Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation
AI-2009-008
Final

Reliability of Piper PA-31-350 aircraft engine turbocharger units

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Postal address: PO Box 967. Civic Square ACT 2608
Office location: 62 Northbourne Ave, Canberra City, Australian Capital Territory, 2601
Telephone: 1800 020 616, from overseas +61 2 6257 4150
Accident and incident notification: 1800 011 034 (24 hours)
Facsimile: 02 6247 3117, from overseas +61 2 6247 3117
Email: atsbinfo@atsb.gov.au
Internet: www.atsb.gov.au

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Prepared By

Australian Transport Safety Bureau
PO Box 967, Civic Square ACT 2608 Australia
www.atsb.gov.au

Abstract

Following a number of accidents and serious incidents involving Piper Chieftain PA-31-350 aircraft where a failure of one of the engine turbochargers had been central to the occurrence events, the Australian Transport Safety Bureau (ATSB) initiated a safety investigation into the broader issue of PA-31-350 turbocharger operational reliability.

In all of the principal occurrences, the turbocharger turbine wheel had separated from its central shaft. Metallurgical examination of the separated turbine wheel assemblies did not reveal any material/manufacturing anomalies that may have contributed to the failures.

During the course of the investigation, a number of other turbocharger related occurrences were identified. Most of the occurrences had resulted in a reduction in engine power which led to a range of outcomes, including engine shutdown, air returns, and diversions.

While in some occurrences, failure was the result of the separation of the turbine wheel from the turbine shaft, the investigation showed that turbocharger failure could arise from a number of causes, including lubrication issues and foreign object damage. It is likely that some of these mechanisms are interrelated, i.e. fatigue failure of the turbocharger shaft following bearing damage from an interruption or contamination of the oil supply.

No single contributory factor or common set of factors was identified across the failures examined.

Published literature has shown that turbocharger reliability can be significantly enhanced by ensuring that engine, aircraft and turbocharger manufacturer's operational procedures are closely followed – particularly in respect of the application and/or reduction of engine power levels. Specific maintenance attention to the turbocharger lubrication system is also important to ensure preservation and reliable operation of the turbocharger bearings.

Pilots of aircraft powered by turbocharged powerplants are reminded that a failure of the turbocharger system should not result in the complete loss of power from the affected engine. Attention is drawn to a US Federal Aviation Administration, Special Airworthiness Information Bulletin (SAIB) CE-09-11, which provides information for air crew on what to do in the event of a turbocharger malfunction or failure. A copy of that bulletin is included as Appendix B to this report.

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.

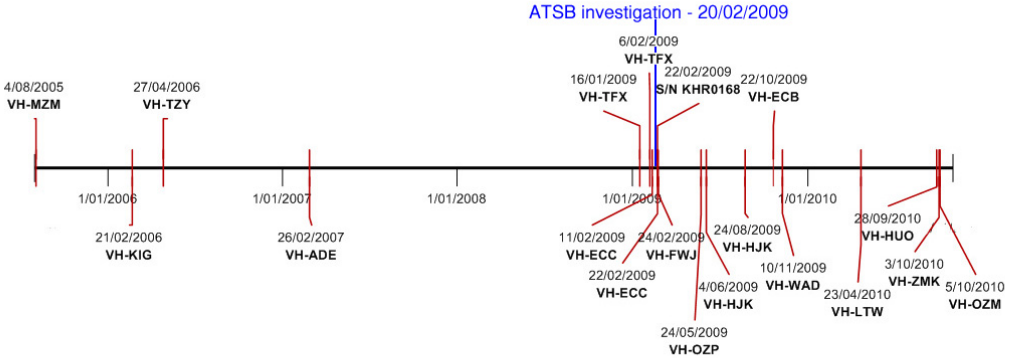
FACTUAL INFORMATION

Background

Following a number of occurrences involving turbochargers on Piper PA-31-350 aircraft, where failure of the turbocharger turbine wheel/shaft had been a contributing factor, the Australian Transport Safety Bureau (ATSB) initiated a safety investigation into the broader issue of PA-31-350 turbocharger operational reliability.

The investigation initially involved a materials failure investigation of the turbine wheel/shaft assemblies to investigate the possibility of a manufacturing or maintenance-related issue with this component. However, during the course of that work, a number of other occurrences involving failure of the turbocharger were recorded and are summarised in the following timeline (Figure 1).

Figure 1: Timeline of turbocharger events recorded for Piper PA31-350 aircraft



The occurrences above the line involved separation of the turbine wheel from the shaft. Those below the timeline were occurrences where failure occurred for other reasons and separation of the turbine wheel had not occurred. The ATSB did not examine the turbochargers from the majority of the failures and relied upon the engineering reports submitted by the involved parties. The failed turbochargers from VH-MZM and VH-TZY had previously been investigated by the ATSB (report 200601367).

Table 1 includes additional details on the above failures, including time in service where available, location and phase of flight.

Table 1: Summary of turbocharger failures

Registration	Turbo serial number	Time in service	Location	Phase of flight	Effect on flight
VH-MZM	GGR00460	0	Dubbo, NSW	Climb	precautionary landing
VH-KIG	-	-	Moorabbin, Vic	Climb (4000ft)	engine shut down - return to departure aerodrome.
VH-TZY	FAR1635	241	Hobart, Tas	Climb (9000ft)	engine shut down - return to departure aerodrome.
-	KFR00103	2.7	USA	-	-
-	LDR00320	2.5	USA	-	-
VH-ADE	-	200 to retirement	Geraldton, WA	Climb (200ft)	precautionary landing
VH-TFX	YEO30243	0.3	Darwin, NT	Climb (3500ft)	return to departure aerodrome
VH-TFX	FCR2123	new	Darwin, NT	Takeoff (aircraft failed to climb)	ditched
VH-ECC	-	<1	Dysart, QLD	Climb (5000ft)	engine shut down - continued to destination.
VH-ECC	-	<2.5	Hervey Bay, QLD	Climb (6500ft)	diversion
VH-FWJ	-	-	Swan Hill, QLD	Climb	return to departure aerodrome
-	KHR0168	-	-	-	
VH-OZP	LDR00322	11.7	Marree, SA	Climb (500ft)	return to departure aerodrome
VH-HJK	DFN00242	1771	Cessnock, NSW	Cruise (9000ft)	return to departure aerodrome
VH-HJK	-	-	Marree, SA	Top of climb - transition to cruise (9500ft)	diversion
VH-ECB	CDN00747	727	Townsville, QLD	Climb (8300ft)	return to departure aerodrome
VH-WAD	-	8.9	Grafton, NSW	Cruise (10000ft)	diversion

VH-LTW	-	-	Launceston, Tas	Climb (7000ft)	continued to destination
VH-HUO	JDR00472	1042.4	Inverell, NSW	Takeoff	return to departure aerodrome
VH-ZMK	-	-	Mackay, QLD	Takeoff	rejected takeoff
VH-OZM	-	591	Canberra, ACT	Landing	shut down on taxiway

Table cells marked '-' indicate that the information was unknown or unavailable.

The most common reasons for the turbocharger failures provided to the ATSB included shaft seizure, bearing failure or seal leakage. It was often difficult to ascertain an exact reason for the failure, as the majority of the turbochargers were returned directly to the manufacturer as a complete unit for replacement.

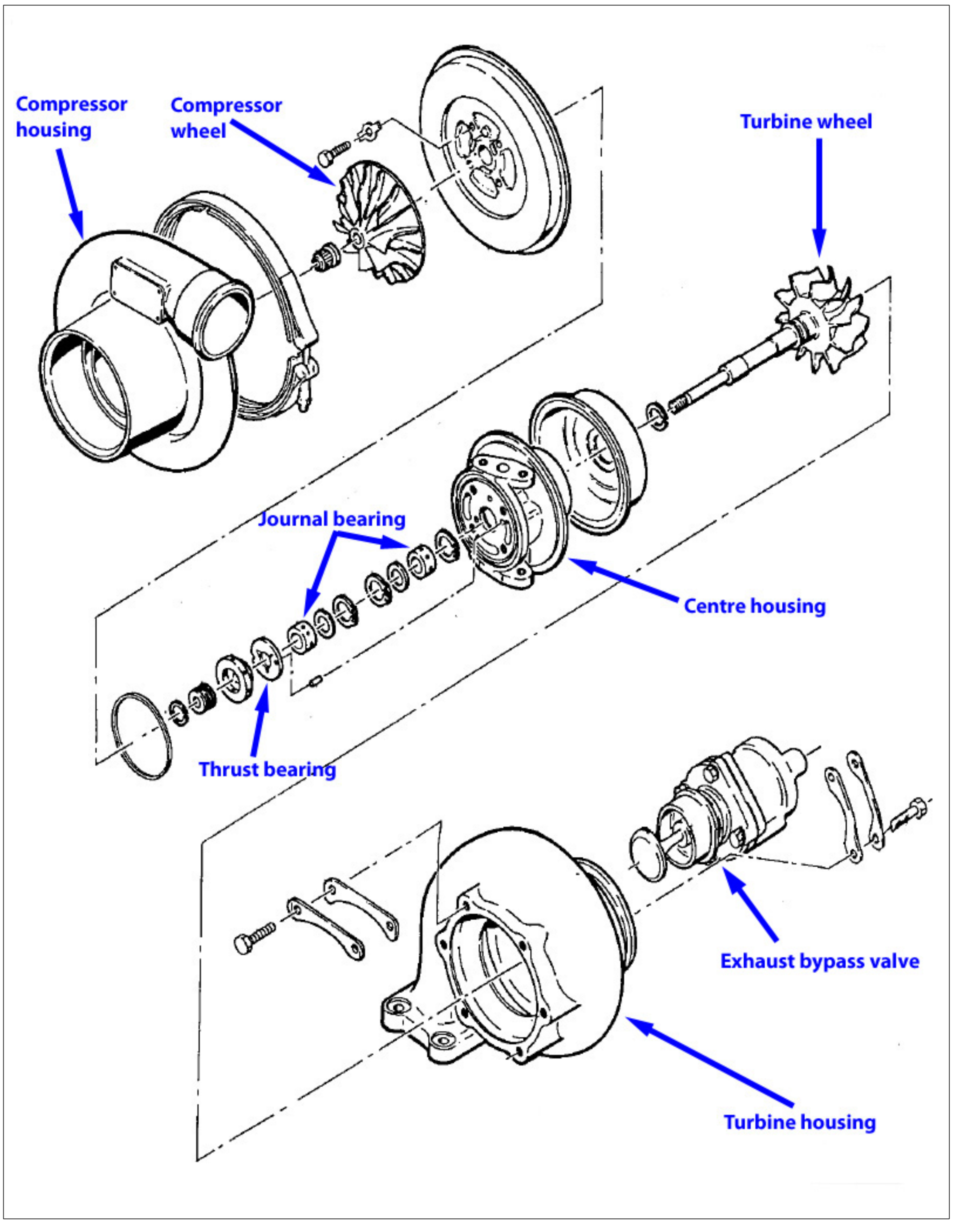
Turbocharger system description

The Piper PA-31-350 aircraft engine, a Lycoming TIO-540-J2BD, is equipped with a Kelly Aerospace TH08A series turbocharger, part number 409170-1. The turbocharger unit is the principal component in the engine forced-induction system and serves to increase engine power output by compressing the air entering the engine combustion chambers. The turbocharger control systems act to maintain a desired manifold pressure at a given throttle setting, regardless of varying conditions of ambient air temperature and pressure.

In the case of the model TH08A turbocharger, a centrifugal compressor is attached by a common shaft to a centrifugal exhaust-gas turbine. The turbocharger output is controlled by the bypass valve assembly, which regulates the amount of exhaust gas fed to the turbine wheel.

Figure 2 shows the turbocharger exploded parts diagram.

Figure 2: Exploded view of turbocharger model TH08A[1]



The turbine wheel is supplied as a single unit and comprises a nickel-based high-temperature alloy rotor, inertia/friction welded to an alloy steel shaft.

The turbocharger manufacturer indicated that it had sold a total of 4,803 turbine wheels of part number 406787-0010 from March 2001 to February 2009. This included individual component sales and turbine wheels installed in new and factory rebuilt engines.

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[1] Kelly Aerospace Power Systems, Overhaul Manual – 400 Series Turbocharger, Part Number 400600-000, Figure 2.30 – Series TH08 Turbocharger.

Turbocharger examination

The following turbochargers, which had failed by separation of the turbine wheel from the shaft, were retained by the ATSB for examination. The details of these units are listed below, together with the aircraft registration and the date of the occurrence;

- Serial number: YEO30243 (ex VH-TFX, 16 January 2009)
- Serial number: FCR2123 (ex VH-TFX, 6 February 2009)
- Serial number: CDN00747 (ex VH-ECB, 22 October 2009)

Background to the occurrences

Serial Number YEO30243

Turbocharger serial number YEO30243 failed while fitted to the right engine of PA-31-350 aircraft, registered VH-TFX.

On 16th January 2009, the aircraft was scheduled to conduct a private, instrument flight rules (IFR) flight from Darwin to Groote Eylandt, Northern Territory. There were four passengers and the pilot on-board. The pilot reported that pre-flight inspection and engine run-up on the morning of the flight revealed no abnormalities. At approximately 1745 CST[2] the aircraft departed from Darwin Airport on runway 29. While passing 3,500 ft on climb to 9,000 ft, the pilot reported observing the right engine manifold pressure (MP) dropping to 26 inches of mercury (inHg). When the throttle was increased to full, the MP slowly dropped to 24 inHg. Darwin air traffic control was then notified, and the passengers were briefed. A visual landing was conducted at Darwin on runway 29, without further incident.

The right engine turbocharger was disassembled at an overhaul facility prior to its arrival at the ATSB's Canberra technical facilities. The engineering report received by the operator noted that an oil supply inspection was carried out and found to be satisfactory.

Information provided by the operator indicated that the turbocharger had a time since overhaul (TSO) of less than 1 hour when the failure occurred.

The turbocharger had the following markings on the identification plate attached to the turbine housing;

FACTORY OVERHAULED	BRG SIZE 00-00
TURBOCHARGER	S/N YEO32043
CUSTOMER P/N LW12463	
M/N TH08A60	GARRETT P/N 409170-9001
Garrett Turbochargers	Allied Signal AUTOMOTIVE

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[2] Central Standard Time (CST) was Coordinated Universal Time (UTC) + 9:30 hours.

Serial Number FCR2123

Turbocharger serial number FCR2123 also failed while fitted to the right engine of VH-TFX; this failure occurring on 6 February 2009. The aircraft was on departure from Darwin Aerodrome, Northern Territory at approximately 0830 CST when the right engine gradually lost power. The aircraft failed to climb, and as power decreased further, the pilot shut the right engine down and feathered the propeller. The aircraft was unable to maintain altitude, and gradually descended before the pilot elected to ditch the aircraft into Darwin Harbour. The pilot and 5 passengers all safely escaped the aircraft and walked to shore in knee-deep water. No injuries were reported.

The turbocharger was removed from the aircraft and sent to the ATSB's Canberra facilities in the assembled condition.

The following information was included on the data plate attached to the turbine housing;

> FIELD OVERHAULED
> TURBOCHARGER SERIAL No. FCR2123
> Customer Part No. LW-12463
> Model No. TH08A60 Part No. 409170-9001
> Aerocomponents

Serial Number CDN00747

Turbocharger serial number CDN00747 was removed from a Piper PA31-350 aircraft, registered VH-ECB, following an incident that occurred on 22 October 2009. During climb after departure from Townsville Airport, the pilot reported a drop in the right engine manifold pressure. The pilot increased power on the left engine in an effort to maintain height; however, the aircraft continued to descend and the pilot elected to return to Townsville.

The turbocharger was removed from the aircraft and sent to the ATSB's Canberra facilities for further examination.

Information provided by the operator indicated that the turbocharger had a TSO of 727 hours at the time of the failure.

The following information was obtained from the data plate attached to the turbine housing;

> FACTORY REBUILT
> TURBOCHARGER S/N CDN00747
> LW12463-85
> M/N TH08A60 P/N 409170-9001
> RAJAY TURBOCHARGER KELLY AEROSPACE

Component examinations

Turbine wheels and shafts

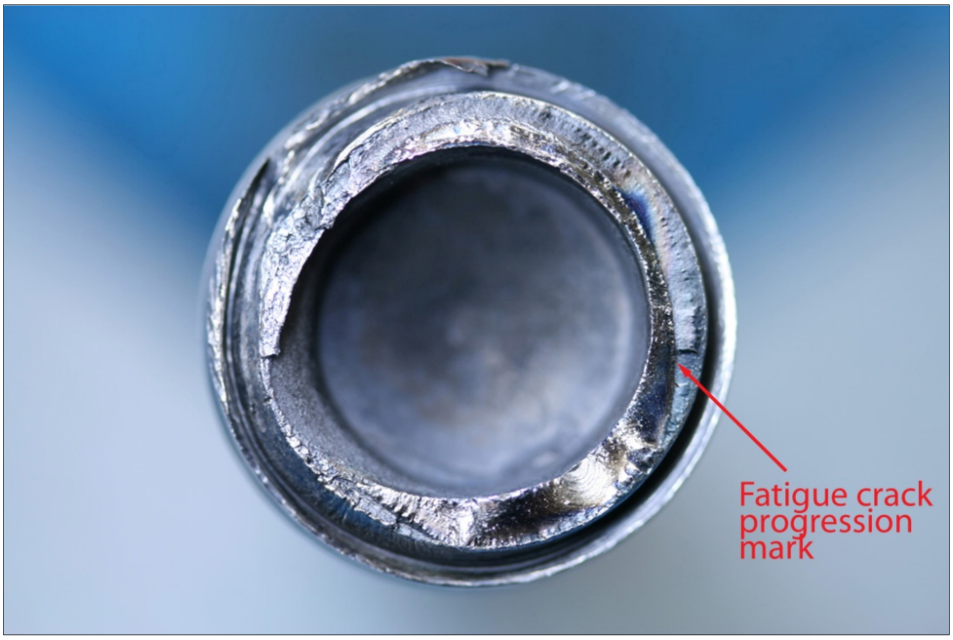
In all three occurrences, the turbine shaft had fractured from the turbine wheel transversely through the sealing ring groove location (adjacent to the shaft/rotor friction weld). Measurements taken on all assemblies confirmed the ring groove outer diameter and width were consistent with the serviceable dimensions; however, representative measurements were difficult to obtain due to the damage associated with the failure. No evidence of surface abnormalities or pre-existing damage was observed at any location.

The turbine wheels showed minimal damage, other than some discolouration and blade tip rub and abrasion.

While the fracture surfaces of all components were obscured by heavy post-failure mechanical damage, the surfaces of the turbine wheel on YEO30243 contained areas of original fracture and were selected for further examination.

The YEO30243 assembly fracture surfaces presented several chordwise, crescent-shaped features that were indicative of fatigue crack initiation and growth from an external surface origin (Figure 3).

Figure 3: Fracture surface (shaft) of turbine wheel YEO30243.



Scanning Electron Microscopy (SEM) conducted on this region confirmed the presence of fatigue features, and the extensive damage to the surfaces in some areas.

The material properties of the wheel and shaft components, including chemical analysis, microstructure and hardness, were consistent with the material types specified by the manufacturer. No physical or metallurgical anomalies were observed within the inertia-welded joint that could have led to an increased propensity for failure at this location (refer to Appendix A for further detail).

Bearings

Both the compressor and turbine-end shaft bearings were removed from YEO30243; however, due to the damage sustained by FCR2123 or CDN00747, these bearings were unable to be removed from the housing without causing further damage.

Both bearings removed from YEO30243 appeared to be in relatively good condition. The oil holes appeared free and clear, with evidence of the original chamfered surface visible on the internal surface, which indicated that the bearings had sustained little wear.

The compressor-end bearing from FCR2123 and CDN00747 (visible from the outside of the centre housing) appeared to exhibit significant wear and distortion of the internal diameter, with noticeable smearing of the internal surfaces.

A metrological study of the bearings compared to data in overhaul manual was performed; with most of the bearing internal diameters exceeding the serviceable limits (refer to Appendix A for full results).

Previous failure investigations

A previous ATSB investigation (200601367) into two earlier turbine wheel/shaft separations identified the piston ring groove as a stress raiser, which increased the propensity for a fatigue failure at that location when exposed to cyclic loading conditions. It also found that neither of the failures were attributable to manufacturing anomalies, inadequate maintenance or incorrect operation.

From December 2000 to February 2009, the manufacturer was aware of a total of eight head/shaft separations (four in Australia) involving all TH08 series turbochargers that incorporate this and other wheel assemblies.

The turbocharger manufacturer made available a number of investigation reports from these previous turbine wheel/shaft failures. The findings attributed failure to foreign object damage (FOD) or lack of lubrication / insufficient lubrication at some time during operation.

The FOD conclusion was reached based on the damage sustained by the turbocharger, which included blade fractures, deformation and loss of material. This resulted in an out of balance condition, torsional vibrations and rotor instability, which led to rapid bearing wear and shaft fracture.

The lubrication issues were evidenced by the heat soaking and discolouration of the shaft at the turbine journal diameter and excessive wear of the turbine journal bearing inside diameter.

Assembly and overhaul

The three turbocharger units examined by the ATSB as part of this investigation had been overhauled at a facility in Queensland, Australia. The overhaul facility was approved by the Australian Civil Aviation Safety Authority (CASA), and the authorised release certificates for each of the turbochargers were made available to the ATSB.

There were only a small number of turbocharger overhaul facilities operating in Australia, with the majority of replacement turbochargers purchased as complete units from the manufacturer through their sole supplier. The supplier advised the investigation that they were an importer and distributor only, and that in the case of warranty claims or quality control issues, the components were forwarded back to the manufacturer.

A review of the overhaul facility's documented practices and procedures found no evidence of any activities or omissions that could have contributed to the reliability issues experienced. The facility followed the instructions in the manufacturer's overhaul manual (OHM), had good record keeping practices and had knowledge and experience in dealing with turbochargers. During discussions with representatives from the overhaul facility, the following items were highlighted;

- The overhaul facility purchased complete new turbocharger assemblies in order to use the parts for overhaul of similar units.
- Upon receipt of turbine wheels for overhaul, the facility completed a 100% external inspection, which included a visual examination for chips and dents, measurement of the ring groove and bearing journals, straightness, and balancing left and right. The part was not accepted for overhaul and given a 'goods received number' (GRN) until it had passed these checks and inspections.
- The procedures specified in the manual for balancing the assembly were followed using a digital balancing machine. It was reported that the balancing procedure was carried out at 85,000 rpm and was performed at several stages during the assembly process, including after the locknut was secured on the end of the compressor wheel. Although not required by the manufacturer's procedures, balancing was performed at this stage as it had been found that nut tensioning could affect the overall assembly balance. The results of any balancing activities were recorded.
- The overhaul organisation had only encountered wheel/shaft separations with the turbochargers from Piper Chieftain aircraft (PA-31-350). These aircraft have one of the largest and highest-capacity aviation turbochargers fitted, with the units mounted as an integral part of the engine assembly.

It was further mentioned by the overhaul facility that it was routine procedure to perform balance checks on any complete turbochargers supplied by the manufacturer prior to resale or installation.

Operational procedures

A research of the available literature highlighted the importance of correct turbocharger operation. Over-boost conditions, i.e. excessive manifold pressures, have been shown to be detrimental to the life and performance of the engine, and in severe cases, could require major overhaul of the engine and crankshaft replacement.

The Piper PA-31-350 Pilot Operating Handbook (POH) and a number of articles released by the manufacturer were consistent in the operational advice provided to pilots regarding turbocharger operation. The main points of note were:

> *The throttle or throttles must be operated smoothly or the engines will surge, which is hard on the turbocharger and the engine. For a turbocharger with an automatic control system, all elements of the system must stabilise following any movement of the throttle. The control system is designed to prevent over-boost, but there can be a certain amount of overshoot. Good advice is to move the throttle controls slowly and wait.*
>
> *The power sequence is very important with the turbocharged engine. To increase power, enrich mixture, increase RPM then MP* [manifold pressure]. *To decrease power, decrease MP, then RPM.*
>
> *High altitude flight means higher turbine speeds and hotter cylinder head temperatures.*
>
> *Following landing, the minimum necessary taxi power will aid in engine cool down. Extending the ground idle cooling period reduces the turbocharger temperature and reduces the tendency of turbo coking*[3] *following hot engine shutdown. Ideally a five minute minimum cooling period is desirable.*[4]

Service Documentation

A number of service documents related to the TH08A turbocharger model were identified during the course of the investigation.

Kelly Aerospace (KAES), Service Information Letter (SIL) A-117, *General recommendations for TH08A series turbocharger handling*, was issued on 28 November 2006. The SIL explained that the TH08A series turbochargers exhibit a characteristic where the turbine wheel assembly end cap extends beyond the turbine housing and the turbine outlet wall dimensions, and as such was susceptible to damage from rough or improper handling. The SIL contained instructions on transport and storage to eliminate bumps/shocks that may cause the turbocharger to go out of balance. The letter also noted the use of packaging and cardboard to provide additional shock absorption.

The Federal Aviation Administration (FAA) released Special Airworthiness Information Bulletin (SAIB), CE-09-11, *Turbocharged engines* on 9 February 2009 (Appendix B). The SAIB was the result of an accident in the United States, where failure of a turbocharger was identified as a contributing factor. The SAIB was issued to provide information to registered owners and operators of aircraft with turbocharged engines of appropriate and recommended actions in the event that the aircraft sustains a turbocharger system malfunction or failure during flight.

KAES Service Bulletin (SB) No. 039, *Turbine wheel replacement*, was issued on 10 November 2009, and CASA followed up with an Airworthiness Bulletin (AWB) 81-001, *Kelly Aerospace – Turbocharger turbine wheel replacement,* on 28 January 2010. The bulletin stated that KAES had become aware of an in-house processing condition affecting some turbine wheel assemblies reclaimed for a number of rebuilt turbocharger models. It further stated that the failure may result in an inoperable turbocharger and partial or total loss of engine oil. As field inspection of

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[3] Coking occurs because the surface temperatures and oil residence times are both higher than the stability limitations of the oil.

[4] Lycoming, *Lycoming Flyer Key Reprints, Chapter 3 – Operations*, Issue number 53, pp 57-61.

the turbine wheel for a suspect condition was not feasible, the bulletin stated that turbochargers must be removed and evaluated using specialised equipment not generally available in most repair centres. The bulletin also cautioned that continued operation of the turbocharger with a suspect turbine wheel may result in a complete loss of turbocharger function without warning, causing a partial or total loss of engine power.

The SB mandated the removal and replacement of suspect turbine wheel assemblies as installed by KAES between January 2007 and June 2009, and provided a list of affected part and serial numbers. Three of the turbochargers listed in Table 1 were identified as having serial numbers that may have been affected by the processing condition.

An accompanying FAA Airworthiness Directive (AD 2010-07-08) was also issued which provided some additional information to the KAES SB. The AD stated that KAES had become aware that a steel wire brush had been used to remove accumulated coking during turbocharger overhaul. The cleaning process may have created a rough surface finish that could have disrupted the required formation of a hydrodynamic layer of oil between the shaft and bearings.

In February 2009, the turbocharger manufacturer released revision A of its overhaul manual for the TH08A turbocharger assembly. That revision called for mandatory replacement of the turbine wheel and shaft at overhaul, rather than cleaning, inspection and return-to-service as previously permitted.

ANALYSIS

Turbine wheel/shaft separation failures

While the examination of the turbocharger turbine wheel/shaft assemblies was limited by the degree of post-failure damage, it was evident that the components from turbocharger serial number YEO30243 had fractured as a result of a bending fatigue cracking mechanism.

The fractures were coincident with a change in cross-section associated with a sealing ring groove, and had propagated under unidirectional bending loads. 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 an imbalance or misalignment condition existing or developing within the turbocharger rotor, the cantilever support of the turbine wheel assembly induces 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 corner profile, and the local metallurgical effects of the weld and heat affected zone, would have increased the propensity for cracking in this location.

It was considered that imbalance or misalignment conditions within the turbocharger rotor assembly could arise from numerous sources, including shaft/rotor damage, lubrication issues, or heavy bearing wear. The damage sustained by the examined turbine wheels meant that the investigation could not be conclusive in this regard. Although the bearing wear was in excess of the limits proscribed in the overhaul manual, it was likely that this occurred following separation of the turbine wheel from the shaft.

Evaluation of turbocharger failures

During the course of the investigation, a number of turbocharger failures involving Piper Chieftain PA-31-350 aircraft were identified. Data from engineering reports was collected on each of the failures to ascertain whether there was any relationship between events and, as such, identity the existence of any common safety issues.

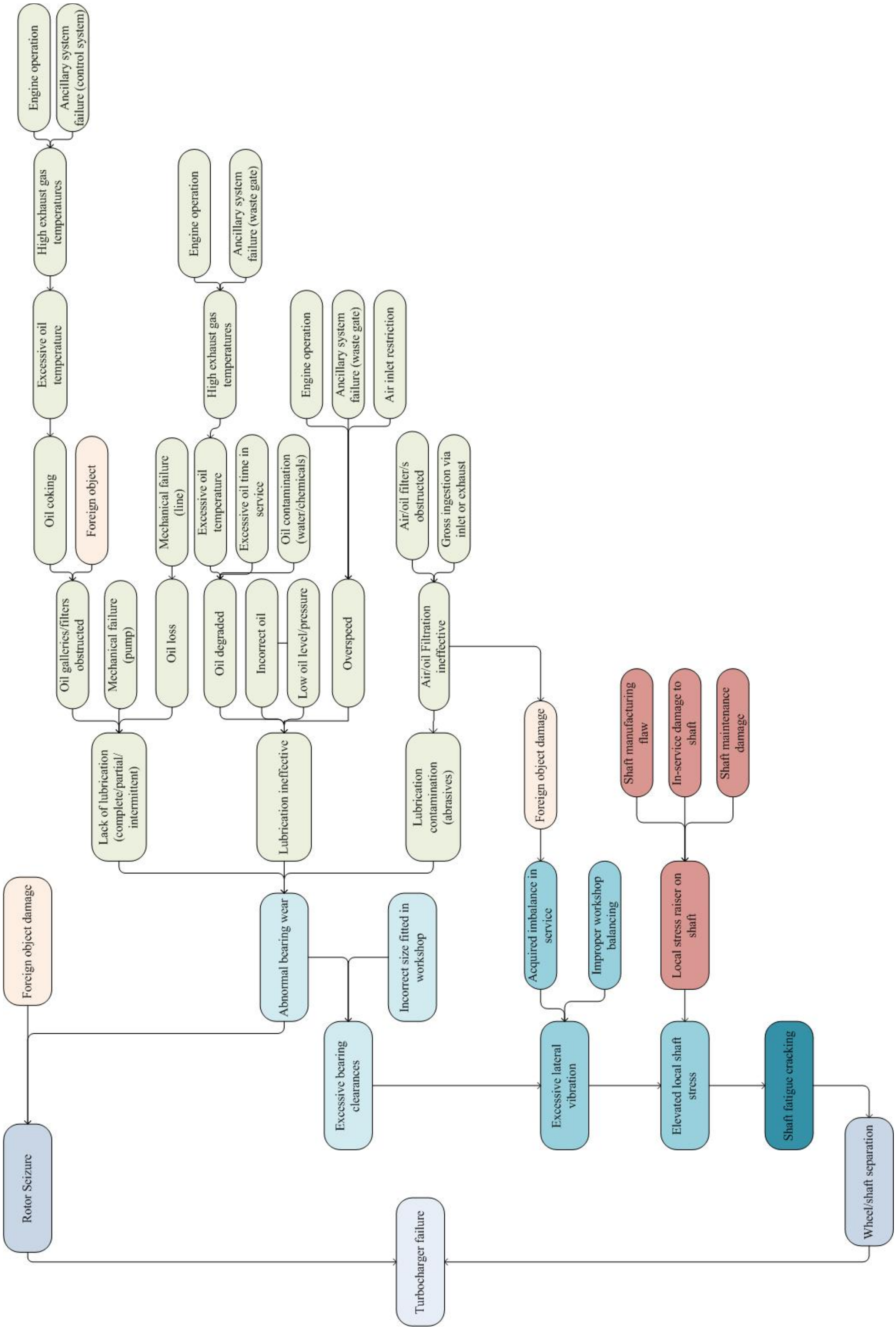
The information below presents a summary of the outcomes following an examination of each of the occurrences collected throughout the duration of the investigation. There was no single common causal factor identified:

- Some turbochargers exhibited a common failure through turbine wheel/shaft assembly, while the majority had failed for a variety of different reasons. These included shaft seizure, foreign object damage (FOD), oil seal leaks and bearing failures.
- An out-of-balance condition from manufacture, assembly, or field operation would lead to rapid failure of the turbocharger. While this may have contributed to some of the failures examined, an examination of the relevant overhaul shops' records did not highlight any deficiencies in their processes. Also, a number of the turbochargers examined had a very high time since overhaul (TSO) and were unlikely to have been out of balance from initial installation.

- The turbocharger failures were not specific to a particular workshop, as the failed units had been field overhauled, factory rebuilt, and new.
- Not all failures were associated with the same geographical location, so it was considered unlikely that local conditions such as temperature, environmental conditions or operating altitude were contributing factors.
- Failures were reported across the industry and independent of any specific operator.
- The lubrication system was reported to be functioning for YEO30243, and disassembly of FCR2123 revealed evidence of oil within the unit. CDN00747 was also disassembled at the ATSB, and while there appeared to be a significant level of 'coked' oil between the centre housing and the backing plate, it was reported that this was not unexpected for a turbocharger of this age.
- No anomalies were identified on the turbine wheel/shaft assembly that could have contributed to the failures. The bearings, although outside the required dimensional limits, exhibited the appropriate material characteristics, and the observed wear was most likely incurred during the failure sequence.
- The failures could not all be attributed to foreign object damage (FOD). While it was clear that some displayed evidence of FOD, such as broken/damaged vanes on the turbine and compressor wheels, this was not the case for the wheel/shaft separations examined in the ATSB's laboratories.
- An examination of potential operational issues was explored through a review of the pilot operating handbook, the engine manufacturer's flyers and discussions with experienced pilots. A number of items were identified that could contribute to premature failure of a turbocharger, such as manifold pressure over-boost from incorrect operating technique during climb or shut down. It was possible that pilot handling may have been a factor in some cases, but due to the widespread nature of the failures, including some very low time events, it was considered an unlikely contributing issue for all of the examined failures.
- Lubrication issues, such as an interruption to the supply, were also examined as one of the potential causes. While the ATSB was unable to eliminate this as a possible contributing factor (as the overall engine systems were not examined as part of the investigation), the components examined showed no evidence of significant heat distress on the shaft bearing surfaces.
- There was no evidence to suggest contamination of the oil supply with abrasive materials had occurred in any of the examined cases. None of the components showed scratches, cuts or grooves in the rotating parts, or embedded material in the soft aluminium bearings. No such findings were included in the engineering reports supplied to ATSB.

In addition to the above observations, it was also determined that the nature of the turbocharger system was such that there appeared to be two common failure modes; seizure of the turbocharger following wheel contact with the housings, or wheel/shaft failures. Not only could these failures result from a variety of contributing factors, but the same contributing factor could lead to a different outcome, as shown in Figure 4. The example shown on the following page is not an exhaustive list, but is presented to demonstrate the number of influences which may produce a similar failure.

Figure 4: Potential contributing factors to turbocharger failure.



FINDINGS

From the investigation undertaken, the following key findings are made with respect to Piper Chieftain PA-31-350 aircraft engine turbocharger unit reliability. The findings should not be read as apportioning blame or liability to any particular organisation or individual.

Key findings

- The investigation identified two principal modes of turbocharger failure – wheel seizure and shaft fracture/turbine wheel separation.
- Turbocharger reliability (and hence the susceptibility to failure as above) could be influenced by a broad range of operational and maintenance-related factors.
- There was no individual factor or set of factors that were present across the range of failures examined, to the extent that would suggest the existence of a specific or systemic safety issue.
- Turbocharger reliability can be enhanced by adherence to the manufacturers' instructions and guidance material for the correct operation of turbocharged aircraft engines.
- The safe flight of an aircraft that has sustained a turbocharger failure can be assisted by the pilot's awareness of the indications of turbocharger malfunction, and the appropriate management of the affected engine in accordance with published procedures.

SAFETY ACTION

While no safety issues were identified during this investigation, the Australian Transport Safety Bureau would like to highlight the following safety actions that have been taken with regards to turbochargers on Piper PA-31-350 aircraft during the course of the investigation.

Kelly Aerospace

Kelly Aerospace issued a service information letter, a service bulletin and incorporated some changes into the overhaul manual;

> Kelly Aerospace (KAES), Service Information Letter (SIL) A-117, *General recommendations for TH08A series turbocharger handling*, 28 November 2006.
>
> KAES Service Bulletin (SB) No. 039, *Turbine wheel replacement*, 10 November 2009
>
> Kelly Aerospace Energy Systems, LLC, *Overhaul Manual – 400 Series Turbocharger, Part Number 400600-0000 – Rev A,* February 2009.

Federal Aviation Administration

Following an accident where failure of the turbocharger was considered to have been a contributing factor, the Federal Aviation Administration (FAA) issued a Special Airworthiness Information Bulletin to highlight the importance of the operational response to a suspected turbocharger failure. The FAA also issued an Airworthiness Directive in support of the KAES Service Bulletin 039 which enforced a date of compliance of 19 April 2010.

> The Federal Aviation Administration (FAA) Special Airworthiness Information Bulletin (SAIB), CE-09-11, *Turbocharged engines,* 9 February 2009
>
> FAA Airworthiness Directive (AD 2010-07-08), *Kelly Aerospace Energy Systems, LLC Rebuilt Turbochargers*, 19 April 2010.

Civil Aviation Safety Authority

The Civil Aviation Safety Authority issued an Airworthiness Bulletin following the release of KAES Service Bulletin 039.

> Airworthiness Bulletin (AWB) 81-001, *Kelly Aerospace – Turbocharger turbine wheel replacement,* on 28 January 2010.

APPENDIX A: TECHNICAL ANALYSIS REPORT

ATSB TECHNICAL ANALYSIS
AI-2009-008

Analysis of failed Piper PA-31-350 aircraft engine turbocharger units

Released in accordance with section 25 of the *Transport Safety Investigation Act 2003*

FACTUAL INFORMATION

Introduction

Following a number of accidents and serious incidents involving Piper Chieftain PA-31-350 aircraft, where a failure of one of the engine turbochargers had been central to the occurrence events, the Australian Transport Safety Bureau (ATSB) initiated a safety investigation into the broader issue of PA-31-350 turbocharger operational reliability.

As part of that investigation, the failed turbocharger units from several of these events were obtained by the ATSB for physical and metallurgical examination, to characterise the breakdown mechanisms and assist in identifying any common or systemic issues.

This appendix presents the results of the physical and metallurgical analyses. The reader is referred to the main body of the report for a broader examination and analysis of the key issues.

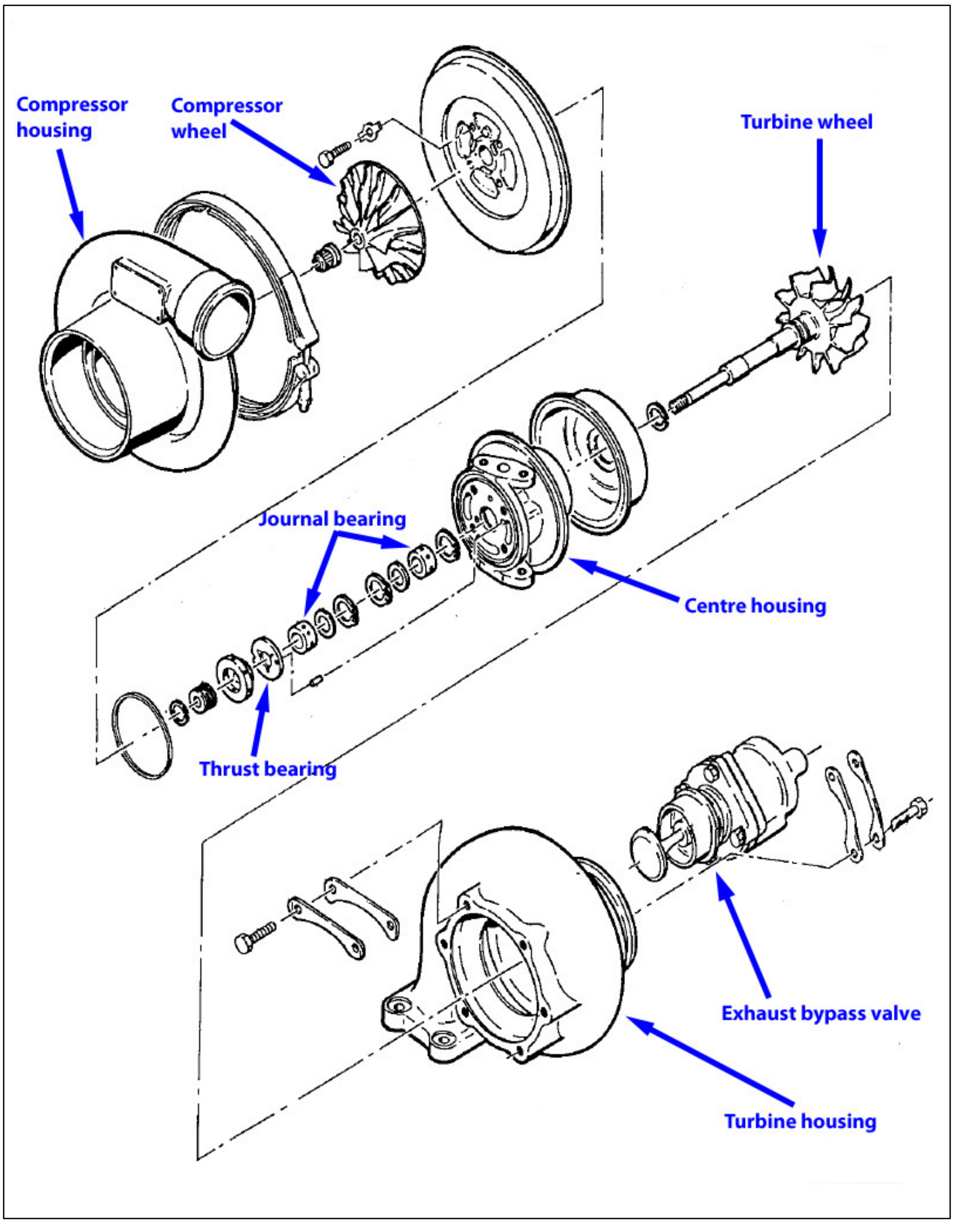
Scope of the examination

- To carry out an evaluation of the turbine wheel and shaft components recovered from the turbochargers from VH-TFX (turbocharger serial numbers *YEO30243* and *FCR2123*) and VH-ECB (turbocharger serial number *CDN00747*). These components were to be examined, along with the floating (main shaft) bearings, to identify the failure mechanism and confirm the material properties.
- To assess the information obtained from the failure analyses and identify the existence and contribution of any common engineering characteristics to the in-service and premature failure of the turbocharger units.

Turbocharger identification and construction

The Piper PA-31-350 aircraft is equipped with a Kelly Aerospace TH08A series turbocharger, part number 409170-1. Figure 1 shows the turbocharger exploded parts diagram.

Figure 5: Exploded view of turbocharger model TH08A[5]



The TH08A turbocharger utilised a common shaft design, whereby the compressor and turbine wheels were supported in a cantilever fashion by a centre housing assembly. The main shaft was supported by two aluminium alloy plain metal bearings located within the centre housing (Figure 2). Pressurised lubricating oil is fed to the two bearings via the centre housing, and a circumferential 'piston ring' is employed as a seal to prevent oil ingress into the turbine housing.

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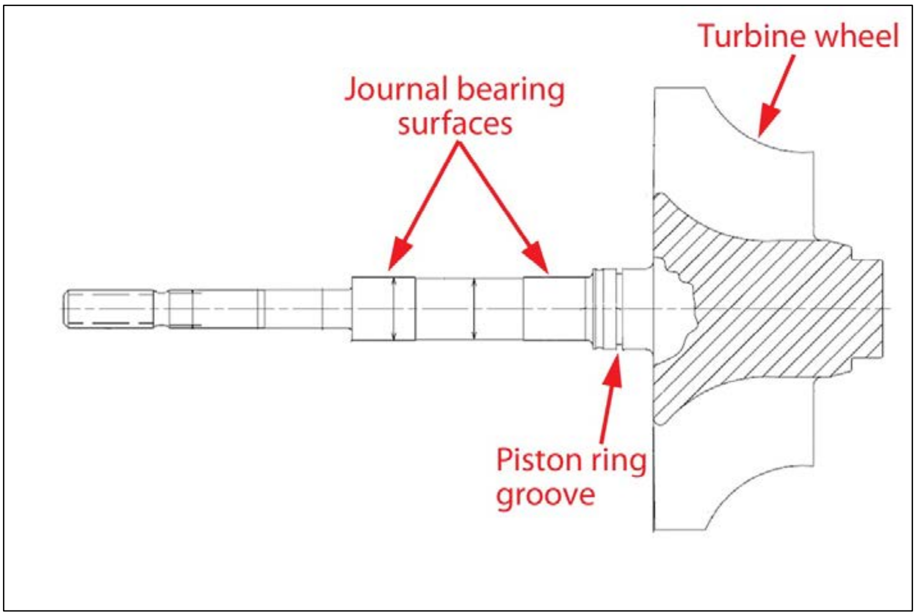
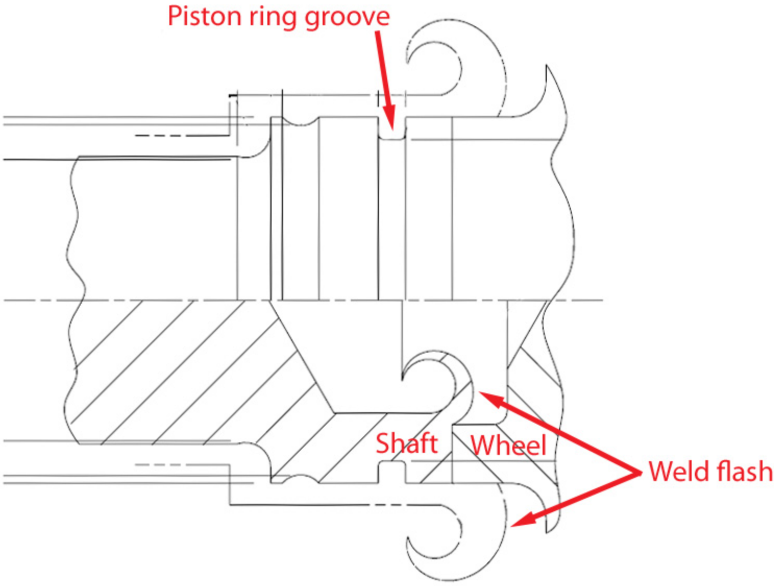
[5] Kelly Aerospace Power Systems, Overhaul Manual – 400 Series Turbocharger, Part Number 400600-000, Figure 2.30 – Series TH08 Turbocharger

Figure 6: Schematic representation of the turbine wheel and integral shaft



The TH08A turbine wheel (part number 406787-10) consisted of shaft and wheel components, friction welded[6] at a location approximately 12.5 millimetres from the rear face of the turbine wheel (Figures 2 & 3). The friction welding process included a machining stage to remove the external weld flash, and a post-weld heat treatment to relieve the induced residual stresses.

Figure 7: Magnified view of turbine wheel showing location of weld



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[6] Friction (inertia) welding is a process used for welding dissimilar and/or high temperature alloys. The materials to be welded are rotated at high speed and forced together to achieve fusion.

Examination of turbine wheel and shaft

Visual examination

Identification marks on the shaft of the turbine wheel from YEO30243 and FCR2123 showed the part number and manufacturing date: *406787 FAA PMA 0708 (July 2008)*. No markings on the shaft from CDN00747 were legible. Information supplied by the overhaul facility indicated that YEO30243 and FCR2123 had a time since overhaul (TSO) of less than 1 hour at the time of the failure, while CDN00747 had a TSO of 727 hours.

The turbine wheels from YEO30243 and FCR2123 appeared to be in relatively good condition, with minor deformation on the tips of the blades and some minor discolouration. The damage on the blade tips was consistent with contact marks observed on the turbine housing. The wheel from CDN00747 exhibited more general discolouration than the other two wheels, with a brownish powdery residue built up on the surfaces. Some evidence of a darker, blackish powdery substance was also observed. These features were consistent with the longer time in service for this turbocharger and most likely represented an accumulation of combustion (exhaust gas) deposits.

As with the turbine wheels, the shafts also appeared to be in relatively good condition, with the shaft from CDN00747 showing signs of its longer life. A notable deposit of a black powdery substance (typical of overheated oil) was also found between the centre housing and turbine wheel shroud.

The turbine wheel had fractured from the shaft at a similar location on all three samples examined. The fracture was approximately 5 mm below the underside of the wheel (Figures 4 to 7).

Figure 8: Failed turbine wheel/shaft ex turbocharger YEO30243

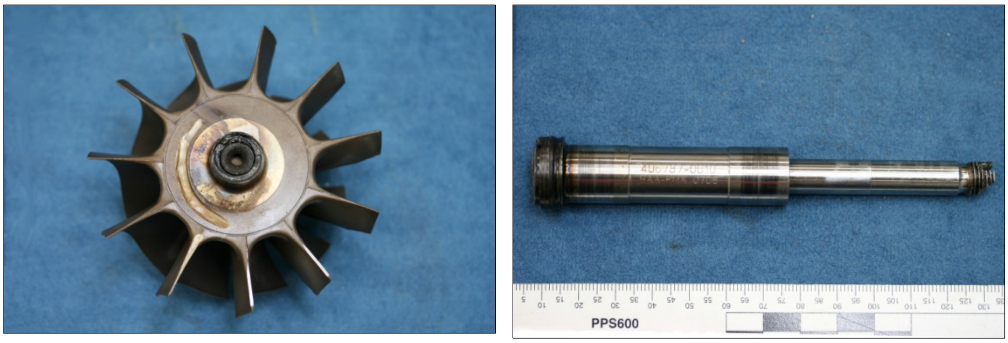
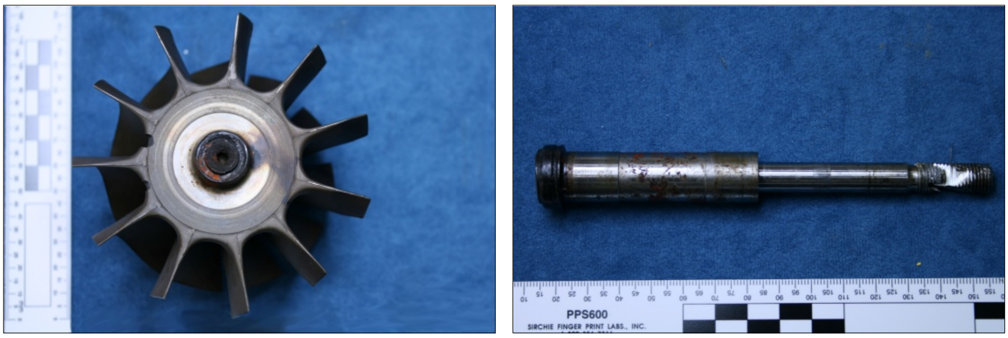


Figure 9: Failed turbine wheel/shaft ex turbocharger FCR2123



In all cases, the fracture had occurred transverse to the principle axis of the shaft, at a location coincident with the bottom of the piston ring groove (Figures 2 and 3).

Figure 10: Magnified view of failed end of turbine shaft (YEO30243) showing location of fracture and turbine end journal bearing surface.

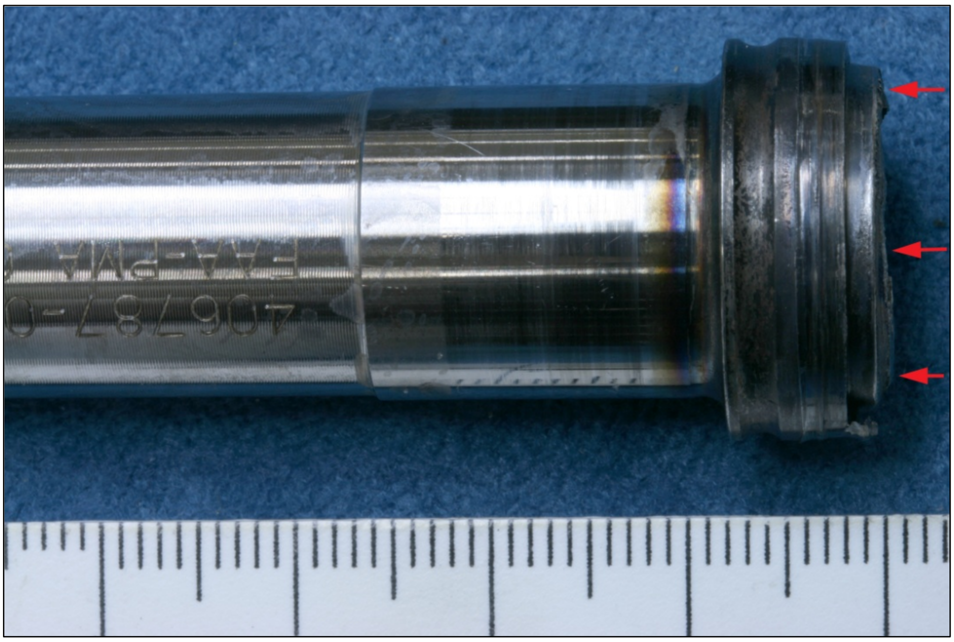
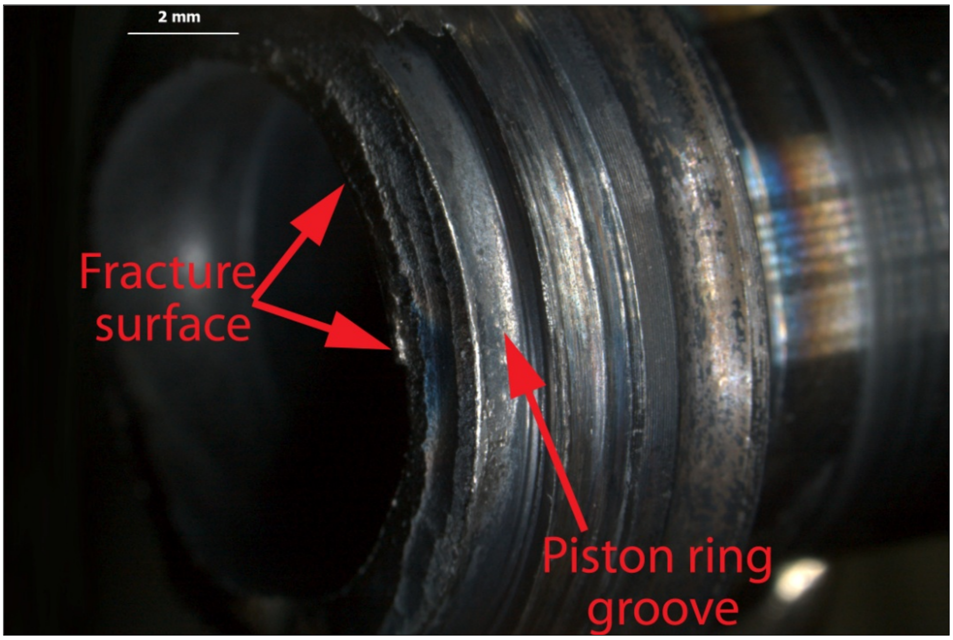


Figure 11: Side view of the turbine shaft fracture (YEO30243) showing location of failure with respect to the piston ring groove.



Some minor heat tint/discolouration was observed on the journal bearing surfaces. A dimensional evaluation of the bearing surfaces revealed them to be within the limits supplied in the overhaul manual. The CDN00747 shaft exhibited more circumferential scoring on the journal bearing surfaces, and a thick black oily residue on the central shaft. Again, this was considered to be a result of the longer time in service than the other two components.

The fracture surfaces of all three components exhibited heavy post failure mechanical damage, which made examination difficult. However, the turbine wheel removed from YEO30243 appeared to exhibit features associated with the original shaft fracture.

Following cleaning, several crescent shaped marks were observed extending radially across the fracture surface. These features were indicative of fatigue crack initiation and growth from the base of the external piston ring groove (Figures 8 and 9).

Figure 12: Turbine shaft fracture surface (YEO30243).

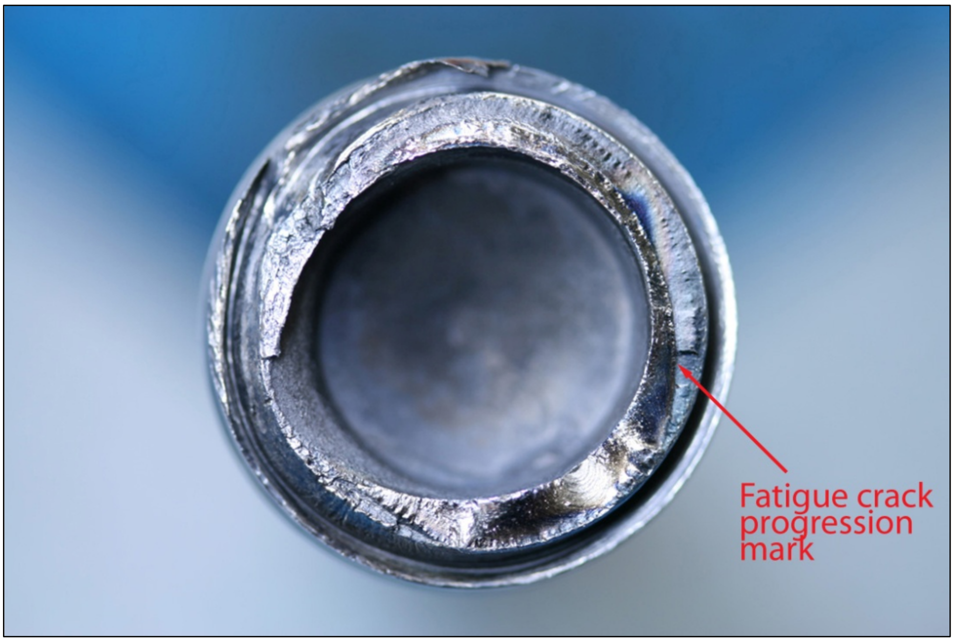
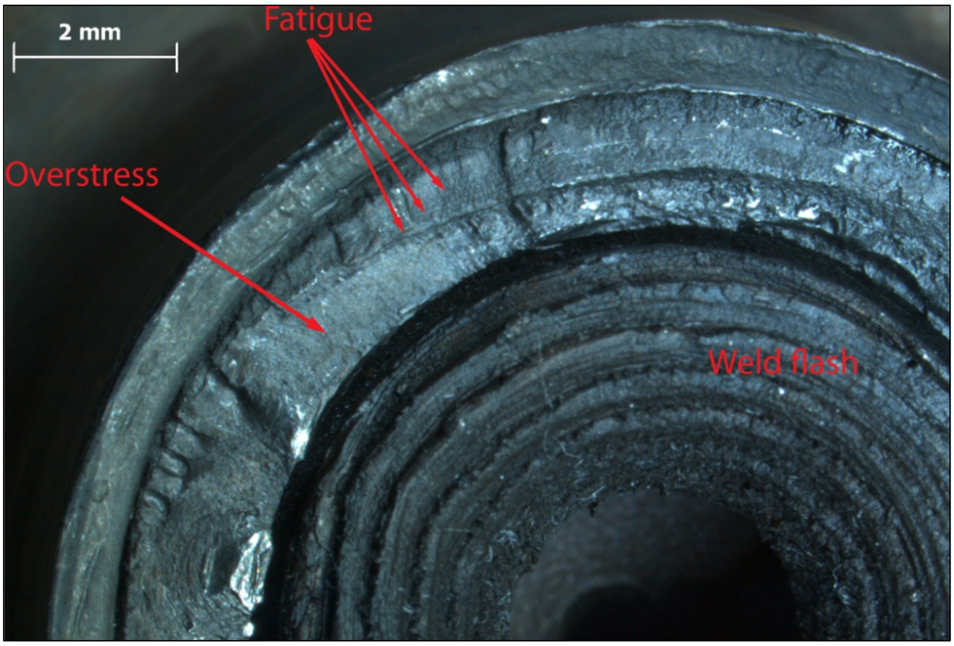
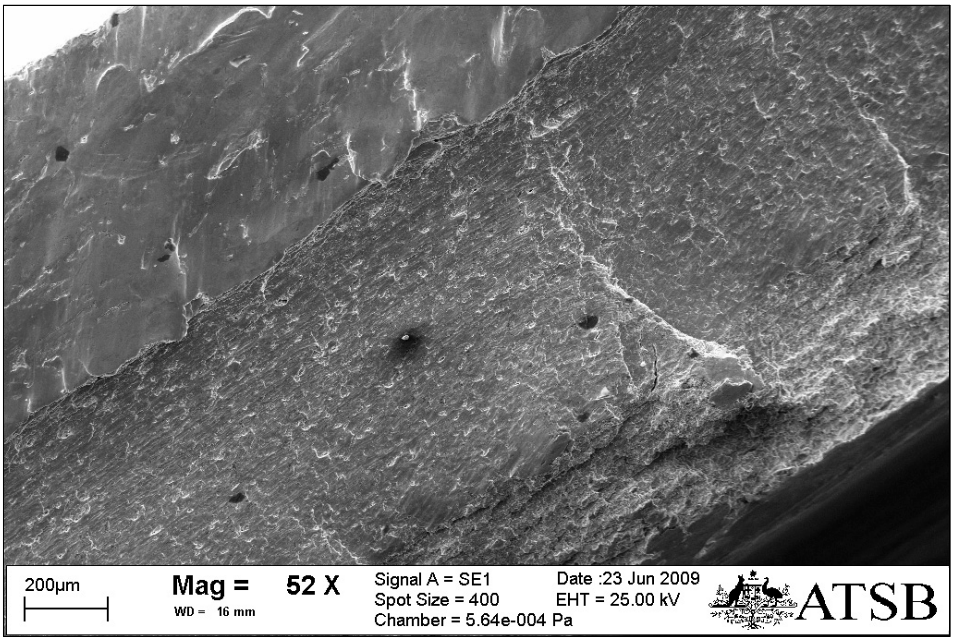


Figure 13: Magnified view of Figure 5 showing fatigue crack propagation features initiating from outer surface.



Scanning electron microscopy (SEM) confirmed the presence of a fracture surface demarcation between two distinct regions of failure mode (Figure 10). Closer examination towards the external surface revealed finer progression marks, consistent with fatigue crack growth.

Figure 14: SEM of shaft fracture (YEO30243) showing demarcation between surface areas.



Material evaluation of turbine wheel and shaft

Chemical composition

Chemical analyses of the turbine wheel and shaft from YEO30243 were performed with the results given below (Table 1 and 2).

Table 2: Chemical analysis results of turbine wheel shaft (weight %)

Element	Fe	C	Mn	Si	S	P	Cr	Ni	Mo	Cu
Result	97.3	0.34	0.83	0.23	0.01	0.01	0.92	0.05	0.18	0.09

Table 3: Chemical analysis results of turbine wheel (weight %)

Element	Fe	C	Mn	Si	Cr	Ni	Mo	Ti	Al
Result	11.1	0.18	0.29	0.51	16.8				

The chemical analysis results for the shaft were consistent with an AISI/SAE grade 4140; a medium carbon, chromium-molybdenum steel.

The analysis results for the wheel were consistent with a GMR-325 nickel-based precipitation-hardening high-temperature casting alloy.

Microstructural examination

The sample was sectioned longitudinally to bisect the fracture face in the region of the fatigue origin. After metallographic preparation and etching, the fracture was observed approximately 2.5 mm axially from the weld line, on the shaft side (Figure 11). The fracture was coincident with the bottom of the piston ring groove on the side closest to the turbine wheel (Figure 12).

Figure 15: Wheel fracture face showing location of fracture with respect to the weld.

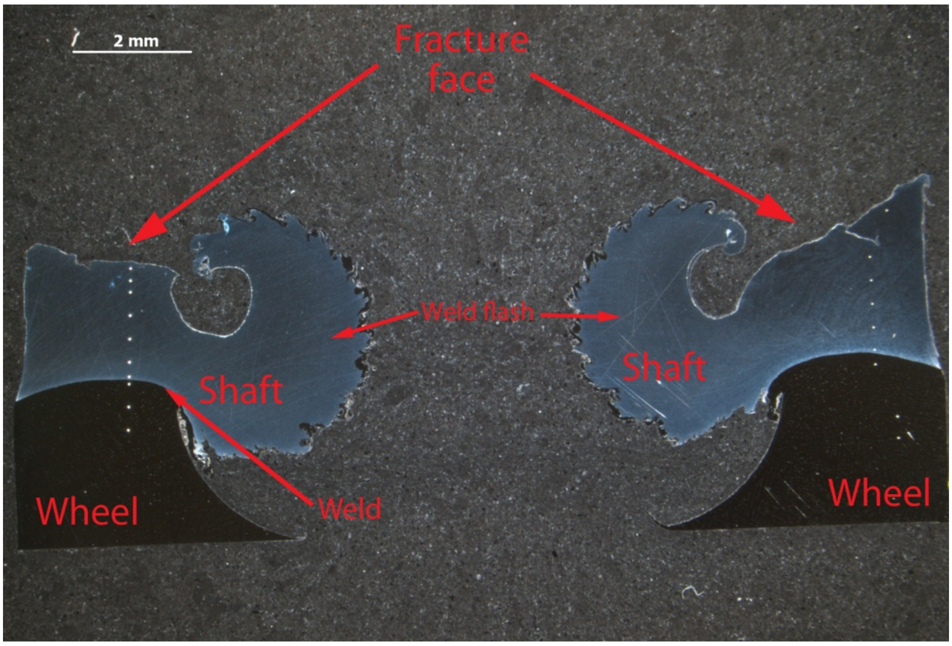
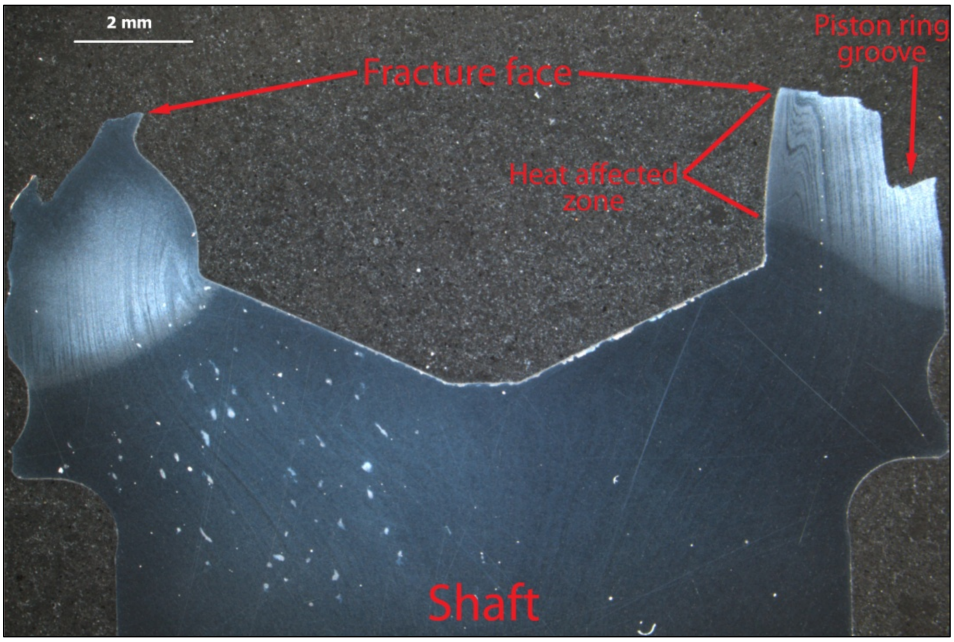


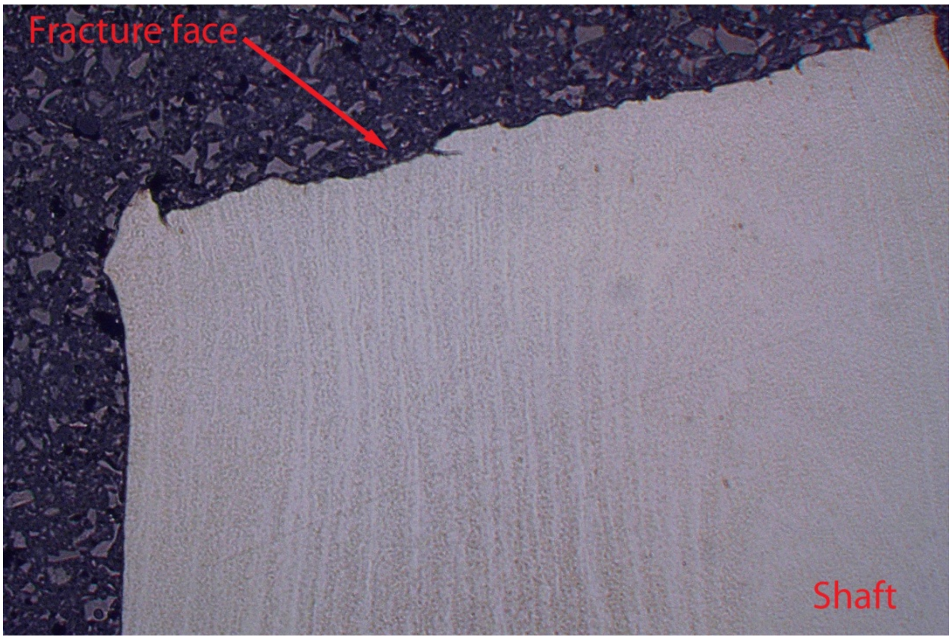
Figure 16: Shaft fracture face showing location of fracture with respect to piston ring groove.



The shaft material exhibited a fine, tempered martensite microstructure, consistent with the material type. Evidence of grain flow and a heat affected zone (HAZ) were observed when viewing the shaft side of the fracture macroscopically (Figure 12). The HAZ extended for approximately 2 to 3mm from the fracture face. Evidence of weld flash was observed on the shaft side of weld line within the internal cavity of the shaft.

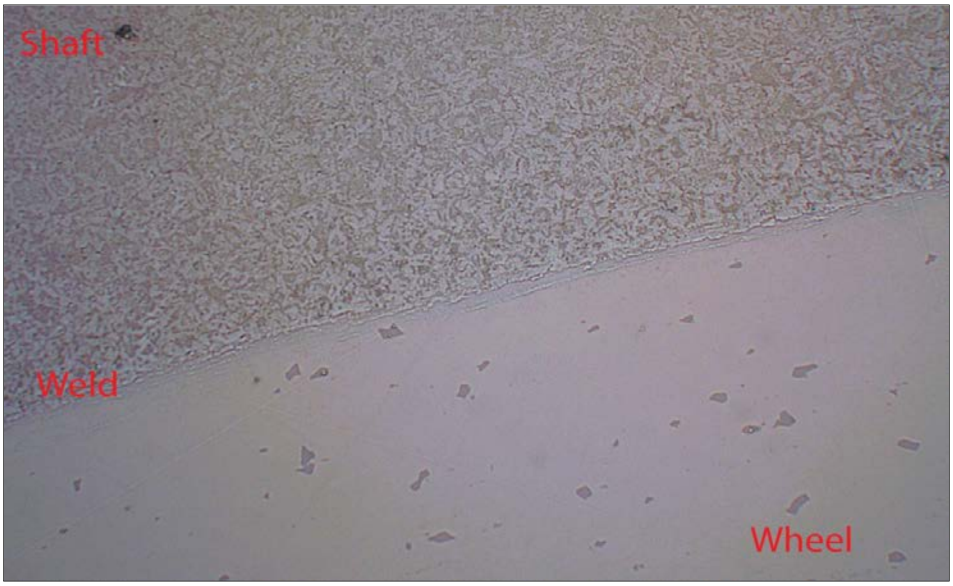
The fracture face was generally smooth and flat across the sample, and presented a transgranular propagation path - consistent with a fatigue failure mechanism (Figure 13).

Figure 17: Shaft fracture surface micro.



The weld fusion boundary appeared sound, with no evidence of incomplete fusion, inclusions or other deleterious features (Figure 14). The wheel bulk material exhibited finely distributed precipitates within a uniform matrix - consistent with the material type.

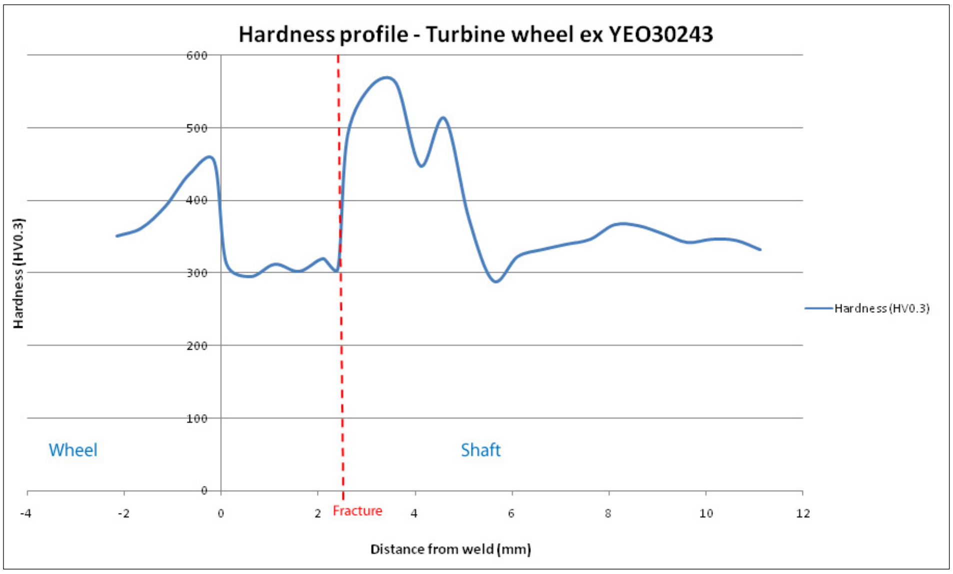
Figure 18: Shaft fracture face showing location of fracture with respect to piston ring groove.



Hardness evaluation

A hardness traverse was conducted across both halves of the shaft fracture face, through the weld, into the turbine wheel. The testing was performed in accordance with *AS1817.1 Vickers hardness test*, using a 300 g load. The results are given in Figure 15; the location of the fracture is shown by the red dotted line, and the zero position on the x-axis indicates the weld line.

Figure 19: Hardness profile across weld and fracture.



Examination of floating bearings

Visual examination

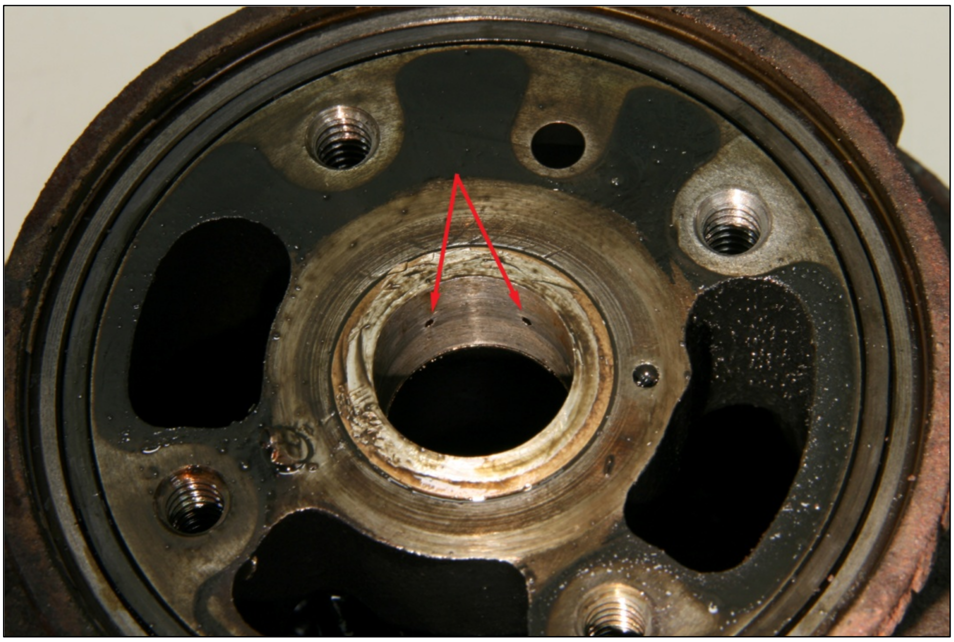
The compressor-end bearing was removed from the centre housing of turbocharger YEO30243; however they was unable to be removed from either FCR2123 or CDN00747 due to the gross plastic deformation of the bearings. Similarly, the turbine-end bearing within the centre housing of YEO30243 could also be removed, but could not be retrieved from FCR2123 or CDN00747 without forcing the compressor end bearing out.

The bearings removed from YEO30243 appeared to be in relatively good condition. Evidence of circumferential scoring was noted on the external and internal surfaces, which appeared to be more severe on the compressor end bearing (Figure 16). The oil holes appeared free and clear, with evidence of the chamfered corners visible, suggesting the bearings had suffered little wear.

Figure 20: Internal surface of bearing showing scoring damage (YEO30243).

The compressor end bearing from CDN00747 exhibited significant wear and distortion of the internal diameter (Figure 17). The oil holes were significantly reduced in size on the internal surfaces – consistent with the effects of plastic deformation, metal flow and wear.

Figure 21: **Compressor end bearing in-situ showing damage to the oil feed holes.**



A dimensional study of the bearings was compared to data supplied in the overhaul manual (Table 3). The manufacturer's maintenance data specified a minimum shaft journal diameter of 0.6251 in, and a maximum bearing internal diameter of 0.6272 in; allowing a lateral float limit of 0.00105 in.

Table 4: **Shaft and bearing measurements and calculated lateral float (measurements in inches)**

	YEO30243		FCR2123		CDN00747	
	Turbine	Comp*	Turbine	Comp*	Turbine	Comp*
Shaft journal OD (min)	0.6245	0.6240	0.6245	0.6275	0.6240	0.6250
Journal bearing ID (max)	0.6265	**0.6420**	**0.6315**	**0.6540**	**0.6940**	**0.6920**
Lateral float (max)	0.0010	0.0090	0.0035	0.0135	0.0350	0.0335

* Compressor end bearing

Most of the bearing internal diameters were greater than the limits specified in the overhaul manual (shown in bold in Table 3).

Material evaluation of bearings

Chemical composition

Chemical analysis of the turbine end bearing from YEO30243 was performed with the results given below (Table 4).

Table 5: Chemical analysis results of turbine wheel shaft (weight %)

Element	Al	Si	Cu	Fe	Mg	Zn	Cr	Ni	Mn	Ti
Result	95.3	0.26	1.89	0.43	078	0.04	<0.01	1.11	0.03	0.11

The results approximated an Alloy 2618 (2.3Cu-1.6Mg-1.1Fe-1.0Ni-0.18Si-0.07Ti), typically used in rotating aircraft engine parts for operation at elevated temperatures.

Hardness testing

Hardness testing was performed on the bearing in accordance with Australian Standard *AS1816.1 Brinell hardness testing*, using a 1mm ball and a 15kg load. The average result was 78.1 HB.

ANALYSIS

Turbine wheel separation

The three turbochargers examined had failed as a result of separation of the turbine wheel from the shaft. The failures occurred through the shaft section of the component at a location consistent with the base of the piston ring groove.

The fractures exhibited features consistent with fatigue cracking that had initiated from the bottom corner of the piston ring groove. The reduced diameter associated with the ring groove would be expected to act as an inherent stress-raiser; predisposing the shafts to failure in this area under the influence of elevated cyclic stresses.

All examined turbochargers exhibited an increase in both the compressor and turbine-end journal bearing inner diameters, producing an excessively large lateral float between the respective turbine shaft and bearings. This condition, if present or developing during turbocharger operation, could lead to a large lateral imbalance in the rotating assembly, producing a significant increase in the cyclic bending stresses within the shaft-wheel components and potentially resulting in contact between the turbine and/or compressor wheels and their housings. These conditions could lead directly to the separation of the turbine wheel from the shaft in the manner observed.

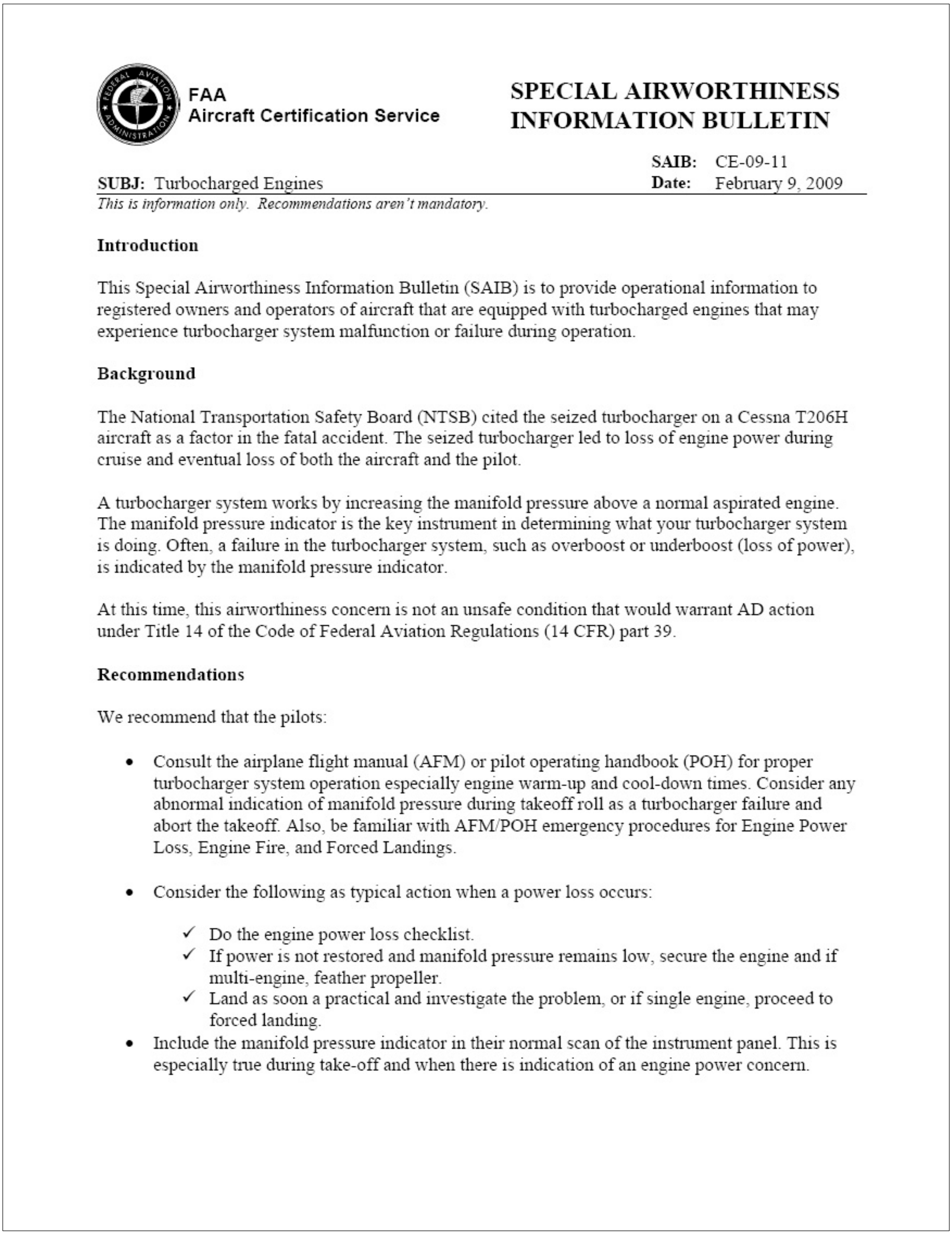
The material properties of the turbine wheel, shaft and bearings were consistent with the material properties specified by the manufacturer. No other anomalies were observed that may have been a factor in the failures.

CONCLUSIONS

The following conclusions were drawn from the metallurgical analysis of the failed turbocharger assemblies:

- The turbine wheels examined failed as the result of fatigue cracking that had initiated at a location coincident with the piston ring groove.
- Separation of the turbine wheel from the shaft resulted in seizure of the turbocharger
- The material properties of the turbine wheel, shaft and floating bearings were consistent with those specified by the manufacturer and were considered suitable for use in this application.

APPENDIX B: FAA SAIB CE-09-11



FAA
Aircraft Certification Service

SPECIAL AIRWORTHINESS INFORMATION BULLETIN

SAIB: CE-09-11
Date: February 9, 2009

SUBJ: Turbocharged Engines

This is information only. Recommendations aren't mandatory.

Introduction

This Special Airworthiness Information Bulletin (SAIB) is to provide operational information to registered owners and operators of aircraft that are equipped with turbocharged engines that may experience turbocharger system malfunction or failure during operation.

Background

The National Transportation Safety Board (NTSB) cited the seized turbocharger on a Cessna T206H aircraft as a factor in the fatal accident. The seized turbocharger led to loss of engine power during cruise and eventual loss of both the aircraft and the pilot.

A turbocharger system works by increasing the manifold pressure above a normal aspirated engine. The manifold pressure indicator is the key instrument in determining what your turbocharger system is doing. Often, a failure in the turbocharger system, such as overboost or underboost (loss of power), is indicated by the manifold pressure indicator.

At this time, this airworthiness concern is not an unsafe condition that would warrant AD action under Title 14 of the Code of Federal Aviation Regulations (14 CFR) part 39.

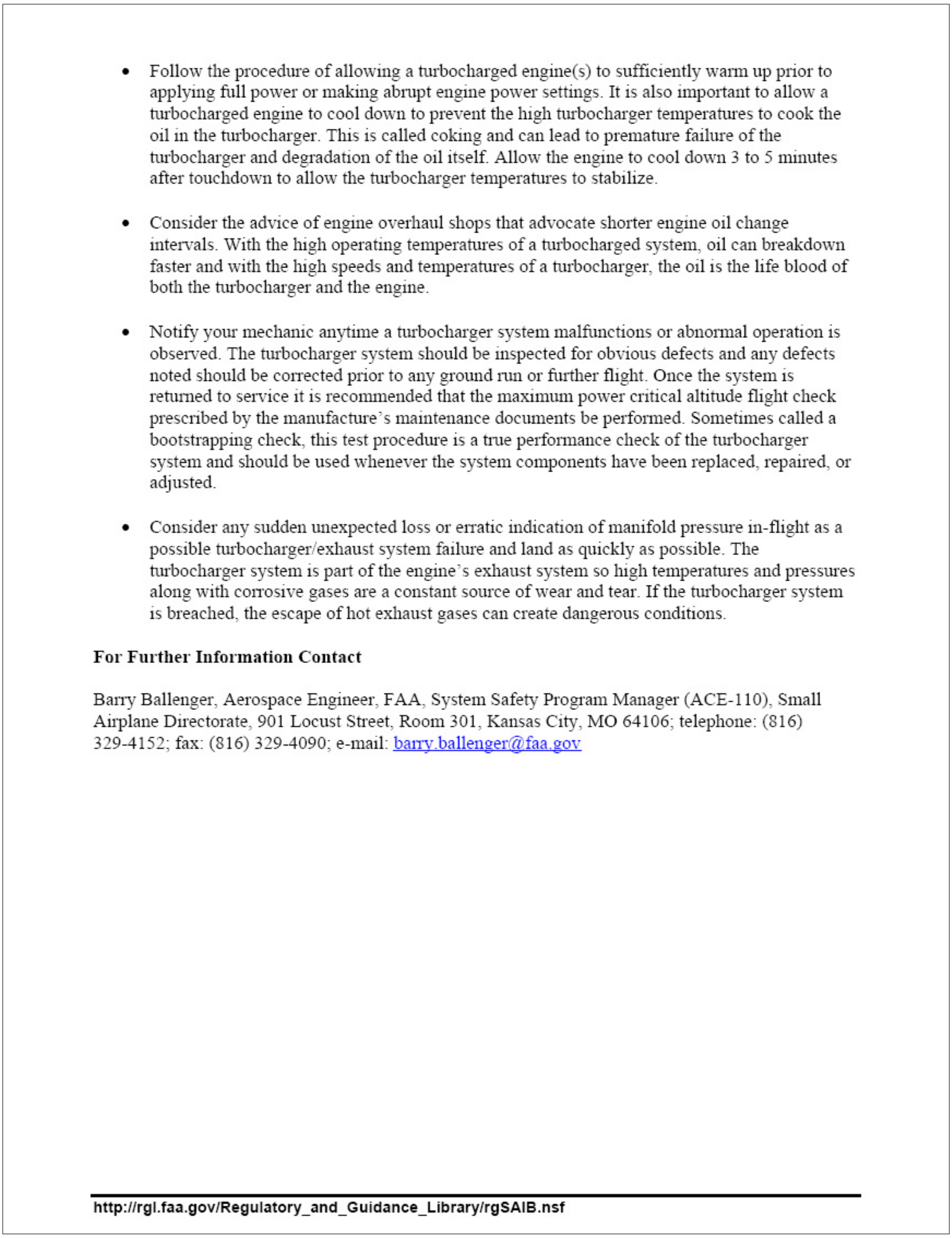
Recommendations

We recommend that the pilots:

- Consult the airplane flight manual (AFM) or pilot operating handbook (POH) for proper turbocharger system operation especially engine warm-up and cool-down times. Consider any abnormal indication of manifold pressure during takeoff roll as a turbocharger failure and abort the takeoff. Also, be familiar with AFM/POH emergency procedures for Engine Power Loss, Engine Fire, and Forced Landings.

- Consider the following as typical action when a power loss occurs:

    - ✓ Do the engine power loss checklist.
    - ✓ If power is not restored and manifold pressure remains low, secure the engine and if multi-engine, feather propeller.
    - ✓ Land as soon a practical and investigate the problem, or if single engine, proceed to forced landing.
- Include the manifold pressure indicator in their normal scan of the instrument panel. This is especially true during take-off and when there is indication of an engine power concern.



- Follow the procedure of allowing a turbocharged engine(s) to sufficiently warm up prior to applying full power or making abrupt engine power settings. It is also important to allow a turbocharged engine to cool down to prevent the high turbocharger temperatures to cook the oil in the turbocharger. This is called coking and can lead to premature failure of the turbocharger and degradation of the oil itself. Allow the engine to cool down 3 to 5 minutes after touchdown to allow the turbocharger temperatures to stabilize.

- Consider the advice of engine overhaul shops that advocate shorter engine oil change intervals. With the high operating temperatures of a turbocharged system, oil can breakdown faster and with the high speeds and temperatures of a turbocharger, the oil is the life blood of both the turbocharger and the engine.

- Notify your mechanic anytime a turbocharger system malfunctions or abnormal operation is observed. The turbocharger system should be inspected for obvious defects and any defects noted should be corrected prior to any ground run or further flight. Once the system is returned to service it is recommended that the maximum power critical altitude flight check prescribed by the manufacture's maintenance documents be performed. Sometimes called a bootstrapping check, this test procedure is a true performance check of the turbocharger system and should be used whenever the system components have been replaced, repaired, or adjusted.

- Consider any sudden unexpected loss or erratic indication of manifold pressure in-flight as a possible turbocharger/exhaust system failure and land as quickly as possible. The turbocharger system is part of the engine's exhaust system so high temperatures and pressures along with corrosive gases are a constant source of wear and tear. If the turbocharger system is breached, the escape of hot exhaust gases can create dangerous conditions.

For Further Information Contact

Barry Ballenger, Aerospace Engineer, FAA, System Safety Program Manager (ACE-110), Small Airplane Directorate, 901 Locust Street, Room 301, Kansas City, MO 64106; telephone: (816) 329-4152; fax: (816) 329-4090; e-mail: barry.ballenger@faa.gov

APPENDIX C: SOURCES AND SUBMISSIONS

Sources of Information

Pilot of VH-TFX

Turbocharger overhaul facility

Civil Aviation Safety Authority

The turbocharger manufacturer

The engine manufacturer

Various operators and maintainers of Piper Chieftain PA-31-350 aircraft

References

Lycoming Flyer – Key Reprints

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 Civil Aviation Safety Authority, the operator and insurer of VH-TFX, the turbocharger overhaul facility, the turbocharger manufacturer and the engine manufacturer.

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

Reliability of Piper PA-31-350 aircraft engine turbocharger units