected using a dye penetrant method.

The introduction section of the CMM recommended that maintenance should be performed on-condition[4]. However, for the original wheel design where fatigue cracking had been identified as an issue, the CMM indicated that overhauls should be performed at maximum intervals of five tyre changes, or every 1,500 landings. Those guidelines were contained in a service letter, GS-SL-36 Revision No. 7, which had been issued by the wheel manufacturer in January 2006. The operator indicated that the overhaul schedule for all wheels in their inventory (original and revised designs) was consistent with those guidelines.

A review of the component maintenance records and the wheel bay history card display supplied by the operator, confirmed that the failed wheel had been inspected in accordance with the frequencies detailed in GS-SL-36.

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[3] Component Maintenance Manual with Illustrated Parts List, AP-724 Main Wheel Assembly, Part Number 5010488-1, 5010488-2, 5010488-3, 5010488-4 Used on Saab 340 Aircraft.

[4] On-condition is maintenance performed only when the condition of the item demands, instead of scheduled intervals.

ANALYSIS

Component failure

Failure of the left outboard main landing gear wheel from Saab 340B aircraft, VH-KDQ, was a result of the fracture and separation of a section of the inner rim in an area adjacent to the tyre bead seat. Cracking and fracture was typical of a progressive fatigue cracking mechanism, which had initiated on the internal bead seat transition radius. Fatigue cracking had propagated for approximately 100 mm circumferentially around the rim before final overstress fracture. In conventional pneumatically-pressurised wheel designs, the internal bead seat radius is typically a region of high bending stresses, and is thus predisposed to the initiation and growth of fatigue cracking. Operational stresses arising from tyre flexure during taxiing and landing can further contribute to this mechanism.

The Australian Transport Safety Bureau (ATSB) investigation found that bead seat radius fatigue cracking and failure of the original Part Number 5010488 main landing gear wheel was a known issue, with numerous prior occurrences world-wide. To improve the overall reliability of the Saab 340B main wheel assembly, the wheel manufacturer had released a revised wheel design (Part Number 5010488-1) in 1995, incorporating features aimed at extending the component fatigue life. The failed wheel from VH-KDQ was of the earlier (original) design.

Wheel inspection

The operator's maintenance records showed that the wheel had been in service for 293 flight cycles since its last overhaul, during which it underwent detailed non-destructive inspection. The wheel had been further inspected using eddy-current techniques at the time of the last tyre change, 40 flight cycles prior to the failure. Given that the wheel had been examined and no cracks were found during both those periods of maintenance, two scenarios were identified to account for a fatigue crack reaching its critical failure size without detection:

- the initiation and rapid growth of cracking in the interval since the last non-destructive inspection, or
- a crack that had already initiated at the last non-destructive inspection was not detected.

Crack growth rate information could not be reliably determined from the examined fracture surfaces. As such, it was not possible to differentiate between the identified possibilities on the basis of laboratory observations alone. However, on the basis of the relatively large size of the fatigue zone on the fracture face and the relatively low number of flight cycles since the last eddy-current inspection, the presence of fatigue cracking at the time of the last tyre change (and the failure to detect that cracking) was considered most likely.

Both the fluorescent dye penetrant and eddy-current inspection methods prescribed by the Component Maintenance Manual (CMM) were considered to be suitable methods for the detection of bead seat cracking of the nature sustained. It should be noted however, that both methods can be influenced by factors that have the effect of reducing the probability of crack detection during an inspection. Eddy current inspection, which has the advantage of not requiring the removal of surface coatings (paint), can be affected by variables such as:

- inspector skill level
- probe proximity to defect
- location/orientation of defect
- surface preparation/condition.

FINDINGS

From the evidence available, the following findings are made with respect to the left outboard main landing wheel failure from the Saab 340B aircraft and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The design of the wheel rim had been shown to be susceptible to fatigue cracking in the bead seat region. *[Minor safety issue]*
- Fatigue failure of the left outboard main landing gear, which initiated at the tyre bead seat radius, caused a section of the wheel rim to fracture leading to deflation of the tyre upon landing.
- It was probable that a juvenile fatigue crack was present at the time of the last wheel non-destructive (eddy-current) inspection, and was not detected during that inspection.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety 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 responsible organisations for the safety issues identified during this investigation were given 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.

Wheel manufacturer

Susceptibility of wheel rim design to fatigue cracking

Minor safety issue

The design of the wheel rim had been shown to be susceptible to fatigue cracking in the bead seat region.

Action taken by wheel manufacturer

In 1995, the manufacturer introduced a new main wheel assembly, which incorporated an improved bead seat radius profile that increased the fatigue resistance of the components. While the original rim assembly was no longer supplied, there was no requirement to replace the existing wheel assemblies with the new items. The manufacturer has amended the Component Maintenance Manual and issued a service letter with mandatory inspection intervals for wheels manufactured prior to October 1995.

ATSB assessment of response/action

The ATSB is satisfied that the action taken by the wheel manufacturer adequately addresses the safety issue.

Aircraft operator

Minor safety issue

The design of the wheel rim had been shown to be susceptible to fatigue cracking in the bead seat region.

Action taken by aircraft operator

In response to the occurrence, the operator conducted a review of its current wheel inspection practices and schedules. Responding to the ATSB, the operator indicated that all procedures used were found satisfactory and compliant with the wheel manufacturer's guidelines. The operator also advised that a third party audit of the non-destructive inspection (NDI) facility was commissioned and carried out, with no major deficiencies identified during that audit. Personnel qualifications and currency were also examined and found satisfactory. In view of the level of risk presented by the development of wheel cracking, and the fact that this instance of failure was the first sustained in a long history of wheel maintenance, the operator indicated they were not planning any specific revisions to their maintenance procedures and practices.

ATSB assessment of response/action

The ATSB is satisfied that the action taken by the operator adequately addresses the safety issue.

APPENDIX A: SOURCES AND SUBMISSIONS

Sources of Information

Aircraft owner and operator

Component manufacturer

References

ASM Handbook, Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International, November 1993.

Cambridge Aerospace Dictionary

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the 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 aircraft owner and operator, the wheel manufacturer and the Civil Aviation Safety Authority.

Submissions were received from the aircraft operator, the component manufacturer and the Civil Aviation Safety Authority. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

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