



**Australian Government**

**Australian Transport Safety Bureau**

**ATSB TRANSPORT SAFETY INVESTIGATION REPORT**

Aviation Occurrence Report – 200601367

Final

**Analysis of failed turbocharger turbine wheel shafts  
Garrett model TH08A  
Piper PA-31-350 aircraft VH-MZM and VH-TZY**





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### Abstract

On 4 August 2005, a Piper PA-31-350 Chieftain aircraft, registration VH-MZM, departed Dubbo Airport, NSW, for a local post-maintenance acceptance flight following an engine change. Shortly after departure, the pilot reported that the right engine manifold pressure fluctuated then dropped and maintained 28 inHg. The aircraft was returned to Dubbo with reduced power to the right engine.

Examination of the aircraft by the overhaul engineers revealed the newly-installed turbocharger turbine wheel had failed. The turbocharger was supplied to the ATSB for further examination and analysis.

During the course of the investigation, a second, similar turbine wheel failure occurred in a Piper PA-31-350, registration VH-TZY. Similarly to the first incident, the pilot observed significant manifold pressure fluctuations during cruise flight of the aircraft and the right engine was shut down. The aircraft was returned to the departure aerodrome. The turbocharger had been in service for approximately 241 hours and was subsequently forwarded to the ATSB.

Analysis of both turbine wheels revealed fracture characteristics indicative of a fatigue cracking mechanism. The failures had both occurred through a sealing ring groove, adjacent to the friction-welded joint between the turbine wheel and shaft components. While the post-failure damage of the fracture surfaces in both instances prevented the identification of the prime factor/s giving rise to the initiation of fatigue cracking, it was likely that the stress-raising effect of the ring groove location, geometry and associated microstructure, when combined with pre-existing cyclic loading conditions, was sufficient to initiate fatigue cracking and consequent turbine wheel failure.

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# THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

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 enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, 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 proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

**About ATSB investigation reports:** How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site [www.atsb.gov.au](http://www.atsb.gov.au).

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# FACTUAL INFORMATION

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## Background

On 4 August 2005, a Piper PA-31-350 Chieftain aircraft, registration VH-MZM, departed Dubbo airport, NSW, for a local post-maintenance acceptance flight following an engine change. Twelve minutes after departure, the pilot reported that the right engine manifold pressure suddenly dropped from 38 to 30 inHg, surged to 38 inHg<sup>1</sup>, before reducing to 28 inHg. The aircraft was returned to Dubbo with reduced power to the right engine.

Examination of the aircraft by the overhaul engineers revealed the newly-installed Garrett TH08A turbocharger turbine wheel had failed. The turbocharger was supplied to the ATSB for further examination and analysis.

During the course of this investigation, a second turbine wheel (also from a Garrett model TH08A) failure occurred in a Piper PA-31-350, registration VH-TZY. In this incident, the pilot observed significant manifold pressure fluctuations during cruise and the right engine was shut down. The aircraft was returned to the departure aerodrome. During the subsequent taxi, smoke was observed to be coming from the right engine, however there was no evidence of fire. This turbocharger had been in service for approximately 241 hours. This turbocharger assembly was also forwarded to the ATSB to assist in this investigation.

## *Related incidents*

A review of the Civil Aviation Safety Authority (CASA) and Federal Aviation Administration (FAA) Service Difficulty Reports between 1996 and 2006, revealed six similar turbine wheel failure incidents. These incidents included dropping of manifold pressure, turbocharger compressor/shaft failure and seizing of the turbocharger. Time since overhaul for these turbochargers ranged between one to 1,936 hours.

## Assembly information

The function of a turbocharger is to increase the density of the fuel-air charge entering the engine cylinders, resulting in increased engine output. In the case of the model TH08A turbocharger, it does this by utilising a centrifugal compressor attached by a common shaft to an exhaust-gas turbine. By regulating the amount of exhaust gas fed to the turbine wheel, the turbocharger output is controlled. Figure 1 shows the turbocharger model TH08A exploded parts diagram<sup>2</sup>.

The TH08A turbine wheel assembly from VH-MZM and VH-TZY consisted of discrete shaft and wheel components, friction welded at a location approximately 0.5" from the rear face of the turbine wheel (see figure 1). The friction welding

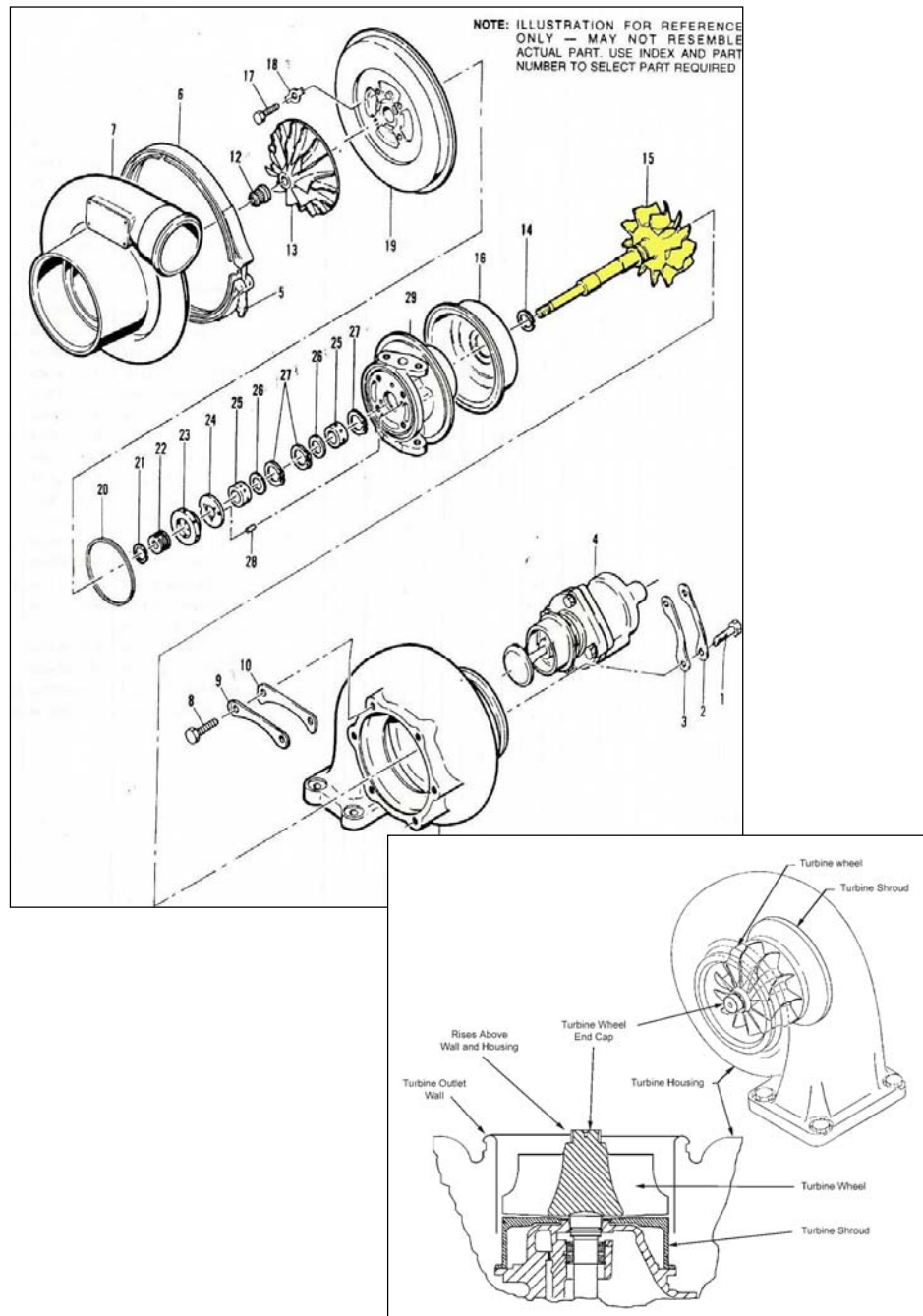
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<sup>1</sup> inHg – Inches of mercury, a measurement of barometric pressure (1 inHg = 3.386 KPa)

<sup>2</sup> Garrett Turbochargers, Turbocharger model TH08A parts manual and Kelly Aerospace Power Systems SIL A-117 (inset)

process<sup>3</sup> incorporated a heat treatment operation to relieve residual stresses induced by the welding process. Courtesy of the TH08A turbocharger's common shaft design, the compressor and turbine wheels were supported in a cantilever fashion by a centre housing assembly. Of note in the TH08A design, the turbine wheel end cap protruded slightly from the housing inlet (see inset in figure 1).

**Figure 1: Exploded parts diagram of the turbocharger assembly, model TH08A<sup>1</sup>. The turbine wheel assembly is shaded yellow.**



<sup>3</sup> Friction (inertia) weld- used for welding dissimilar and/or high temperature alloys. Materials are rotated at high speed and forced together to achieve fusion.

## Visual examination

### Fracture characteristics

Figure 2 shows the turbine wheel assemblies as received. The wheels themselves showed minimal damage, other than some discolouration and heavy blade tip rub and abrasion. Both assemblies carried the identification '406787-0010 FAA-PMA 05-04' etched on the central shaft section.

In both instances, the turbine shaft had fractured from the hub of the turbine wheel transversely through the ring groove location (adjacent to the friction weld). As far as practicable, given the damage associated with the fractures, measurements taken for both assemblies confirmed the ring groove outer diameter and width were within specified service limits, with no surface abnormalities observed.

**Figure 2: Turbine wheel components in their 'as received' condition.**



The fracture surfaces of the VH-TZY components were obscured by heavy post-failure mechanical damage, preventing any meaningful visual or microscopic interpretation.

The VH-MZM assembly fracture surfaces presented several chordwise crescent shaped features that were indicative of fatigue crack initiation and growth from an external surface origin (see figure 3). Scanning Electron Microscopy (SEM) conducted on this region confirmed the presence of fatigue features. An extensive coverage of uniform indentations or 'dimples' observed across the fracture surfaces obscured much of the finer fracture detail, limiting further examination. Those features were later confirmed as the product of a shot/bead blasting procedure carried out before the components were submitted to the ATSB. A bead of extruded material, typical of welding flash, was observed on the wheel side of the fracture between the shaft bore and the limit of the welded section.

### Shaft bearings

The TH08A turbocharger main shaft was supported by two aluminium alloy plain metal bearings located within the centre housing. The bearings from both examined assemblies showed light circumferential surface scoring and moderate plastic

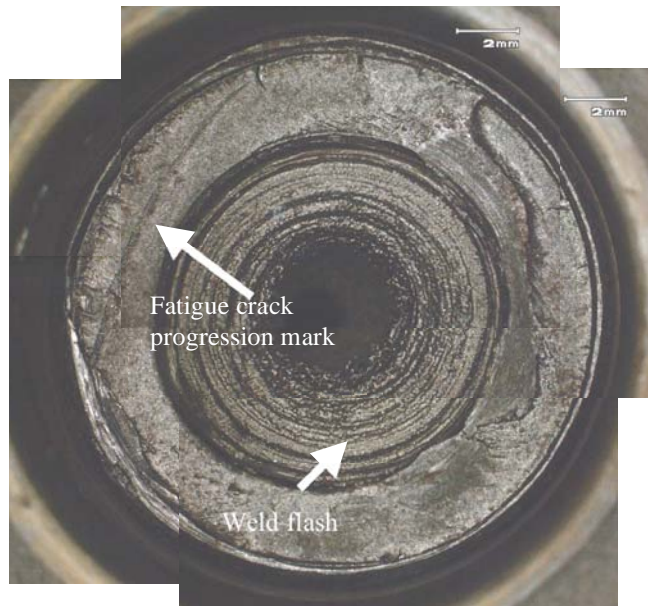
deformation and distress. There was no evidence of thermal distress, overheating, adhesive wear (galling) or other indications of lubrication inadequacy.

The internal diameters of the turbine and compressor end bearings from both VH-MZM and VH-TZY centre housings were measured in situ, with results presented in Table 1. The manufacturer’s maintenance documentation for the turbocharger specified a minimum shaft journal diameter of 0.6251” and a maximum bearing internal diameter of 0.6272”, producing a lateral float limit of 0.00105”. Although not specified in the manufacturer’s component overhaul manuals, the maintenance provider for the two turbochargers indicated that the units typically exhibit a 0.0470” clearance between the turbine blade tips and housing walls.

**Table 1: Shaft and bearing measurements (post failure) and calculated lateral float (measurements in inches)**

	VH-MZM		VH-TZY	
	Turbine End	Comp. End	Turbine End	Comp. End
Shaft journals	0.6245 – 0.6250	0.6245 – 0.6250	0.6250 – 0.6250	0.6250 – 0.6250
Bearings (ID)	0.6490 – 0.6525	0.6705 – 0.6775	0.6800 – 0.6825	0.7005 – 0.7145
Float (max)	0.0140	0.0265	0.0287	0.0447

**Figure 3: Fracture surface features of the turbine wheel component (VH-MZM).**



## Material characterisation

### Chemical composition

Chemical analyses<sup>4</sup> of the turbine wheel and shaft components from the VH-MZM turbocharger were coordinated by the maintenance provider, with results supplied to the ATSB (see tables 2 and 3). From the analyses, it was evident that the turbine shaft had been manufactured from a wrought medium-carbon Cr-Mo alloy steel, similar in chemistry to a UNS 4140 grade. The turbine wheel presented as a Nickel based superalloy, approximating the chemical composition of a GMR-235 precipitation-hardening high temperature casting alloy.

**Table 2: Chemical Composition of the turbine wheel shaft (weight %)**

Element	Fe	C	Mn	Si	S	P	Cr	Mo
Max	Balance	0.39	0.86	0.25	0.009	0.009	1.05	0.20

**Table 3: Chemical composition of the turbine wheel rotor (weight %)**

Element	Ni	Cr	Fe	Mo	Mn	Si	C	Al	Ti
Max	Balance	15.0	10.9	4.60	0.31	0.35	0.05	3.30	1.90

### Microstructural examination

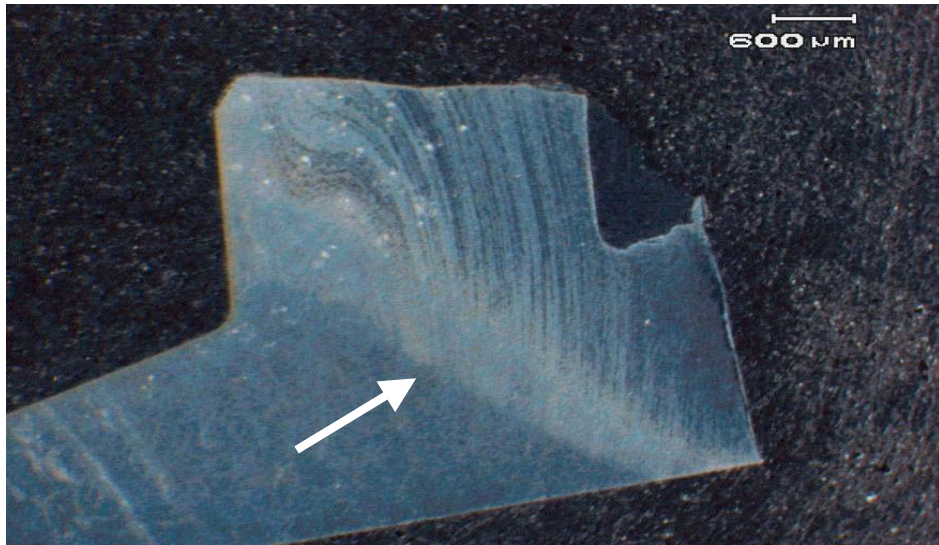
Several axially-oriented cross-sections were taken through the region of failure of the VH-MZM turbine wheel and prepared for metallographic examination. Initial study confirmed the fracture to have originated within the recessed shaft ring groove, located approximately 0.120" from the fusion boundary of the weld between shaft and turbine wheel, see figure 5. The microstructure of the alloy steel material in the vicinity of the failure presented as a fine, tempered martensite, with some evidence of thermally-induced transformation effects, consistent with the weld heat-affected zone (HAZ), or frictional heating post-failure (see figure 4). The weld fusion boundary showed no evidence of incomplete fusion or other entrained defects.

The turbine wheel parent material showed a homogeneous fine cored (dendritic) microstructure, consistent with the nickel alloy material and production of the wheel as a casting.

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<sup>4</sup> Analysis conducted by Pearl Street Energy Services ETRS, NATA approved laboratory.

**Figure 4: Thermally affected region adjacent to shaft fracture**



### Hardness profile

A hardness profile was taken between the hub of the turbine wheel and the shaft, across the fracture region (see figure 5). Sixteen hardness readings in total were taken, approximately 2 mm from the outer edges of the sample. Hardness measurements were compared to those taken from the alloy steel parent material (remote from the weld region), with results presented in figure 6.

The graphical representation shows the variation in hardness across the fracture zone, with the values obtained correlating with the microstructural observations. The nominal 370 – 380 HV shaft parent metal hardness was as expected and consistent with the alloy having undergone a hardening and tempering heat-treatment.

**Figure 5: Micro-section with features and location of hardness profile indicated**

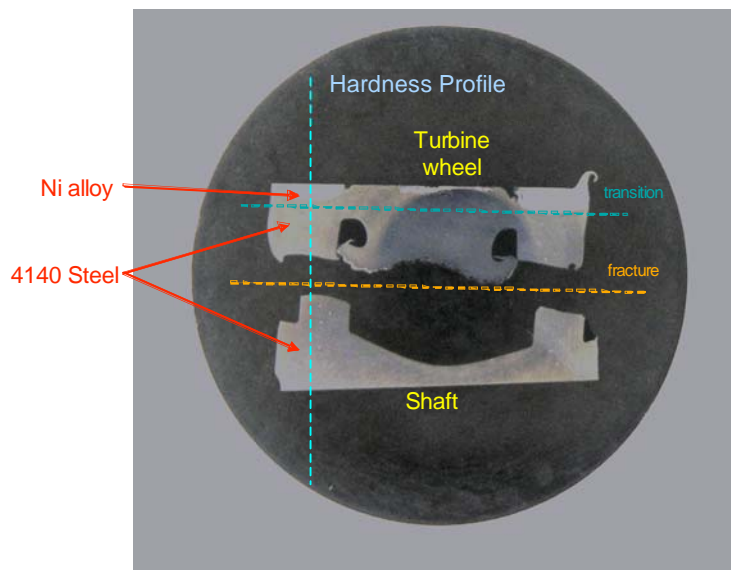
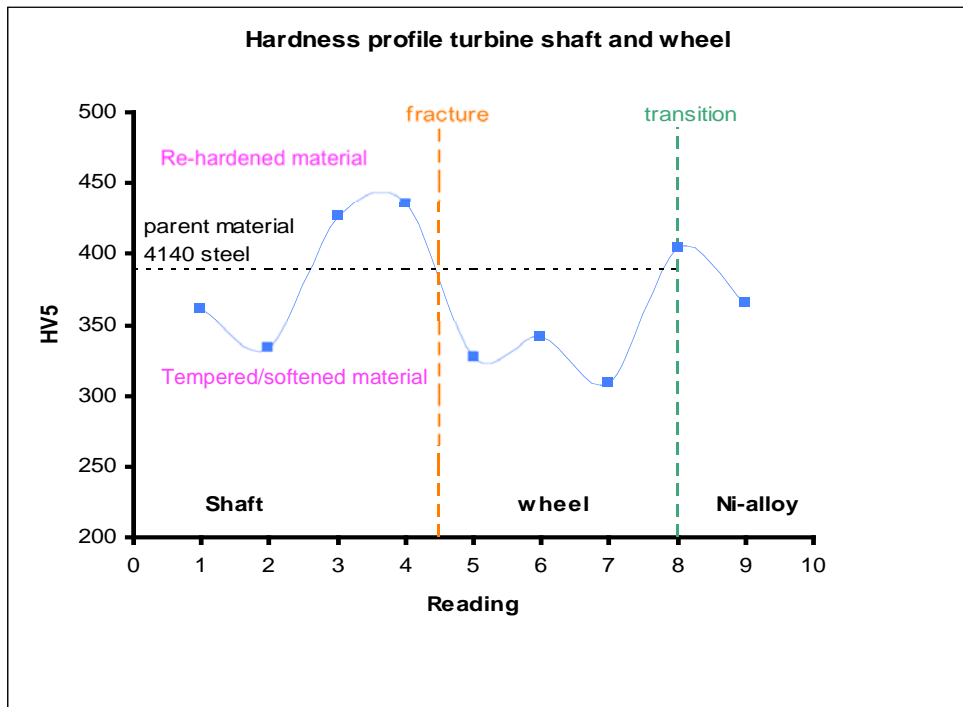


Figure 6: Hardness measurements from profile



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## ANALYSIS

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While the examination was limited by the degree of post-failure damage, it was evident that the turbine wheel/shaft assemblies from both VH-MZM and VH-TZY turbochargers had fractured as a result of a bending fatigue cracking mechanism.

The fractures occurred at a design change in cross-section associated with a sealing ring groove, and had propagated under unidirectional bending loads. The shaft ring groove was located adjacent to the friction weld between the turbine wheel and shaft. Changes in microstructure and hardness observed around the fracture region were considered to be associated with the HAZ of this weld and the frictional effects of post-failure mechanical damage. There were no material defects/inconsistencies or gross surface abnormalities identified near the fracture region that were potentially contributory to the failure.

In the event of a mass imbalance or lateral misalignment condition existing or developing within the turbocharger rotor, the single-point cantilever support of the turbine produces dynamic bending stresses within the shaft section, outboard of the centre housing bearing. Under such conditions, the combined stress-raising effects of the ring groove cross-sectional change, the groove corner profile and the local metallurgical effects of the proximal weld and HAZ, were considered to have predisposed the turbocharger shafts to the localised initiation and propagation of fatigue cracking in the manner observed.

While imbalance or misalignment conditions within the turbocharger rotor assembly could arise from numerous sources, including shaft/rotor damage, or heavy bearing wear, the absence of any conclusive evidence of such meant that the investigation could not be conclusive in this regard. Although bearing wear within both assemblies was in excess of the serviceable limits, it was likely that this resulted from the abnormal conditions associated with the failure event. Similarly, all damage presented by the turbine wheels and shafts was consistent with the mechanical interference and distress associated with the failure events.

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## **FINDINGS**

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### **Contributing safety factors**

The incorporation of a square-edged sealing ring groove within the TH08A turbocharger turbine shaft design (outboard of the shaft support bearing and adjacent to a welded joint between the shaft and turbine wheel), predisposed the shaft to fatigue failure in that location, by providing for the concentration and elevation of any rotationally-induced bending stresses that may arise from imbalance, misalignment or other conditions that could produce dynamic shaft loading.

### **Other key findings**

Neither of the failures in the turbocharger assemblies from VH-MZM or VH-TZY could be attributed to deficiencies within the manufacturing process or materials of fabrication.

There was no evidence to suggest that either unit had been inadequately maintained or operated in such a way as to promote premature failure.

The Garrett TH08A turbocharger turbine wheel assembly, by virtue of its design, is predisposed to damage due to rough or improper handling. That damage may come about through loads inadvertently placed on the turbine wheel end cap, which protrudes beyond the turbine housing and outlet wall. Damage sustained as such, could predispose the turbocharger to failure in the manner presented by the units from VH-MZM and VH-TZY. There was, however, no direct evidence to indicate that either of the units in question had sustained such damage.

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## **SAFETY ACTION**

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On 28 November 2006, the turbocharger manufacturer (Kelly Aerospace Power Systems) released Service Information Letter (SIL) number A-117, providing general recommendations for the handling of TH08A series turbocharger assemblies. The service letter detailed the safety issue resulting from the extension of the turbine wheel end cap beyond the housing, and presented recommendations for the handling, assembly, disassembly and shipping of the turbocharger units, so as to minimise the likelihood of damage to the wheel and shaft components.

Given that shaft or wheel damage could contribute to the type of in-service failures sustained by the units from VH-MZM and VH-TZY, it is likely that adherence to the requirements of the SIL will reduce the risk of this type of failure occurring in the future.



