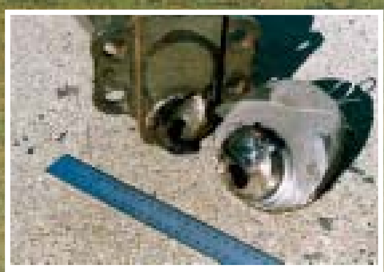
ATSB
Australian Transport Safety Bureau

AUSTRALIAN TRANSPORT SAFETY BUREAU

**AVIATION SAFETY REPORT**
**200002157**

# Piper PA31-350 Chieftain VH-MZK
# Spencer Gulf SA

**31 May 2000**

COMMONWEALTH DEPARTMENT OF TRANSPORT AND REGIONAL SERVICES

Department of Transport and Regional Services

Australian Transport Safety Bureau

INVESTIGATION REPORT
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# Spencer Gulf SA
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Released under the provisions of Section 19CU of Part 2A of the *Air Navigation Act 1920*

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

In terms of aviation, the ATSB is responsible for investigating accidents, serious incidents, incidents and safety deficiencies involving civil aircraft operations in Australia, as well as participating in overseas investigations of accidents and serious incidents involving Australian registered aircraft. The ATSB also conducts investigations and studies of the aviation system to identify underlying factors and trends that have the potential to adversely affect safety. A primary concern is the safety of commercial air transport, with particular regard to fare-paying passenger operations.

The ATSB performs its aviation functions in accordance with the provisions of the *Air Navigation Act 1920*, Part 2A. Section 19CA of the Act states that the object of an investigation is to determine the circumstances surrounding any accident, serious incident, incident or safety deficiency to prevent the occurrence of other similar events. The results of these determinations form the basis for safety recommendations and advisory notices, statistical analyses, research, safety studies and ultimately accident prevention programs. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

Under the Air Navigation Act, it is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and conclusions reached. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. 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.

**Report structure**

The structure of this report follows the format recommended by the International Civil Aviation Organisation (ICAO) in the Appendix to Annex 13 to the Convention on International Civil Aviation. An additional ATSB feature is the inclusion of 'observations' throughout the factual part of the report. The purpose of observations is to provide a brief analysis of each section, where appropriate, to assist reader comprehension.

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**ATTACHMENTS**

# EXECUTIVE SUMMARY


On the evening of 31 May 2000, Piper Chieftain, VH-MZK, was being operated by Whyalla Airlines as Flight WW904 on a regular public transport service from Adelaide to Whyalla, South Australia. One pilot and seven passengers were on board. The aircraft departed at 1823 central Standard Time (CST) and, after being radar vectored a short distance to the west of Adelaide for traffic separation purposes, the pilot was cleared to track direct to Whyalla at 6,000 ft. A significant proportion of the track from Adelaide to Whyalla passed over the waters of Gulf St Vincent and Spencer Gulf. The entire flight was conducted in darkness.

The aircraft reached 6,000 ft and proceeded apparently normally at that altitude on the direct track to Whyalla. At 1856 CST, the pilot reported to Adelaide Flight Information Service (FIS) that the aircraft was 35 NM south-south-east of Whyalla, commencing descent from 6,000 ft. Five minutes later the pilot transmitted a MAYDAY report to FIS. He indicated that both engines of the aircraft had failed, that there were eight persons on board and that he was going to have to ditch the aircraft, but was trying to reach Whyalla. He requested that assistance be arranged and that his company be advised of the situation. About three minutes later, the pilot reported his position as about 15 NM off the coast from Whyalla. FIS advised the pilot to communicate through another aircraft that was in the area if he lost contact with FIS. The pilot's acknowledgment was the last transmission heard from the aircraft. A few minutes later, the crew of another aircraft heard an emergency locater transmitter (ELT) signal for 10–20 seconds.

Early the following morning, a search and rescue operation located two deceased persons and a small amount of wreckage in Spencer Gulf, near the last reported position of the aircraft. The aircraft, together with five deceased occupants, was located several days later on the sea–bed. One passenger remained missing.

On 9 June 2000, the wreckage of the aircraft was recovered for examination. Aside from the engines, no fault was found in the aircraft that might have contributed to the accident. Both engines had malfunctioned due to the failure of components of the engines.

The crankshaft of the left engine fractured at the Number 6 connecting rod journal. Fatigue cracking was initiated by the presence of a planar discontinuity in the journal surface. It was evident that the discontinuity had been caused by localised thermal expansion of the nitrided journal surface following contact with the edge of the Number 6 connecting rod big end bearing insert. The crankshaft failed approximately 50 flights after fatigue crack initiation.

The Number 6 bearing insert was damaged during engine operation through the combined effect of:

- high bearing loads created by lead oxybromide deposit induced preignition, and
- lowered bearing insert retention forces associated with the inclusion of an anti-galling compound between the bearing inserts and the housings.

Fatigue cracking in the Number 6 connecting rod big end housing had developed following the gradual destruction of the bearing insert. The left engine probably continued to operate for 8–10 minutes after the final fracture of the Number 6

connecting rod housing before the final disconnection of the Number 6 journal of the crankshaft. It is likely that the engine would have displayed signs of rough running and some power loss during this time. The final disconnection of the crankshaft resulted in a loss of drive to the magnetos, fuel pump, camshaft and, consequently, the sudden stoppage of the engine. The left propeller was in the feathered position when the aircraft struck the water, confirming that the engine was not operating at that time.

The physical damage sustained by the right engine was restricted to the localised melting of the Number 6 cylinder head and piston. The piston damage had allowed combustion gases to bypass the piston rings. The overheating of the right engine combustion chamber components was a result of changes in heat transfer to cylinder head and piston surfaces created by combustion end-gas detonation. The carbonaceous nature of the residual deposits on the piston crowns indicated that detonation had occurred under a rich fuel–air mixture setting. Rich mixture settings are used with high engine power settings.

The damaged piston would have caused a loss of engine oil and erratic engine operation, particularly at higher power settings. Engine lubrication was still effective at impact, indicating that oil loss was incomplete and that the piston holing occurred at a late stage of the flight.

Examination of the right propeller indicated that the blades were in a normal operating pitch range (i.e. not feathered) when the aircraft struck the water. It could not be confirmed that the right engine was operating when the aircraft struck the water, although it most probably was operating when radar contact was lost as the aircraft descended through 4,260 ft when 25.8 NM from Whyalla.

The aircraft was not fitted with a Flight Data Recorder (FDR) or a Cockpit Voice Recorder (CVR), nor was it required to be. Analysis of recorded radar data confirmed that the aircraft performed normally during the flight until the latter stages of the cruise segment when the speed gradually decreased. Speed variations, accompanied by track irregularities, then became more pronounced. Analysis of recorded voice transmissions revealed that propeller (and engine) RPM during the climb from Adelaide was 2,400. The RPM was 2,200 after the aircraft levelled at 6,000 ft. These were normal climb and cruise engine settings used by the company and the performance achieved by the aircraft during these segments was consistent with normal engine performance. Just prior to the commencement of descent, an RPM of 2,400 was identified. That was not a normal engine power setting for that stage of the flight.

The aircraft speed and propeller RPM information, coupled with the engine failure analysis, was consistent with the following likely sequence of events:

- The power output from the left engine deteriorated during the first third of the cruise segment of the flight after the Number 6 connecting rod big end housing had fractured. The engine ceased operating completely 8–10 minutes later.
- In response to the failure of the left engine, the pilot increased the power setting of the right engine.
- Increased combustion chamber component temperatures via detonation within the right engine led to the Number 6 piston being holed. That resulted in the erratic operation of the right engine with reduced power and controllability and left the pilot with little alternative but to ditch the aircraft.
- The double engine failure was a dependent failure.

Examination of eight failures of Textron Lycoming engines from a number of operators that had occurred over the period January 2000 to November 2001 revealed that deposits of lead oxybromide on combustion chamber surfaces were not restricted to the engines from MZK; seven other engines had such deposits. The inclusion of a copper–based anti-galling compound between the bearing insert and big end housing was noted in three of the engines examined. The quantity of anti-galling compound present varied between those engines.

Lead oxybromide deposits and anti-galling compounds act in different ways to weaken the defences for reliable engine operation. The relative contribution to engine failure of the factors cannot be predicted easily because of variations in the extent of each effect and the complexity inherent in engine assembly and operation. It is likely that the formation of lead oxybromides that cause deposit induced preignition is linked to the temperature of the fuel–air charge temperature in the combustion chamber just prior to the passing of the flame front. Leaning the mixture during climb, and using near 'best economy' cruise power settings appeared to favour the formation of lead oxybromide deposits that resulted in deposit induced preignition. Mixture settings of 'full rich' mixture during climb and 'best power' cruise settings appeared to favour reactions that resulted in less extensive and different deposits being formed. The Whyalla Airlines procedure was to lean the mixture during climb, and to use a cruise power setting close to 'best economy'. Those procedures were in accordance with the US Federal Aviation Administration (FAA) approved Pilot's Operating Handbook for the Piper Chieftain aircraft.

The combination of the use of leaded aviation gasoline, mixture leaning during climb, and leaning for best economy during cruise was not restricted to Lycoming engines. The ATSB also found evidence of high combustion loads and lead oxybromide deposits during the examination of components from two Teledyne Continental TIO-520 engines that were defective.

Anecdotal reports indicated that there were fewer engine problems (including component failures) in engines that were operated full rich during climb, and 'best power' during cruise, compared with those where the mixture was leaned during climb and 'best economy' cruise power was used. A comparison of the engine operating procedures of twelve other operators of Piper Chieftain aircraft revealed considerable disparity in procedures, particularly for climb and cruise. In fact, no two operators used the same procedure.

The incidence of lead oxybromide deposits in engines that had experienced defects, coupled with the range of fuel leaning techniques used, indicated a deficiency in the operation and maintenance of those engines, at least among some of the operators of high–powered piston engine aircraft in Australia.

On 30 October 2000, the ATSB issued a recommendation that the Civil Aviation Safety Authority alert operators regarding the risks of detonation, and encourage the adoption of conservative fuel leaning practices.

This report includes further recommendations addressing the following:

- the engine operating conditions under which combustion chamber deposits that may cause preignition are formed (addressed to the US Federal Aviation Administration);
- the effect on engine reliability of the use of anti-galling compounds between connecting rod bearing inserts and housings (addressed to the US Federal Aviation Administration and the engine manufacturer); and

- the reliability of high–powered aircraft piston engines operated in Australia (addressed to CASA).

This accident was the first recorded ditching involving a Piper Chieftain aircraft in Australia. Available records world–wide of previous Piper Chieftain engine failure/ditching events illustrate that, in most instances, successful night ditchings occurred in better visibility and weather conditions than those confronting the pilot of MZK. The relatively minor injuries suffered by the occupants of the aircraft indicated that the pilot demonstrated a high level of skill in ditching the aircraft. The report includes a recommendation to CASA regarding guidance material for pilots on ditching.

It is likely that the survival prospects of the occupants would have been enhanced had the passenger seats been fitted with upper body restraints, and life jackets or equivalent flotation devices had been available to the occupants. As a result of a separate investigation, the Bureau issued a recommendation concerning upper body restraints on 31 March 1999. On 30 October 2000, arising from the Whyalla investigation, the ATSB issued recommendations to the Civil Aviation Safety Authority concerning the provision of adequate emergency and life saving equipment for the protection of fare-paying passengers in smaller aircraft during over–water flights.

Full details of safety action including the CASA response to recommendations made on 31 March 1999 and 30 October 2000 are in Section 4 of this report.

The investigation included a detailed examination of the regulatory history of Whyalla Airlines from June 1997 to June 2000. In common with the published findings of other reports on CASA surveillance activities, there was a significant under-achievement of surveillance of the company against CASA's planned levels during that period. However, there was insufficient information to conclude that the level of surveillance achieved was of significance with respect to the accident.

With regard to Whyalla Airlines itself, issues were identified in the company that had the potential to adversely influence safety. There was insufficient information to conclude that any of these issues were of significance with respect to the accident.

As a result of the accident and ATSB's investigation, improved refuelling procedures were introduced nationally by the refuelling organisation to reduce the chance of error.

# 1 FACTUAL INFORMATION

## 1.1 Sequence of events

On the evening of 31 May 2000, Piper Chieftain aircraft VH-MZK was being operated as Whyalla Airlines Flight WW904 on a regular public transport service from Adelaide to Whyalla, South Australia. There were seven passengers and one pilot on board the aircraft. The flight was planned to track to Whyalla via airway W315 at an altitude of 6,000 ft. The entire flight would be conducted in darkness.

The aircraft departed Adelaide at 1823 Central Standard Time (CST), eight minutes after the scheduled departure time of 1815. After take-off, the pilot contacted the Adelaide Approach radar controller who vectored the aircraft a short distance to the west of Adelaide. Subsequent relevant events are displayed in table 1 below. This information is also included in the diagrams at figures 1 and 2. The information was obtained from recorded audio and radar data. Aircraft track, altitude (ft) and groundspeed (kts) information was obtained from recorded radar data for MZK.

**Table 1:**
**Sequence of relevant events WW 904 – 31 May 2000**

| *Time* | *Event* |
|---|---|
| 1823:14 | The pilot of MZK advised the Adelaide controller that the aircraft was passing 500 ft on climb.<br>*Audio analysis of this transmission indicated propeller RPM of 2,400.* |
| 1829.51 | *MZK reached top of climb (6,000 ft) and 152 kts.* |
| 1831:43 | The Adelaide controller instructed the pilot of MZK to track from his present position direct to Whyalla. |
| 1833.01 | *MZK reached its maximum cruise speed of 183 kts, altitude 5,955 ft.* |
| 1833.54 | The pilot advised the Melbourne Centre controller that the aircraft was maintaining 6,000 ft.<br>*Audio analysis of this transmission indicated propeller RPM of 2,200.* |
| 1837.41 | *Recorded groundspeed began to decrease.* |
| 1847:15 | *Aircraft diverged to the right of the direct track to Whyalla. This was accompanied by a significant speed reduction.* |
| 1852:30 | Aircraft track drifted right and then corrected towards GIBON[1]. |
| 1855:37 | Pilot of MZK acknowledged advice from the Melbourne Centre controller that radar services were terminated.<br>*Audio analysis of this transmission indicated propeller RPM of 2,400. It could not be determined whether the signal was from one or both propellers.* |

1. GIBON is an IFR reporting point on the aircraft's flight planned track, 34 NM south east of Whyalla.

| | |
|---|---|
| 1855:54 | *Top of descent.* |
| 1856:01 | The pilot contacted Adelaide flight service and advised that the aircraft was 35 miles to the south-south-east of Whyalla, commencing descent from 6,000 ft, estimating Whyalla at 1908. |
| 1900:19 | *Last valid recorded radar data point for MZK as the aircraft descended below radar coverage. The aircraft was at 4,260 ft and 25.8 NM from Whyalla.* |
| 1901:10 | The pilot of MZK transmitted:<br>'Adelaide Adelaide this is MAYDAY MAYDAY MAYDAY MAYDAY Mike Zulu Kilo has experienced two engine failures we'll be um landing we're going to have to ditch we're trying to make Whyalla at the moment we've got no engines so we'll be ditching we have eight POB I repeat again eight POB and ah most likely we're currently ah about one five miles off the coast of Whyalla on the GIBON Whyalla track request someone come out and help us please'<br>*Analysis of a signal present at the beginning of the transmission indicated that the landing gear unsafe horn[2] had activated.* |
| 1901:52 | The pilot of MZK requested that the company be contacted as fast as possible. |
| 1902:49 | FIS asked the pilot of MZK to confirm whether he was still heading straight for Whyalla or if he was heading for the coast. The pilot confirmed that he was heading straight for Whyalla.<br>*Analysis of a signal present at the beginning of the transmission indicated the stall warning horn[3] had activated.* |
| 1903:13 | The crew of VH-FMC contacted FIS and advised that they were maintaining FL140 and estimating Port Augusta at 1916. FIS requested that the crew divert and try to be of assistance to MZK. |
| 1904:03 | The pilot of MZK advised that he was currently 15 miles. FIS acknowledged and advised the pilot to communicate with the crew of FMC if he lost contact with FIS. |
| 1904:15 | The pilot acknowledged the transmission from FIS. This was the last recorded transmission from the aircraft. In subsequent conversation, the crew of FMC also reported that they heard no further transmissions from MZK. |
| Approx.<br>1906:38 | The crew of FMC heard an ELT transmission on the international distress frequency 121.5 MHz that continued for 10–20 seconds. |

2. The landing gear unsafe horn sounded if one or both throttle levers was reduced below a throttle lever angle equivalent to approximately 12 inches manifold pressure with the landing gear retracted or not down and locked.

3. The stall warning horn warns of an approaching aerodynamic stall and sounds about 4–10 kts before a stall actually occurs.

**Figure 1:**
**Track of VH-MZK – WW904 on 31 May 2000**

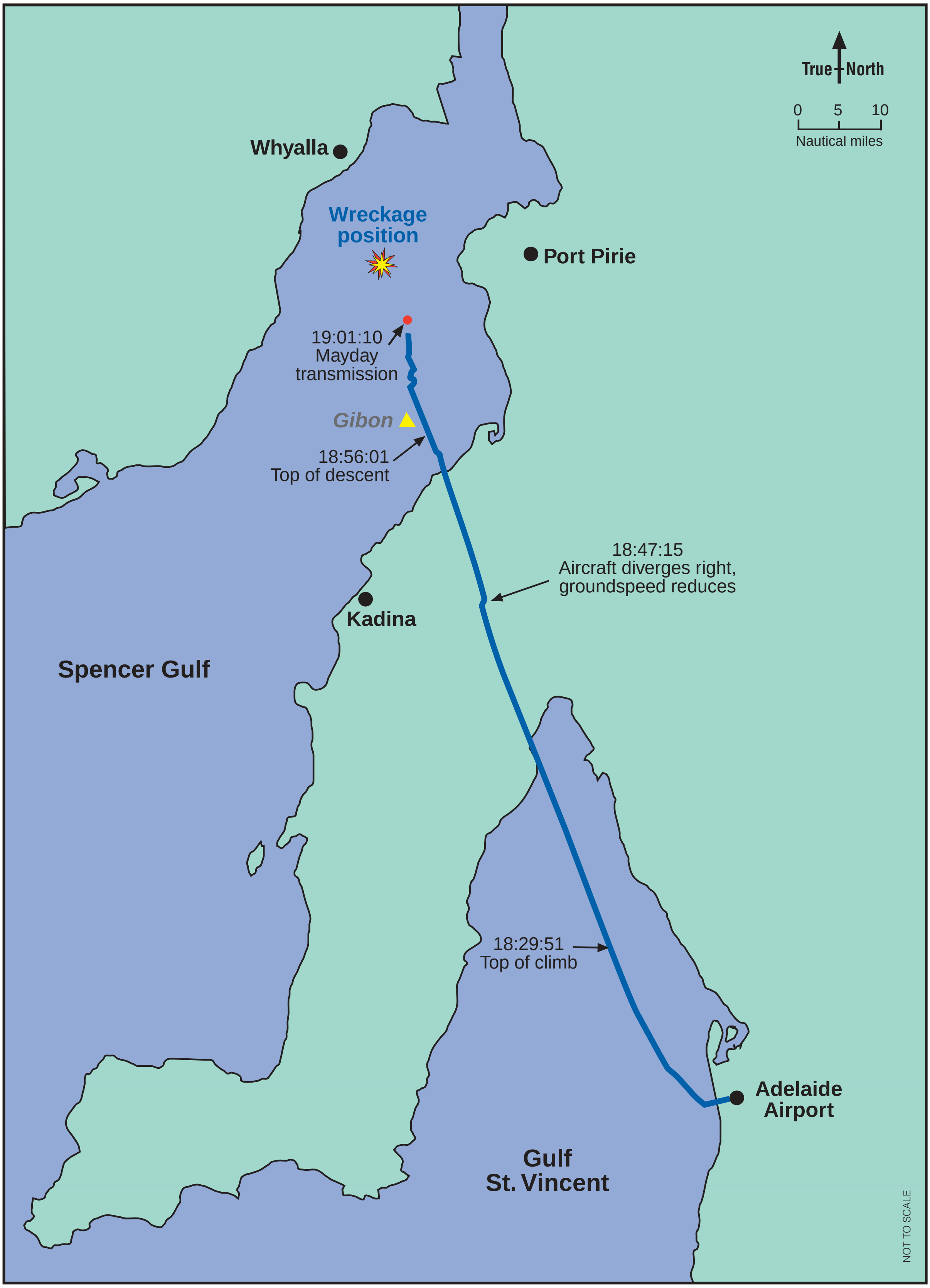
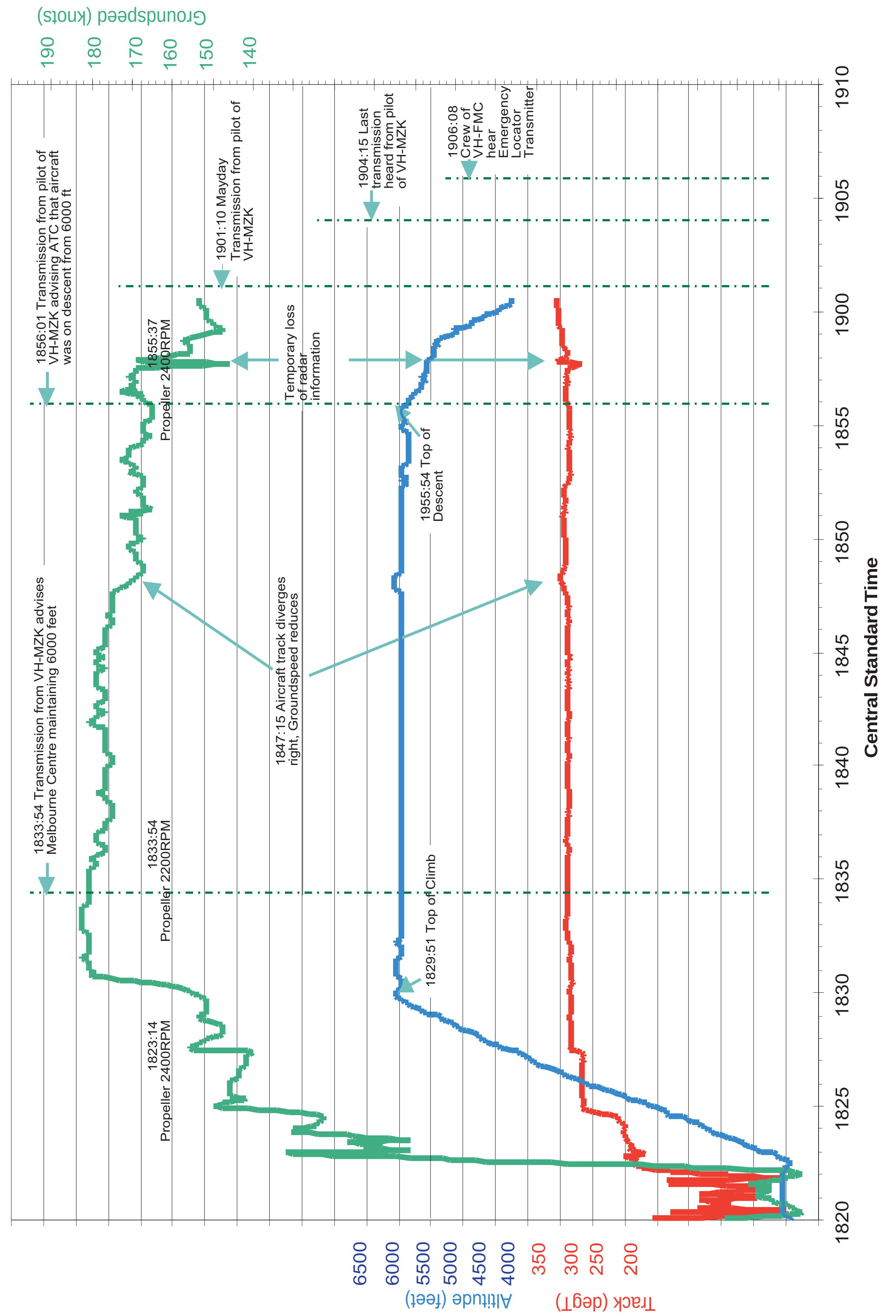


**Figure 2:**
**Recorded data from Piper Chieftain VH-MZK flight WW904 from Adelaide to Whyalla on 31 May 2000**



## 1.2 Injuries to persons

The pilot and six passengers died in the accident. A seventh passenger remained missing, presumed deceased.

## 1.3 Damage to aircraft

The aircraft was destroyed when it impacted the sea.

## 1.4 Other damage

There was no other damage.

## 1.5 Personnel information

### 1.5.1 Pilot in command

| | |
|---|---|
| Age: | 22 years |
| Licence category: | Commercial |
| Instrument rating: | Command (multi-engine aeroplane) |
| Medical certificate: | Class 1 |
| Total hours: | 2,211.7 |
| Total on type: | 1,133.1 |
| Total last 90 days: | 254.1 |
| Total last 30 days: | 82 |
| Total on type last 30 days: | 82 |
| Total last 24 hours: | 2.6 |
| Last Check: | 2, 3 and 5 January 2000 |
| Last Check on type: | 2, 3 and 5 January 2000 |

**Observation:**

The pilot was appropriately qualified to carry out the intended flight to Whyalla.

### 1.5.2 Pilot training and experience

The pilot began flying training in February 1996 with an organisation in regional Victoria and obtained a private pilot licence in July of that year. He obtained a commercial pilot licence in November 1996 and a Grade Three instructor rating the following month. The Chief Pilot of that company described the pilot as being conscientious and of above average ability. In April 1998, the pilot was endorsed to fly Piper Chieftain aircraft.

Between June 1997 and August 1998, the pilot worked for the same organisation as an instructor on both single and multi-engine aircraft. In addition, he carried out some charter work and ferry flights. Colleagues at the time described the pilot as an excellent instructor who developed a very good rapport with students.

During November and December 1998, the pilot worked for an aero club in regional New South Wales, mainly engaged in flying instruction. The Chief Flying Instructor reported that the pilot had been very well trained.

In January 1999, the pilot began working for Whyalla Airlines. At that time he had a total aeronautical experience of 895 hours, with 383 hours on multi-engine aircraft, including 46 hours on Piper Chieftain aircraft.

The Whyalla Airlines operations manual required that pilots undergo an induction program of ground and flying training and checks before being cleared to conduct line operations. The induction program included training in the following areas:

**Theoretical knowledge:**

- procedures following an engine failure during cruise
- single-engine planning, performance and operations
- emergency evacuation
- emergency equipment
- glide speed
- ditching
- survival methods on land or water
- passenger control during emergencies
- night flight

**Practical demonstration:**

- single-engine cruise considerations
- single-engine approach and landing
- feathering and unfeathering a propeller
- night flight
- operation of normal and emergency exits
- location and use of emergency equipment
- location of survival equipment

The pilot completed the induction program on 21 January 1999.

Subsequent ongoing proficiency checks were required at least twice each year and at least four months apart. The pilot successfully passed a command instrument rating flight test, including single–engine handling, on 26 July 1999. The pilot again successfully completed a proficiency check on 5 January 2000. That check included an assessment of his theoretical knowledge of single–engine operations, night flight, survival methods on land or water and passenger control during emergencies. The check also required the pilot to demonstrate single–engine handling, night flight, operation of normal and emergency exits, and location of survival equipment.

At the time of the accident, the pilot, and another pilot who had joined Whyalla Airlines at about the same time, were the two most senior line pilots. They had been with the company for approximately 17 months.

### 1.5.3 Pilot flight and duty time records

The Whyalla Airlines computerised flight and duty time records indicated that during the five days before the accident the pilot was rostered for duty as follows:

| | |
|---|---|
| Saturday 27 May | rostered day off. |
| Sunday 28 May | 1630 to 2125. |
| Monday 29 May | 0700 to 1000, 1630 to 1800. |
| Tuesday 30 May | 0630 to 1030. |
| Wednesday 31 May | 1430 to 2200. |

The company's record of the pilot's flight and duty times for the above period was inaccurate in some respects. In particular, flight times for 29 May had not been entered into the record, and the flight details for 30 May were inconsistent with the pilot's diary. Information from that diary was used to complete the summary of flights as detailed below. That information was subsequently confirmed as correct by Whyalla Airlines.

- **28 May.** The pilot flew the 1700 scheduled service from Adelaide to Cleve and Wudinna, and then the 1900 return service to Adelaide. The pilot then travelled from Adelaide to Whyalla as a passenger on the company's 2035 flight, scheduled to arrive at 2130.
- **29 May.** The pilot flew the 0730 service from Whyalla to Adelaide, and the return service scheduled to arrive back in Whyalla at 0945. During the day he studied for an aviation theory examination. He then travelled to Adelaide as a passenger on the company's 1700 flight.
- **30 May.** The pilot flew the 0730 service from Adelaide to Cleve and Wudinna, and then the 0850 return service to Adelaide scheduled to arrive at 1010. The pilot was at home that afternoon and evening.
- **31 May.** The pilot operated a charter flight in MZK that departed from Adelaide at 1500 for Port Pirie. He then continued from Port Pirie to Whyalla, arriving at about 1630. He then flew the 1700 Whyalla to Adelaide scheduled service. The accident occurred on the 1815 return service to Whyalla.

During the 72 hours before the accident, the pilot was reported to have slept and eaten normally. The pilot was apparently well rested prior to commencing duty on the afternoon of Wednesday 31 May 2000.

**Observation:**

The information available does not indicate that the pilot was affected by fatigue at the time of the accident.

## 1.6 Aircraft information

### 1.6.1 Aircraft Data

| | |
|---|---|
| Aircraft Manufacturer: | Piper Aircraft Corporation |
| Model: | PA31-350 Chieftain |
| Serial Number: | 31-8152180 |
| Registration: | VH-MZK |
| Country of Manufacture: | USA |
| Year of Manufacture: | 1981 |
| Certificate of Registration Holder: | Whyalla Airlines Pty Ltd |
| Number: | BKN/01561/03 |
| Issued: | 27 March 1995 |
| Certificate of Airworthiness: | Normal |
| Number: | BK1561 |
| Issued: | 2 June 1988 |
| Maintenance Release Number: | 358 |
| Issued: | 30 May 2000 at 11,830.2 hours time in service |
| Valid to: | 30 May 2001 or 11,930.2 hours time in service |
| Total airframe hours at occurrence: | 11,837.6 hours time in service (estimated) |

### 1.6.2 Engines and Propellers

| | |
|---|---|
| Engine Manufacturer: | Textron Lycoming |
| Model: | TIO-540-J2B (Left) |
| | LTIO-540-J2B (Right) |
| Hours since last overhaul: | 262.1(Left) (estimated) |
| | 1,395.3 (Right) (estimated) |
| Propeller Manufacturer: | Hartzell |
| Model: | HC-E3YR-2A (Left) |
| | HC-E3YR-2ALTF (Right) |

### 1.6.3 Weight and balance

| | |
|---|---|
| Allowable take-off weight: | 3,342 kg |
| Estimated take-off weight: | 3,160 kg |
| Estimated weight at occurrence: | 3,080 kg |
| Allowable centre of gravity limits: | 3,175 mm to 3,429 mm aft of datum |
| Centre of gravity at occurrence: | 3,351 mm aft of datum (estimated) |

Prior to the flight the pilot had completed an approved Whyalla Airlines load sheet indicating the weight and balance of the aircraft was within approved limits. ATSB calculations for the same take-off weight confirmed the centre of gravity to be within limits.

### 1.6.4 Maintenance and serviceability

The aircraft had been maintained in accordance with the Whyalla Airlines approved system of maintenance and variations to that system as approved by the Civil Aviation Safety Authority (CASA). A review of the aircraft maintenance documentation revealed that there was no maintenance outstanding at the time of the release of the aircraft from the last periodic maintenance inspection. Maintenance that would have been required prior to the expiry of the maintenance release was recorded in the appropriate section for this purpose, but had not fallen due.

The Whyalla Airlines approved system of maintenance for their Piper Chieftain aircraft required that a Check 2, Check 3, Check 2A and Radio Check be conducted at appropriate intervals. The Check 2 and 3 schedule was to be completed every 100 hours (maximum) time in service or 12 months (whichever was the earlier). The Check 2A was to be completed 50 +/- 5 hours time in service after the Check 2 and 3 was completed. The Radio Check was to be conducted within 10 hours of the Check 2 and 3. A list of the items that were to be covered in each check is at Attachment B.

Maintenance Release Number 358 was valid at the time of the accident. However, due to the loss of the aircraft into the sea, it was not possible to locate the original document to determine if any subsequent entries had been made in the approximately five flight hours the aircraft completed on the day of the accident. There was no other evidence found to indicate that the aircraft was other than serviceable at the commencement of its final flight.

Maintenance documentation for the left and right engines for the period between their installation in the aircraft and the accident was examined. The following listing summarises the maintenance actions conducted. (The number of hours refers to the total time in service of the aircraft since manufacture.)

**30 May 2000 – 11,830.2 hours.** Check 2 and 3 carried out.

**15 May 2000 – 11,811.8 hours.** Right engine starter motor replaced.

**10 May 2000 – 11,791.6 hours.** The right magneto on the left engine was bench tested. The defect was recorded as 'missing at altitude'. The worksheet was endorsed with '500 hourly inspection completed on magneto. No defects found apart from contacts open excessively and consequently "E" gap out. Contacts and timing reset. Magneto bench tested satisfactory'.

**9 May 2000 – 11,789.2 hours.** The maintenance release was endorsed with "left eng [engine], left mag [magneto] not working properly". No clearing certification was made. Maintenance worksheets recorded the problem as "LH [left] magneto on LH [left] engine missing" and maintenance action included removal of the magneto, a 500 hourly inspection, spark plugs tested, refitting of the magneto and ground runs. No defect was identified.

**8 May 2000 – 11,784.5 hours.** Check 2A carried out.

**22 April 2000 – 11,730.7 hours.** Check 2 and 3 carried out.
Fuel calibration carried out

**30 March 2000 – 11,682.1 hours.** Check 2A carried out. Left propeller governor leaking. Replaced with overhauled governor.

**9 March 2000 – 11,632.2 hours.** Check 2 and 3 carried out. Left oil temperature wire crimp replaced. Right firewall shutoff seals replaced. Four spark plugs on right engine replaced.

**4 March 2000 – 11,630.6 hours.** The maintenance release was endorsed with "LE [left engine] sometimes runs on when shutting down", "RH (right hand) fire shutoff stiff to operate" and "LE [left engine] oil T [temperature] hi [high], sometimes unsteady?". Each defect was cleared by being categorised as non-major, and entered on the deferred defects list.

**21 February 2000 – 11,583.5 hours.** Check 2A carried out on right engine.

**13 February 2000 – 11,575.6 hours.** Left engine replaced with factory overhauled engine. New EGT probe installed on the left engine. Left engine baffle repairs carried out as necessary. Left engine mounts replaced. Left engine mount frame paint stripped, weld repair, leg straightened and tested. Left engine hoses re-manufactured. Left engine overhauled propeller governor installed. SI5.1 (Special Inspection) – Right engine crankshaft de-sludge.

**7 January 2000 – 11,575.6 hours.** The maintenance release was endorsed with "LE [left engine] u/s [unserviceable] the aircraft is unairworthy".

**30 December 1999.** Partially blocked left engine #4 fuel injector nozzle cleaned.

**29 December 1999 – 11,558.6 hours.** The maintenance release was endorsed with "LE [left engine] slight miss idle, high ffs [fuel flows], low EGT [exhaust gas temperature]? Is an injector blocked".

**17 December 1999 – 11,533.5 hours.** Check 2 and 3 carried out.
SI5.2 (Special Inspection) – Oil coolers flushed. Right engine right magneto timing adjusted. Right engine baffle seal replaced. Three spark plugs on right engine replaced.

**1 December 1999 – 11,487.4 hours.** Check 2A carried out.

**12 November 1999 – 11,433.5 hours.** Check 2 and 3 carried out.

**2 November 1999.** The items listed in table 2 were found during CASA surveillance and an Aircraft Survey Report (ASR), Code B (items to be assessed and rectified as necessary) was issued to Whyalla Airlines.

**Table 2:**
**Summary of CASA Aircraft Survey Report issued to Whyalla Airlines**

| ***CASA Aircraft Survey Report*** | ***Maintenance organisation rectification action*** |
|---|---|
| Compass calibration card out of date. | Compass card updated with figures from last calibration. |
| Spring back inadequate on right throttle at full throttle, right and left mixture at full rich, and right and left propeller at full fine. | Right throttle, mixture and pitch controls adjusted. Left mixture and propeller cables adjusted. |
| Hydraulic flexible hose damaged adjacent to left landing gear actuating cylinder. | Hose replaced. |
| Lower left cowl fastener missing on left cowl. | Cowl fastener replaced. |
| Left alternator drive belt tension inadequate. | Alternator belt tension adjusted. |
| Corrosion on underside of left horizontal stabiliser spar. | Corrosion removed and the area was painted. |
| Elevator trim tab has excessive play. | Elevator trim upper bushes replaced |
| Right aileron has excessive free play. | Right aileron control rod aft rod end renewed. |

**14 October 1999 – 11,377.5 hours.** Check 2A carried out.
New turbocharger fitted to left engine.

**30 September 1999 – 11,334.0 hours.** Check 2 and 3 carried out.
Right engine magnetos timing adjusted. Two spark plugs on right engine replaced .

**9 September 1999 – 11,289.4 hours.** Check 2A carried out.

**20 August 1999 – 11,234.6 hours.** Check 2 and 3 carried out.

**2 August 1999 – 11,182.1 hours.** Check 2A carried out.

**16 July 1999 – 11,136.6 hours.** Check 2 and 3 carried out.
Six spark plugs right engine replaced.

**28 June 1999.** Check 2A carried out.

**9 June 1999 – 11,037.8 hours.** Check 2 and 3 carried out.
Three spark plugs on left engine replaced.

**21 May 1999 – 10,990.1 hours.** Check 2A carried out.
Overhauled propeller fitted to the left engine.

**6 May 1999 – 10,939.6 hours.** Check 2 and 3 carried out.
Left engine #4 exhaust stack replaced.

**8 April 1999 – 10,840.1 hours.** Check 2 and 3 carried out.
One spark plug left engine replaced.

**10 March 1999 – 10,741.3 hours.** Check 2 and 3 carried out.
Two spark plugs on left engine replaced.

**23 February 1999 – 10,689.5 hours.** Check 2A carried out.

**19 February 1999 – 10,673.0 hours.** Overhauled propeller installed on the right engine.

**12 February 1999 – 10,641.3 hours.** Check 2 and 3 carried out.

**29 January 1999 – 10,594.2 hours.** Check 2A carried out.

**15 January 1999 – 10,542.4 hours.** Check 2 and 3 carried out.

**4 January 1999 – 10,520.1 hours.** Right engine #5 and #6 fuel injectors cleaned.

**29 December 1998 – 10,493.8 hours.** Check 2A carried out.

**4 December 1998 – 10,442.4 hours.** Check 2 and 3 carried out.

Right engine replaced. Right engine baffles replaced. Right engine mount frame overhauled.

**Observations:**

- The maintenance work conducted on the left magneto of the left engine on 9 May 2000 was about 49 hours, and 63 flights before the accident.
- The maintenance work conducted on the right magneto of the left engine on 10 May 2000 was about 47 hours, and 59 flights before the accident.

### 1.6.5 Engine life extension program

At the time of the accident, CASA had approved Whyalla Airlines (in common with many other operators) to operate the engines of their Chieftain aircraft for 2300 hours before they were overhauled. Certain conditions were linked to that approval. CASA occasionally approved certain Whyalla Airlines Chieftain engines to operate beyond 2300 hours before overhaul. Neither of the engines installed in MZK had been approved to operate beyond 2300 hours and neither had done so.

### 1.6.6 Automatic pilot

The aircraft was equipped with a King KFC-200 automatic pilot. The unit manipulated elevator trim, elevator and aileron surfaces to affect aircraft pitch and roll but did not control the rudder.

### 1.6.7 Engine instrumentation

The position of the engine instruments on the instrumentation panel of MZK are depicted in figure 3. Engine gauges for displaying exhaust gas temperature (EGT), fuel flow, oil temperature, oil pressure and cylinder temperature (CHT) are shown in figures 3 to 6.

Figure 3:
Instrumentation layout of MZK

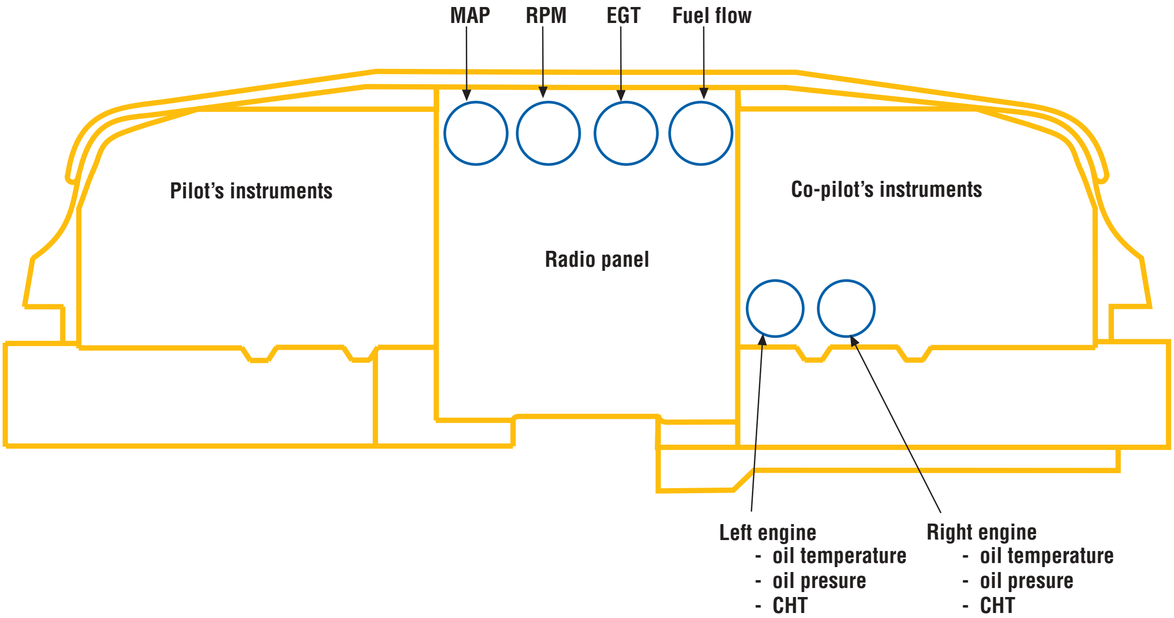



Figure 4:
Exhaust gas temperature (EGT) gauge, Piper Chieftain (as per MZK)

**Figure 5:**
**Fuel flow gauge MZK**


**Figure 6:**
**Left and right triplex gauge (oil temperature, oil pressure and cylinder head temperature), Piper Chieftain (as per MZK)**


## 1.6.8 Trend monitoring

The trend monitoring data for MZK from 17 Dec 1999 to 30 May 2000 was examined. The values recorded for the various parameters were within the limits prescribed in the Pilot's Operating Handbook (POH) except as follows:

- On 29 February 2000, the pilot operating MZK at the time recorded the left engine oil temperature as 250°F. That was above the maximum oil temperature limit of 245°F. The aircraft was flown every day from 29 February to 5 March 2000, and on each flight the left engine oil temperature was recorded as between 220°F and 250°F. On the next flight (9 March), the temperature was recorded as 250°F. Maintenance action was taken (Section 1.6.4 refers) and the aircraft returned to service on 9 March 2000. The left engine oil temperature was not recorded as more than 200°F after that time.

**Observation:**

Based on maintenance records, it is likely that the elevated oil temperature indications were false and were caused by a wiring fault.

### 1.6.9 High temperature engine component usage

An examination of Whyalla Airlines maintenance records suggested that there may have been a relatively high frequency of replacement of high temperature engine components (such as exhaust stack segments, spark plugs, EGT probes, valves and cylinder assemblies) for company Chieftain aircraft compared with other operators of the type. Initial information from two other organisations that maintained Chieftain aircraft seemed to support that suggestion. Some further work was undertaken in an attempt to quantify this information. However, some difficulties arose. For example, in most instances, while the maintenance document recorded that a particular part had been replaced, no reason for the replacement was given (nor was one required). There were also differences in the types of operation the various aircraft were involved in, engine operating techniques, and operator maintenance policies and practices. Under those circumstances, it became apparent that any comparison of the information would require many assumptions to be made and that a rigorous analysis was not realistically achievable.

## 1.7 Meteorological information

For a flight in accordance with the instrument flight rules (IFR), the pilot in command was required to obtain either a flight forecast for the route being flown, or an area forecast and destination aerodrome forecast.

The Bureau of Meteorology provided meteorological services for civil aviation in Australia. Area and aerodrome forecasts were issued on a routine basis and were available on request. Australia was divided into meteorological forecast regions to facilitate the provision of area forecasts. The planned route from Adelaide to Whyalla was contained within the Area 50 forecast region. The pilot of MZK had received current weather forecasts for the intended flight.

### 1.7.1 Forecast weather conditions

An amended Area 50 weather forecast was valid from 1300 to 2330 CST. The forecast overview indicated that there would be isolated showers and drizzle associated with broken low cloud, chiefly about the coast, to sea, and around the ranges. The forecast wind up to 7,000 ft was 180°T at 20 kts.

There were forecast areas of broken stratus between 800 ft and 2,500 ft, with scattered cumulus between 2,500 ft and 6,000 ft, together with areas of broken strato-cumulus between 3,500 ft and 6,000 ft. Visibility was expected to reduce to 4,000 m in drizzle and 6,000 m in showers. The freezing level was estimated to be 6,000 ft with no icing. Turbulence was forecast to be light to moderate in cumulus cloud.

A terminal area forecast (TAF) for Adelaide became valid at 1530 CST. The TAF indicated that there would be scattered cloud at 2500 ft and 3500 ft and light showers.

The TAF for Whyalla that became valid at 1730 CST indicated that there would be scattered cloud at 1500 ft and 3000 ft and light showers.

End of daylight was calculated to be 1741 CST. There was no moon visible at the time of the accident, being two days prior to the new moon.

### 1.7.2 Observed weather conditions

The Bureau of Meteorology advised that analysis of actual weather data covering the period of the flight indicated that the 6,000 ft wind was from 160°T at 20 kts for the route flown by MZK. The temperature at 6,000 ft was plus 5°C. The Bureau advised that those conditions would have existed along the entire route. No sudden changes in wind and/or temperature were likely.

Accounts of the weather conditions in the vicinity of the accident site by the crews of aircraft involved in the search for the aircraft and its occupants were generally consistent with the forecast conditions. The reported cloud base was between 2,000 ft and 2,500 ft with some lower patches, and cloud tops around 5,000 ft. Rain showers were present in the area, particularly to the west over land. Crews commented that there was a light southerly wind with no turbulence. They also indicated that it was a particularly dark night with no moon. The crew of one aircraft stated that the weather conditions deteriorated throughout the four and one half hour period they were involved in the search.

An experienced mariner involved in the surface search activities on the night of the accident reported that the surface wind was south-south-easterly at approximately 15 kts and that the sea conditions varied, with southerly wind waves between 0.5m and 1.0m.

**Observations:**

- The performance of the aircraft was unlikely to have been affected by any unusual or sudden change in atmospheric conditions.
- Because the outside air temperature at 6,000 ft was above 0°C, the performance of the aircraft was unlikely to have been affected by airframe or propeller icing.
- The pilot would have had difficulty discerning the horizon and water surface in the overcast, dark, moonless conditions.

## 1.8 Communications

The aircraft was fitted with two VHF radio communications systems appropriate for the flight being undertaken. The quality of all radio communications between the pilot and air traffic services throughout the flight was considered to be normal.

Relevant communications between the pilot of MZK and various air traffic services agencies are included in the sequence of events in section 1.1.

## 1.9 Aerodrome information

There were two aerodromes adjacent to the Adelaide to Whyalla track suitable for use by a Chieftain aircraft at night.

MZK's track passed approximately 14 NM north-east of Kadina aerodrome and 27 NM south–east of Port Pirie aerodrome. Both aerodromes were equipped with pilot–activated runway lighting. Neither was equipped with a ground–based navigation aid or an associated instrument approach procedure. There was no published GPS approach for either aerodrome.

Port Pirie aerodrome was used for night training by Whyalla Airlines and the pilot of MZK had operated into that aerodrome earlier on the day of the accident. There was no record that the pilot had operated into Kadina.

Figure 1 at page 3 shows the location of Port Pirie and Kadina.

## 1.10 Aids to navigation

Other than Whyalla and those in the Adelaide area, there were no aerodromes served by both a ground–based navigation aid and associated instrument approach procedure in the vicinity of the Adelaide to Whyalla track.

## 1.11 Recorded information

### Flight recorders

Regulations did not require Piper Chieftain aircraft to carry flight recorders and none were fitted to MZK.

### Radar Information

Primary radar systems operate on a single frequency and utilise a high power transmitter that transmits a pulsed signal. These pulsed signals are reflected off a target and received back at the radar antenna.

Secondary surveillance radar (SSR) is comprised of an airborne transmitter/receiver called a transponder and a ground based transmitter/receiver. An interrogating pulse is transmitted from the ground station to the aircraft transponder, which generates a reply. The reply from the aircraft consists of a set of pulses that can be encoded to provide positional information (Mode A) and altitude information (Mode C).

The Australian Advanced Air Traffic System (TAAATS) is capable of utilising radar from different sensors and providing an image of the track an aircraft makes as it progresses along a flight path. The system records the radar data that is received from each sensor and then presents that information as a system track to the air traffic controller.

Radar data was obtained from sensors at Adelaide Airport (Terminal Area Radar, TAR) and Summertown (Route Surveillance Radar, RSR). The Adelaide TAR consisted of a 40 NM range primary radar and a 200 NM range SSR transmitter and receiver. Summertown consisted of a 200 NM range SSR transmitter and receiver. However, that range reduces as the altitude of target aircraft reduces.

### Recorded radar data

The aircraft was under air traffic control radar coverage for part of the flight. AirServices Australia recorded the radar data in a digital format as part of the TAAATS environment. It is an ICAO (Annex 11) standard to record Air Traffic Service radar information. Relevant details concerning the radar environment and the analysis of the recorded data include the following:

- Data included tracking information from the Adelaide TAR and the Summertown RSR. A combination of data from these two sensors was recorded as a TAAATS system track.
- Radar sensors tracked MZK by Secondary Surveillance Radar. Transponder replies from the aircraft contained positional information, Mode A reply, and altitude information, Mode C.
- The radar sensor antenna rotates at 16.6 RPM and can provide updated positional and altitude information about every 3.6 seconds. Consequently dynamic manoeuvres made by an aircraft that occur within 3.6 seconds may not be captured.

- Aircraft Mode C altitude reply is referenced to standard atmospheric pressure (1013.25 millibars) and is processed in 100 feet increments. The radar system provides a barometric correction for local air pressure that is provided by a local sensor and altitude above mean sea level is calculated.
- Aircraft groundspeed, heading and position were derived from the Mode A reply by the radar tracker.
- Replies from the Adelaide Terminal Approach Radar were limited by the facility coverage at 6,000 ft of approximately 95 NM.
- Replies from Summertown were limited by the facility coverage at 4,000 ft, approximately 110 NM, and also appeared to be subject to loss of data due to a phenomenon called multi-path fading. That was due to the mixing of a direct and a reflected signal from the aircraft that can be subtractive and result in reduced signal strength (amplitude) at the receiving radar antenna. Signal strength, the parameter required to positively identify this phenomenon was not recorded.
- Recorded radar data was recovered from the TAAATS recording and analysed to produce aircraft track, groundspeed, and altitude information.
- Between 1400 on the 31 May and 0700 the following day, MZK and two other Piper Chieftain aircraft departed Adelaide following similar tracks to MZK on the accident flight. Data for the cruise segments of the three flights showed variations of less than 5 knots in groundspeed, and less than 4 degrees in heading. This contrasted with the information from the accident flight. The initial cruise segment showed minor groundspeed and track variations. However, after 1847:15 the track diverged approximately 19 degrees right and the groundspeed reduced from about 177 knots to 167 knots. Further significant variations in track and groundspeed were observed during the remainder of the period the aircraft was within radar coverage.

Information from the radar and audio analysis has been included in section 1.1.

**Observation:**

- The consistency in the data from the flights by the other two Chieftain aircraft, and the earlier flight by MZK, provided a high level of confidence in:
    - the validity of the recorded radar information regarding the accident flight, and
    - the consistency of weather conditions (i.e. the wind) along the route during the period of the accident flight.
- Assuming a tailwind of 20 kts, a groundspeed of 167 kts is equivalent to a true airspeed of 147 kts. According to documentation provided to the ATSB by Piper, the engine power required to achieve that speed was about 375 brake horse power (BHP). The Lycoming Operators Manual for the engine indicated that at 2,575 RPM, 46 inches manifold pressure (MAP) would provide about 375 BHP. The chart for 2,400 RPM engine operation did not include any data for MAP greater than 40 inches (approximately 315 BHP).
- The FAA type certificate for the aircraft engine included the maximum continuous operating conditions as 350 BHP, 2,575 RPM, at a standard density critical altitude of 15,000 ft. The FAA type certificate for the Piper Chieftain stated that the maximum manifold pressure was 49 inches hg. and that, below 15,000 ft, this pressure should not be exceeded.

### Recorded audio data

AirServices Australia recorded radio transmissions in both analog and digital formats. It is an ICAO (Annex 11) standard that audio information generated by Air Traffic Services should be recorded. Relevant details concerning the audio environment and the analysis of the recorded data included the following:

- The audio information was recorded on three separate recorders in two facilities, Adelaide Terminal Control Unit, TCU, and Melbourne Air Traffic Service Centre, TMA. Signals relating to the operation of MZK were analysed using audio recording and analysis software.
- Records of relevant conversation between MZK and Air Traffic Services were made. Detailed analysis of individual transmissions and pauses in speech during transmissions from MZK were carried out to ascertain if any signals may be present to indicate mechanical aspects of the aircraft operation. Signals were detected that related to propeller rotational speeds. The signals did not allow differentiation of the operation of individual propellers, or the determination of whether one or two propellers were operating. Those signals were verified by comparison with recordings made by other Piper Chieftain aircraft operating on similar routes on the same day, using the same air/ground radio frequencies.
- Limitations in the quality of recorded information precluded any information regarding propeller RPM being obtained from transmissions after 1856.

Information from the analysis has been included in section 1.1.

## 1.12 Wreckage and impact information

### 1.12.1 Accident site description

During the impact sequence the aircraft broke into several large pieces which settled to the ocean floor. All of those pieces came to rest within a 50 meter radius of the main fuselage wreckage at GPS position 33.16.484S 137.38.363E, approximately 14 NM south-south-east of Whyalla in Spencer Gulf. An amount of windshield perspex and metal fragments was found about 50 metres south-east of the main wreckage. All major components and flight control surfaces were present. The location of the wreckage was consistent with an impact point related to the last known track of the aircraft.

The wreckage was recovered on the afternoon of 9 June 2000 in a marine salvage operation commissioned and supervised by the ATSB. It was then transported to a land facility for further examination.

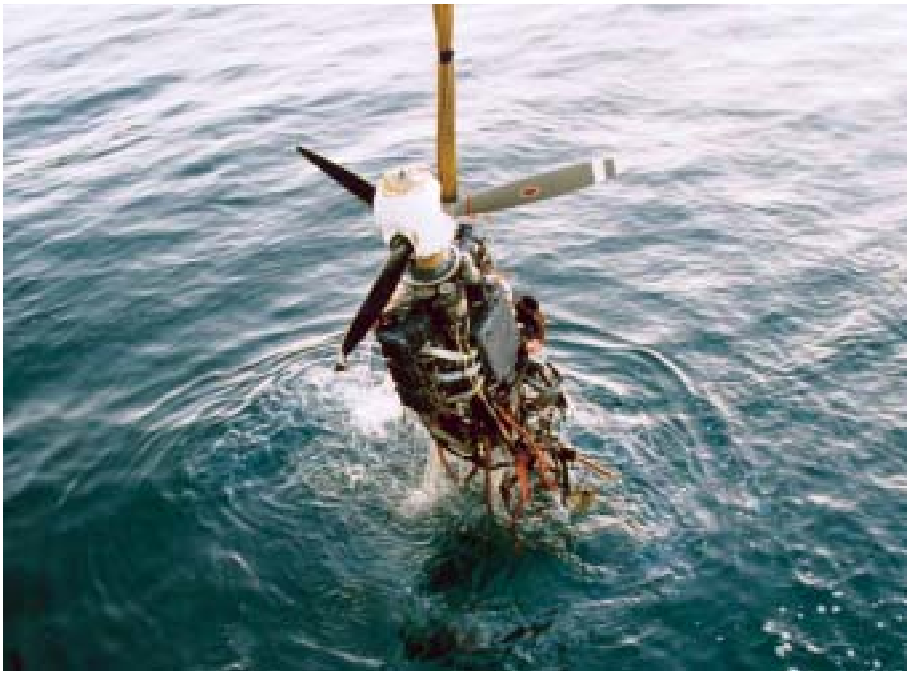
**Figure 7:**
**Aircraft wreckage – rear view**

**Figure 8:**
**Aircraft wreckage – side view**

**Figure 9:**
**Right wing**

**Figure 10:**
**Aircraft propellers (left at rear, right in foreground)**

**Figure 11:**
**Left engine/propeller**



### 1.12.2 Structure

Examination of the wreckage indicated that the initial contact with the sea surface occurred on the outboard section of the right wing. The aircraft was upright at the time and in a shallow nose down attitude, with the wings level, or banked slightly right. Deformation of the right wing spars and skin was consistent with the contact occurring on the lower side of the leading edge and lower wing surface only. The onset of the loads caused the wing to tear off in an upward and rearward direction, slewing the aircraft severely to the right. The fuselage to water contact occurred initially on the front right side of the fuselage. Contact with the water caused disintegration of the nose section and the cockpit area. Rapid and forceful ingress of water is considered to have further aggravated the initial impact damage and contributed to rapid sinking.

A combination of fuselage deformation and inrushing water forced the doors, most windows and the emergency escape hatch to come out of their respective retaining frames. (A more comprehensive description of the doors, windows and emergency escape hatch can be found at sections 1.12.7 and 1.12.8.)

Inertia loads associated with the rapid deceleration caused the left wing to move forward, tearing the rear spar to fuselage attachment lug. Both engines, subjected to inertial loads, were torn from their respective wing nacelle.

The deformation of the right engine mounts was consistent with the engine separating in a downward and inboard direction. Deformation of the left engine mounts was consistent with the engine separating in a predominantly outboard direction. Those departure modes were consistent with the aircraft slewing to the right at impact. Although the landing gear was found partially extended, damage to the landing gear doors was consistent with the landing gear being retracted at the time of impact. The landing and taxi lights were attached to the nose landing gear.

All structural failures were due to overload. There was no evidence found of any pre-existing condition that would have contributed to the aircraft disintegration.

### 1.12.3 Engines and propellers

See section 1.17.1 to 1.17.5

### 1.12.4 Flight controls

No evidence of any pre-existing fault in the flight controls was found. The wing flaps were in the retracted position at impact.

### 1.12.5 Cockpit instruments

No useful information could be gained from pressure sensitive instruments such as the air speed indicators, vertical speed indicators, altimeters and manifold pressure gauges due to salt water immersion, and the depth of water in which the aircraft came to rest. Engine instruments were also affected by salt-water immersion and did not provide any reliable information.

The only gyroscopic instruments recovered were the two vacuum powered[4] attitude indicators and one of the electrical powered turn and balance instruments. Examination of the attitude indicators revealed that they were capable of normal operation, but could not confirm that they were operating at impact. There was evidence of rotational damage to the turn and balance gyroscope.

**Observation:**

Rotational damage to the turn and balance gyroscope indicated that the instrument was operating at impact, was probably providing reliable information, and that the electrical system in the aircraft was operating.

### 1.12.6 Position of cockpit switches and controls

The positions of relevant cockpit switches and controls in the wreckage were documented as soon as the aircraft was recovered from the seabed. The amount of useful information was limited by the extent of damage to the forward fuselage and cockpit area. No useful information could be obtained from the circuit breaker panel. The landing gear selector had been damaged and was in the UP position. The master switch was damaged, but was in the ON position.

The positions of the engine controls and switches observed after the wreckage was recovered from the seabed are shown in table 3.

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4 The gyroscopes that provided pilot and co-pilot attitude and heading information were driven by two mechanically driven vacuum pumps, one in each engine bay. The pumps were part of two independent vacuum systems, each of which could power all four vacuum-powered flight instruments.

**Table 3:**
**Position of engine controls and switches after wreckage recovery**

| *Item* | *Left engine* | *Right engine* |
|---|---|---|
| Throttle control | Not determined | Not determined |
| Propeller control | Not determined | Not determined |
| Mixture control | Not determined | Not determined |
| Left magneto switch | On | On |
| Right magneto switch | On | On |
| Fuel boost pump switch | Off | Off |
| Alternator | Not determined | Not determined |

**Observations:**

- It is likely that the position of some of the controls and switches moved during the impact sequence.
- It is possible that recovery of the wreckage from the seabed interfered with some of the switches and controls.

### 1.12.7 Emergency exits and doors

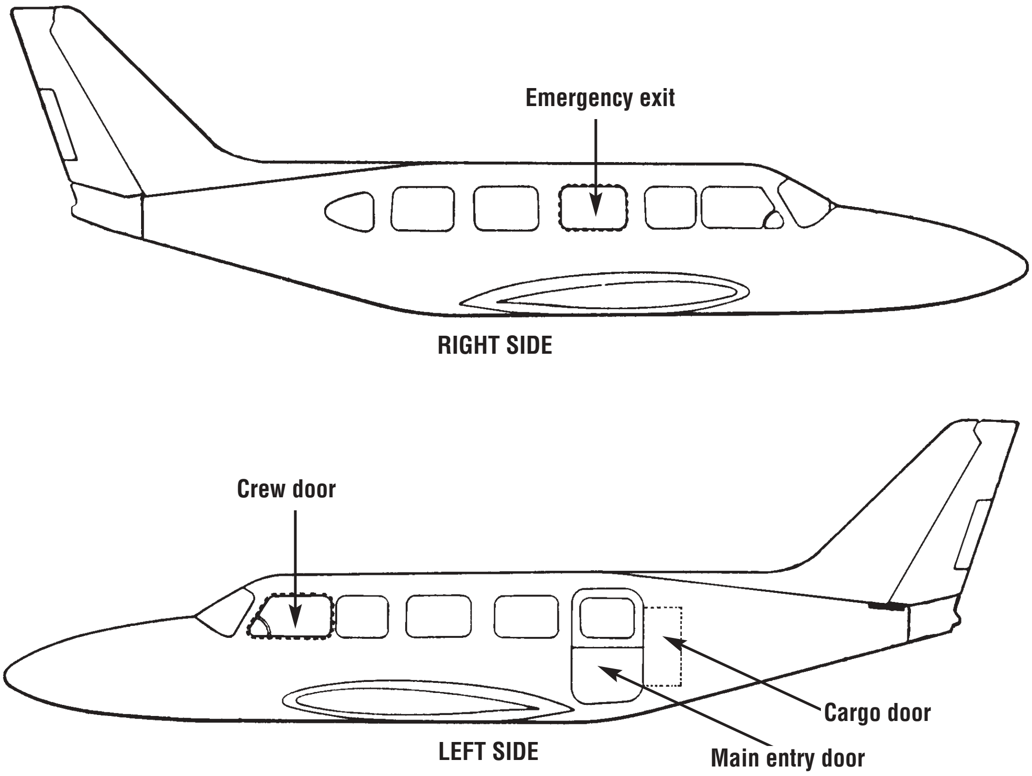
The aircraft was fitted with a two–section (upper and lower) main entry door located at the rear of the cabin on the left side. Each section opened outwards and was attached by two hinges. Although the front hinges had failed during the impact, the upper and lower sections remained attached by their rear hinges. Wreckage examination revealed that the locking handles and pins were in the closed position but that the doors were open.

A cargo door was located adjacent to and behind the main entry door. That door also opened outwards. The door locking mechanism was in the closed position but the door was open.

The aircraft was fitted with a crew door located on the left side of the aircraft beside the pilot seat. Although the door had separated during the impact sequence, the locking mechanism was in the closed position.

An emergency exit was located at the third row on the right side of the fuselage, but had separated and was missing. The locking handle and pins were in the closed position.

**Figure 12:**
**Location of Windows, doors and emergency exit.**




## 1.12.8 Windows

The position of aircraft windows is depicted in figure 12. Only the rear two windows on each side of the fuselage remained in place.

> **Observation:**
> There was no evidence of any door being open at impact. The doors and windows were opened by impact forces rather than by deliberate action.

## 1.12.9 Emergency Locater Transmitter

An Emergency Locater Transmitter (ELT) was fitted to a mounting bracket in the dorsal fin, forward of the vertical stabiliser on the aircraft. ELTs are equipped with devices that are designed to automatically activate the unit if it is subject to shock loads such as impact forces. The ELT then commences transmission of a coded signal on the international distress frequency 121.5 MHz and can be detected by satellites and aircraft.

When the ELT was recovered the switch was in the 'armed' position. The crew of an aircraft in the vicinity at the time of the accident stated that they heard an ELT signal for 10–20 seconds. Given the extensive airframe damage, with wing separation and forward cabin and cockpit disintegration, a short transmission period from an impact activated ELT would be expected before the fuselage sank. The ELT was not capable of underwater transmission, nor was it required to be.

> **Observation:**
> The absence of an ELT signal precluded rescue aircraft from quickly locating the crash position.

## 1.13 Medical and pathological information

Two deceased passengers were recovered from the sea about five and one half hours after the accident. The bodies of the pilot and four passengers were recovered some days later from the aircraft wreckage. One passenger remained missing.

Injuries sustained by the seven recovered occupants of the aircraft were described in the autopsy reports. The reports indicated that:

- One passenger died from multiple injuries.
- Six of the occupants (the pilot and five passengers) died from salt water drowning.
- Four of the passengers suffered injuries that may have affected their ability to egress from the aircraft and/or survive in the water for any length of time.
- One passenger suffered no major physical injuries.
- The pilot suffered no major physical injuries.

The pilot held a current Class 1 medical certificate issued by the Civil Aviation Safety Authority. No evidence was found to suggest that his ability to function normally was affected by any medical condition. Toxicological examination did not reveal the presence of any drug, including alcohol, which might have impaired his ability to carry out his duties.

## 1.14 Fire

There was no evidence of fire in any part of the wreckage.

## 1.15 Survival aspects

### 1.15.1 The ditching

The Civil Aviation Safety Authority did not publish any official guidance material regarding ditching. A case study of a ditching event was published in the CASA publication *Flight Safety Australia* Volume 2 Number 3 (September 1997). However, that did not address ditching techniques in much detail and night ditching was not discussed.

The US Federal Aviation Administration *Aviation Information Manual*, Section 6-3-3 discussed ditching procedures. Much of the discussion in that document related to assessing sea-state and selecting the most appropriate heading for the ditching.

The UK CAA General Aviation Safety Sense Leaflet 21A Ditching stated that 'the ditching itself is generally successful, although subsequent survival and rescue do not necessarily follow'. It also stated that UK and USA data suggested that '88% of controlled ditchings are carried out with few injuries to pilots or passengers. There is no statistical difference between high wing and low wing aeroplanes'. The leaflet went on to state that the pilot should not lower the landing gear in retractable gear aircraft[5], and that the pilot should '[h]old the aircraft off the water so as to land taildown at the lowest possible forward speed; do not stall into the water from a height of several feet'.

A search of Australian and overseas aircraft accident databases revealed at least 13 Piper Navajo and Chieftain ditching occurrences (excluding MZK). Of those, two resulted in fatalities. A brief summary of those occurrences is at Attachment C.

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[5] MZK was equipped with landing and taxi lights mounted on the nose landing gear strut, meaning that the landing gear had to be down for the lights to provide forward illumination.

### Accident ditching

The aircraft heading and speed at impact were not able to be determined.

There were 3 minutes and 5 seconds between the MAYDAY call and the last transmission from the pilot. There were approximately 2 minutes and 23 seconds between the last transmission and the ELT being activated.

## 1.15.2 Seats and seat restraints

The aircraft cabin contained ten seating positions, in five rows of two single seats separated by an aisle (see fig. 13). The seats were attached to seat tracks in the cabin floor structure. Seats 1 and 2 were fitted with three point harnesses – the lap belt was secured to the seat and the shoulder harness to the aircraft structure. The remaining seats were fitted with lap belts only. These were secured to the seat. There were no failures of seat belts or buckles.

Table 4 shows the results of the examination of the seats and seat harnesses in the wreckage. The seat number is as depicted in figure 13 below.

**Figure 13:**
**Aircraft cabin seating positions**

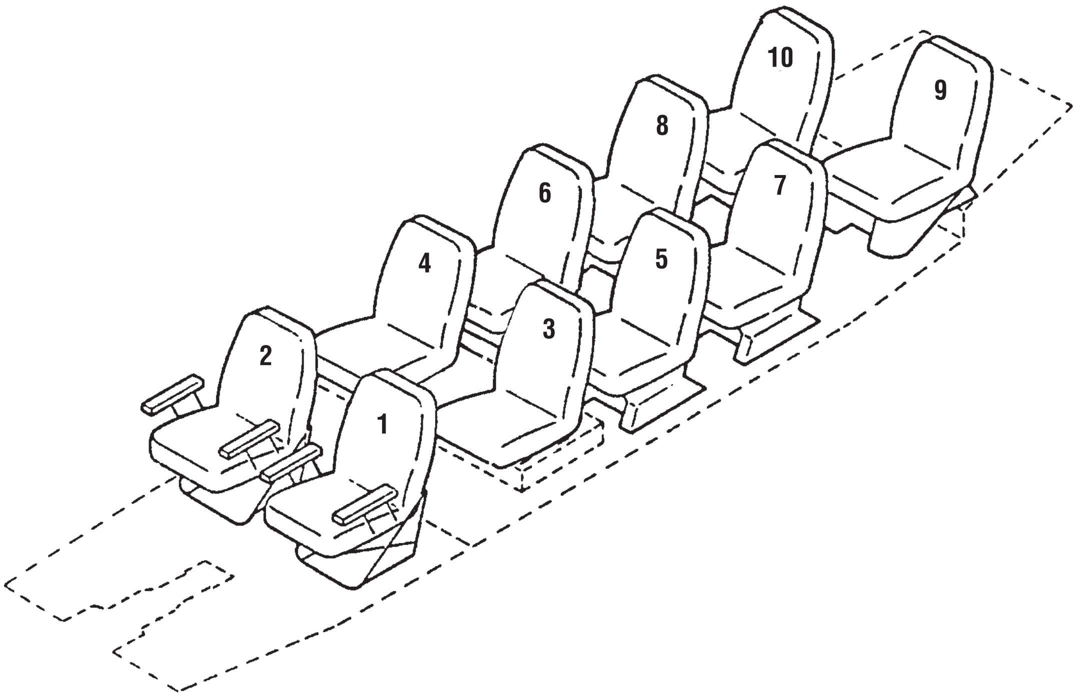

**Table 4:**
**Results of seat and seat harness examination**

| *Seat no.* | *Seat/floor attachment failed* | *Seat occupied at impact* | *Safety harness fastened* |
|---|---|---|---|
| 1 | yes | yes | yes |
| 2 | yes* | Not determined | no** |
| 3 | no | Not determined | no |
| 4 | no | yes | yes |
| 5 | no | Not determined | no |
| 6 | yes | Not determined | no |
| 7 | yes | Not determined | no |
| 8 | no | yes | yes |
| 9 | yes | Not determined | no |
| 10 | yes | Not determined | no |

Notes: * Seat No 2 was found on the seabed outside the aircraft

** Seat No 2 lap belt was unfastened but the shoulder harness remained attached to the male section of the lap belt.

It was not possible to determine the seating positions of all the passengers at the time of the accident, as specific seat allocation was not provided for in this class of aircraft.

Because of the absence of any information regarding the precise speed and attitude of the aircraft at impact, it was not possible to calculate the deceleration forces that the seats, harnesses, and occupants were subjected to during the impact sequence. The certification standard applying to the seat structures and harnesses required the ability to withstand maximum accelerations of 3.0 g upward, 9.0 g forward, and 1.5 g sideward. The seat and harness attachments were required to withstand 4.0 g upward, 12.0 g forward and 2.0 g sideward. From the seat and harness examinations, it appeared likely that in at least some parts of the cabin, the deceleration forces were below those levels.

### Upper body restraint

Research has shown that shoulder harnesses provide substantial injury protection against impact forces, in some cases up to six times greater than that provided by a lap belt. Evidence from accident investigations suggested that occupants without upper body restraint might have received disabling injuries that prevented them escaping from burning or sinking wreckage.

### Regulatory requirements

There was no regulatory requirement for Chieftain aircraft to be fitted with upper body restraint to other than the front row of seats. In December 1985, an amendment to the US Federal Aviation Regulations (FAR) Subpart 23.2 required all aircraft in this category with less than nine passenger seats, manufactured after 12 December 1986, to have each seat fitted with a safety belt and shoulder harness. Australian–registered aircraft were similarly required by the then Civil Aviation Authority (CAA), to comply with Airworthiness Directive AD/General/67 *Passenger Safety Harnesses*, by 31 July 1989.

Neither the US Federal Aviation Administration (FAA) nor the CAA required retrospective application of that AD. The effectiveness of an improved restraint system in aircraft manufactured before 12 December 1986 could not be guaranteed because of the possible design inadequacies of the seats and aircraft structures. That was a significant problem with the seats installed in many cabin-class multi-engine aeroplanes (such as the Chieftain). Some manufacturers chose to make available modification kits to some of their existing aircraft fleets in order that owners could upgrade their aircraft to meet the amended safety standard.

An inspection of the Australian aircraft register revealed that the majority of light aircraft (FAR Part 23 certified) in Australia were manufactured prior to 12 December 1986 (MZK was manufactured in 1981). The major US aircraft manufacturers had ceased light aircraft production in the early to mid-1980s.

Consequently, the protection afforded to passengers by the requirement for the provision of upper body restraint has not been extensively provided. Anecdotal evidence suggests that only a small percentage of these aircraft engaged in fare-paying passenger operations in Australia meet the amended safety standard (FAR 23.2).

#### Aircraft manufacturers' actions

The requirement for compliance with manufacturers' service bulletins was, and continues to be, driven by warranty and product liability issues and not necessarily by certification criteria. Determination of the legal applicability of service bulletins was the responsibility of the regulatory authority, in this case the US FAA.

Piper Aircraft Corporation issued Service Bulletin No. 896 on 28 November 1988, purporting to 'mandate' the installation of shoulder harness kits within one calendar year of the date of issue of the service bulletin. The applicable aeroplane models were all the Cherokee range of single–engine aircraft, including the derivatives Arrow, Lance and Saratoga, the Malibu and the multi-engine Seneca and Seminole aircraft. Some other manufacturers issued similar instructions.

The FAA did not issue an Airworthiness Directive that would have mandated compliance with those service bulletins or instructions. In Australia, the then CAA adopted the decision of the original certifying authority in accordance with its policy at the time.

Details of safety action taken by the ATSB and CASA with respect to upper body restraint are at section 4.

### 1.15.3 Post impact survival

Survival time at sea depends on many factors including age, gender, build, water temperature, sea state, and the extent of any injury. The wearing of a life jacket can extend survival time. In cold water, a life jacket or flotation device provides extra insulation and reduces body heat loss. The added confidence afforded by a life jacket or flotation device can be an important psychological factor in a survival situation.

Locating an individual in the water can be difficult, particularly in poor visibility conditions. A survivor wearing a brightly coloured life jacket will be more conspicuous than one who is not. The carriage of additional location aids such as lights (as required under ANO Part 103/TSO C131e) and whistles further enhance the likelihood of the wearer of a life jacket being located.

The Canadian Defence and Civil Institute of Environmental Medicine has developed a Cold Exposure Survival Model (CESM) to predict survival time for cold water immersion. The CESM model predicts two survival times – the time after initial exposure before a person begins to be incapacitated by hypothermia and the time before critical hypothermia sets in. The individual characteristics of the occupants, and other variable factors such as the clothing they may have been wearing, will produce a range of predicted survival times.

The sea water temperature in Spencer Gulf on 31 May 2000 in the area of the accident was reported to have been about 14°C. Data from the CESM model indicated that for these conditions prevailing at the time of the accident, incapacitation due to hypothermia would have occurred between three and ten hours after immersion. The survival of injured occupants without life jackets beyond that time would have been unlikely, due to their inability to continue the movement needed to remain afloat. The CESM model predicted that critical hypothermia would have been likely between six and 15 hours after immersion.

### 1.15.4 Carriage of life jackets or individual flotation devices

The aircraft did not carry life jackets or individual flotation devices. The requirements for the carriage of such equipment for overwater flights by aircraft engaged in regular public transport operations were specified in Civil Aviation Orders (CAO) Section 20.11, issued by the Civil Aviation Safety Authority. Multi-engine land aircraft authorised to carry nine passengers or less on flights up to 50 NM from land were not required to carry life jackets, approved flotation devices or life rafts. The air route from Adelaide to Whyalla was less than 50 NM from land.

Almost all ditchings recorded on the ATSB incident/accident database involved aircraft operating within 50 NM from land. Furthermore, many of those ditchings involved multi-engine aircraft. Although CAO 20.11 did not require those aircraft to carry life jackets, past experience and research data indicate that life jackets significantly enhance survivability.

**Observations:**

- There would have been sufficient time before impact for the pilot to brief the passengers regarding the emergency, and for the passengers to don life jackets (had they been available), secure seat harnesses, and prepare for impact.
- The security at impact of all passenger seat belts could not be determined.
- The state of consciousness of the aircraft occupants at the conclusion of the impact sequence could not be determined.
- The pilot, who was wearing a three-point shoulder harness, was seated in that part of the aircraft that suffered the most structural damage and yet received very minor impact–related injuries. The passengers who only had lap belts were seated in that part of the aircraft that remained relatively intact, yet received comparatively more severe impact–related injuries.
- Survival times of the deceased passengers located floating in the sea could not be accurately determined.
- It was unclear whether the deceased passengers located in the sea egressed of their own accord or were ejected from the cabin during the impact sequence.

- It is highly likely that the chances of survival for the occupants would have been enhanced if the passenger seats had been fitted with upper body restraints and if the aircraft had been carrying life jackets or individual flotation devices. (See section 4 for details of safety action taken with regard to the carriage of life jackets and upper body restraint.)

## 1.16 Fuel aspects

Fuel storage in the Chieftain consisted of main and auxiliary rubber bladder type tanks housed within each wing structure. Each inboard or main tank was housed forward of the main spar, extending from near the fuselage to wing mating joint, to just outboard of the engine nacelle. Each outboard or auxiliary tank was located behind the main spar, extending outboard of the engine nacelle. Separate filling caps for each tank were located outboard of the engine nacelles, one forward and one aft of the main spar.

MZK was fitted with inserts at each fuel tank filler point which were designed to physically prevent inadvertent refuelling with aviation turbine fuel (Avtur).

### 1.16.1 Pilot responsibilities

Regulation 234 of the Civil Aviation Regulations provided that an aircraft must not commence a flight unless the pilot in command and the operator have taken reasonable steps to ensure the aircraft is carrying sufficient fuel and oil to enable the proposed flight to be undertaken in safety. The regulation did not specify the method of determining what is sufficient fuel in any particular case.

At the time of writing this report, CASA was developing the new Civil Aviation Safety Regulations (CASR). CASR Part 91 was intended to 'prescribe the requirements of a general nature governing the operation and airworthiness control of aircraft.' The proposed CASR 91.25 (2) stated that

> [t]he aircraft operator, the pilot in command, the fuel supplier, the person who has management of the fuelling operation, and the person fuelling an aircraft must take steps to:
>
> (b) ensure that the aircraft is replenished with the amount of fuel and oil ordered by the person responsible for ordering the replenishment.

CASR Part 91 was intended to be supported by explanatory material contained in Advisory Circular (AC) 91.19(0). Material in ACs was advisory only. Section 8.2 of AC 91.19(0) indicated that unless an aircraft's fuel tanks were full or a totally reliable method of establishing fuel quantity was available and used, the pilot should use at least two different methods to establish the fuel quantity on board.

### 1.16.2 Wreckage examination – fuel system

#### Right wing fuel tanks

The inboard (main) tank had been badly holed during impact and subsequent wing separation. As a result, no fuel samples could be obtained. The fuel filler cap was correctly secured. The plumbing from the tank to the inboard edge of the wing had been torn from the aircraft. The right wing tank selector and filter bowl were retrieved from the ocean floor by the salvage operation. The filter bowl exhibited internal corrosion and contained seawater.

The outboard (auxiliary) tank was found intact, but contained no significant amount of liquid. The fuel filler cap was found in place. Approximately 250mL of seawater was recovered from the damaged connecting line between the fuel tank selector and the right auxiliary fuel tank.

#### Left wing fuel tanks

The left wing leading edge just outboard of the engine nacelle had incurred a strike from debris during the impact and break-up sequence. That in turn had pushed the deformed and damaged leading edge skin rearwards, puncturing the main tank bladder high up on the forward edge of the tank. The fuel filler cap was found in place. Approximately 7.5 L of seawater was decanted from the tank. There was no fuel present.

The auxiliary tank was found intact and the fuel filler cap in place. The plumbing had separated at the inboard edge of the wing where it connected to the fuel selector valve. During the examination approximately 25 L of seawater and approximately 16 L of what appeared to be Avgas were decanted from that tank (see section 1.16.3 on fuel quality).

#### Other fuel system components

The fuel tank selector valve, filter, firewall shut-off valve and electric boost pumps were removed and examined. Between 5 and 10mL of fuel was decanted from the emergency (crossfeed) fuel pump drain line. A very small amount of what appeared to be Avgas was observed in the connecting line between the boost pump and the firewall shut off valve for the left engine. About 150mL of fuel was drained from the fuel filter bowl for the left engine.

The cockpit fuel tank selector panel was found badly distorted as a result of impact forces. The fuel crossfeed selector was found selected to OFF. The left fuel tank selector was in the MAIN position. The right fuel tank selector was found over-rotated as a result of the floor distortion. When the left and right firewall shut-off valves were disassembled both were found in the ON (open) position.

### 1.16.3 Fuel quality

The recovered fuel samples were sent for laboratory analysis. The test data was typical of Aviation Gasoline 100/130. That grade of fuel was in accordance with the fuel specifications of the Piper Chieftain Pilot's Operating Handbook and the Australian Flight Manual for MZK. There was no evidence of the Avgas being contaminated with Aviation Turbine fuel.

Fuel samples taken from the refuelling facility, including the tanker reportedly used to refuel the accident aircraft, and a sample of the fuel recovered from the aircraft's left auxiliary fuel tank, were subjected to laboratory analysis. The analysis indicated that the fuel was free from contamination and was within the required specifications.

### 1.16.4 Adelaide refuelling procedures

The airline had arranged with a refuelling agent in Adelaide for an aviation gasoline tanker to attend the general aviation parking area to refuel their aircraft in accordance with the airline schedule. As the operating pilot was generally very busy in processing passengers and preparing for the next flight, refuelling was usually done without the pilot in attendance. Procedures in place at the time of the accident required the pilot of each aircraft to advise the refueller of the amount of fuel required by placing a written note on top of the aircraft's instrument glare shield. The note could be read by the refueller through the front windscreen. The refueller would mark the tread of the nosewheel tyre of the aircraft to indicate that it had been refuelled as requested. The refueller was also required to record the quantity of fuel loaded, the time, and the aircraft registration in a pocket notebook. Those details would later be transferred onto a daily multiple delivery docket back at the fuel facility.

### 1.16.5 Refuelling prior to the accident flight

It was reported that prior to the accident flight, the pilot of MZK had indicated on the note for the refueller that he required full inboard tanks and that he required information regarding the fuel split (the quantity of fuel loaded into each tank rather than just the total load). The refueller reported that he commenced refuelling MZK immediately after the passengers from the arriving flight from Whyalla had disembarked. However, he forgot to record the details of the refuelling (i.e. the quantity added, the time, and the aircraft registration) in his notebook.

A witness who was waiting at Adelaide Airport to meet a passenger on the incoming flight from Whyalla later reported that although he saw a refuelling tanker stopped near the Whyalla Airlines aircraft when it arrived, he did not believe the aircraft was refuelled. He said that although his view was partially obstructed while waiting for the passenger's luggage to be unloaded, he noticed the tanker drive away after what he believed to have been no more than about four minutes and surmised that the aircraft had not been refuelled. The manager of the fuel facility said that it typically took a total of 10–15 minutes to complete the refuelling process for a Chieftain aircraft. The refueller reported that only 3–4 minutes was actually taken with pumping fuel, the remaining time being taken with associated tasks such as connecting earth leads and preparing hoses.

The refueller did not initially recall refuelling MZK before its departure but later on the night of the accident recalled that he had refuelled MZK with 232 L of Avgas, with a split of 113 L and 119 L, and that he had marked the aircraft's front tyre accordingly. A reconciliation of the quantity of fuel remaining in the tanker indicated that about 234 L of fuel was not accounted for in the refueller's notebook. Allowing for normal wastage and gauge accuracy, that amount was consistent with the refueller's recollection. A review of the refueller's notebook indicated that MZK routinely took between 210 and 240 L when refuelled at Adelaide. During the course of the investigation it was found that the refueller had not used totaliser readings[6] for his fuel log entries. Rather he just added the amount of fuel delivered on each occasion to the previous figure.

Refuelling procedures at Adelaide Airport were discussed with other company pilots. The information they provided included the following:

- Some considered that time pressure during turn-arounds (see also section 1.19.5) could result in a pilot forgetting to check that the aircraft had been refuelled.
- One pilot had seen other pilots depart without checking the front tyre for the amount of fuel added.

[6] Totaliser readings refer to the gauge on the Avgas tanker which displayed an ongoing total of the amount of fuel delivered by that tanker.

- One pilot had been ready to depart on four or five occasions when he found out that the aircraft had not been refuelled.
- Another pilot had departed Adelaide without the aircraft having been refuelled and elected to return to Adelaide to refuel.
- Fuel tank caps had been left off on a few occasions.

### 1.16.6 Fuel quantity

The standard fuel load for the flight from Adelaide to Whyalla, as detailed in the company operations manual, was full inboard tanks (402 L) against a flight planned requirement of 218 L (including reserves but excluding any holding/alternate requirements). Company practice was to carry not more than 5 to 10 L in the auxiliary tanks in order to keep the bladders wet. That amount of fuel was considered to be unusable.

As a part of the investigation, calculations were carried out to determine if the aircraft would have had sufficient fuel to fly from Adelaide to Whyalla as flight WW904, assuming that no fuel had been added in Adelaide after its earlier flight from Whyalla. The calculations were based on data from the Chieftain Pilot's Operating Handbook and established that the aircraft would have had about 131 L remaining after arriving from Whyalla.

Calculations for the accident flight based on a 'fuel on board' total of 131 L ex Adelaide indicated that the aircraft would have had 21 L remaining on arrival at Whyalla. However, that did not account for true airspeeds less than the published figures, the additional track miles flown during departure from Adelaide, and any variation in engine operation and leaning procedure that the pilot may have used. The same calculation using data from the Whyalla Airlines Operations Manual indicated that there would have been a shortfall of about 2 L.

**Observations:**

- The wreckage examination did not permit a conclusion to be drawn regarding the amount of fuel on board the aircraft at impact.
- It was not possible to establish categorically that the aircraft had been refuelled after arriving at Adelaide from Whyalla. However, on the information available, the likelihood is that the aircraft was refuelled.
- No anomalies were found regarding fuel quality.
- The fuel tank selection established from wreckage examination was consistent with normal operation whereby the engines were being fed from the main fuel tanks.
- The observation of fuel in the boost pump, firewall shut-off valve, and filter bowl for the left engine indicated a high probability that fuel was available to the left engine when it ceased operating. Impact damage negated similar information being available from these components for the right engine.

Shortly after the accident, while the ATSB's investigation was underway, the refuelling organisation introduced revised aircraft refuelling procedures that applied nationally. (See also Safety Action section 4.)

## 1.17 Engines and Propellers

This section of the report addresses the examination and testing of components and the operation of the aircraft engines and propellers and associated issues. Salt-water corrosion affected some components of the aircraft, reducing the amount of information available.

#### Terminology

Technical descriptors (be it one word or a phrase) serve a vital role in communication about complex phenomena. The common understanding associated with the descriptor allows communication to occur.

The shortcomings of the use of technical descriptors lie in the sometimes imperfect connection between desciptor and phenomenon, leading to differing understandings by various people when a desciptor is used. Additionally, especially during investigation processes, the interpretation of the evidence of phenomena may lead to inconsistencies in classification – different technical descriptors may be applied to one phenomenon. For example, the use of the term 'failure' may sometimes be taken to refer to component fracture, loss of function of a component or mechanism, or a change from the normal function of a component, mechanism or process.

It is recognised that no one definition of a technical descriptor is necessarily adequate. It is also recognised that multiple definitions do lead to misunderstandings. Unless the context makes usage clear, where technical descriptors are used in this section, short definitions will be given to clarify their use.

### 1.17.1 Introduction

An essential element of an aircraft is the propulsion system. That system provides the forward thrust necessary for flight. While gas turbine engines are the basis for propulsion systems for many aircraft, especially large civil transport aircraft, reciprocating engines coupled to propellers are used to provide the propulsive force for many smaller aircraft types. The high power variants of horizontally opposed, six–cylinder, air-cooled reciprocating engines coupled to constant speed propellers are used to power many aircraft employed in low capacity public transport operations. For example, the Piper Chieftain (PA-31-350) aircraft, powered by two Lycoming turbocharged six–cylinder engines, (L)TIO-540-J2B, is widely used to provide transport links within Australia.

It is important to recognise that, in reciprocating engine installations, the engine and propeller form an interdependent system. Constant speed propellers are used in conjunction with high power reciprocation engines. That type of installation allows the propeller speed and engine power to be set separately to obtain the best combination of performance and fuel economy for all phases of flight.

Just as the engine and propeller form an interdependent system, the engine and fuel consumed in the engine form an interdependent system. Engine performance and fuel properties are closely linked. The history of engine development has been a process of mechanical refinement to extract the available energy contained in a fuel (aviation gasoline) under controlled combustion conditions and a concurrent refinement of gasoline formulation to allow advantage to be taken of mechanical refinements.

The safe operation of aircraft relies on the correct operation of all the systems that combine to allow aircraft to function. The propulsion system is one of these systems.

## Expectations of the propulsion system

Propulsion systems must have a high power to weight ratio, they must be economical, but above all they must be reliable.

The capability of an engine to produce the power specified by the engine manufacturer reliably throughout flight is a fundamental requirement of safe operation. Conversely, the failure of engines to produce specified power levels or the complete failure of an engine during flight is a threat to safe operation. That expectation is expressed simply in the design standard for aircraft engines, e.g. Federal Aviation Regulations Part 33 Airworthiness Standards: Aircraft Engines:

> Engine design and construction must minimise the development of an unsafe condition of the engine between overhaul periods.

The international standards for airworthiness of aircraft are contained in Annex 8 to the Convention on International Civil Aviation (the Chicago Convention). Annex 8 stated:

> The engine complete with accessories shall be designed and constructed so as to function reliably within its operating limitations under the anticipated operating conditions when properly installed in the aeroplane.

### How expectations are met

The confidence that an aircraft engine will perform reliably is achieved by regulatory authority certification that the engine has passed an extensive testing program combined with approved instructions for operating limits, lubrication, inspection, component replacement, testing and adjustment. These design requirements form the basis of a comprehensive safety system.

Feedback on actual engine performance/behaviour is an essential element in determining the adequacy of the safety system and, if necessary, making adjustments to the safety system.

### Structural efficiency

Structural efficiency in design is necessary to achieve high power to weight ratios. The requirement that an engine design is reliable, within defined operating limitations, is demonstrated by performing the test program contained within the engine design standard (FAR 33). Instructions for maintenance are designed to ensure continued airworthiness under operational conditions. Operating limitations are determined for horsepower, RPM and manifold pressure at rated maximum continuous power. Items such as fuel grade, oil grade, cylinder head temperatures, oil temperatures, turbine inlet temperatures and component life are specified.

The strength and robustness of engine components and mechanisms, within the defined engine operating limits, is achieved by using materials that comply with standard specifications (to guarantee that the properties of the materials used match those assumed in design), and by a comprehensive test program. FAR 33 stated:

> The engine must be designed and constructed to function throughout its normal operating range of crankshaft rotational speeds and engine powers without inducing excessive stress in any of the engine parts because of vibration and without imparting excessive vibrational forces to the aircraft structure[7].

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[7] Federal Aviation Regulations Part 33, Airworthiness Standards: Aircraft engines, subpart C, Design and Construction; Reciprocating Aircraft Engines, Section 33.33 Vibration.

Further demonstration of the adequacy and robustness of the engine is provided by an endurance test (FAR 33, subpart D, section 33.49). Engines are subjected to blocks of engine operation under a variety of operating conditions to a total of 150 hours of operation. At the conclusion of the endurance test the condition of components and mechanisms is assessed during a teardown inspection. Each component must retain the functioning characteristics that were established at the beginning of the test.

### Energy from combustion

The heart of aircraft powerplants is the conversion of the energy available in liquid hydrocarbons to mechanical energy. The primary requirement for spark ignition engines is that, under the conditions existing in the combustion chambers of the engine, the gasoline should burn smoothly without exploding. The smooth, controlled, pressure increase in the combustion chamber results in the maximum conversion of chemical energy to mechanical energy. The essential process in the operation of reciprocating internal combustion engines is the non-continuous burning of a pre-mixed fuel air charge in a chamber that allows the gas pressure created during combustion to act against a moving piston. Normal combustion in spark ignition engines commences with ignition from a spark, followed by the steady propagation of the flame front through the fuel–air charge. The ratio of the fuel–air mixture, the timing of spark ignition, the temperature of the fuel–air mixture in the combustion chamber and the magnitude of combustion chamber pressure are four critical variables that determine satisfactory engine operation.

There are limiting ratios of fuel to air beyond which combustion does not occur. Typically, gasoline will burn if mixed with air in a ratio between 1 part fuel to 8 parts of air and 1 part fuel to 18 parts of air[8] (ratios based on weight). These ratios provide the lean (excess oxygen) and rich (excess fuel) flammability limits for fuel–air mixtures. Because the mixture delivered to each cylinder of an engine may vary, one cylinder will be closer to the lean mixture flammability limit and will misfire before other cylinders. Scattered misfiring results in a rough running engine and imposes limits on engine operation, e.g. the lean misfire limit.

The chemically correct ratio for complete combustion of the reactants (known as the stoichiometric ratio) is approximately 1 part of fuel to 15 parts of air. Satisfactory spark ignition and flame propagation depends on the ratio of fuel to air being close to the stoichiometric ratio. Studies of engine performance have found that the maximum power output from an engine occurs with a rich mixture. Under those conditions, all of the available oxygen is consumed. However, as the unreacted fuel is wasted, power is maximised at the expense of fuel economy. Maximum economy is achieved by operating the engine with a lean mixture. All the available fuel is consumed at the expense of some power reduction. Mixtures are adjusted to meet the requirements of different phases of flight.

A feature of lean fuel–air mixtures that has an impact on engine operation is the speed of flame propagation. Mixtures leaner than the stoichiometric ratio burn more slowly and have a lower maximum temperature than the stoichiometric mixture. Combustion of lean mixtures may result in flame propagation still occurring when the exhaust valve is open. This can cause valve overheating (overheated valves may then lead to other combustion abnormalities). At the leanest mixtures, flame propagation may be so slow that a flame may be present when the inlet valve opens to admit a new fuel–air charge resulting in backfiring.

[8] Aircraft Powerplants, R D Brent and J L McKinley, Aviation Technology Series, 1978, page 74.

### Detonation limits

Combustion in spark ignition engines is designed so that a flame front moves across the premixed fuel–air charge in the combustion chamber resulting in a controlled increase in gas pressure. Under certain conditions, rapid oxidation reactions occur at many locations within the unburned charge, leading to very rapid combustion throughout the volume. This essentially volumetric heat release in an engine is called autoignition, and the very rapid pressure rise leads to the characteristic sound of engine knock[9]. Within the aviation industry this process of autoignition or knock is referred to as 'detonation'.

Detonation of the fuel–air charge in a reciprocating engine is the principal factor limiting the maximum power that can be produced by an engine. FAR 33, subpart D, section 33.47 required that:

> Each aircraft engine type must be tested to establish that the engine can function without detonation throughout its range of intended conditions of operation.

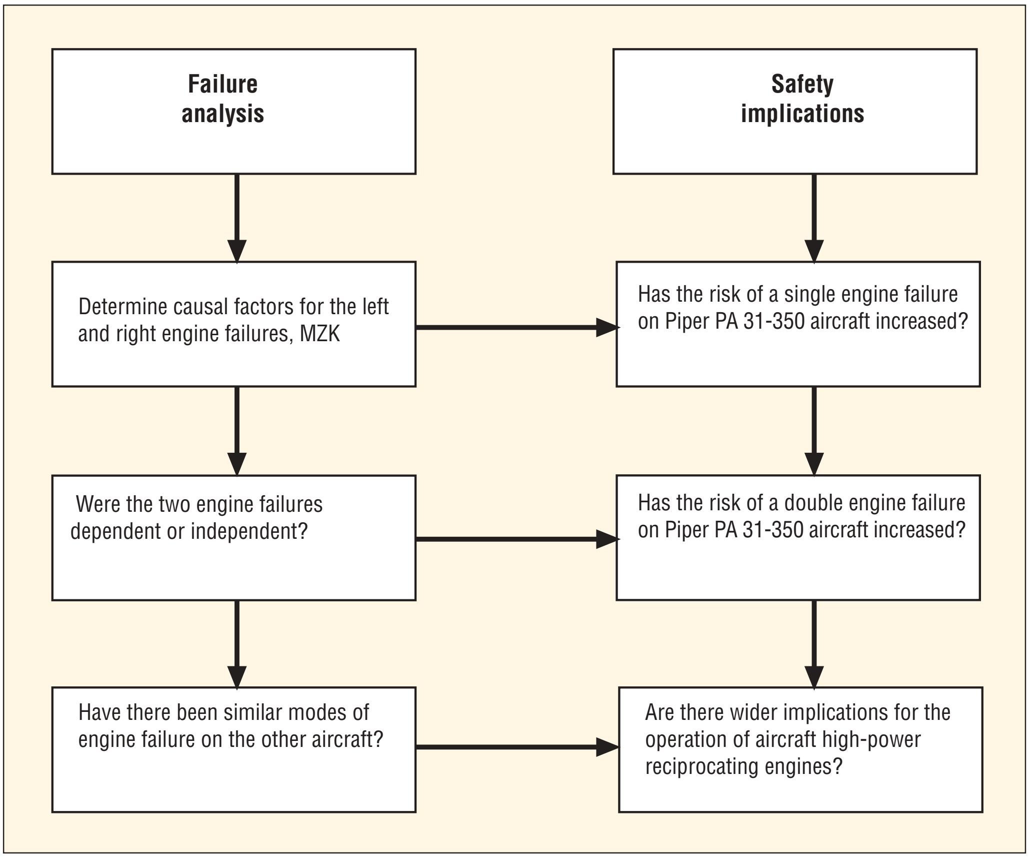
Avoidance of detonation is achieved primarily by the use of fuel with a known resistance to detonation (octane or performance number rating scales) under engine combustion conditions (a function of the engine design). Detonation–free operation is not solely dependent on fuel properties. Factors such as charge temperature, mixture strength, ignition timing and spark plug type can also affect the combustion process in an engine. Detonation maps define the combinations of engine power and mixture strength for a variety of limiting conditions (charge and combustion component temperatures) that do not result in detonation.

### Propulsion system failure analysis overview

The purpose of this analysis is to establish the factors associated with the failure of both engines on MZK, and to examine the safety system that has been developed to minimise the risk of reciprocating engine failure. An outline of the analysis logic is shown in figure 14.

[9] An Introduction to Combustion, Concepts and Applications, S R Turns, McGraw-Hill, 1996, p6.

**Figure 14:**
**Engine failure analysis logic diagram**

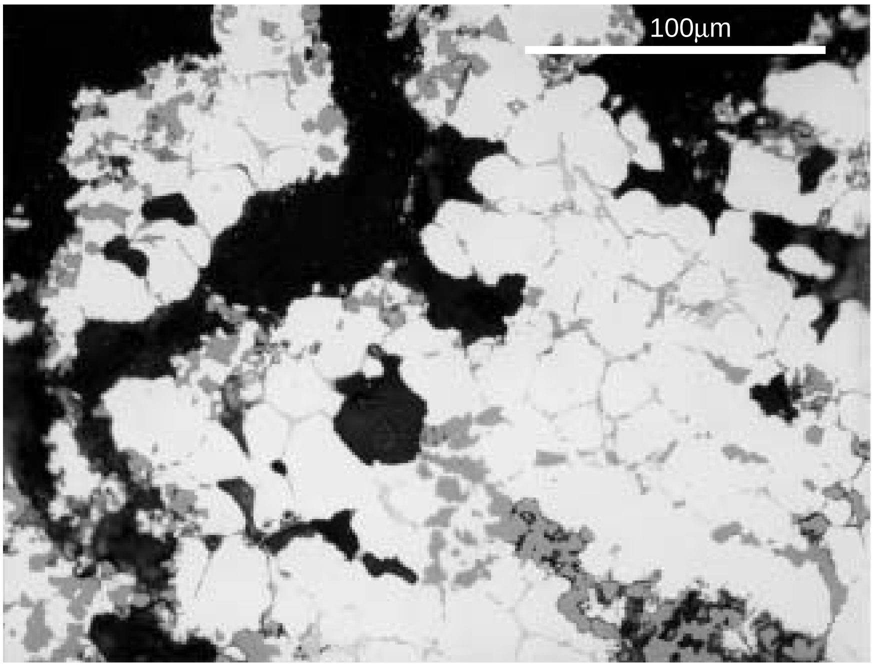



### 1.17.2 Right propulsion system failure analysis

Examination of the right engine revealed that the Number 6 piston had been holed in the vicinity of the upper ring groove (see fig. 15). It was noted during the examination of the engine and aircraft wreckage that engine oil had been lost as a result of crankcase pressurisation. The quantity of oil remaining in the sump at the time of ditching could not be determined as oil may have been lost during the period the engine was on the seafloor and during recovery. The oil remaining in the oil filter assembly had a blackened appearance consistent with exposure to higher than normal temperatures. Carbonaceous material was suspended in the oil. No other engine components had failed mechanically. The crankshaft assembly was free to rotate.

**Figure 15a:**
**The melted edge of the Number 6 piston, right engine MZK**

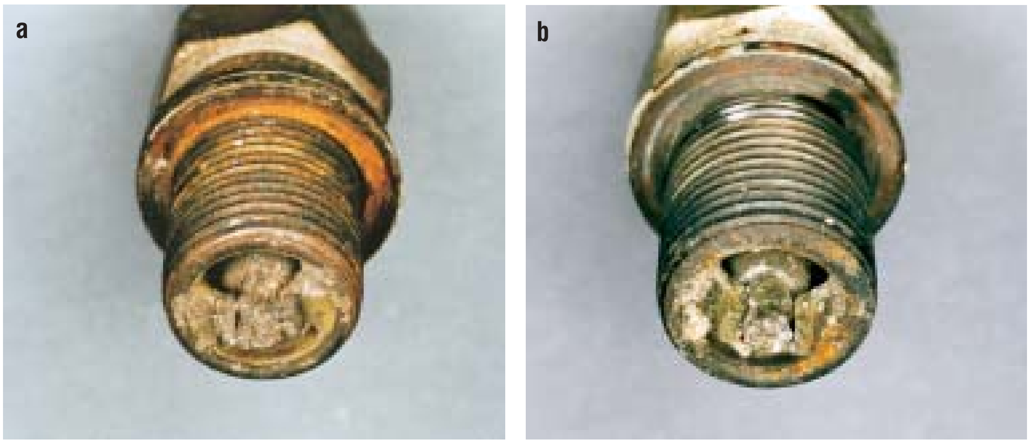
**Figure 15b:**
**The microstructure of the Number 6 piston in the region affected by overheating**




It was also noted during the disassembly examination that material had been lost from the combustion chamber surface of the Number 6 cylinder head. The region of material loss was confined to an area extending from the upper spark plug to the exhaust valve seat (see fig. 16). Molten material from the piston and cylinder head had solidified on the spark plugs fitted to the cylinder. Non-destructive examination of the spark plug electrode region at magnifications up to 20X, revealed that the ceramic insulator surrounding the electrode was intact.

**Figure 16a:**
**The region of melting in the Number 6 cylinder head, right engine MZK**

**Figure 16b:**
**The spark plugs removed from the Number 6 cylinder, right engine MZK, showing the deposits of aluminium alloy on the electrodes, top (a), bottom (b)**




### Characteristics of the defect

The visual appearance of the crown of the Number 6 piston and the ring grooves on one side of the piston was consistent with metal loss associated with the localised heating of the piston to its melting point. Once the gas sealing action of the piston rings had been affected, further piston damage was caused by the flow of combustion gases to the crankcase.

Examination of the microstructure of the piston confirmed that the temperature at the site of damage had reached the incipient melting range of the aluminium alloy. Alloys melt over a range of temperatures. Melting that occurs at a temperature below the liquidus (the temperature at which the alloy is entirely molten) is known as 'incipient melting'. The pistons were manufactured from aluminium alloy 4032 (Al, 12.2% Si, 1% Mg, 0.9% Cu, 0.9% Ni). The incipient melting point of this alloy is 532°C while the liquidus temperature is 571°C[10].

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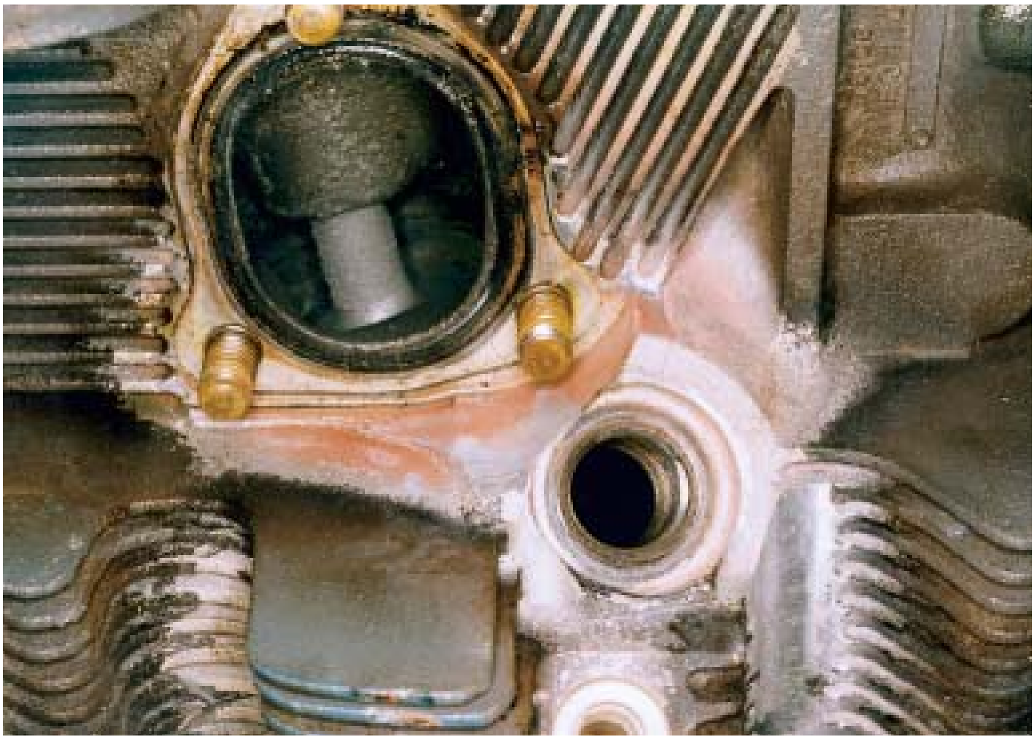
[10] Metals Handbook, Vol 2 ninth edition, American Society For Metals, 1979, p96.

The visual appearance of the localised region of material loss from the Number 6 cylinder head was consistent with localised melting. This site of localised cylinder head melting is not unusual. It is apparent that the cooling of various parts of the cylinder head differs. While the outer surface of the aluminium alloy head is covered with fins to facilitate heat removal by air–cooling the region of the cylinder head between the upper spark plug hole and the exhaust valve (the region where localised melting occurred) backs onto the exhaust gas port in the head (see fig. 17). The less effective removal of heat from this region would cause it to be hotter than other parts of the cylinder head. In the event of an overall cylinder head temperature increase, the hottest region of the head would reach the melting temperature range of the alloy first.

**Figure 17:**
**View of Lycoming TIO-540 cylinder head showing the relationship between the upper spark plug and the exhaust port**

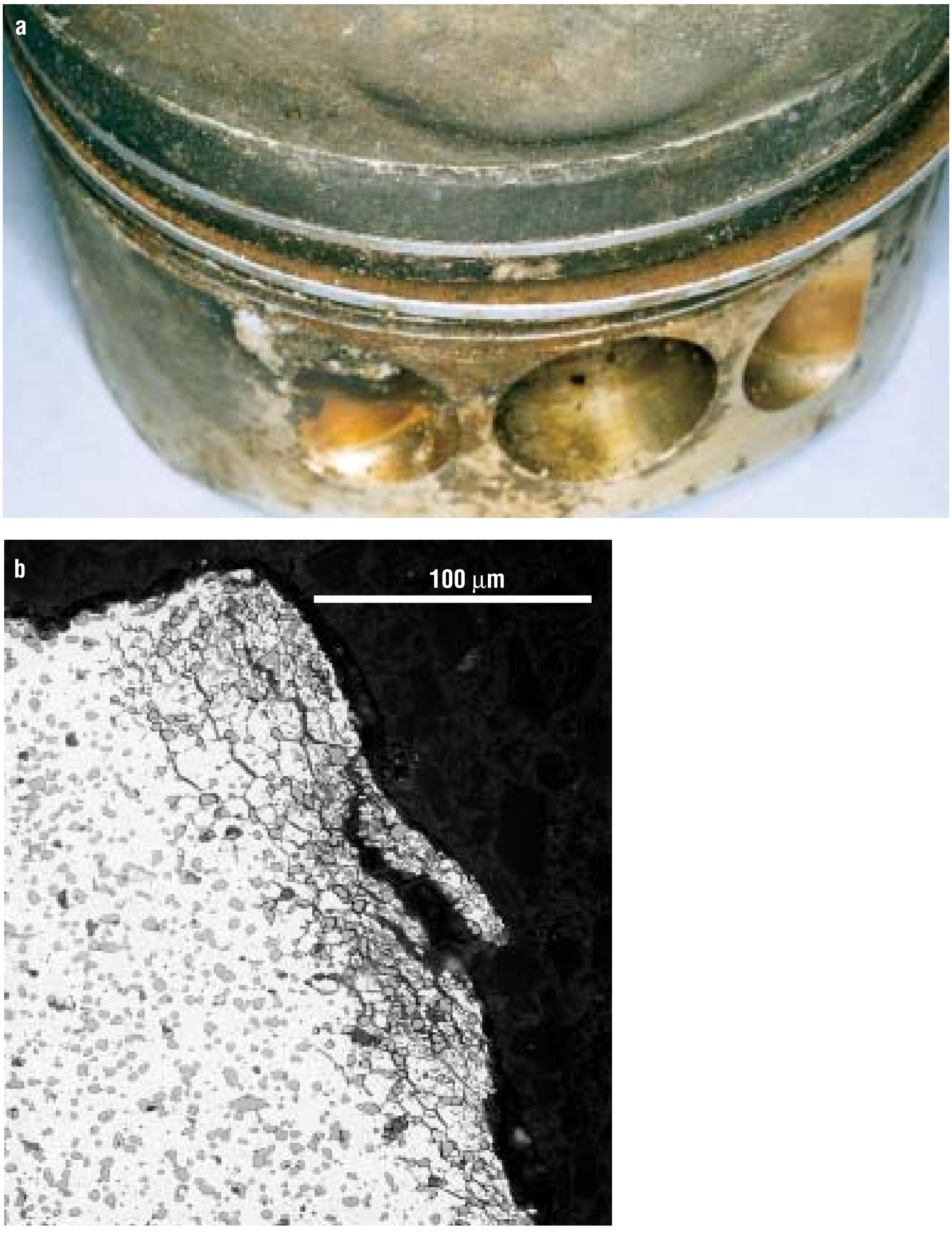


### Extent of effect

Extensive loss of piston material was restricted to the Number 6 piston. The remaining five pistons from the right engine displayed some piston crown edge damage (see fig. 18). The nature of the damage was investigated by removing a section and examining the microstructure. It was evident that incipient melting had not occurred, however, it was apparent that the region had been softened by exposure to high temperatures and that material had been removed from the piston by sliding contact against the cylinder barrel. Hardness testing in association with the metallographic examination revealed that the material had been exposed to a thermal cycle that resulted in alloying element 're-solution' and 'age hardening'. Such a cycle would occur if the material was heated at the re-solution temperature, for a period of time, followed by subsequent cooling and natural age hardening. The solution heat treating temperature range for the alloy used in the manufacture of the pistons (aluminium alloy 4032) is 504 – 516°C[11] .

[11] ibid.

**Figure 18:**
**An example of the piston damage (Number 5 piston) displayed by the remaining five pistons, right engine MZK (a). The microstructure of the piston adjacent to the damage is shown in the photomicrograph (b)**

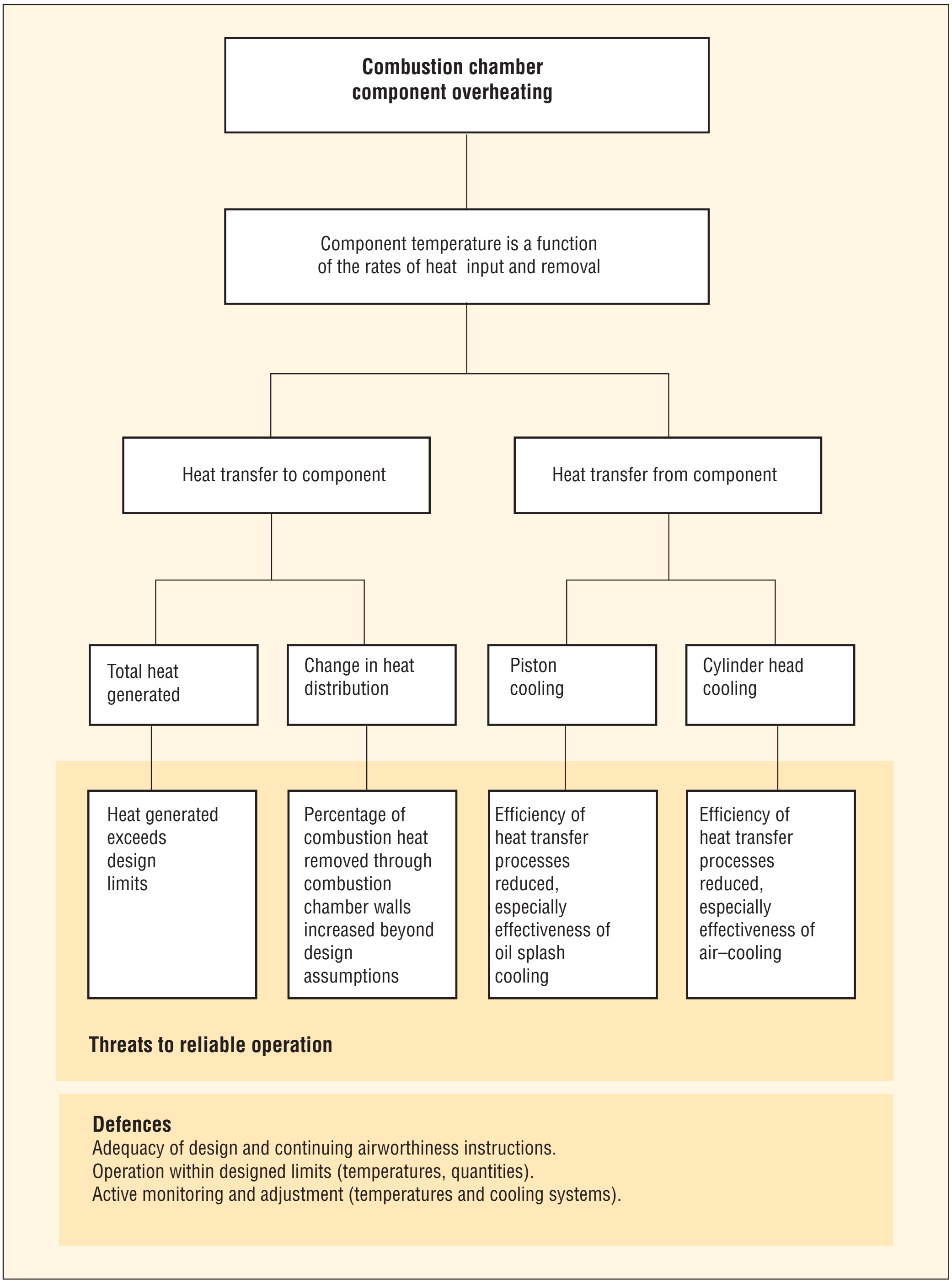



Localised melting of the cylinder head combustion chamber surface was restricted to the Number 6 cylinder.

### Combustion chamber component localised melting

The engine cylinder and piston form a variable volume chamber in which the combustion reactions occur. The combustion chambers of spark ignition engines are designed to operate at a particular temperature. Some heat is required to ensure that the charge is vapourised. However, excessive temperatures can result in a breakdown in the required smooth combustion process and may also result in combustion chamber component deterioration or fracture.

**Figure 19:**
**Combustion chamber overheating failure analysis logic diagram**



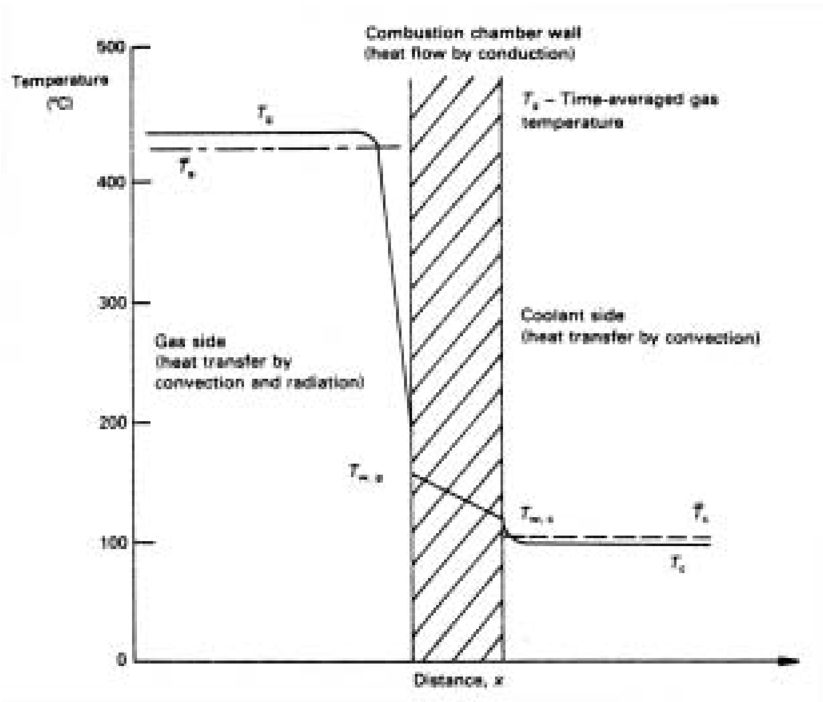

The total heat generated per unit time of engine operation is a function of the mass flow of fuel and air through the engine. The maximum rate of heat generation coincides with the maximum power setting of the engine and is limited by design.

It is in the nature of internal combustion engines that only about 20% of the energy available from the combustion of the fuel–air charge is converted to mechanical energy at the crankshaft. The remaining energy is lost through the heated exhaust gases and through the combustion chamber walls. The transfer of heat through the components of the combustion chamber is a critical process in the ongoing normal operation of the engine.

Heat transfer through combustion chamber components involves the mechanisms of radiation, convection and conduction. Initially, heat from the combustion gases is transferred to the inner surface of the cylinder head and the crown of the piston by radiation and convection. Heat transfer through the cylinder head and piston occurs by conduction. Finally heat is transferred to the air surrounding the outer surface of the cylinder head by convection and from the piston by conduction through the piston rings and convection to the oil spray/splash on the under side of the piston.

The overall rate of heat transfer is a result of each of these processes. The rate controlling step has been identified as the convective heat transfer through the gas boundary layer on the inner surface of the combustion chamber (see fig. 20). Engine cooling systems are designed to maintain combustion chamber temperatures within designed limits.

**Figure 20:**
**Schematic of the temperature distribution across a cylinder head wall, showing the large temperature drop across the combustion gas boundary layer[12]**




Changes in heat transfer conditions will result in changes in the operating temperatures of combustion chamber components and may result in the components being heated to temperatures greater than the design limits.

Changes in the quantity of heat transferred to combustion chamber surfaces during the engine cycles will occur with changes in hot-gas residence time, which is related to engine operating conditions such as speed and ignition timing. Advanced ignition timing increases the amount of heat transferred to the combustion chamber by increasing the temperature of the charge (higher compression heating) and in the combustion products (less expansion cooling).

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12 Introduction to Internal Combustion Engines. R Stone, Second Edition, The Macmillian Press Ltd, London, 1992, p437.

Changes in the rate of heat removed from the combustion chamber components will also affect the temperature of the components. Decreases in the rate of heat removal will result in the increase of component temperatures. Factors that decrease the ability of the external airflow and/or oil spray/splash to transfer heat are important in determining the ability of an engine to operate normally.

Small increases in temperatures above design limits may result in component failure after a long period of exposure. For example, softening of heat treated aluminium alloys (temperatures greater than, approximately 200°C) may result in failures relating to loss of mechanical strength (creep in upper ring groove, fatigue failure associated with high cyclic thermal stresses and high differential stresses created by high thermal gradients). Sustained exposure of pistons to temperatures exceeding 200°C in the piston ring region can also result in lubricating oil decomposition. Carbon deposits from the decomposition of oil can affect the normal functioning of the rings.

Large increases in combustion chamber component temperatures above the design limit over a short time can lead to fuel–air charge detonation.

As the gaseous boundary layer on the inner surfaces of the combustion chamber controls the rate of heat transferred to the combustion chamber, any factor or condition that disturbs the boundary layer will have a marked effect on the amount of heat transferred to the combustion chamber components. The result will be a rapid increase in component temperature. It has been reported that the rate of temperature increase can be in the order of one degree Fahrenheit per second[13].

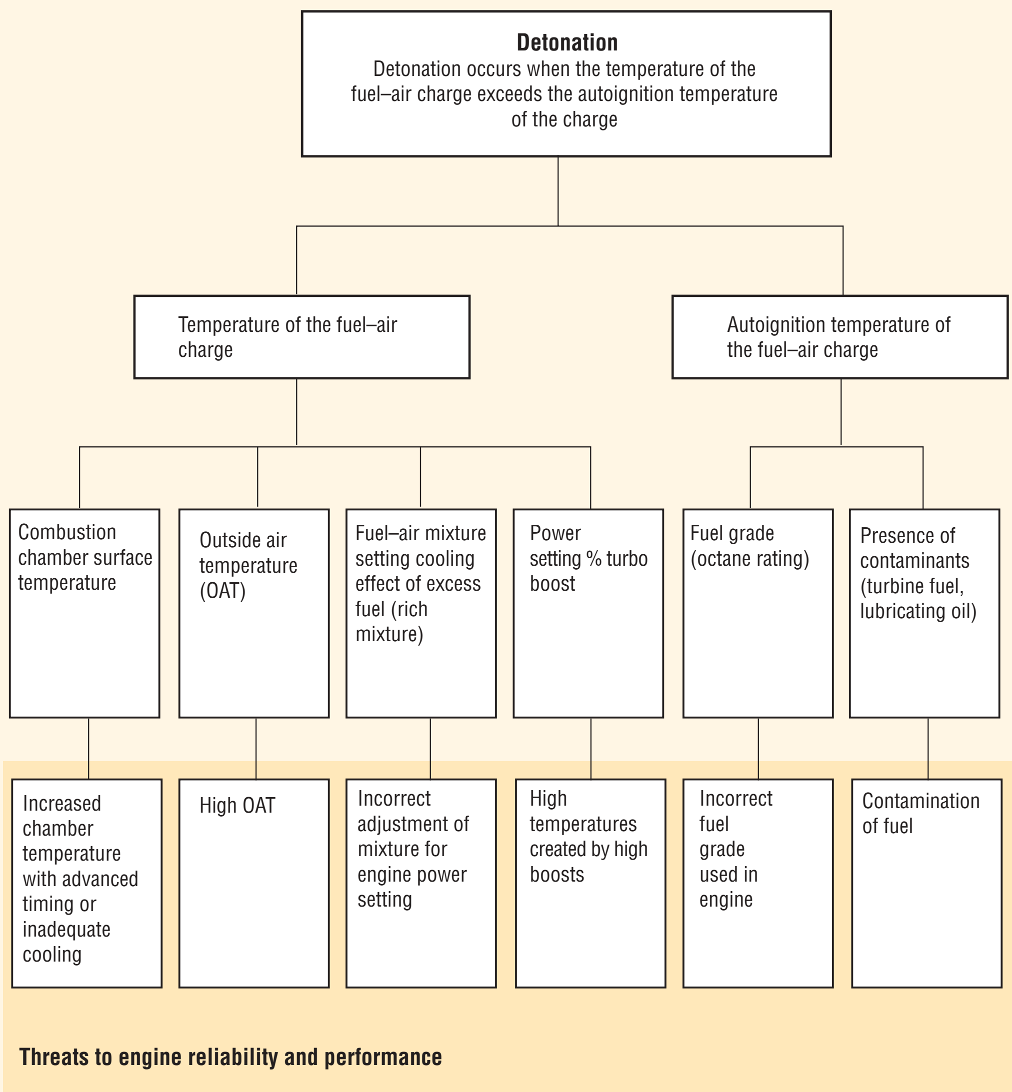
It has been identified[14] that the turbulence associated with detonation disrupts the gaseous boundary layer at the surface of cylinder heads and pistons and leads to rapid increases in component temperature to high levels.

Detonation is a major factor in combustion chamber component overheating.

[13] http://www.avweb.com/articles/pelperch/graphics/pp43-detonation-heavy-lg.jpg

[14] Introduction to Internal Combustion Engines. R Stone, Second Edition, The Macmillian Press Ltd, London, 1992, p426.

**Figure 21:**
**Detonation process logic diagram**




**Defences**
Mixture control in accordance with power setting
temperature moinitoring and control within defined limits
Use of correct grade of fuel

The threat to engine reliability created by detonation varies with the intensity of detonation–light, medium, and heavy. Medium detonation may result in component mechanical failure. Heavy detonation will result in rapid component overheating and localised melting. Detonation may also have an effect on engine performance – the magnitude of the effect varying with detonation severity.

### Detonation mechanisms

The oxidation of fuel (combustion of the fuel–air charge) in spark ignition engines is a complex process[15]. Prior to reactions occurring within the flame front, reactions involving the breakdown of hydrocarbons in the fuel–air charge to other compounds have occurred. These reactions are commonly known as 'pre-flame' reactions. The nature and extent of pre-flame reactions is a dominant factor, along with charge temperature, in determining the autoignition resistance of the remaining charge or end–gas. In general, any factor that promotes pre-flame reactions or allows time for pre-flame reactions to occur will increase the tendency for end–gas detonation. Many factors have been found to promote pre-flame reactions: compression ratio, degree of turbocharging, shape of combustion chamber, positioning of valve ports and spark plugs, the presence of combustion chamber deposits, temperature and pressure of the charge, mixture strength, turbulence within the cylinder, ignition timing and type of spark plug[16].

The operating limitations of a particular aircraft engine design are established by conducting a detonation survey with the engine installed in the airframe. The primary variables are fuel properties, mixture settings and charge temperature.

### Fuel properties

Different hydrocarbons show marked variations in their pre-flame behaviour (with other factors constant).

The detonation resistance of a fuel may be improved by the addition of very small quantities of tetraethyl lead (TEL). It has been established[17] that the mechanism by which TEL improves detonation resistance is through the creation of a fine dispersion of lead oxide throughout the charge. The presence of lead oxide inhibits pre-flame reactions.

### Mixture settings

The ability to manage detonation over a range of engine power settings is achieved in high power, horizontally opposed, air-cooled, aircraft engines by adjusting the fuel–air mixture strength. Mixtures containing fuel in a ratio greater than the stoichiometric amount allow higher engine power to be used without detonation. The excess fuel actively cools the charge through the effect of the latent heat of vapourisation. Reducing the amount of excess fuel (leaning the mixture) increases the temperature of the charge and increases the likelihood of detonation for a particular power setting.

The effect of mixture strength on power for a given fuel is shown schematically in figure 22. Increments in turbo–boost (manifold pressure) create a family of power verses mixture curves for all other factors remaining constant. For each curve the point of incipient detonation is established. Connecting each of the points of incipient detonation creates a detonation map.

It is important to note that detonation can occur over a range of mixture settings. There are two limiting conditions for detonation free operation:

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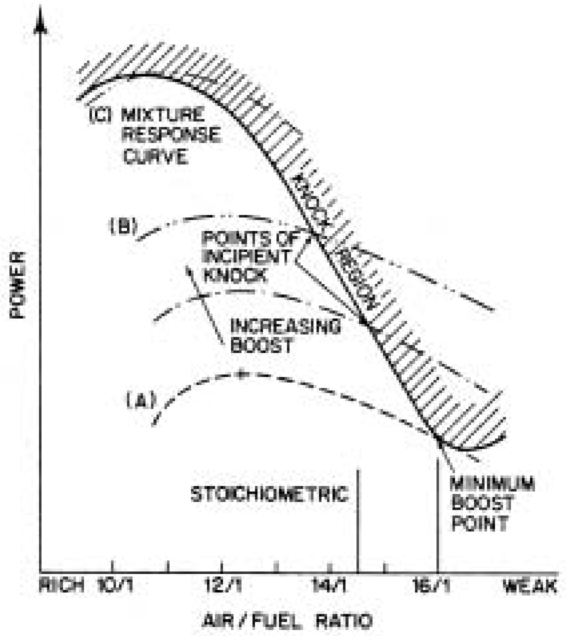
15 Fuels for Spark Ignition Engines, K Owen, Modern Petroleum Technology 5th Ed Edited by G D Hobson, Wiley and Sons 1984 p777.

16 Aviation Fuels, R A Vere, Modern Petroleum Technology, op. Cit., p727.

17 K Owen, op. Cit., p785.

- the maximum boost setting beyond which further mixture enrichment will not increase detonation resistance, and
- the minimum boost setting below which the mixture may be leaned without encountering detonation.

**Figure 22:**
**Schematic showing the determination of the detonation limits as a function of engine power setting and fuel-air mixture setting (Vere, p730)**




### Temperature monitoring

Indications of engine operating temperatures are presented to the pilot by means of cockpit instruments, e.g. exhaust gas temperature and cylinder temperature instruments. The active monitoring of a number those temperatures is an important function in maintaining a detonation free state. The accuracy of the information provided by these instruments is limited by human and mechanical factors (i.e. the location in the engine of temperature sensors, the type of sensor, and what operating factors may influence the temperature).

In engine operation there are a number of ways to influence temperatures. For example, exhaust gas temperatures are affected by changes in power setting and mixture setting. Cylinder head temperatures are affected by the rate of heat generated by combustion and the rate of heat removal. Temperature increases due to changed combustion conditions may be masked by the adjustment of cowl flaps to increase the effectiveness of air–cooling.

The usefulness of oil temperature measurement as an indicator of piston temperature in the Piper Chieftain is limited as the temperature sensor is placed after the oil cooler. Any increase in oil temperature from changed combustion conditions will not be detected until the capacity of the oil-cooler to cool the oil to the preset operating temperature has been exceeded.

### Comparison with other occurrences

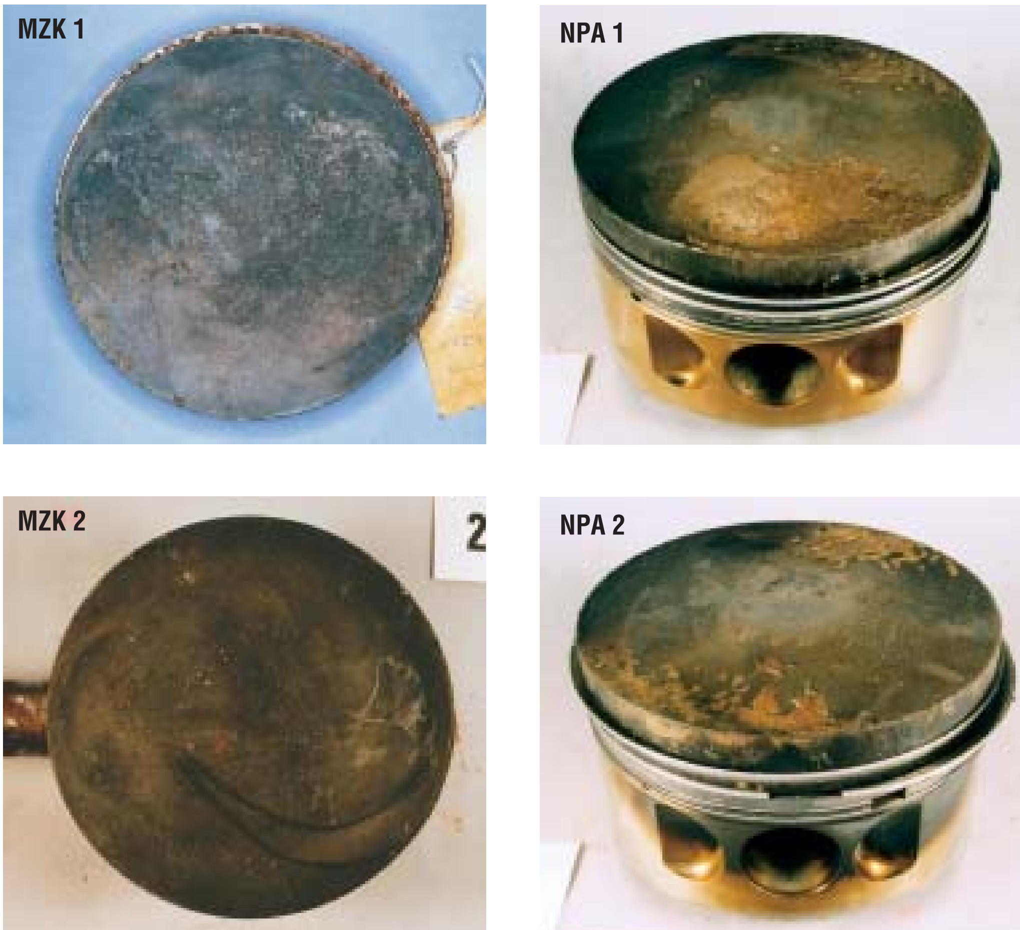
The overheating and localised melting of pistons and cylinder heads is not an event that was restricted to the operation of the right engine of MZK. Similar events have occurred involving the same engine type, as well as other Lycoming engine models. Failures have also occurred in engine types from other manufacturers. The mechanism of combustion chamber overheating is clearly and simply linked to a change in the mechanism of heat transfer, and the factors that lead to the change in heat transfer are those that influence the onset of detonation.

A comparison of the physical evidence associated with the failure of the right engine in another Chieftain aircraft, VH-NPA with MZK's right engine, highlights the diversity of factors that may lead to combustion chamber component melting.

It was established that the engine operating procedures followed in the operation of NPA allowed specified temperature limitations to be exceeded during cruise power mixture leaning. The result was the localised melting of the Number 3 piston and cylinder head. The ceramic electrode insulator of one of the Number 3 cylinder spark plugs had fractured and was lost (spark plug electrode insulators may be damaged mechanically prior to or during installation or they may fracture as the result of the excessive heating and thermal expansion of the electrode during operation).

The piston crown deposits on the remaining pistons from NPA were very different from those evident in the right engine of MZK, indicating that the combustion conditions in NPA were different from those leading to the melting of the Number 6 piston and cylinder head of MZK (see fig. 23).

**Figure 23:**
**Comparison of piston crown deposits, right engine MZK (left) , and right engine VH-NPA (right)**




MZK 3
3


NPA 3


MZK 4
4


NPA 4


MZK 5
5


NPA 5


MZK 6
6


NPA 6

The distinctive carbon 'swirl' pattern deposits present on the pistons recovered from the right engine of MZK were similar to the deposits shown in an illustration on the Sacramento Sky Ranch web site[18] (see fig. 24). The illustration shows a piston from a Continental IO-520 engine that had been damaged by edge melting. Piston overheating was attributed to detonation/preignition that resulted from the combustion of contaminated fuel. The octane (performance) rating of the aviation gasoline had been reduced by the addition of aviation turbine fuel. It is likely that failure would have occurred, in this case, after a short time of operation under high–power, rich–mixture, conditions.

**Figure 24:**
**Combustion deposits associated with detonation/preignition resulting from the combustion of aviation gasoline contaminated with aviation turbine fuel (Sacremento Sky Ranch)**


Fuel–air charge detonation, with consequent effects on the combustion chamber heat transfer, may occur over the range of rich to lean mixtures. The characteristics of the piston crown deposits remaining on the pistons from MZK's right engine indicate that detonation is likely to have occurred under rich mixture conditions. That is, the detonation–free operating limits were exceeded at a high engine power setting.

### Consequences of the defect

Combustion chamber temperature increases to approximately 500°C are well in excess of the normal temperature of approximately 200°C. It is likely that a temperature increase of this magnitude would result in some degree of charge detonation.

The holing of the piston allowed the crankcase to be pressurised with the result that oil was blown out of the crankcase breather. Once started, this process would result in a reduction in engine oil quantity to the point where engine lubrication became ineffective and component seizure occurred. It is likely that this process would occur over a short period, depending on such things as the size of the hole in the piston and the engine operating parameters. The lack of engine seizure would indicate that the holing of the Number 6 piston occurred towards the end of the accident flight.

Piston holing also affects engine performance. Once a piston is holed, there would be a loss of engine power commensurate with the number of cylinders affected and the total

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18 http://www.sacskyranch.com/photopis.htm

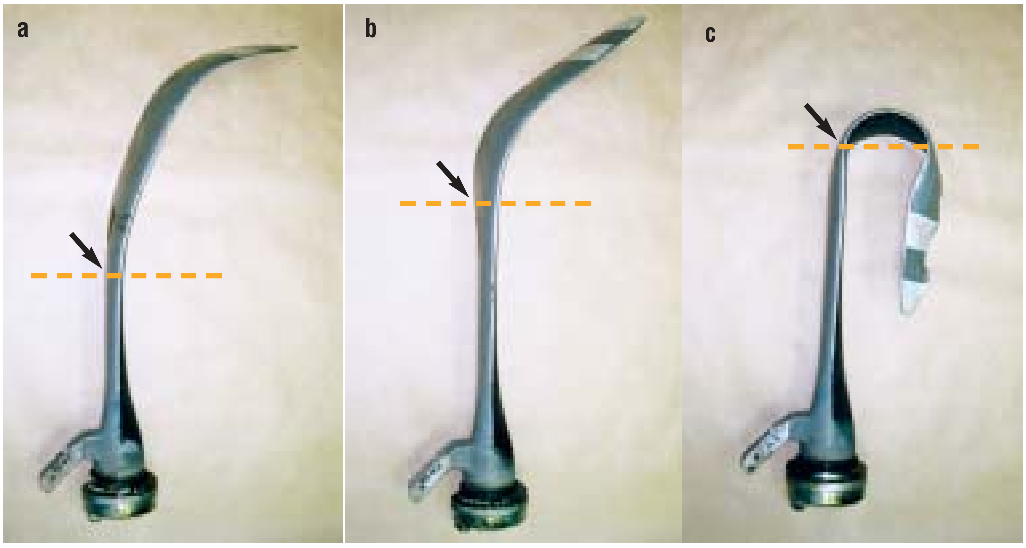
number of cylinders on the engine. A further effect on the performance of turbocharged engines (such as those in MZK) is related to the effect of manifold pressure variations accompanying the valve opening and closing on the affected cylinder and the inertia of the turbocharger control system. Pressure variations coupled with control inertia may result in turbocharger surging and consequent erratic engine operation.

### Right propeller

The right propeller was recovered, still attached to the right engine, with the propeller blades in the feathered position.

Out-of-plane bending forces acting on the camber side (front side) of the blades had bent all three blades to varying degrees (see fig. 25). Although blade Number 3 exibited the least amount of bending from contact with the water, it exhibited evidence of additional bending through contact with some other structure. Blue paint had been transferred during the contact.

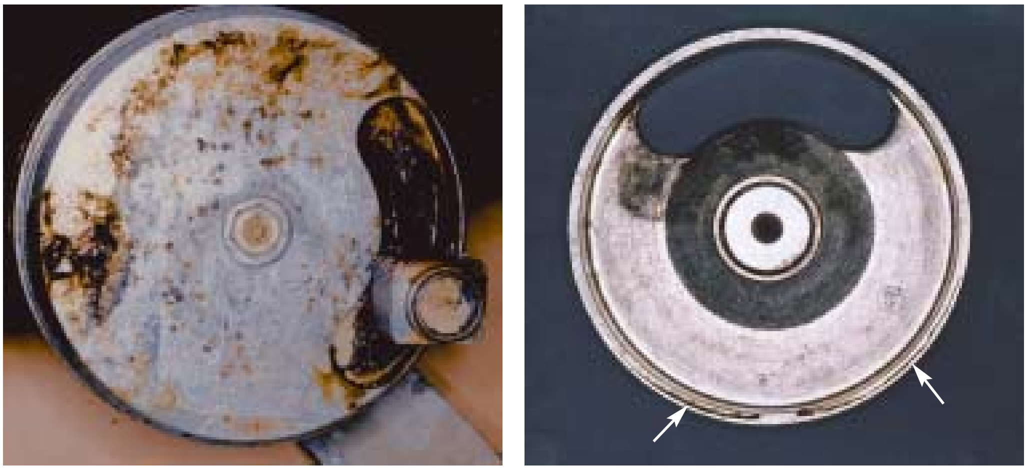
**Figure 25:**
**The extent of blade bending, right propeller MZK: blade 1 (a), blade 2 (b), blade 3 (c), plane of bending arrowed**




The progressive increase in bending, from blade Number 3 (least i.e. point of bending furthest from the blade root) through to blade Number 1 (greatest i.e. point of bending closest to blade root), is consistent with the aircraft descending into a dense medium (water) with a significant forward velocity.

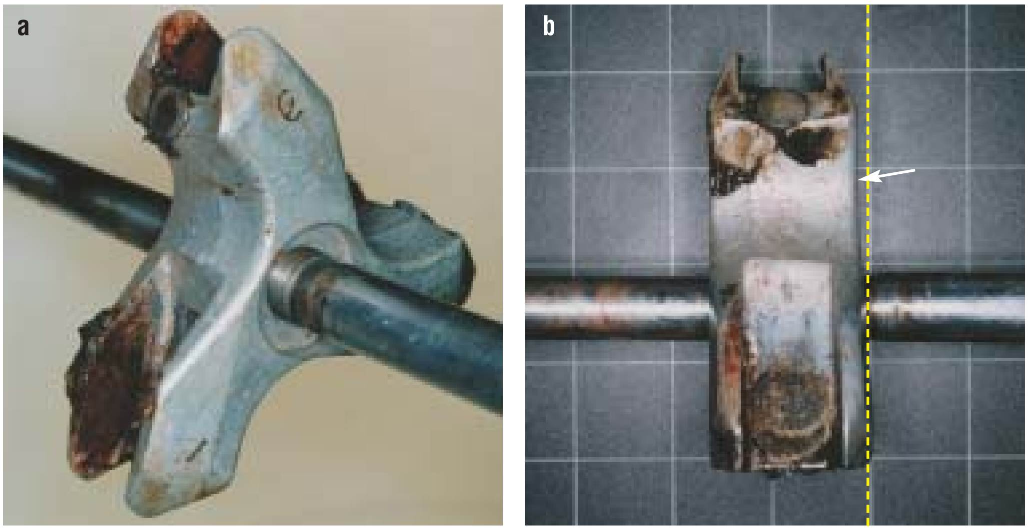
Blade Number 1 had been subjected to the greatest bending load. Disassembly of the propeller revealed that the lip of the bearing preload plate (blade 1) had fractured. The shear fracture extended around, approximately, one third of the circumference on the leading edge side of the propeller blade (see fig. 26).

**Figure 26:**
**Propeller blade bearing preload plate damage, blade 1 right propeller MZK (the shear fracture of the lip that bears against the propeller hub is arrowed)**



The alignment of the pitch change fork on the actuator shaft had been altered by the rearward rotation of the Number 1 propeller blade (see fig. 27).

**Figure 27:**
**Propeller pitch change fork, right propeller MZK (a). The rearward displacement of the Number 1 blade fork is shown in (b)**




The damage sustained by the right propeller indicates that a high force acted on the front face of the blade, through contact with water, while the blade was in a normal operating pitch range (i.e. not feathered), resulting in combined bending and twisting, while the aircraft was moving forward.

It is possible that the blades could move to the feather position at a later time as a result of oil pressure leak down. (The right propeller blades were in the feathered position when the propeller was recovered.)

### 1.17.3 Left propulsion system failure analysis

The Lycoming TIO-540-J2B engine, s/n L-4727-61A was reported to have completed 262.1 hours since last overhaul. The overhaul was carried out by the engine manufacturer.

The disassembly of the engine following wreckage recovery revealed that the Number 6 connecting rod big end housing and the Number 6 crankshaft[19] journal had fractured. Oil remaining in the engine showed no signs of overheating.

#### Crankshaft journal fracture

The fracture was caused by fatigue crack growth (see figs. 28 and 29).

**Figure 28:**
**Crankshaft journal fracture, crankarm side, Number 6 journal, left engine MZK**

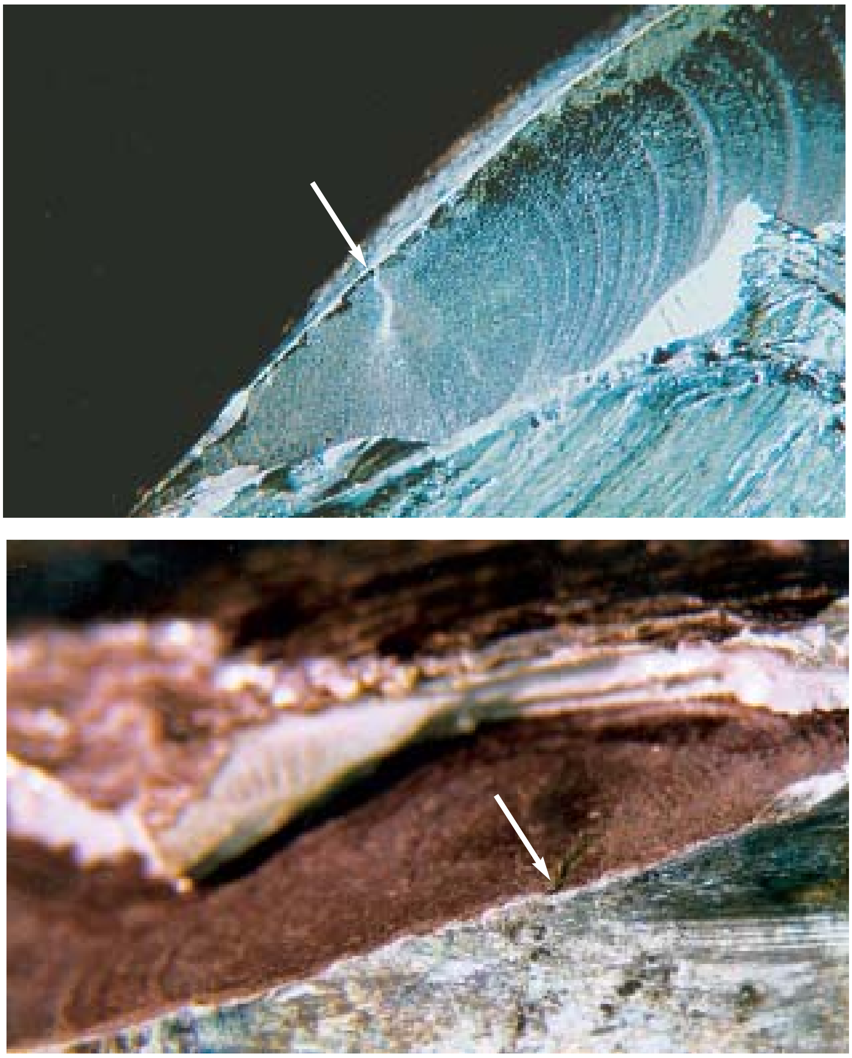
**Figure 29:**
**Crankshaft journal fracture, journal side, Number 6 journal, left engine MZK**

[19] Crankshaft journals of Lycoming engines are numbered from the front of the engine (i.e. Number 6 crankshaft journal is at the rear of the engine).

### Fatigue crack initiation

Fatigue cracking initiated at a depth of approximately 1mm (the depth of the nitrided zone) below the surface of the Number 6 bearing journal at the transition from the journal surface to the fillet radius (see fig. 30). The initiation site was located in the region between the crankarms at a point aligned with the centreline of the crankarms. It was evident that a planar discontinuity extended from the fatigue crack initiation site to the surface of the journal.

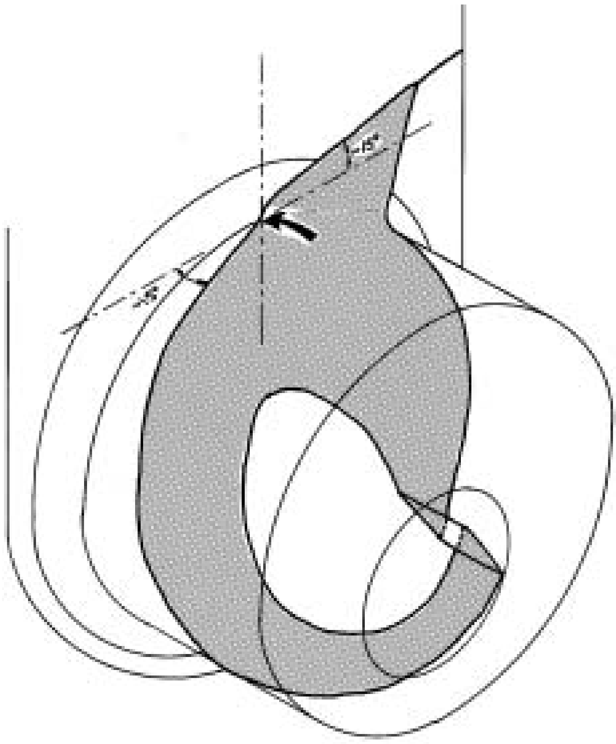
**Figure 30:**
**Site of fatigue crack initiation, Number 6 journal, left engine MZK. The planar discontinuity at the site of fatigue crack initiation is arrowed**



### Fatigue crack growth

The plane of cracking over the initial stages of crack propagation, approx 15° to the short axis of the crankarm, indicates that the maximum bending component of the alternating stresses was applied while the journal was positioned 15° after top dead centre. It was also apparent that the alternating–stress state contained a torsional component, resulting in the plane of crack growth forming an acute angle with the journal cross-section, (see fig. 31). Both bending and torsional alternating loads are normal forms of loading in engine crankshafts.

**Figure 31:**
**Schematic showing the plane of fatigue crack growth (shaded) and the orientation of the plane of crack growth with respect to the axis of the crankarm. The site of fatigue initiation is arrowed.**



### Crankshaft loading

Fatigue cracking involves the incremental extension of a crack front with each alternating load cycle for which the crack tip stress intensity exceeds a threshold value. Crack extension is a function of crack tip stress intensity, which in turn, is a function of the stresses created by the applied loads and the geometry of the crack (crack depth and shape).

Crankshafts are subjected to both bending and torsional stresses during normal operation. These stresses arise from centrifugal and inertia forces created by crankshaft rotation, reciprocating masses and gas loads.

The form of a crankshaft, an assembly of crankarms, connecting rod journals and main bearing journals, results in masses being distributed at distances and various angles to the centre of the shaft. The rotation of a component of this form results in local tensile stresses being created at various locations in the shaft, particularly at the junction of crankarms and journals due to elastic deflections of the shaft. Crankshafts in engines that appear to be free of vibration will still contain local tensile stresses. Balance is achieved through the cancelling of bending moment couples within the engine crankcase structure. The forces on main bearings may be high[20]. Forces and stresses created by shaft rotation increase with the square of the rotational speed.

The action of periodic gas loading on reciprocating pistons attached to the crankarms gives rise to torsional loading and further local bending at journal crankarm junctions.

A further loading condition may be created if the frequency of load application interacts with the elastic response of the shaft to create a condition of resonance. This

20 Kempe's Engineers Yearbook 1983, 88th edition edited J P Quayle, Morgan Grampian 1983 pF6/12; ACL Engine Manual No. 413, Gregory's Scientific Publications, 1991, p36.

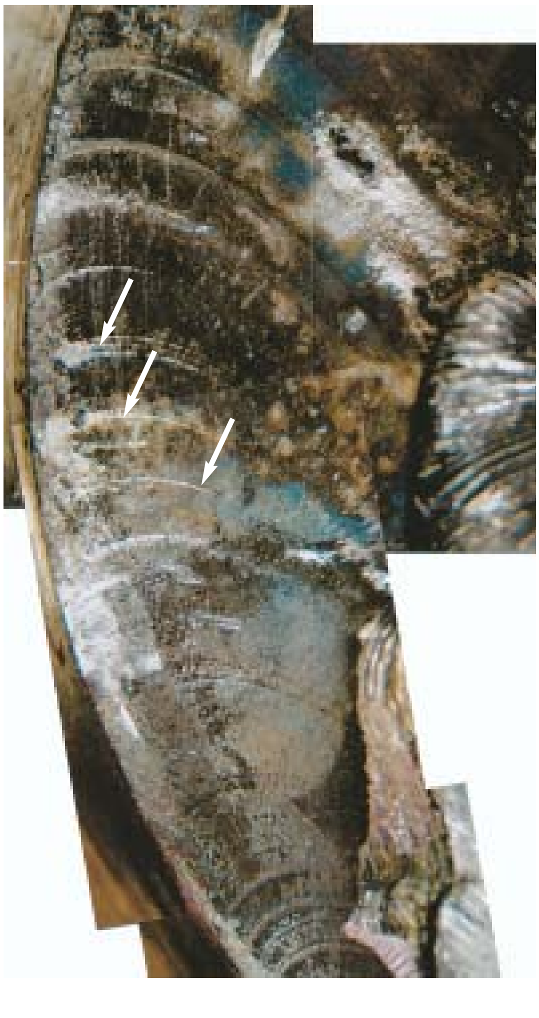
condition is an abnormal operating condition. Its occurrence is minimised by design and operational limitations that prevent engines being operated at critical speeds.

In summary, a crankshaft will be subjected to a complex variable alternating load spectrum during normal operation. A major load cycle will be associated with each period of crankshaft rotation from rest to maximum operational speed and back to rest. Superimposed on this low frequency load cycle will be cycles associated with engine speed change, vibration and gas pressures (created by fuel–air charge combustion once every second engine revolution). It should also be recognised that the process of journal surface nitriding has a significant impact on fatigue resistance through the creation of a surface residual compressive stress state.

### Fatigue fracture surface features

A number of distinctive fatigue crack progression marks (features that delineate the crack front at particular times during crack growth) were identified on the fatigue fracture surface (see fig. 32). These features are formed when a major change occurs in the alternating loads applied to the shaft. The identified progression marks on crankshaft fatigue fractures are likely to be related to the major load cycle that is associated with rotation from rest to maximum engine speed and back to rest, that is, the cycle associated with each engine start/stop cycle (or one aircraft flight).

**Figure 32:**
**Photomontage of a region of the fatigue crack surface, Number 6 journal left engine MZK, showing the surface features (progression marks) attributed to the once per flight alternating load cycle. Examples of the progression marks are arrowed**



The incremental extension of a fatigue crack is a function of both the tensile stress created by the applied loads or strains and the geometry of the crack at the time of incremental extension – in short, the stress intensity at the crack tip. Because of this relationship only the higher stresses in the variable amplitude stress spectrum will contribute to crack growth at small crack sizes. As the crack size increases the lesser alternating stresses will contribute to crack growth.

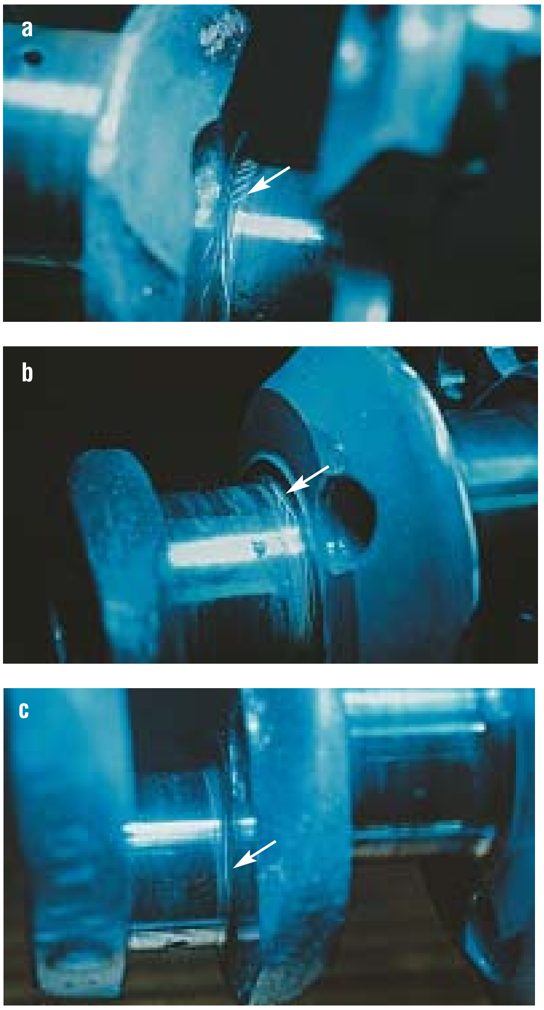
The fracture surface features formed as a result of variable amplitude block loading are distinctly different from those features formed under constant amplitude loading. In the case of constant amplitude loading, incremental crack extension occurs with each stress cycle once cracking has initiated. The magnitude of each incremental extension of the crack increases with increases in stress intensity.

On the basis that the progression marks are related to aircraft flight cycles, it is estimated that crack growth occurred over a period of approximately 50 flights.

### Cracks in other journals

Fluorescent magnetic particle inspection of the crankshaft indicated the presence of cracking in the Number 5 connecting rod and Number 3 main bearing journals (see fig. 33).

**Figure 33:**
**Fluorescent magnetic particle inspection indications of the secondary cracks present in the Number 5 connecting rod journal (a), the Number 3 main bearing journal (b) and the Number 4 connecting rod journal (c), left engine MZK**

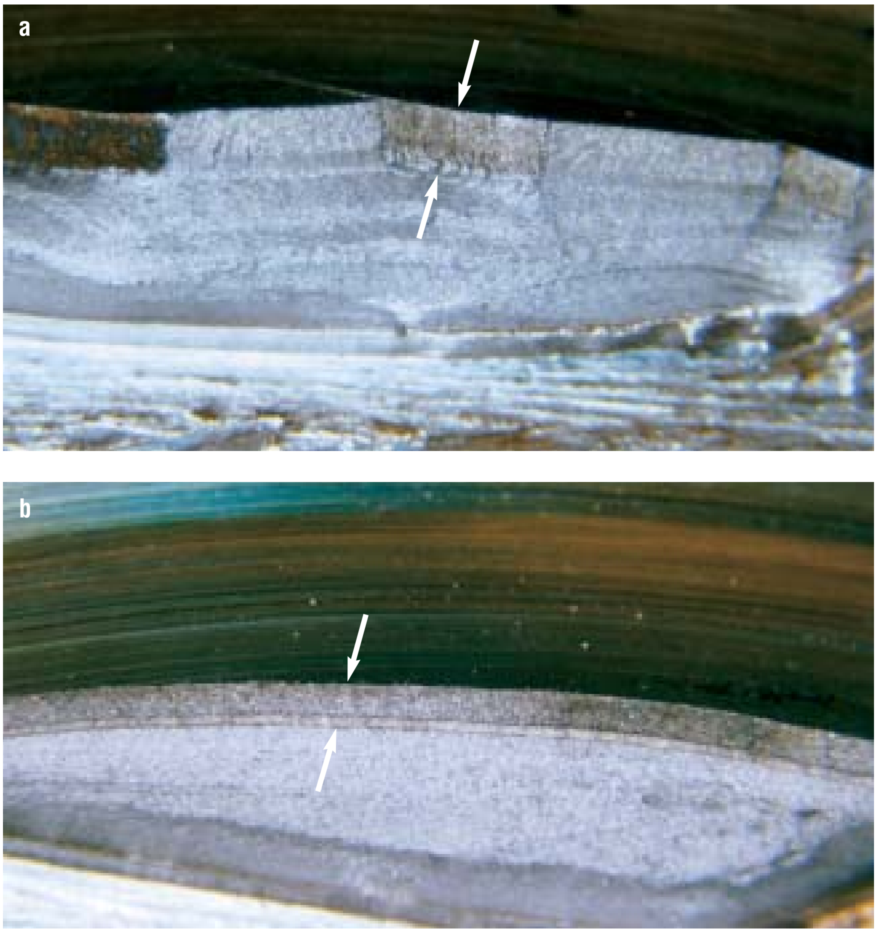


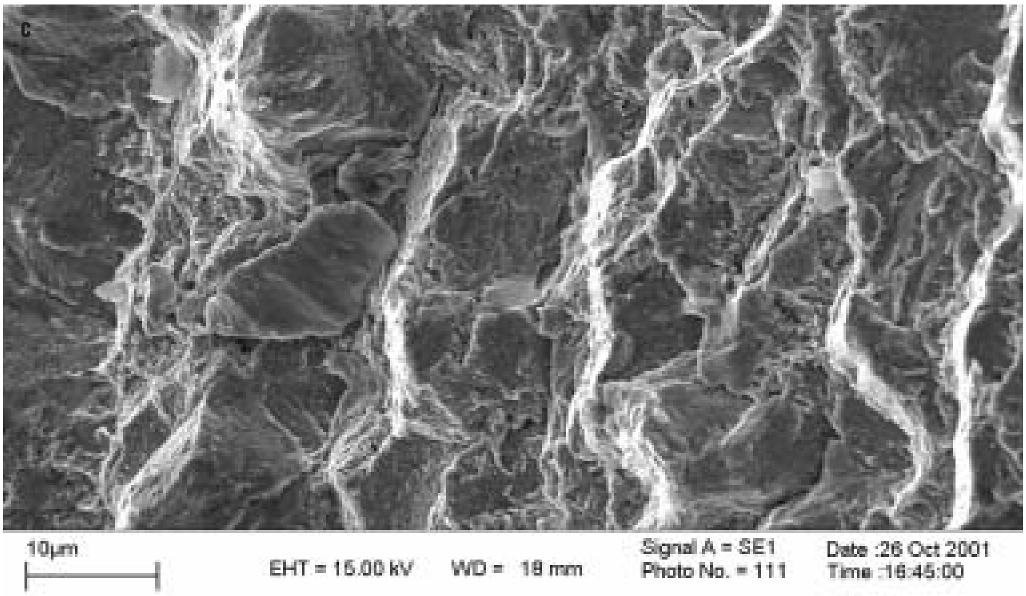
Regions of cracking from the forward fillet radius of the Number 5 connecting rod journal and the rear fillet radius of the Number 3 main bearing journal were opened in the laboratory to allow the crack surfaces to be examined. In each case, the mechanism of cracking was identified as fatigue (see fig. 34). Fatigue cracking initiated at the journal surfaces and, in each case, was not restricted to one particular site or defect. The nature of the orientation of the cracks and the initiation of cracking are consistent with an abnormal loading condition.

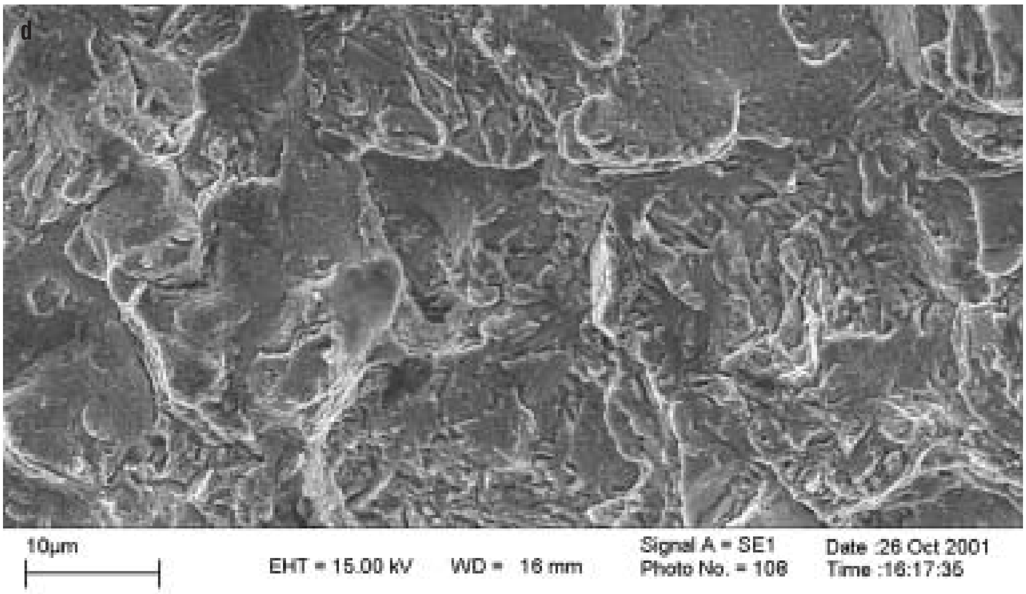
The fatigue fracture of the Number 6 crankshaft and the fracture of the Number 6 connecting rod big end housing resulted in abnormal alternating loads being imposed on the adjacent journals (Number 5 and Number 4 connecting rod journals, and Number 3 main journal).

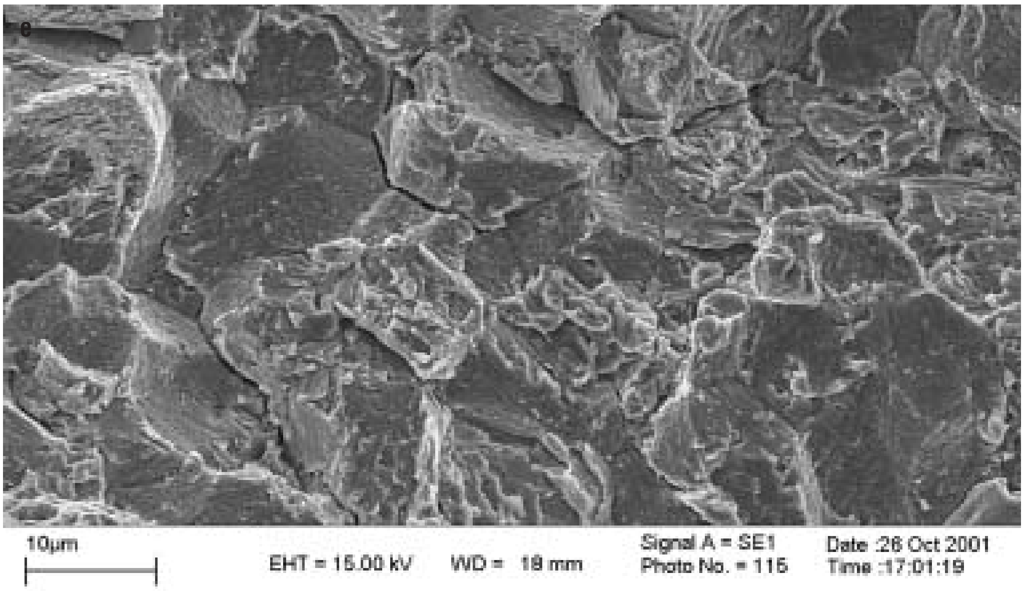
Fatigue cracking striations could be resolved under a microscopic examination of the crack surfaces. The uniform spacing of the striations indicated that a constant amplitude loading had been applied to the journals. An estimate of the number of striations as a function of the depth of each crack was made: Number 5 journal, crack depth 0.73mm, 21,900 striations; Number 3 journal crack depth 0.64mm, 19,200 striations. If crack growth occurred as a result of loads applied with every rotation of the crankshaft and the engine was operating at the normal cruise speed setting of 2,200 RPM, then the number of striations indicates that crack growth would have occurred over a period of 8 to 10 minutes.

**Figure 34:**
**Fatigue crack features, Number 5 connecting rod journal (a, c) and Number 3 main journal (b, d). An example of brittle fracture in the journal surface zone is shown for comparision (e)**




c
10µm
EHT = 15.00 kV
WD = 18 mm
Signal A = SE1
Photo No. = 111
Date :26 Oct 2001
Time :16:45:00


d
10µm
EHT = 15.00 kV
WD = 16 mm
Signal A = SE1
Photo No. = 108
Date :26 Oct 2001
Time :16:17:35


e
10µm
EHT = 15.00 kV
WD = 18 mm
Signal A = SE1
Photo No. = 115
Date :26 Oct 2001
Time :17:01:19

### Crankshaft manufacture

The function of an aircraft reciprocating engine crankshaft, and the nature of the loading applied to the crankshaft, has implications for its design and manufacture. Aircraft engine crankshafts are manufactured from steel alloys that have been heat-treated to high strength, surface hardened and processed in a manner to control non-metallic inclusion size and distribution.

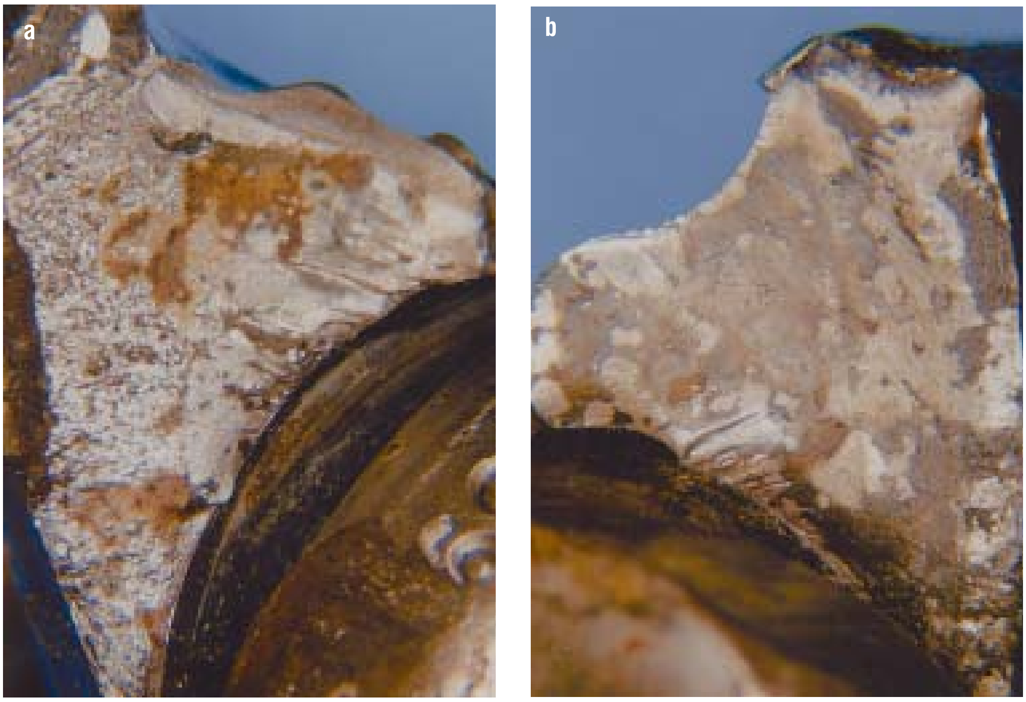
The fractured crankshaft manufacture, Serial Number V5379129, complied with the engine manufacturer's proprietary manufacturing standards concerning steel quality (chemistry, strength, non-metallic inclusion content), journal surface nitriding and journal diameter.

### Connecting rod big end housing fracture, Number 6 connecting rod assembly

The big end bearing housing of the Number 6 connecting rod assembly had fractured in several locations and one bolt had fractured (see fig. 35). Fatigue cracking was associated with two of the fractures in the bearing housing. Fatigue cracking initiated at the outer surface of the housing, at the region of transition between the bolt hole boss and the remainder of the housing (see fig. 36).

**Figure 35:**
**The Number 6 connecting rod assembly, left engine MZK, showing the extent of damage**

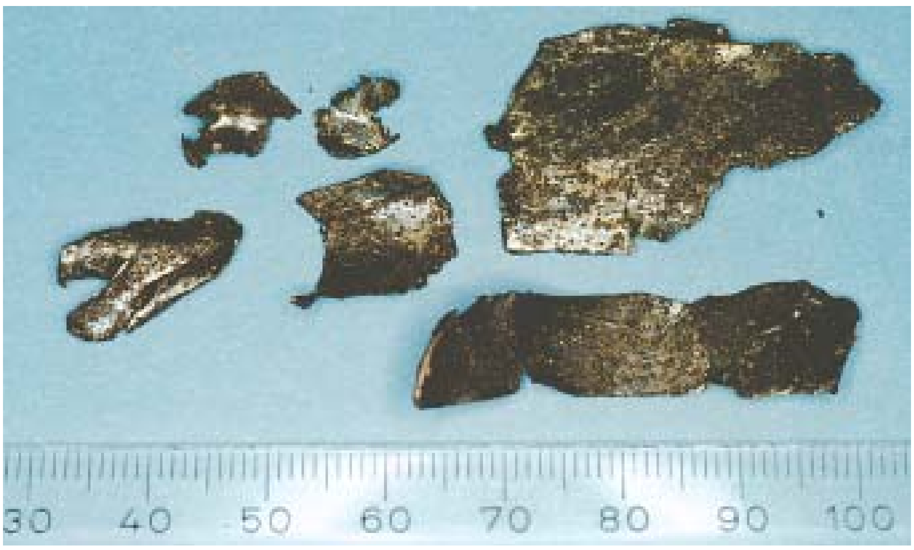
**Figure 36:**
**The regions of fatigue fracture in the Number 6 connecting rod big end bearing housing, detailed views of the fatigue fracture surface are shown in (a, b)**




The mating surfaces of the big end bearing housing had been affected by fretting and galling[21]. That type of surface damage indicated that sliding movements over small distances had occurred between the mating surface during engine operation.

The bearing inserts fitted to the Number 6 connecting rod assembly had been destroyed. Several pieces of bearing–insert backing material (low carbon steel) were recovered from the engine sump (see fig. 37). The pieces of backing material had been extensively deformed but had not been subjected to high temperatures. Only a small quantity of bearing insert debris was recovered from the engine sump, suction screen and filter during engine disassembly.

**Figure 37:**
**Remnants of bearing insert steel backing recovered from the left engine sump**




21 Fretting is a wear process in which material is removed by oxidation and abrasion from contacting surfaces subjected to repeated sliding over small distances. Galling is the process of adhesive wear in which repeated welding on a microscale and subsequent weld zone fracture occurs between two surfaces that are subjected to repeated sliding over small distances.

The nut fitted to one of the connecting rod bolts was partly engaged. There was evidence of fretting wear between the bolt threads and hole. It appears that nut loosening had occurred some time prior to the final failure of the engine.

It was evident that sliding contact had occurred between the central guide sections of the connecting rod assembly bolts and the journal surface. Contact of that type can only occur after the destruction or loss of the bearing inserts. The heat generated by sliding contact between the bolts and journal surface would result in the thermal expansion of the bolts. Bolt expansion will reduce the clamping force of the bolts and allow joint movement and the loosening of nuts.

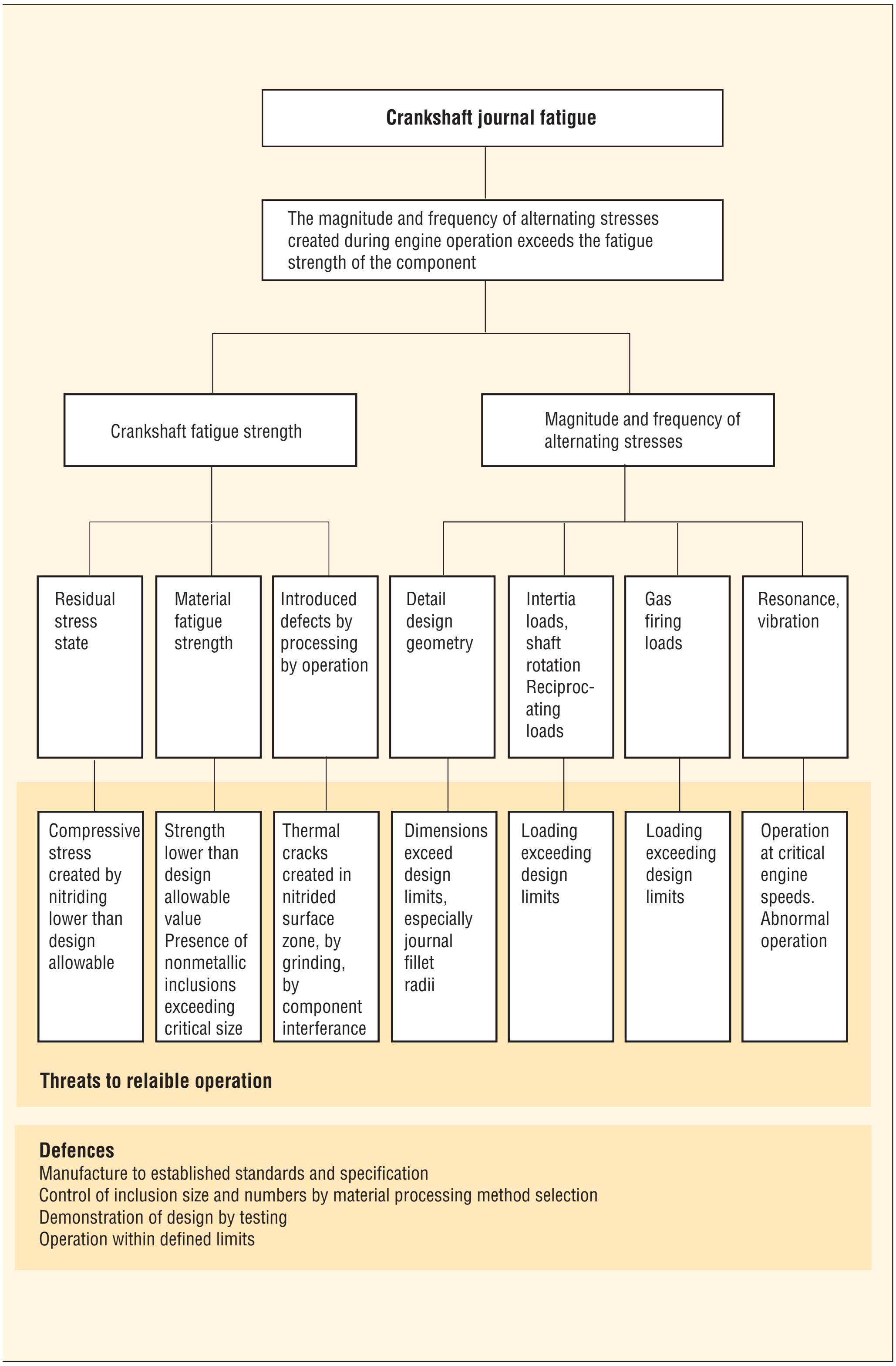
Measurement of bolt stretch and bearing interference fit (nip) confirmed that the remaining five connecting rod bearing housings had been assembled correctly.

#### Left propeller

The left propeller was recovered attached to the left engine. The propeller blades were in the feathered position. The blades had not been bent during the impact sequence. There was a small amount of mechanical damage to one blade tip.

## Crankshaft journal fatigue cracking

**Figure 38:**
**Crankshaft journal fatigue failure analysis logic diagram**



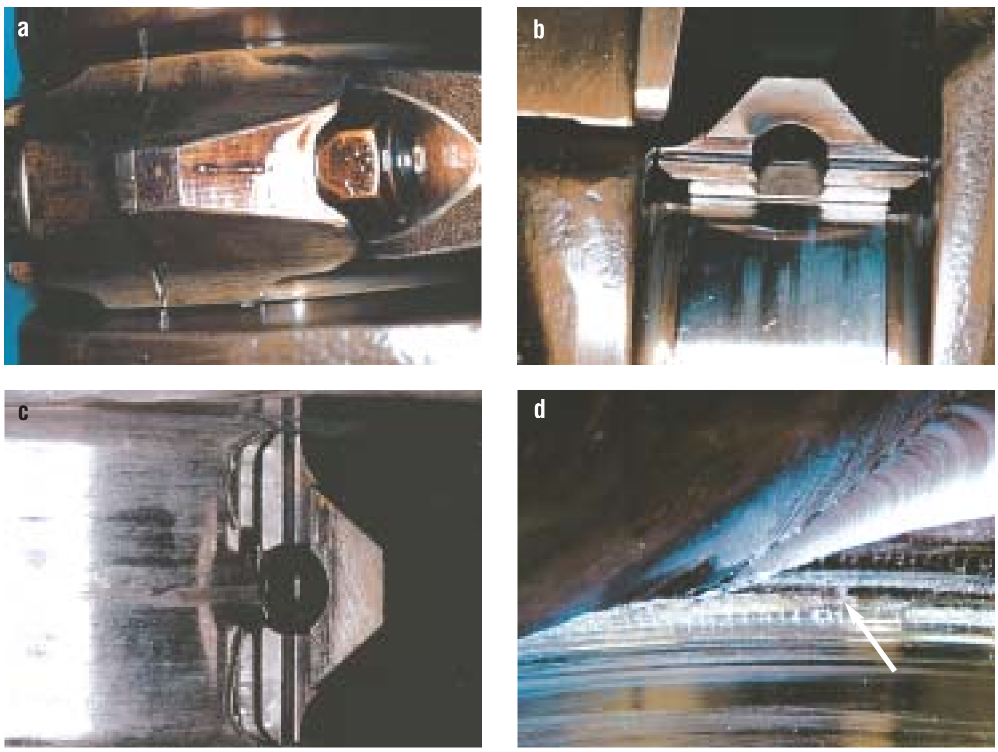
The crankshaft of an aircraft engine is designed to have an operational life that is not limited by the development of cracks and fracture. Crankshafts do not have a fixed time retirement life (safe life) based on a need to remove the component from service prior to the development of fatigue cracking. Generally, crankshafts are subjected to inspection at specified operational intervals and are removed when dimensional limits are exceeded in areas that are subjected to wear.

Fatigue cracks may occur in crankshafts when deviations from design conditions result in the magnitude of the local alternating stresses exceeding the component fatigue strength. In an analysis of fatigue cracking in crankshafts the effect of the alternating stress parameters and component fatigue strength need to be examined.

An assurance that the fatigue strength of a crankshaft meets the design expectations is established by compliance with manufacturing standards. The crankshaft from MZK's left engine complied with the manufacturing standards.

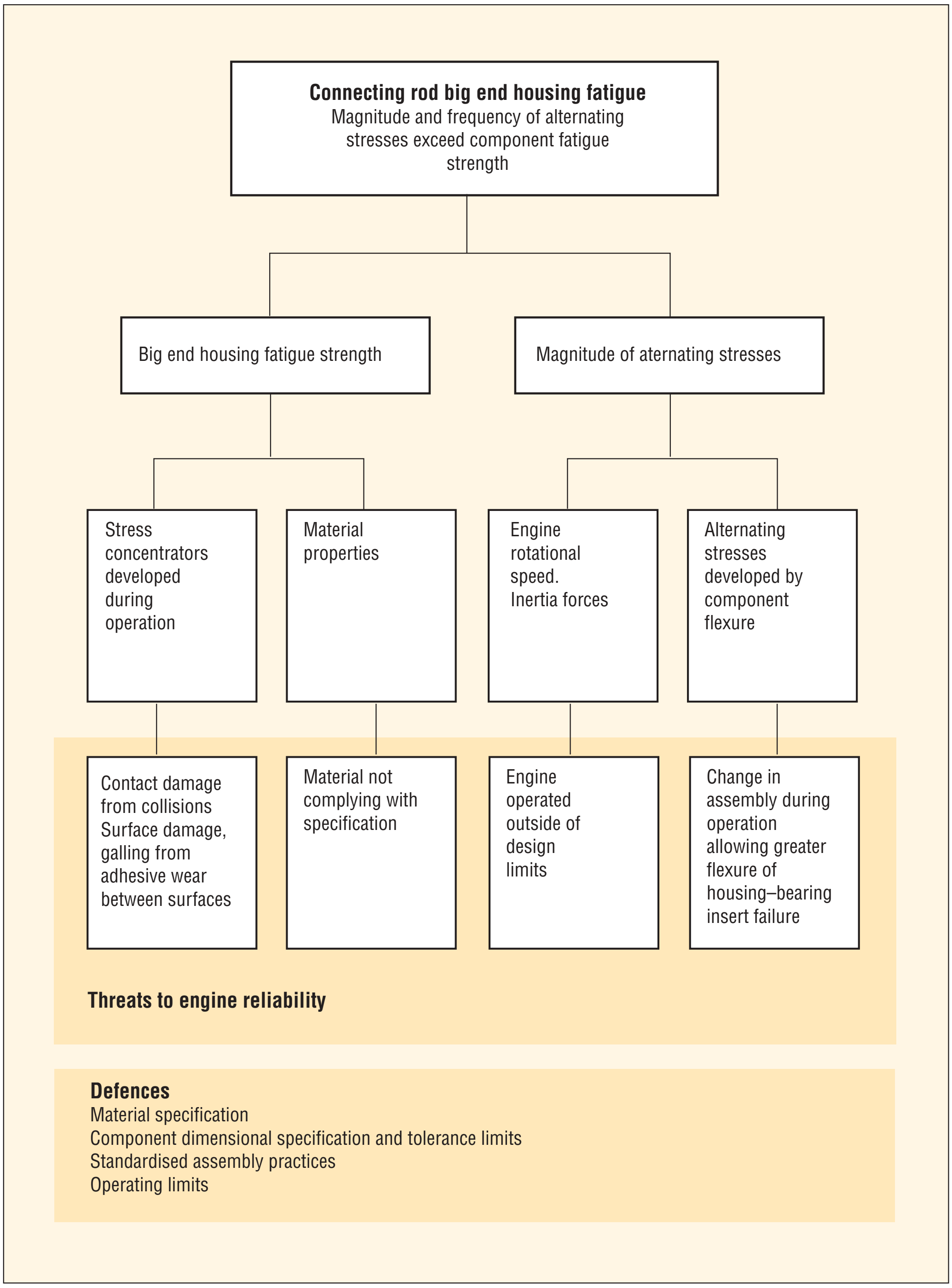
Fatigue cracking may be initiated under normal loading conditions if stress-concentrating features are created during operation or maintenance. A planar discontinuity was associated with the initiation of fatigue cracking in the crankshaft from MZK's left engine. The nature of this defect is consistent with thermal cracking of the nitrided layer. High surface stresses may be created by the restrained thermal expansion that accompanies localised heating. There are a number of ways crankshaft journal surfaces may be heated in a manner that causes thermal cracking; typically, journal surface grinding processes and surface sliding interactions that breakdown oil film lubrication, e.g. bearing fillet ride (see fig. 39). Thermal cracking at the transition from the journal surface to the journal fillet is consistent with bearing fillet ride.

**Figure 39:**
**View of a connecting rod big end bearing assembly showing the clearance between the housing and crankshaft (a), the clearance between the bearing insert and journal fillet (b) and bearing insert damage (c). An example of thermal cracking in a journal fillet (arrowed) caused by bearing insert contact (d)**



### Connecting rod big end housing fatigue analysis

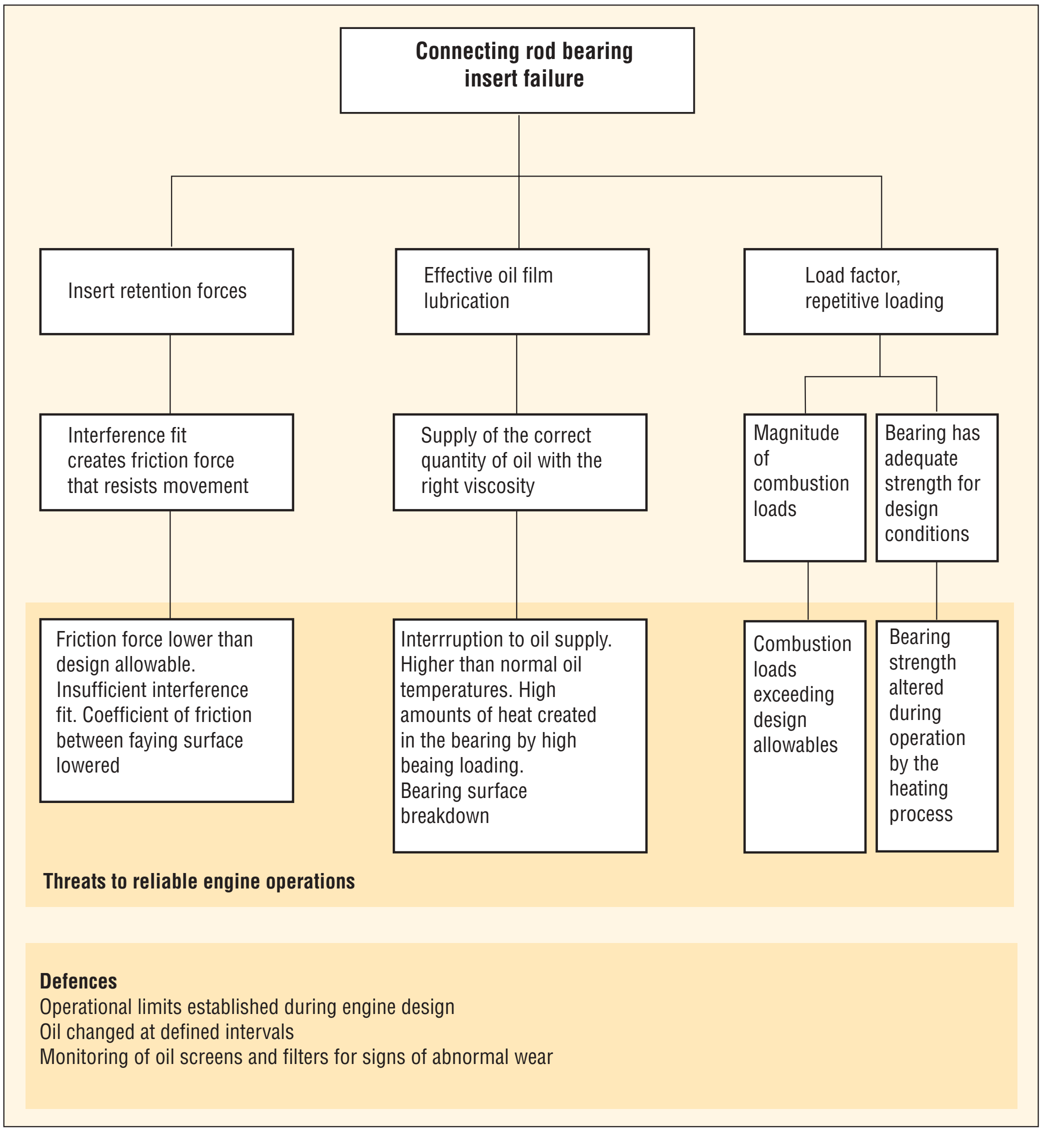
**Figure 40:**
**Connecting rod big end bearing housing failure analysis logic diagram**




Fatigue cracking in the Number 6 connecting rod initiated at the outer surface of the housing. Initiation of fatigue cracking at the outer surface is an indicator of a change in the big end bearing housing assembly that leads to increased flexure of the housing and high alternating stresses at the outer surface. Increased bearing clearance associated with bearing breakdown leads to increased housing flexure and fatigue initiation at the housing outer surface.

### Connecting rod 'big end' bearing insert failure analysis

**Figure 41:**
**Connecting rod big end, bearing-insert, failure analysis logic diagram**




The connecting rod big end bearings of Lycoming TIO-540 engines are based on the use of precision insert bearings. These bearing inserts consist of three layers; a top layer of a lead–tin bearing alloy (babbit alloy), an intermediate layer of an aluminium–tin bearing alloy and a low–carbon steel backing layer. The bearing inserts are retained in the connecting rod housing by the interference fit forces created during assembly. Under normal operation, an oil film separates the bearing surfaces and transmits the forces between the components. The oil film is established by the slight eccentric rotation of the journal within the bearing in an action known as hydrodynamic lubrication.

#### Bearing life limiting factors, reciprocating engines

The performance of bearing inserts in hydrodynamic bearings is limited by two factors: the load endurance factor which incorporates fatigue resistance, load carrying capacity, compatibility and conformability; and the surface endurance factor which incorporates compatibility, score resistance, wear resistance, corrosion resistance and embedability[22]. On one hand, the bearing must have the strength to withstand the load applied through the oil film to its surface and on the other, a property of softness, imparting an ability to endure contact with the shaft when the oil film becomes thin or contaminated with dirt.

Babbitt alloys (lead–tin alloys) remain the best materials for bearing surface endurance. They have, however, a limited resistance to alternating pressure loads. The resistance to alternating pressures is increased by reducing the thickness of the babbitt alloy layer. Trimetal bearings achieve their high load rating by reducing the babbitt alloy layer thickness to a minimum. The higher strength aluminium–tin alloy provides a suitable bearing surface in the event the babbitt layer is breached during operation.

The load endurance factor of a bearing depends on the fatigue strength of the various bearing layers. Tin–aluminium alloys and copper–lead alloys are used as intermediate layers in trimetal bearings because of their higher fatigue strength.

Bearing selection is made on the basis of load factors established by testing under conditions of alternating load. Bearing design is aimed at maintaining the magnitude of alternating loads/pressures within the limits of the bearing load factor.

Load factors are not a simple function of applied load magnitude. Operating conditions which affect oil film thickness and, subsequently, the heat generated at the bearing surface and the temperature of the bearing material have been found to influence bearing life and load carrying capacity markedly[23]. As oil film thicknesses decrease, the heat generated at the bearing and journal surfaces increases. If there is a breakdown in the oil film and direct contact between the journal and bearing then excessive bearing heating and deterioration may occur. Bearing temperature is an important variable in determining the performance of a bearing type.

Bearing temperature may affect the fatigue resistance of trimetal bearings through microstructural changes in the aluminium–tin layer. The fatigue strength of the aluminium–tin layer depends on the nature of the dispersion of the softer tin phase throughout the stronger aluminium phase.

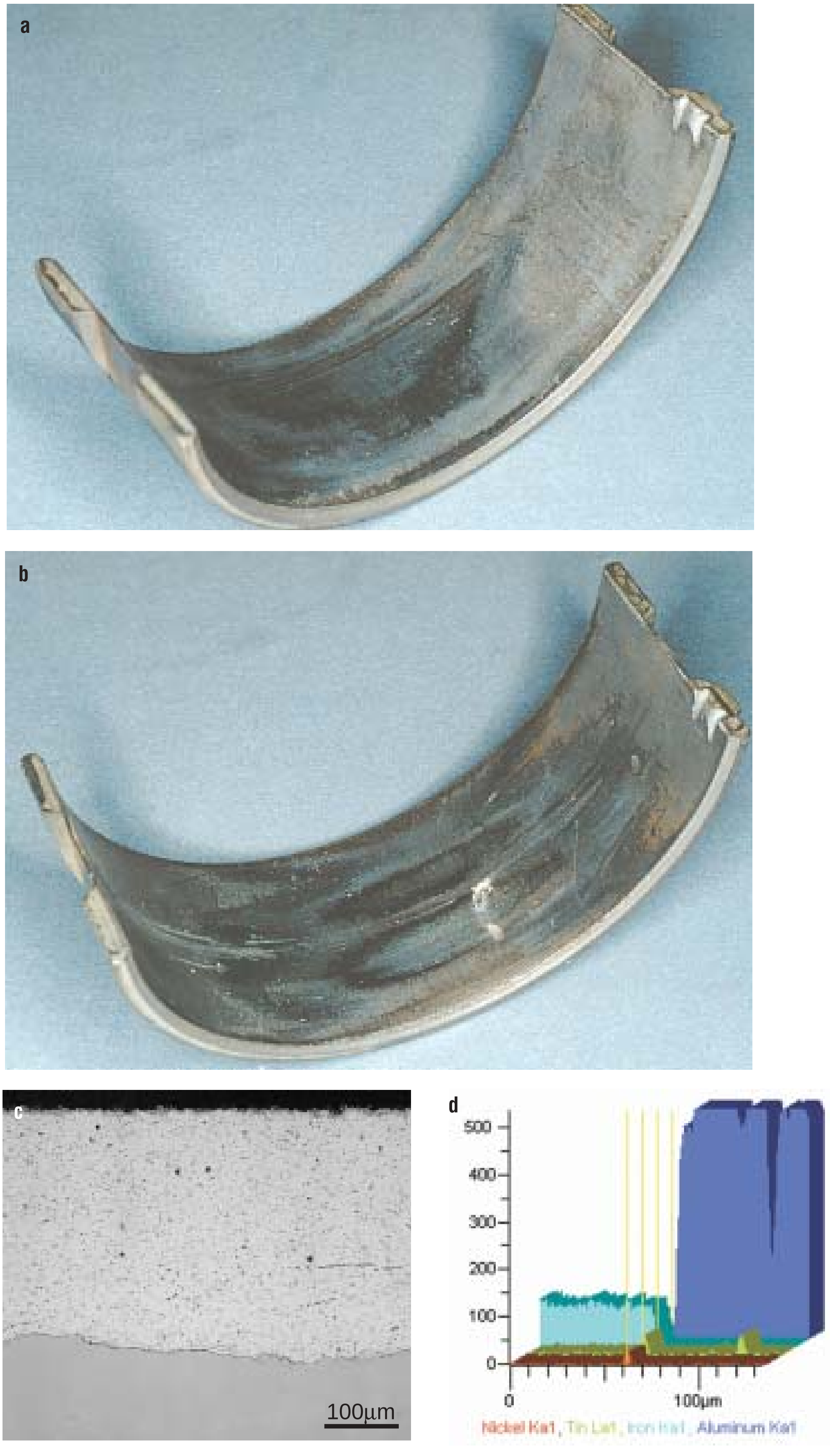
Normally, for the aluminium alloy used in Lycoming engine trimetal bearings, the tin phase is dispersed as fine globules (see fig. 42). In this case, the fatigue strength, or spalling resistance, under repeated bearing pressure loading is dependent on the properties of the aluminium alloy.

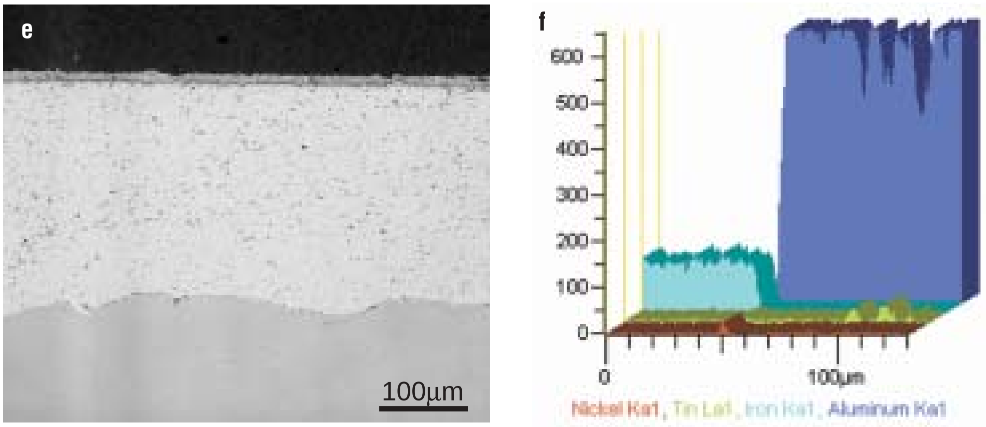
However, if the bearing is heated excessively during operation, the dispersion of the tin phase may change by a process of tin diffusion and agglomeration. Large lakes of the tin phase are formed in the bearing layer (see fig. 42), effectively changing the fatigue strength of the region to that of the tin phase. It was noticeable that spalling was present on bearings that exhibited surface wear from periods of ineffective lubrication. Microstructural examination revealed that the tin phase had agglomerated into large lakes at the interface between aluminium–tin alloy and the nickel plating on the steel backing (see fig. 42).

22 ACL Engine Manual, Gregory's Scientific Publications, p179.

23 ibid.

**Figure 42:**
**Two examples of bearing wear, VH-ODE (a, b). The microstructural differences between worn and undamaged bearings are shown in (c) worn and (e) undamaged. The distribution of tin at the interface between the steel backing and the aluminium–tin alloy interface is shown in the elemental linescans (d) worn, (f) undamaged**

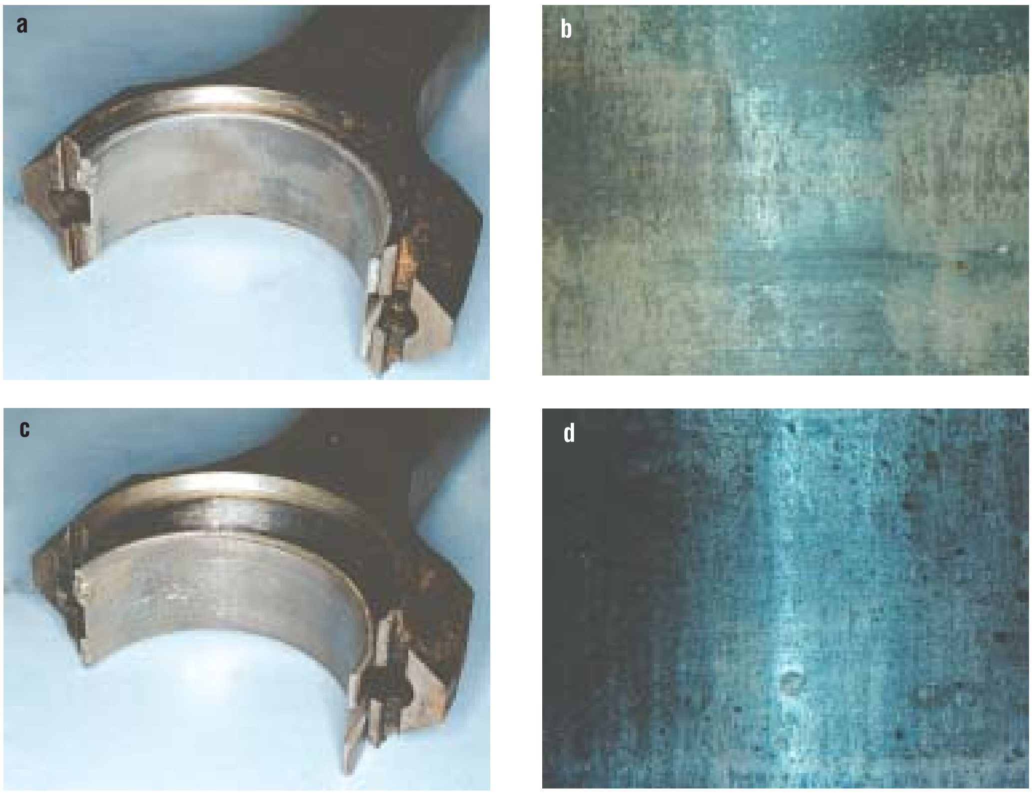





The nature of hydrodynamic oil film lubrication in the plain bearings of a reciprocating engine results in two limiting conditions that determine bearing life. One limit is the minimum oil film thickness, which is generally more critical under longer duration, inertia loads, created by the acceleration and deceleration of the connecting rods and pistons. These effects are generally evident on the cap side of a connecting rod big end bearing. The second limit is the maximum oil film pressure created by the applied loads being concentrated over a small area of the bearing. The pressure factor is at its highest for the short duration of gas firing load. The maximum oil pressure effect is usually evident on the rod side of the connecting rod big end bearing.

Bearings examined from both engines from MZK showed varying degrees of bearing surface distress (see fig. 43).

**Figure 43:**
**Examples of bearing insert surface wear, left engine MZK (a, b), right engine MZK (c, d)**



In addition to bearing surface distress, there was evidence that the bearing inserts had been sliding repeatedly, over small distances, against the bearing housing. An example of the evidence of repeated movement is the creation of a relief impression of the bearing identification marks on the housing surface (see fig. 44).

**Figure 44:**
**Detailed view of the surface relief created on the number 4 connecting rod big end housing, MZK, by the relative movement between the housing and the bearing insert. The housing surface is shown in (a), the corresponding surface of the insert is shown in (b).**

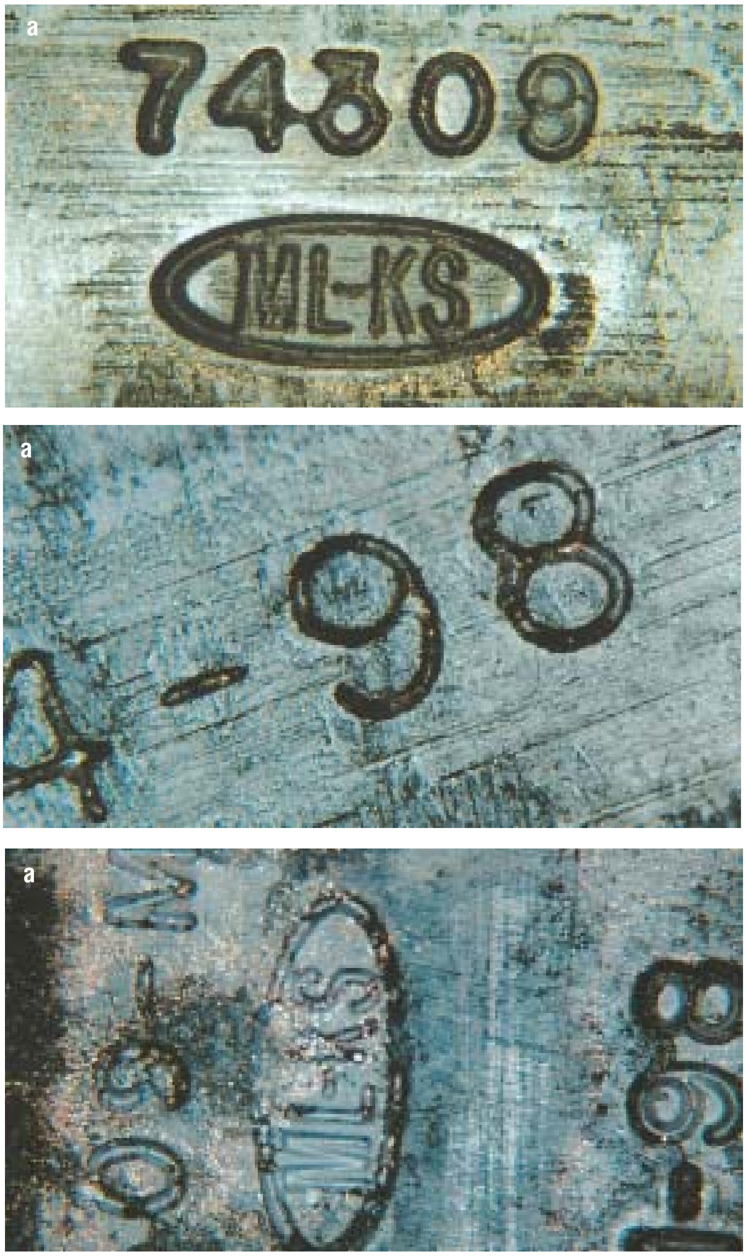

The effective retention of bearing inserts in the bearing housing is dependent on the creation of a sufficiently high friction force to the resist the forces imposed on the bearing assembly during engine operation. The magnitude of the friction force is dependent on two factors – the coefficient of friction between the contacting surfaces (back of the bearing insert and surface of the bearing housing), and the magnitude of the force developed perpendicular to the contacting surfaces.

Various factors may affect the coefficient of friction; these include surface finishes and the inclusion of other compounds. The force perpendicular to the surface is affected by the geometry of the housing and bearing inserts (degree of difference in the diameters) which determines the magnitude of radial compression (interference fit) and the magnitude of the bolt clamping force developed during assembly (sufficient to 'crush' the bearing insert).

Examination of the remaining connecting rod assemblies from the left engine revealed that each big end bearing had been assembled with the correct parts and the bolts had been tightened to the specified stretch (measure of clamping force). However, it was observed that relative movement had occurred between the inserts and the housings.

Detailed examination of the insert and housing surfaces revealed that a copper–based anti-galling compound[24] had been applied to the faying surfaces (see fig. 45). While this compound would reduce the likelihood of defects generated by adhesive wear (galling) it would also reduce the coefficient of friction between the housing and insert. The insert retention force would be reduced in comparison with similar bearings assembled to specification but without the inclusion of the anti-galling compound.

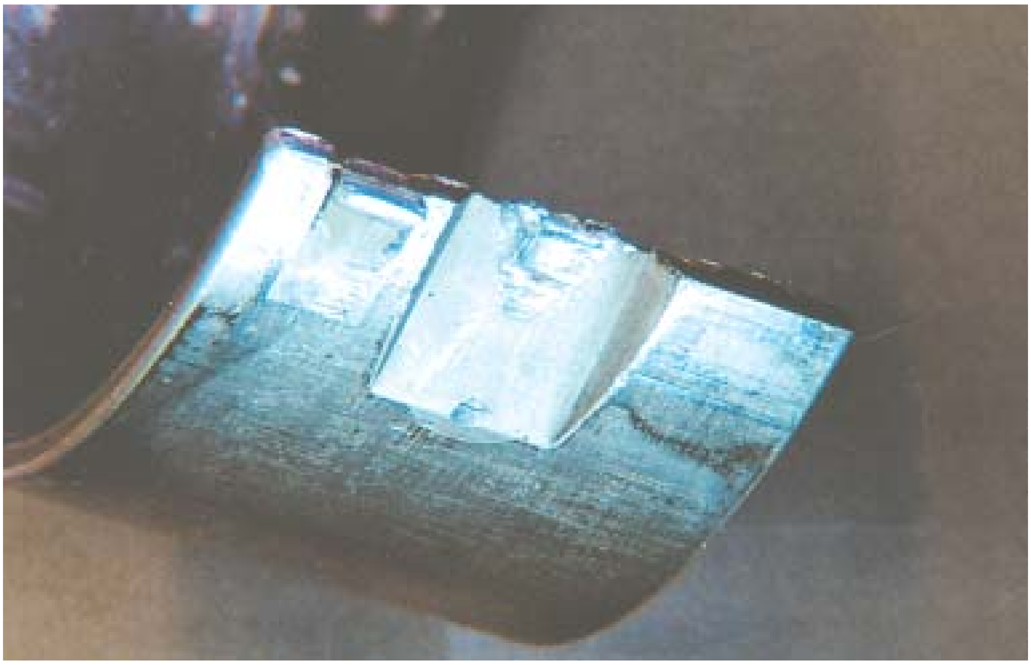
**Figure 45:**
**The residue of copper-based anti-galling compound on the backs of bearing inserts; left engine MZK (a), right engine MZK (b), right engine VH-ODE (c)**




[24] Anti-galling compounds are also known as anti-seize lubricants. Copper–based formulations are characterised by suspensions of copper and graphite in a high quality grease.

Bearing insert breakdown occurs through the alternating movement of the inserts in the bearing housing. The insert locating tang is not designed to prevent insert rotation. It has been observed that repetitive movement of bearing inserts in housings progressively damages the inserts. In particular, the interaction of the bolt and insert creates extensive damage (see fig. 46). The segments released are ultimately severely deformed as they are extruded from the space between the big end housing and journal during continued operation.

**Figure 46:**
**Example of damage to the bearing locating lug and bolt recess caused by movement of the insert of the housing, VH-BNN**



### Other engine failures involving connecting rod bearings

Examination of the engines from MZK and other engine failures, e.g. VH-ODE revealed that a copper–based anti-galling compound had been used in the assembly of the engines. It was evident that the quantity of anti-galling used during assembly was variable. It was also evident that anti-galling compound was not a factor for all the engine failures examined, e.g. VH-BNN.

Generally, the examination of connecting rod bearings from the failed engines examined in the course of this investigation revealed that bearing surface distress was common on the insert fitted to the connecting rod side – an indicator that the bearings had been subjected to high pressure loading during operation.

### Summary

The successful retention of connecting rod bearing inserts depends on two factors: the magnitude of bearing insert retention forces and the magnitude of the forces developed during operation that act to produce a rotational load on the bearing. Failure will occur when the retention forces are reduced and/or the operational forces are increased. Insert loss can occur during normal engine operation if the retention forces are reduced greatly or if the forces created during operation are increased. In the case of the left engine from MZK it is likely that loss of the Number 6 bearing insert resulted from the combined effects of lowered retention force and increased operational forces. The effect of the inclusion of an anti-galling compound would depend on the quantity trapped between the housing and the insert and its effect on the coefficient of friction in all areas of contact between the insert and housing.

### Combustion loads

The timing of spark ignition is critical to effective engine operation. Since combustion (by the propagation of a flame front through a premixed fuel–air charge) takes a finite time, the mixture is ignited before the piston reaches top centre, towards the top of the compression stroke. Initiating combustion before the end of the compression stroke results in an increase in compression work. While the increase in compression work is negative work with regard to engine rotational power, the higher pressure at top centre leads to higher pressures during the expansion stroke and a positive effect on engine power. Optimum advance of ignition timing is a trade-off between these two effects. The optimum value is referred to as 'minimum ignition advance for best torque'. Minimum advance for best torque limits the peak pressures and temperatures in the cylinder. Advances in ignition timing beyond the optimum value results in a decrease in engine power.

In addition to ignition timing, combustion chamber pressures are affected by the engine power setting (the quantity of fuel–air charge reacted with each combustion cycle) and the mixture setting (related to the slower rate of flame propagation with mixtures departing from the stoichiometric ratio).

Ignition timing in horizontally–opposed reciprocating aircraft engines is set mechanically and cannot be varied during operation. Changes in ignition timing may occur as a result of magneto defects, mixed spark plug leads, spark plug defects and hot spots in the combustion chamber.

The fuel–air charge drawn into the combustion chamber may be ignited by any heat source of sufficient energy to ignite the fuel–air charge, under the prevailing conditions in the combustion chamber, prior to spark ignition. This effect is known as preignition. As with detonation, many factors may be involved and the outcomes of the phenomenon, in terms of duration and effect on engine components and operation, are variable. An example of the variety of mechanisms and effects identified with the term preignition can be seen in the definition of preignition presented by Owen[25]:

> Preignition occurs when a charge is ignited prematurely, and this can be caused by glowing deposits or by a hot exhaust valve or spark plug. Deposit induced ignition (DIPI) is of a somewhat random nature. Having begun, it may die out as deposits burn off or it may increase in severity and produce mechanical damage: the latter is called run away surface ignition (RSI). RSI is a violently unstable condition in which ignition occurs so early that the heat of combustion cannot be converted into useful mechanical work. The excess heat can burn a hole in a piston in a very short time.

In this report, the use of the term preignition will be applied to all combustion events in which the fuel–air charge is ignited prior to the normal timed spark ignition of the charge. Detonation will be used to describe those combustion events in which the charge or remaining charge undergoes autoignition.

The effect of both phenomena on charge temperature and combustion chamber temperature can result in a cyclic linkage; detonation leading to preignition and preignition leading to detonation.

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25 K Owen, op. cit., p. 795.

In the case of preignition, it is important to note that combustion may progress normally, albeit at an advanced time in the engine cycle, resulting in increased combustion chamber pressures. If the preignition is created by the presence of heated combustion chamber deposits, the process may be related to the cycle of deposit buildup and subsequent dispersal by high temperature reactions, and therefore be discontinuous. However, while deposit formation may be discontinuous, the effect of the periods of increased loading on engine components will be cumulative.

### Defence against deposit induced preignition

Fuel properties may also be significant in the development of preignition, the most important being deposit formation. Two properties of fuel are important in deposit induced preignition:

- the ease with which the fuel–air charge may be ignited by glowing deposits, and
- the deposit forming tendency of the fuel.

The tetraethyl lead (TEL) additions to aviation gasoline, incorporated to improve the detonation resistance of the fuel, result in the production of lead oxides in the combustion chamber. In addition to creating problems by fouling spark plugs and causing corrosion of high temperature components, lead oxide combustion chamber deposits have been identified as deposits that can cause preignition. TEL additions to gasoline improve the resistance of the fuel to preignition caused by glowing deposits and increase the deposit–forming tendency of the fuel. The deposit–forming tendency may out weigh the auto-ignition inhibiting benefit[26].

In the case of fuels for high power reciprocating aviation engines, TEL additions are required to produce fuel of a sufficient auto-ignition level. The deposit-forming tendency is mitigated by the incorporation of a 'scavenging' agent in the fuel. Ethylene dibromide ($C_2H_4Br_2$) is used as the scavenging agent in aviation gasoline. The desired result of the scavenging reaction is the formation of a volatile lead bromide ($PbBr_2$) instead of lead oxide. The volatile lead bromide is removed from the combustion chamber with the exhaust gases.

It has been recognised that bromine remaining after the scavenge reaction can corrode engine components. The addition of ethylene dibromide to aviation gasoline is controlled so that only the right amount is added to react completely with the lead oxides formed. The ratio of ethylene dibromide to tetraethyl lead is termed a 1-T mix[27] (one times theoretical).

The above description of the scavenging process is the ideal, desired, outcome. The conditions in the fuel–air charge in combustion chambers of internal combustion engines are continually varying. A single steady state is not achieved. The products of the reaction of chemical compounds are affected by thermodynamic and kinetic factors. Temperatures, pressures, partial pressures of reactants and catalytic effects of surfaces are important factors.

The failure of the scavenge reaction to remove all lead oxides or to form volatile bromides that are removed with the exhaust will result in the buildup of lead compounds on combustion chamber surfaces. These compounds may initiate preignition if they are heated to a point of incandescence (glowing). The temperature of deposits is a function of local heat transfer. Temperature increase is minimised if the

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26 K Owen, op. cit., p796.

27 R A Vere, op. cit., p731.

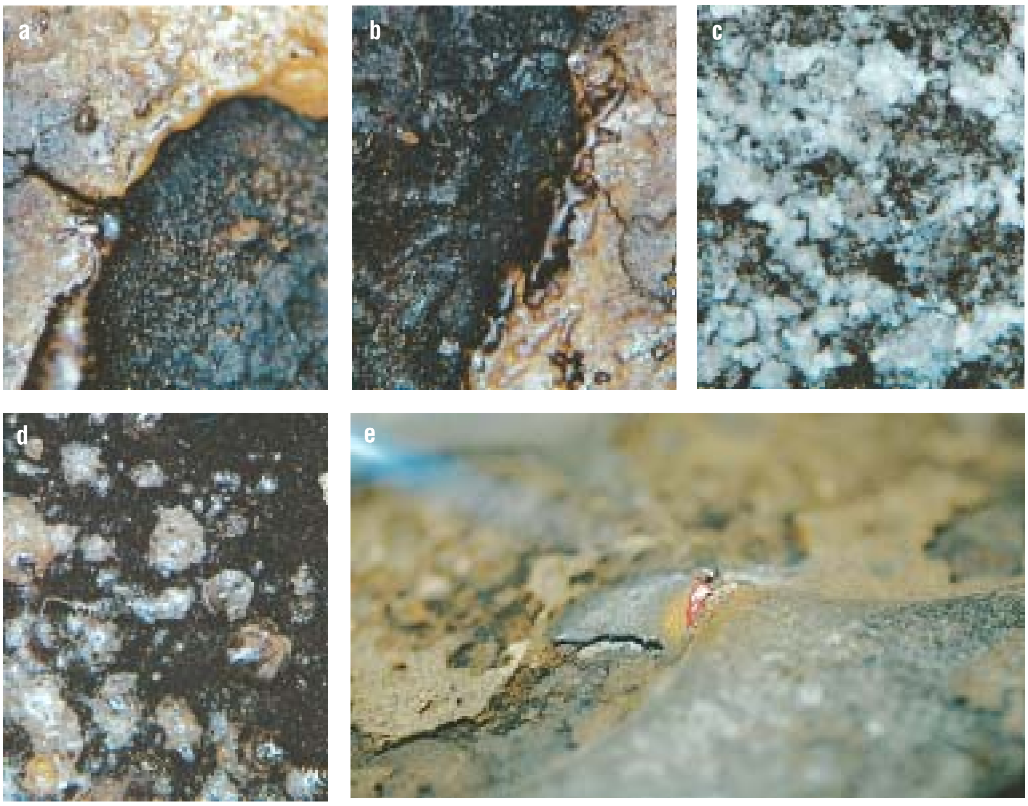
deposits are thin and firmly attached to the combustion chamber surfaces. If the deposits increase in thickness, the poor thermal conductivity of the deposits will result in increased surface temperatures. Similarly if the deposits become partially detached from the surface, the rate of heat removal by conduction will be greatly reduced and the deposits will be heated to high temperatures – to their melting or decomposition temperatures.

A variety of lead compounds may form in engine combustion chambers. For example, lead monoxide (PbO), lead bromide ($PbBr_2$) and complex lead oxybromides. The behaviour of these compounds when exposed to heat varies. PbO melts at 888°C while $PbBr_2$ melts at 498°C and vapourises at 914°C[28]. The behaviour of lead oxybromides is not reported in the general chemical literature.

Chemical analysis of deposits removed from the pistons of a number of high-powered turbo-charged engines has identified that complex lead oxybromide compounds were formed. Compound identification was achieved by employing a variety of techniques, x-ray powder diffraction, Raman spectroscopy and quantitative chemical analysis. The tan coloured deposit prevalent on the piston crowns of these engines was found to be homogeneous and was identified as $Pb_3O_2Br_2$ (which can also be represented by the formula, $2PbO.PbBr_2$). Examples of these deposits are shown in figure 47.

Heating the deposits with a propane flame revealed that the deposits melted at a temperature high enough for the molten deposit to incandesce (see fig. 47). The deposit did not vapourise at low temperatures.

**Figure 47:**
**Examples of lead oxybromide piston crown deposits (a, b) and high temperature glassy reaction products (c, d). The response of deposits to heating is shown in (e)**




[28] Chemical Data Book, G H Aylward and T J V Findlay, 2nd Ed, Halstead Press Sydney, 1968, p 16.

### Failure of the scavenge process

The scavenge process was designed to prevent the formation of deleterious lead compounds in engine combustion chambers by converting lead oxide to lead bromide. It is evident that, in many engines, the desired chemical reaction does not occur during all phases of operation.

It is also evident that many compounds can be formed by the reaction of lead oxide with bromine, ranging from the simple lead bromide to a number of complex oxybromides. As with all chemical reactions the product of a reaction will depend on thermodynamic and kinetic factors. It is likely that there is a strong temperature dependency associated with reaction paths that lead to specific products. This temperature dependency is illustrated to a degree by the reported distribution of lead compounds, as a function of temperature, on spark plug electrode insulators[29].

Because the reaction occurs in the fuel–air charge prior to flame combustion it is likely that the temperature of the fuel–air charge is a significant factor in determining the nature of the products formed by the scavenge reaction. There may be an optimum charge temperature for the formation of lead bromide. There may also be a significant temperature effect on reaction rates. Because the time available for reactions to occur is limited by the very short combustion cycle time, conditions that slow reaction rates may prevent reactions from proceeding to completion.

Operating practices have an effect on the charge temperature. Mixture setting, in particular, has a significant effect. It is important to note that mixture settings for all phases of operation, not just cruise, are important. In the course of this investigation it was evident that, in general, there were two modes of operation of high–powered piston engines. Some operators employed full rich mixture settings during climb combined with best power lean settings during cruise. Other operators employed a variety of lean (reduced quantity of excess fuel) mixture settings during climb combined with best economy mixture settings during cruise (see section 1.17.6, table 5).

The charge temperature for full rich climb power settings would be less than that for lean climb power settings. As the power setting is reduced to a cruise power setting the charge temperature will be reduced. Leaning during cruise to best power cruise settings will result in higher charge temperatures than that when the mixture setting is leaned to best economy cruise.

A comparison of the deposits formed in combustion chambers from engines subjected to each mode of operation revealed that there were significant differences (see fig. 48).

23 Lycoming Flyer Key Reprints, Textron Lycoming 1996, p14; K Owen, op. cit., p.797.

**Figure 48:**
**A comparison of combustion chamber surfaces, piston crowns and cylinder heads, from an engine operated under conditions of full rich climb and best power cruise (a), with an engine operated under conditions of lean climb and best economy cruise (b)**


Reported engine problems related to the use of higher lead content fuels in low power aircraft piston engines[30] may also indicate a temperature dependency for the scavenge process. In low power engines the temperature of the fuel–air charge may be too low to allow for the reaction of lead oxide to lead bromide to proceed to completion in the time available for reaction.

### Bearing corrosion

The formation of lead oxybromides instead of lead bromide will affect the quantity of free bromine remaining after the scavenge reaction. The addition of ethylene dibromide to the tetraethyl lead fluid is based on the formation of lead bromide ($PbBr_2$), the ratio of lead to bromine is 1:2. When lead oxybromide, $Pb_3O_2Br_2$, is formed the ratio of lead to bromine is 1:0.67. Three times as much bromine is required to react with lead oxide to form lead bromide than lead oxybromide. The formation of lead oxybromide will result in a large excess of bromine in the combustion chamber. Excess bromine can find its way into the lubricating oil and form hydrobromic acid. Hydrobromic acid is particularly corrosive to aluminium alloys.

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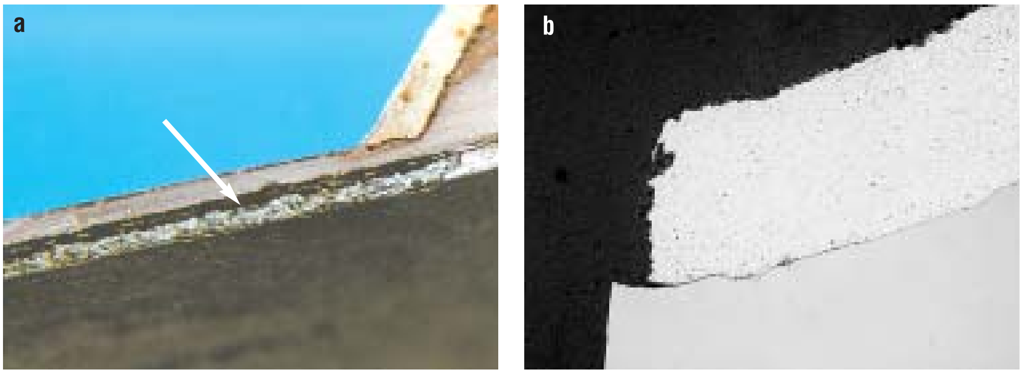
30 R A Vere, op.cit., p. 726.

Note that the problems reported were spark plug fouling and high cylinder head temperatures leading to cracked cylinder heads.

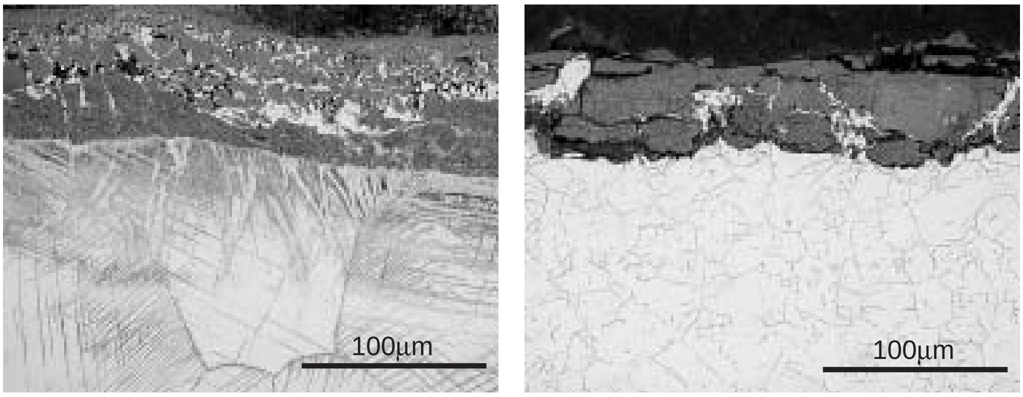
Examination of connecting rod and main bearing inserts from the engines from MZK and other engines that exhibited extensive oxybromide combustion chamber deposits revealed that the aluminium alloy layer in the bearings had been attacked corrosively where the alloy is exposed at the bearing insert ends. The attack progressed more rapidly at the interface between the aluminium alloy and the nickel plating on the steel backing giving the impression of partial bearing delamination (see fig. 49). Bearing corrosion is a further indication of the failure of the scavenging process.

**Figure 49:**
**An example of the corrosion that had affected bearing inserts from an engine that exhibited copious lead oxybromide combustion chamber deposits, photomacrograph (a), metallographic section (b)**




Surface deposits of lead oxide and lead oxybromide will affect the oxidation resistance of components subjected to high temperatures during engine operation. The presence of these compounds interferes with the normal oxide surface films that provide oxidation resistance (see fig. 50).

**Figure 50:**
**An example of the extent of surface oxidation on the inner surface of the exhaust pipe from the left engine MZK**




### The signs and symptoms of preignition

A strong linkage between the presence of combustion chamber deposits of lead compounds and preignition has been established and is widely reported in the literature.

The signs of preignition are generally reported as increases in cylinder head and piston temperatures (these temperatures will only be noticeable if the affected cylinder is instrumented). If special instrumentation is available then preignition may be apparent through engine power drops (torquemeter), the presence of a flame prior to sparking (spark analyser ionisation gap), displacement of peak pressure curves (combustion chamber pressure instrumentation).

The symptoms of preignition are generally reported to be power loss and possibly rough running. The symptoms may be intermittent.

The introductory paragraph to Lycoming Service Instruction (SI) No. 1418, 26 March 1982, Combustion Chamber Cleaning Procedure, also clearly relates the presence of combustion deposits with a reduction in engine performance:

> Numerous reports from the field, along with tests conducted at Avco Lycoming show that cylinder head combustion deposits which are mainly caused by tetraethyl lead in fuel, can result in fouled spark plugs or an indication of a reduction of engine performance. While combustion chamber deposits form in all engines, the degree is affected by the type of operation, such as training or short flights, poor fuel management, improper leaning, and the amount of tetraethyl lead in the fuel.

Lycoming SI 1418 recommended that, before action was required to remove the deposits, a trouble-shooting procedure be followed to address other potential origins of power loss and engine roughness:

> Normal trouble shooting procedures such as an inspection of the induction system, air filters, carburetor heat; if applicable, throttle and mixture controls, fuel metering device for over-rich or over-lean conditions, magnetos, spark plugs, valve clearance, cylinder compression and calibration of tachometer and manifold pressure gauge should be accomplished before proceeding with this cleaning procedure.

Entries in the maintenance log for MZK detail spark plug replacements and magneto timing adjustments for both engines. Entries of possible significance to the operation of the left engine were made on 9 and 10 May 2000, between 46 and 49 hours (59 and 63 flights) prior to the accident (section 1.6.4 refers). References to magneto problems and the engine 'missing' may indicate the presence of an underlying anomaly in combustion conditions in the left engine at that time.

#### Deposit management

It is apparent that lead deposits in engine combustion chambers can be controlled if the operating conditions favour a scavenge reaction that creates volatile lead bromide. The operating conditions need to be managed so that the conditions in the combustion chamber, in particular the fuel–air charge temperature, is optimised for all phases of flight.

If the scavenge reaction conditions cannot be optimised then maintenance actions directed at identifying the presence of lead oxybromides and lead oxides, and their removal by mechanical means, need to be implemented. A procedure for removal of combustion chamber deposits by in situ walnut shell blasting was documented in SI 1418.

### 1.17.4 Engine failure sequence

**Figure 51:**
**Schematic showing the most likely sequence of events leading to the failure of the left engine MZK**

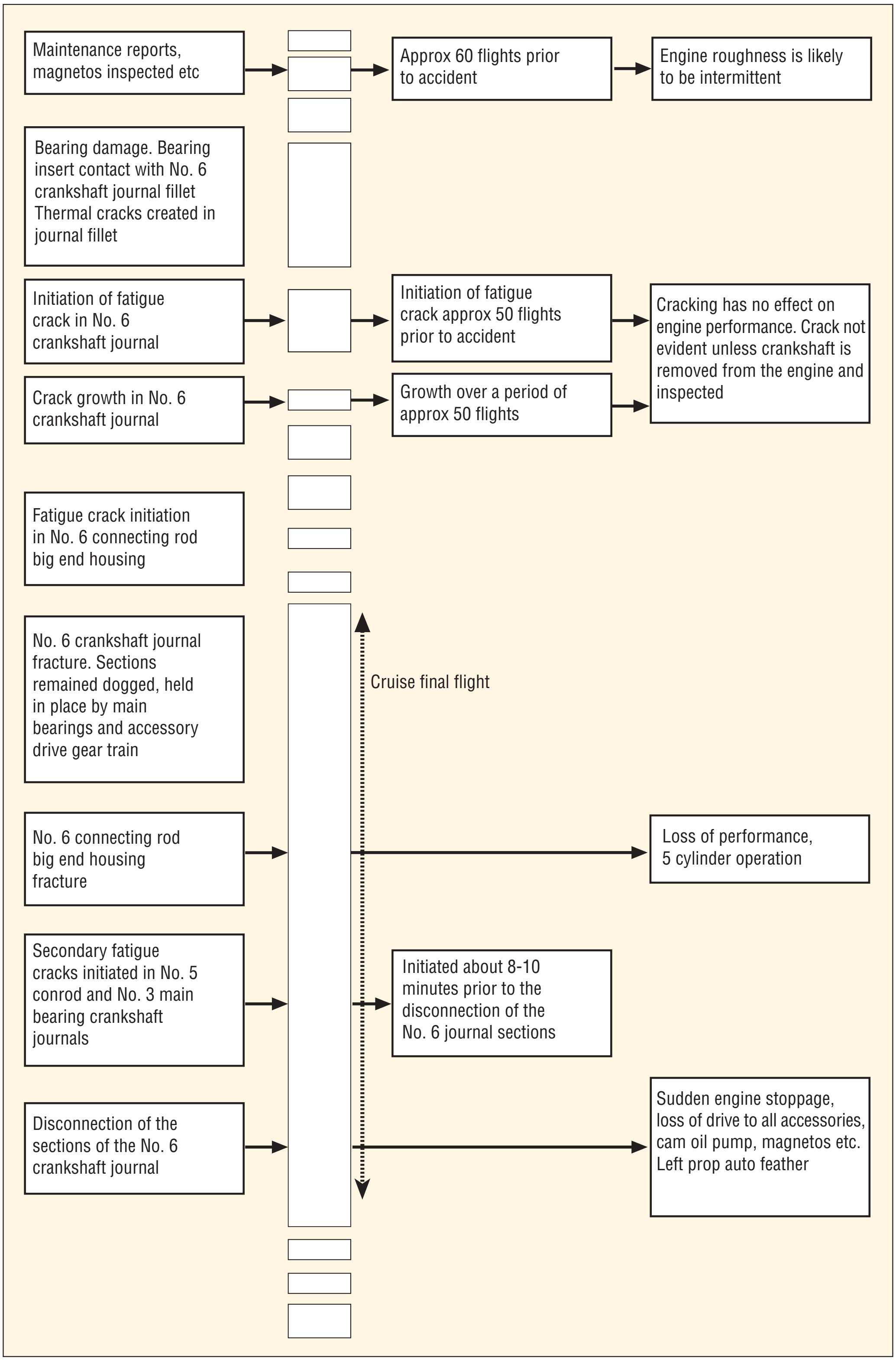
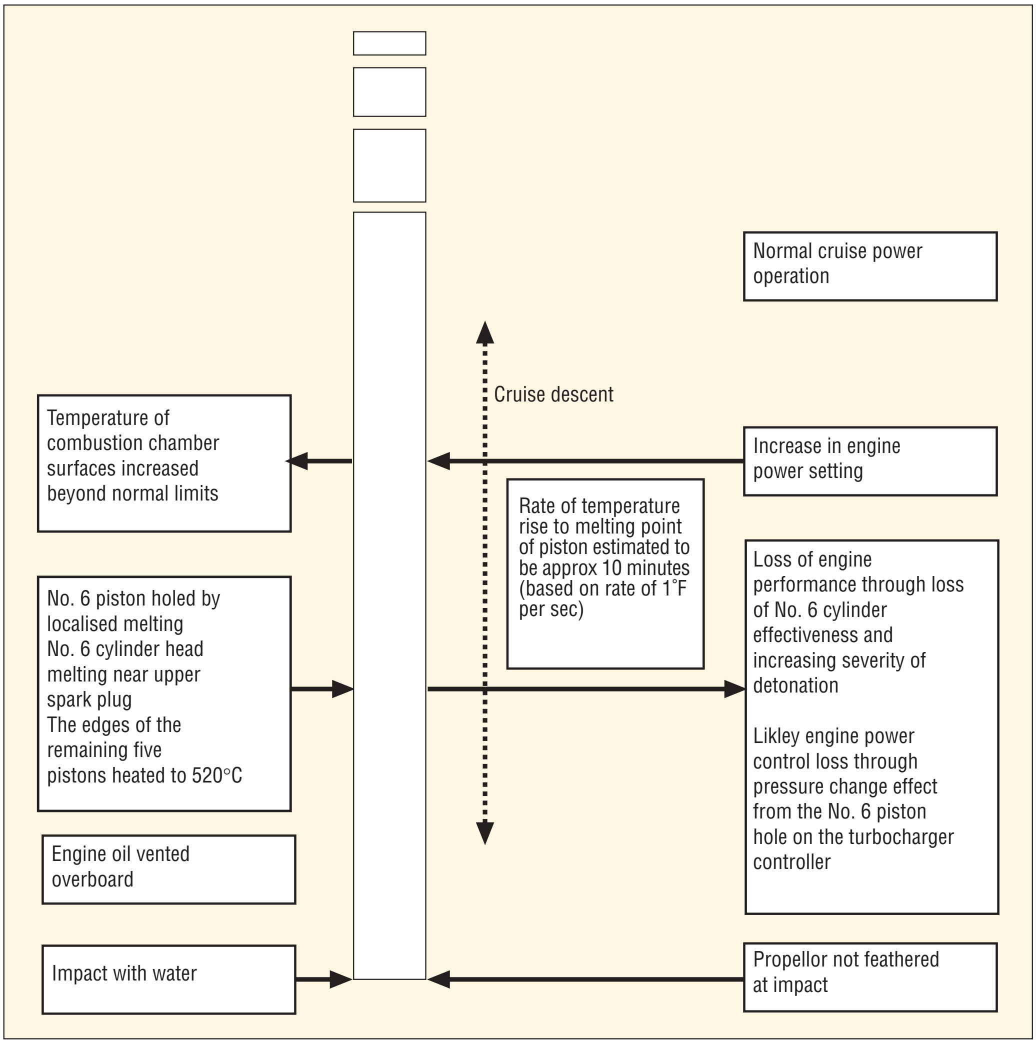


**Figure 52:**
**Schematic showing the most likely sequence of events leading to the malfunction of the right engine MZK**




### 1.17.5 Summary

Detonation and deposit–induced preignition are two modes of abnormal combustion that may be encountered in aircraft piston engine operation. They occur as a result of the need to adjust power and mixture settings for different phases of flight, and the need to use leaded fuels.

Defined operational limits have been established through the process of engine and airframe installation design and certification testing. Detonation occurs when these limits are exceeded. Light detonation over a long period of time may result in mechanical failures through increased combustion gas pressure loads. Heavy detonation will cause rapid overheating of combustion chamber components leading to component melting after a short time.

Deposit induced preignition occurs when lead oxides and lead oxybromides are deposited on combustion chamber surfaces and heated to a temperature sufficient to ignite the fuel–air charge prior to normal spark ignition. The increased combustion gas loads developed through ignition advance result in the mechanical failure of various engine components. Failure modes and sequences are dependent on the variations inherent in engine assembly and construction. These may relate to manufacturing variations and tolerances, assembly practices and procedures, and changes in component properties by the effects of operating conditions or overhaul/maintenance actions.

The failure modes exhibited in the engines from MZK were not unique. The examination of other high power, horizontally opposed, reciprocating engines, which had failed during the period January 2000 to November 2001, revealed that:

- Connecting rod big end housing fatigue, following bearing insert destruction, had occurred on two occasions (TIO-540, VH-LTW; IO-540, VH-BNN).
- Connecting rod big end bearing insert destruction had occurred on one occasion (TIO-540, VH-ODE). An indication of low oil pressure led to the shut down of the engine.
- Piston melting had occurred on one occasion (TIO-540, VH-NPA).

Lead oxybromide deposits were present on the combustion chamber surfaces of these engines. Of the three failures of connecting rod big end bearings, only those from ODE had been installed with copious quantities of anti-galling compound. A determination of the presence of anti-galling in the bearing assemblies from LTW was prevented as the components had been cleaned after engine disassembly.

Other failure modes that may have their origin in high combustion gas loads and high piston temperatures were identified during the examination of four TIO-540 engine failures that occurred in the period January 2000 to November 2001. These failure modes included:

- the fracture of a connecting rod little end bearing housing (VH-MZK, January 2000),
- the fatigue fracture of cylinder base attachment studs (VH-FIA),
- cylinder head fatigue fracture (VH-MJA), and
- crankshaft main bearing fatigue cracking following bearing insert fillet ride (VH-TTX).

In each case, an examination of combustion chamber surfaces (cylinder heads and piston crowns) revealed the presence of lead oxybromide deposits.

The engine operating procedures for, ODE, LTW, BNN, FIA, MJA, TTX, NPA and MZK specified mixture leaning during climb and mixture leaning to achieve reduced fuel consumption during cruise.

Additionally, lead oxybromide deposits were present on the combustion chamber surfaces of two Teledyne Continental Motors TIO-520 engines. In one case, material had been lost from the edge of the piston crowns in a manner consistent with piston overheating. This defect was discovered when the pistons were examined at overhaul. In the other, the engine failed after fatigue cracking in a main bearing journal. Examination of the connecting rod bearing surfaces revealed that the bearings had been subjected to combustion loads of sufficient magnitude to create surface damage.

Teledyne Continental Motors TIO-520 engines also use leaded aviation gasoline and mixtures may be leaned during climb and leaned during cruise to achieve best economy.

## 1.17.6 Engine operating procedures

### Engine operating procedures – aircraft manufacturer

Section 4 of the Piper Chieftain Pilot's Operating Handbook Report: 2046 issued 1 November 1976, included amplified normal procedures to provide detailed information and explanations of the normal procedures necessary for operation of the aircraft.

Paragraph 4.37 (Leaning Procedures) of the POH included the following:

> When leaning below best power is permitted (refer to Maximum Manifold Pressure Vs. Altitude graph in Section 5 – Performance), the engines may be operated at peak EGT or on the lean side of peak EGT as long as stable engine operation results without exceeding any engine limitations during steady state or transient conditions.

Engine operating temperature limits in the handbook were:

| | |
|---|---|
| **CHT** | |
| CHT normal operating range (green arc on gauge) | 100°F to 475°F |
| CHT caution range (yellow arc on gauge) | 475°F to 500°F |
| CHT limit (red radial on gauge) | 500°F |
| CHT maximum continuous | 475°F |
| CHT maximum desirable for maximum engine life | 435°F |
| **Oil temperature** | |
| Oil temperature normal range (green arc on gauge) | 120°F to 245°F |
| Oil temperature limit (red radial on gauge) | 245°F |
| **EGT** | |
| EGT normal operating range (green arc on gauge) | up to 1650°F |
| EGT limit (red radial on gauge) | 1650°F |

### Engine operating procedures – engine manufacturer

The Textron Lycoming Operators Manual published March 1987 contained the following operating limits for the TIO-540J series aircraft engines:

| | |
|---|---|
| **CHT** | |
| CHT absolute maximum | 475°F |
| CHT during performance cruise (75% power) for maximum service life | 435°F |
| CHT during economy cruise (60% power) for maximum service life | 400°F |

**Oil temperature**

| Average ambient air temperature | Desired | Minimum | Maximum |
|---|---|---|---|
| Above -1°C | 180°F | 140°F | 245°F |
| -18°C to 21°C | 170°F | 140°F | 245°F |

Section 3 of the Operators Manual for the Textron Lycoming TIO-540 series aircraft engines included the following operating instructions:

> LEANING TO TURBINE INLET TEMPERATURE OR EXHAUST GAS TEMPERATURE GAGE [sic].
>
> ***Turbocharged engines***
>
> ***Best Economy Cruise*** – Lean to peak turbine inlet temperature (TIT) or 1650°F., whichever occurs first.
>
> ***Maximum Power Cruise*** – The engine must always be operated on the rich side of peak TIT.

The manual included no reference to, or guidance for, operating the TIO–540 series engine at fuel mixtures lean of peak EGT. That was amplified in a reprint of Service Instruction 1094D 'Leaning Textron Lycoming Engines' dated 25 March 1994 which included the following recommendation:

> For maximum service life, maintain the following recommended limits for continuous operation.
>
> (a) Engine power setting – 65% of rated or less.
>
> (b) Cylinder head temperatures – 400°F. or below.
>
> (c) Oil temperature – 165°F. – 220°F.
>
> (d) Turbine inlet temperature – maintain 100°F. on rich side of maximum allowable.

Included in that article was a footnote to the diagram which stated:

> TEXTRON LYCOMING DOES NOT RECOMMEND OPERATING ON THE LEAN SIDE OF PEAK EGT.

### Resolution of inconsistencies between the aircraft manufacturer and the engine manufacturer

Regulation 50E of the *Civil Aviation Regulations 1988* resolved inconsistencies between conflicting requirements. Subregulation (4) (f) placed a higher priority on the instructions issued by the aircraft manufacturer than those issued by aircraft component (including engine) manufacturers.

### Engine operating procedures – Whyalla Airlines

In accordance with the provisions of Section 82.3 of the Civil Aviation Orders, Whyalla Airlines was required to have an Operations Manual detailing how the company flight operations were to be conducted. Part B1.1 of the Whyalla Airlines Operations Manual (Aircraft Technical Data: PA31-350) stated:

> For aircraft technical data refer to the [aircraft] manufacturers handling notes, version REPORT 2046 and the aircraft flight manual.

Report 2046 was not applicable to MZK, having been superseded by Report LK-1208. However, the fuel leaning procedures for use during cruise operations were identical in both reports.

Engine handling procedures for climb, cruise and descent were detailed in the company operations manual. These procedures were:

> **Climb**
> Initial climb speed 110 kts until 500–800 feet
>
> Initial climb power 38–40" map [manifold pressure] 2400rpm 30usg/hr
>
> Cruise climb speed 130 kts
>
> Cruise climb power 36–38"MAP [manifold pressure] 2400 rpm 27 usg/hr or max 1500egt
>
> **Cruise**
> Cruise power 29–30" MAP, 2200rpm, mixture lean to previous average settings for particular aircraft, (note different a/c [aircraft] may have different settings)
>
> Adjust FF (**fue**l flow) & EGT as necessary. Compare actual FBO (fuel burn off) after each sector. Alter FF & EGT if FBO is different to expected amount.
>
> Compare FA (fuel added) each side for even FBO
>
> Left & right engines in the same aircraft may have different settings to achieve correct FBO.
>
> Where possible use fuel in the inboard's during cruise to check actual consumption is less than 140li/hr [L/hour]. About 120li/hr may be possible.
>
> Using the FF & EGT from another PA31 [Chieftain] may result in a rate of consumption higher than 140 li/hr.
>
> **Descent**
> Descent rate 300–500 feet per minute fpm
>
> Power during descent 29" MAP reducing to 24" MAP during circuit entry
>
> RPM maintain 2200
>
> Mixture lean, minimum EGT 1350
>
> (MAP reduction to achieve only a CHT reduction from cruise to touchdown requires a power reduction to be with a speed reduction)

The Manager of Whyalla Airlines was asked to describe the Piper Chieftain engine handling and fuel leaning practices taught by him and used by company pilots. He indicated that he expected all pilots to use the following aircraft speeds, and engine power and mixture settings:

- **Climb.** Accelerate initially to 110 kts, reduce power to 36" MP/2,400 RPM (38" initially if heavy), fuel flow adjusted to 27–30 GPH by leaning the mixtures. EGT to not exceed 1,500°F (if necessary, fuel flow would be increased to avoid exceeding 1,500°F).
- **Cruise.** Normal cruise at 30"MP/2200RPM, mixture initially leaned to 14–15 GPH, then lean to peak EGT before resetting EGT to 25–50°F rich of peak.
- **Descent.** The objective was to gradually reduce cylinder head temperatures during the descent by careful use of power and speed, avoiding excessive cooling. Generally mixtures were kept lean until landing.

The Manager said that newer pilots were taught to use richer mixture settings than more experienced pilots.

With one exception, all current, and some ex-company pilots, reported that the Manager was experimenting with lean of peak operations in the Chieftain. The

Manager also indicated that he had demonstrated lean of peak operations to his pilots, and in particular the fact that the exhaust manifold did not glow as brightly (at night) when operating lean of peak. However, he was insistent that company pilots had not been instructed to operate the engines lean of peak. The Manager was not aware of the engine manufacturer's recommendation against operating the engine on the lean side of peak, nor was he required to be.

#### Engine operating practices – company pilots

During the investigation all company pilots were interviewed. The Chieftain engine handling procedures described by most pilots were generally in accordance with those described by the Manager. Most pilots used a mixture setting in cruise that resulted in an EGT 50°F rich of peak.

One pilot who had no previous experience operating turbo-charged engines, and who had been endorsed on the Chieftain by the Manager, described the technique he had been taught for setting cruise power. Once established at the cruise altitude he would set 29"–30"MP/2200 RPM then lean the mixture until the EGT was lean of peak. He was aware that there was a caution not to operate at more than 1650°F. He said that the procedure he was taught was to operate 50°F lean of peak. He said that he was told that this gave slightly less power but an improved (i.e. more economical) fuel flow. He indicated that he would not make any adjustments just based on fuel flow indications. If the fuel flow for each engine was different it did not matter – he just left the mixtures set to achieve 50°F lean of peak EGT. The pilot could not recall what the EGTs were generally, but was aware that they were usually near the maximum allowable limit. He reported that the Manager had told him that other companies operated their aircraft differently, but the pilot was not aware of what those differences were.

Another pilot, who had joined the company at the same time as the accident pilot, said that he was taught by the Manager to lean the mixtures in cruise to give an EGT of 50°F rich of peak. He believed that the pilot of MZK would have used the same procedure.

A number of the company pilots interviewed during the course of the investigation commented on how the Manager of Whyalla Airlines took a close interest in the amount of fuel each aircraft consumed. The average fuel burn for a Chieftain was 140 L/hour, however, one pilot claimed the Manager said that rate could be reduced to 120 L/hour without harming the engines. The Chieftains of a competitor airline were reported to average about 160 L/hour. The Manager would regularly monitor the fuel usage of each pilot to ensure that excess fuel was not being used, and was reported to use that as an indicator to judge the performance of pilots.

None of the company pilots were aware of the engine manufacturer's recommendation against operating the engine on the lean side of peak EGT.

**Observations:**

- Although there were some differences between individuals, engine handling techniques used by Whyalla Airlines pilots were within the limits published in the Piper Chieftain Pilot's Operating Handbook.
- It was clear that company Chieftain aircraft engines were being operated lean of peak EGT on some occasions.

**Engine operating practices – other operators**

During the course of the investigation, the ATSB obtained details of the engine operating practices of twelve other operators of Piper Chieftain aircraft. They included operators of aircraft that had experienced engine failures and that are referred to in section 1.17.2 and 1.17.3 of this report. Table 5 shows the climb, cruise, and descent engine settings used by those twelve operators, as well as Whyalla Airlines (operator No. 5).

**Table 5:**
**Summary of engine settings used by 13 operators of Piper Chieftain aircraft (including Whyalla Airlines)**

| *Operator* | *Climb* | *Cruise* | *Descent* |
|---|---|---|---|
| 1. | 36"/2,400<br>Full rich unless going high | 30"/2,300<br>Lean to peak EGT, richen to 75°F ROP | 30"/2,300<br>Gradually richen mixtures to keep fuel flows up |
| 2. | 38"/2,400<br>Lean to 1350°F EGT | 31"/2,200<br>Lean to 1450°F EGT | 31"/2,200<br>Adjust mixtures as required to maintain 1450°F EGT |
| 3. | 37"/2,400<br>Lean to 32 GPH or maximum 1,475°F EGT | 30"/2,200<br>Lean to 18 GPH or maximum 1,475°F EGT | Reduce MP by 1" per 1,000 ft<br>Leave mixtures at cruise setting until ~4,000 ft when increased to 18 GPH |
| 4. | 38"/2,400<br>Lean to 30 GPH | 31"/2,250<br>Lean to peak EGT, richen 125°F | 31"/2,250<br>Leave mixtures at cruise setting |
| 5. | 36"/2,400<br>Lean to 27 GPH or maximum 1,500°F EGT | 30"/2,200<br>Lean to between peak EGTand 50°F ROP | 29"/2,200<br>Leave mixtures at cruise setting, minimum EGT 1,350°F |
| 6. | 36"/2,400<br>Full rich | 31"/2,200<br>Lean to peak EGT, richen by 100°F | Reduce MP by 1"/minute<br>Leave mixtures at cruise setting |
| 7. | 38"/2,400<br>Lean to 32 GPH or maximum 1,350°F EGT | 31"/2,200<br>Lean to 18 GPH or maximum 1,400°F EGT | 30"/2,200 |
| 8. | 35"/2,400<br>Lean to 25 GPH | 31"/2,200<br>Lean to between 50°F and 100°F ROP EGT | Reduce MP gradually<br>Leave mixtures at cruise setting, but richen to maintain minimum EGT of 1,500°F |
| 9. | 38"/2,400<br>Lean to 30 GPH | 30"/2,200<br>Lean to peak then richen by 100°F | 28"/2,200<br>Leave mixtures at cruise setting |

| | | | |
|---|---|---|---|
| 10. | 34"/2,400<br>Lean to 30 GPH | 32"/2,200<br>Lean to peak then richen by 100°F | Reduce MP gradually<br>Leave mixtures at cruise setting, EGT not below 1,350°F |
| 11. | 40"/2,400<br>Lean to 125 L/hour/ engine on digital fuel flow gauges | 30"/2,200<br>Lean to 72 L/hour/ engine on digital fuel flow gauges,<br>EGT not above 1,500°F | 30"/2,200<br>Leave mixtures at cruise setting |
| 12. | 37"/2,400<br>Full rich | 30"/2,200<br>Lean to 18 GPH, EGT not above 1,400°F | Initially at 30"/2,200, reduce MP by no more than 1" per minute to 22". Adjust mixtures to maintain minimum EGT of 1,300°F |
| 13. | 38"/2,400<br>Lean to 30 GPH or maximum 1,400°F | 32"/2,300<br>Lean to a previously determined EGT value which is 100°F ROP EGT. Peak EGT is checked approximately every 20 hours. | Initially at 32"/2,300, reduce MP by 1" every 2 minutes to arrive in circuit at 25" MP<br>Leave mixtures at cruise setting |

**Observation:**

There were significant variations between the engine handling techniques used by this group of Piper Chieftain operators, but all techniques were within the limits detailed in the Piper Chieftain Pilot's Operating Handbook.

## 1.18 Emergency procedures

### 1.18.1 Pilots Operating Handbook

Section 3, Emergency Procedures, of the Chieftain Pilot's Operating Handbook (POH) Report: 2046 issued 1 November 1976, contained information regarding the actions to be taken in the event of an engine failure. There was no information concerning a double engine failure – nor was there required to be.

Section 3.3 included an abbreviated emergency checklist for sequential actions for the critical situations of Engine Inoperative, Engine Roughness, and Engine Overheat. Section 3.5 contained amplified emergency procedures that included additional information on the section 3.3 matters to provide the pilot with a more complete understanding of the procedures. Relevant information from these sections has been reproduced at Attachment D.

### 1.18.2 Whyalla Airlines operations manual

The Whyalla Airlines operations manual provided instructions to pilots regarding actions to be taken during emergencies. The relevant sections are reproduced below.

> **A5.1 Declaration of an Emergency:** Company pilots are to notify ATC or FS and their company immediately of any emergency.

**A5.9 Flight by Twin engine aircraft on one engine**

Should one engine fail or be shut down then the pilot shall immediately notify both ATS and the company and advise next intentions. CAO 20.6

The aircraft should land at the nearest suitable aerodrome.

However, should the aircraft perform adequately on one engine, the pilot may proceed to an aerodrome suitable for repairs.

CAO 20.6.3.2

In deciding to proceed to other than the nearest suitable aerodrome, the pilot may consider some of the following,

Will the flight occur over water, life jackets may not be carried

Will the aircraft operate satisfactorily on one engine without overheating

The number of passengers in the aircraft

Is the shutdown engine available for restarting to land

Will extended flight now result in arrival after last light

Is communication with the company available, and are they able to help

## 1.19 Organisation and management

### 1.19.1 Whyalla Airlines organisational structure

Whyalla Airlines Pty Ltd was incorporated in South Australia on 22 October 1987, and issued with Air Operator's Certificate (AOC) number AD433455 on 24 January 1990. At the time of the accident the current AOC was due to expire on 30 September 2000.

The AOC permitted regular public transport (RPT) services over various routes, including Adelaide–Whyalla, as well as charter operations. The types of aircraft permitted to operate on regular public transport services and charter included the Piper Chieftain. In May 2000 the company fleet included four Piper Chieftain aircraft for RPT and charter operations.

The company had two Directors; one occupied the position of Managing Director, while the other was the Manager and Chief Pilot. Both were founding members and shareholders of the company. The Manager/Chief Pilot was heavily involved with the day to day conduct of RPT and charter flight operations, whereas the Managing Director was more involved with the business side of company activities. The Manager obtained the then CAA's approval to act as Chief Pilot on 18 June 1991, and was subsequently granted Training and Check Pilot approval from CASA on 21 March 1995.

No commercial flight operations were permitted without a company Chief Pilot approved by CASA. The Chief Pilot's responsibilities were detailed in CAO 82, and were intended to be detailed in the proposed CASR 119.

### 1.19.2 Whyalla Airlines regulatory history – June 1997 to June 2000

As part of the investigation, the regulation by CASA of Whyalla Airlines for the three years before the accident was examined.

On 29 June 1997 Piper Chieftain MZK, on a charter flight from Forrest WA to Port Augusta SA, was landed in a paddock near Wuddina SA. There were no injuries or damage. The licence of the pilot involved in the incident was suspended by CASA on

3 July 1997, and he was subsequently required to undertake an examination to demonstrate that he possessed the necessary knowledge and skills for the licences he held.

As the 29 June incident involved an RPT operator, CASA formed a special team to conduct a safety audit of the company. The team identified a number of deficiencies in the operations of Whyalla Airlines, which were discussed with the Manager/Chief Pilot of the airline at an exit meeting on 13 August 1997. Although there was no formal audit report issued, an Executive Summary was prepared on 25 August 1997. The summary noted that 35 Non-Compliance Notices, three Aircraft Survey Reports, 12 System Observation Reports, and three Risk Observation Reports were raised by the assessment team and that CASA was conducting further investigations.

On 6 September 1997 the Manager/Chief Pilot was involved in an air safety incident near Adelaide in which he failed to comply with air traffic control instructions. As a result, CASA suspended his Training and Check Pilot approval and Command Instrument Rating on 12 September 1997.

On 27 October 1997, a brief to the CASA Board titled 'Our Safety Assessment' contained the following comments regarding the competency and attitude of the Manager/Chief Pilot (emphasis in original):

> The Chief Pilot has demonstrated a reluctance to provide better administrative procedures or supervision of operations conducted under the AOC. He demonstrates a dogmatic resistance to many regulatory requirements, not because he is trying to gain financial or competitive advantage, but because he feels some form of commitment to resist "unnecessary" fettering of his ability to enjoy aviation.
>
> 'The RPT operations of the company are **of comparable safety to other LCRPT operators and better than some** despite the shortcomings of the Chief Pilot. The route structure and existing operational policies largely provide significant safety buffers, particularly during the Daylight Savings months. The operational deficiencies are not hard to fix and there are no obvious inherent flaws. Rehabilitation of the operation involves **minimal** risk.
>
> Despite the administrative recalcitrance of the Chief Pilot, he provides additional training above the industry standard and spends considerable amount on ensuring the continuing airworthiness status of his aircraft. He is well regarded by his employees and is not regarded adversely by his industry peers. In short, he cannot reasonably be assessed as anti-safety, merely anti-establishment or anti-Authority.

After successfully passing an examination, the Manager had the suspension of his Command Instrument Rating lifted on 14 November 1997. However, his Training and Check Pilot Approval remained suspended and on 26 November 1997 he was asked to show cause why that approval should not be cancelled. The suspension of the Manager's Training and Check Pilot approval was subsequently lifted on 8 December 1998. He continued to hold that approval as at 31 May 2000.

CASA cancelled the Manager's Chief Pilot approval on 26 December 1997. On 30 December 1997, Whyalla Airlines lodged an appeal to the Administrative Appeals Tribunal (AAT) to overturn that decision. On the same day, a company pilot was nominated as a replacement Chief Pilot, but was assessed by CASA to be unsuitable. A second nominee, who was also the company Maintenance Controller, was assessed as suitable and granted Chief Pilot approval by CASA on 5 January 1998 for three months. He subsequently acted in that dual role until 12 April 2000. However, according to most of the Whyalla Airlines pilots, the Manager continued to exercise a close and direct influence on the company's operations (see also section 1.19.4, Safety culture of Whyalla Airlines).

In December 1997, a member of Federal Parliament wrote to the then Minister for Transport and Regional Development expressing concerns regarding the 'fairness and genuine endeavour' with which CASA had handled its relationship with Whyalla Airlines. In response, the then Chairman of CASA proposed that Whyalla Airlines be assessed by a panel of independent experts. The proposal was discussed at the CASA Board Safety Committee on 22 January 1998 and rejected. Instead, the Committee decided that an expert team of CASA officers should conduct an inquiry to:

- Determine whether there was any reason for Whyalla Airlines to be asked to show cause why its AOC should not be varied, suspended, or cancelled;
- Assess the adequacy of internal CASA communications processes (including the actions taken by individual officers); and
- To assess the fairness and propriety of the manner in which Whyalla Airlines and its principles (sic) had been dealt with by CASA Adelaide District Office staff.

A team of four CASA officers, none of whom had any previous dealings with Whyalla Airlines, conducted the inquiry and reported their findings to the Board Safety Committee on 20 February 1998. The findings included:

- There were three matters that provided the basis upon which show cause action might be taken;
- There was reason to believe that Whyalla Airlines conducted an RPT flight in an aircraft that was authorised for only charter operations under the AOC;
- There was reason to believe that the company's management, training and supervision may be unacceptably deficient;
- There was reason to believe that the company had not completed a number of corrective actions; and
- Some information was not placed on the appropriate CASA files. This could have prejudiced the CASA decision making process regarding the Chief Pilot and training and check approvals for the Manager Whyalla Airlines. However, there was no evidence of any deliberate intent by CASA in this regard.

The inquiry found that, in the main, CASA staff had acted fairly and properly in their dealings with Whyalla Airlines. However, where procedural and administrative errors did occur, CASA could have been perceived by Whyalla Airlines management as being prejudiced.

The report noted with concern the insistence by Whyalla Airlines that they had responded in a meaningful and quick manner when safety related deficiencies were brought to their attention. It described the company's response as reactive rather than proactive and concluded that the company did not seem to appreciate how the origins of deficiencies could sometimes be traced back through the company's systems, and that had the system been different, the deficiency may have been avoided.

The inquiry recommended that Whyalla Airlines be given the opportunity to voluntarily request that their AOC be varied to include conditions to ensure that:

> Appropriate changes in the management and operational organisation of the company are introduced and that Whyalla's operations are demonstrably conducted in accordance with a well-developed and practicable program of systematically pro-active safety-oriented procedures and processes; and

> Whyalla employs or otherwise secures the services of personnel qualified to develop, implement, administer and ensure compliance with such procedures and processes as the company will be obliged to introduce.

One of the conditions was that the company became actively involved in safety management issues. This included the development of a safety management program that was to be in place for renewal of the AOC.

On 29 June 1998, the Whyalla Airlines application to the AAT against CASA's decision to cancel the former chief pilot's approval was dismissed by consent. The Manager of the company and CASA entered into an agreement, the major thrust of which, according to CASA's inquiry, was:

> …that although the Authority would not make a determination to lift the suspension of [the former Training and Check and Chief Pilot Approvals], it was prepared to give the applicant a four month period to prove to the delegate by various means set out in the agreement, that he had the requisite knowledge, knew how to apply that knowledge and had the right attitude to be a Training and Check Pilot…

In October/November 1998, the then Chief Pilot failed a series of flight proficiency tests conducted by the Training and Check Pilot under the observation of a CASA FOI. He subsequently passed the flight test on 19 November 1998. On 20 November 1998, another company pilot was approved to act as Chief Pilot on a temporary basis.

On 12 and 13 May 1999, CASA conducted an en-route inspection and a comprehensive periodic inspection of Whyalla Airlines (see also section 1.19.3). The en-route inspection revealed that Whyalla Airlines' operations were conducted in an overall satisfactory manner. The periodic inspection revealed a number of errors and oversights in record keeping.

In early June 1999, Whyalla Airlines Piper Chieftain VH-XMC was involved in two incidents within a few days when the right main landing gear cockpit indication failed. Actions taken by the company in response to these events were considered by CASA to have been appropriate.

On 30 August 1999, CASA conducted an en-route check of a flight involving MZK. The inspection concluded that all aspects of the flight were satisfactory.

Whyalla Airlines' AOC was reviewed and re-issued in September 1999. No specific inspections were undertaken for the re-issue process. Assessments were made on the basis of CASA's knowledge and experience with the operator gained during previous surveillance and general dealings with the company.

CASA conducted an airworthiness audit of Whyalla Airlines on 26 October 1999 (see also section 1.19.3). The audit revealed a number of minor deficiencies relating to three Whyalla Airlines aircraft, including MZK. The items noted against MZK were:

- incorrect compass calibration card,
- insufficient springback on engine controls,
- damaged left landing gear hydraulic hose, and
- engine control fasteners missing.

These deficiencies were satisfactorily acquitted on 7 December 1999.

On 7 January 2000, the left engine of MZK failed during a flight from Whyalla to Adelaide. The pilot (the same pilot who was involved in the subject accident) conducted a precautionary landing at Maitland, on the Yorke Peninsula. There were eight passengers on the aircraft (see further details at section 1.19.6).

On 31 January 2000, Whyalla Airlines requested that the previous Chief Pilot (i.e. the company Manager and current Training and Check Pilot and whose Chief Pilot approval had been cancelled in 1997), be approved to act as Chief Pilot during the absence of the substantive Chief Pilot. CASA advised on 17 February that this arrangement would be acceptable subject to the completion of the formal application and approval process. The formal application was received on 27 March 2000.

On 31 March 2000, the company advised CASA that they wished to nominate a person as deputy Maintenance Controller to act during periods of absence of the substantive Maintenance Controller.

On 10 April, after completing a 'desk top' assessment and an interview with the Manager (and current Training and Check Pilot), CASA approved him to act as Chief Pilot 'during notified absences of the substantive chief pilot'. CASA indicated that in the period since his chief pilot approval had been cancelled in 1997, the Manager had developed a much more positive attitude and willingness to commit to measures that would improve the safety and compliance of the airline's operations. They had conducted numerous tests, checks and observations of the Manager when he was Chief Pilot and more recently as either a trainee or an approved Training and Check Pilot when his regulatory knowledge and ability in flight planning, loading and aircraft performance were directly assessed. CASA was satisfied that, from all of its observations and involvement with the Manager, he had the motivation, ability and intention to avoid the circumstances that led to his chief pilot cancellation and the threat to the company's AOC. A CASA document noted that the approval was 'unqualified'. CASA advised that the intent of this term was that there were no specific conditions or limitations placed upon the approval.

On 13 April 2000, Whyalla Airlines advised CASA that the employment of the substantive Maintenance Controller (and Chief Pilot) had been terminated and that the former Chief Pilot had been appointed Chief Pilot in accordance with the approval of 10 April.

On the same day, CASA advised the company that it could not operate RPT services without a Maintenance Controller and that, since they no longer had a Chief Pilot, the approval for the Manager and Training and Check Pilot to act as Chief Pilot 'during notified absences of the substantive chief pilot' might have no effect. Later the same day, the person nominated as deputy Maintenance Controller received CASA approval to be Maintenance Controller for the company. On the following day, after consideration of the legal position concerning the Chief Pilot, CASA advised the company that it was satisfied that its concern over this issue had been resolved and that, since Whyalla Airlines had a Chief Pilot and Maintenance Controller in place, the company could conduct RPT flights.

On 18 April 2000, CASA conducted airworthiness audits on two Whyalla Airlines Piper Chieftain aircraft (excluding MZK), noting five minor discrepancies. None of those deficiencies were indicative of broader problems that may have contributed to the accident.

CASA had advised the airline of its intention to conduct an annual periodic inspection in May 2000. However, other urgent tasks diverted staff resources within CASA and the inspection had not occurred by the time of the accident on 31 May 2000. (Only three of the seven CASA FOI positions in Adelaide were staffed at that time.)

Following the accident, CASA undertook a joint flying operations and airworthiness periodic inspection of Whyalla Airlines' operations on 2 June 2000. The inspection noted that the company was generally compliant with regard to its flying operations. However, the company operations manual required review. Also, the workload of the chief pilot appeared excessive as he was also the operations manager and a full-time line pilot (he flew 400 hours in the year ending May 1999 and 700 in the year ending May 2000). Regarding airworthiness, both Whyalla Airlines and the maintenance organisation appeared generally compliant. The inspection team recommended a further in-depth audit.

Between 2 and 6 June 2000, CASA received some anonymous reports concerning the relationship between the Chief Pilot of Whyalla Airlines and other company pilots. In response to this information, CASA interviewed four company pilots on 6 June. Four areas of concern arose:

- One pilot stated that he sometimes did not check the fuel tank contents,
- The Chief Pilot's workload appeared excessive and he over-rode the former Chief Pilot,
- The accuracy of flight and duty time records was uncertain, and
- Turn-around times on RPT routes were too short and pilots were put under pressure by the Chief Pilot to maintain scheduled departure and arrival times and that this pressure could have an impact on safety.

A CASA assessment of the interview material noted that the comments were generally consistent between the four pilots but in most cases were not supported by examples or specific details. The assessment concluded that there was insufficient evidence at that time to show that Whyalla Airlines had breached any of the conditions of its AOC but noted that there was evidence to suggest that there may be serious problems in the company regarding:

- maintenance of accurate flight and duty records,
- compliance with the flight and duty provisions applicable to the company,
- company safety culture,
- keeping of fuel records, charter manifests, and
- flight crew instrument recency.

Between 6 and 13 June 2000, CASA undertook a special audit of Whyalla Airlines. The audit focussed on flight and duty time, checking and training records, and passenger manifests and trip reports held by the company. The audit concluded that:

- The deficiencies identified appeared to indicate a breakdown in the Chief Pilot's monitoring of the company's operations in a number of areas.
- The reasons for the breakdown were not fully examined, but the current and previous chief pilots were flying 650–700 hours per year.
- The Chief Pilot's flying rate was considered inappropriate for the chief pilot of a low capacity RPT operator the size of Whyalla Airlines, and was incompatible with allowing adequate time for exercising the full position responsibilities of chief pilot.
- For the rate of flying the Chief Pilot was doing, it was reasonable to assume that the company did not have available sufficient pilots to conduct its normal line operations. This could mean that the operator was not meeting its responsibilities under the Civil Aviation Act 1998.

- The Chief Pilot also held the positions of company Manager, Training and Check captain, and company Director. These additional conditions (sic) could be influencing a component of the chain of command that was also a determinant for the issue and maintenance of an AOC.

A review of the audit report noted that, without significant further investigation, it could not be established whether the matters amounted to deliberate falsification or were limited to deficiencies in monitoring and record keeping. It also noted that some of the issues raised were similar to those referred to when the Manager's Chief Pilot approval was cancelled in 1997, but that most of the findings related to the period that his replacement held the Chief Pilot position (from 1997 to 12 April 2000) – a situation that no longer existed.

On 10 June 2000, CASA suspended Whyalla Airlines' AOC pending further investigation of the areas of concern (except the fuel issue) that arose from the pilot interviews. The AOC remained suspended at the time of publication of this report.

### 1.19.3 CASA surveillance

#### Aviation Safety Surveillance Program (ASSP)

Certificate holders are required to comply with Australia's aviation safety regulatory requirements. CASA developed the Aviation Safety Surveillance Program (ASSP) to determine whether operators and maintenance organisations were meeting those statutory requirements. The ASSP was undertaken to provide an assessment of the aviation industry's safety levels, identify breaches of the regulations and monitor action to correct non-compliance. CASA applied different surveillance parameters, depending on the nature, size and complexity of an organisation.

The responsibility for surveillance planning, to cover those operators, personnel and activities for which a particular office had responsibility, lay with the relevant area and airline team leaders (formerly district office managers). The surveillance planning process was designed to assist in identifying those operators that had a relatively high safety risk and as such, to assist in determining local surveillance priorities. In addition, operator profile sheets, including information such as revenue hours, the type of activity, and class of products, were to be used to determine the frequency of specific ASSP tasks. The investigation did not find evidence that any of those surveillance planning activities had been completed for Whyalla Airlines during the development of the 1999–2000 surveillance program.

#### Planned vs achieved surveillance prior to the accident

The investigation compared actual surveillance achieved against planned surveillance for the 13 month period prior to the accident. Table 6 below details the percentage of planned surveillance achieved for that period.

**Table 6:**
**CASA surveillance of Whyalla Airlines May 1999 to May 2000**

| *Month* | *Flying Operations* | | | *Airworthiness* | | |
|---|---|---|---|---|---|---|
| | *Planned* | *Achieved* | *Per cent* | *Planned* | *Achieved* | *Per cent* |
| May 99 | 4* | 1 (*4) | 25% (*100%) | 3 | 0 | 0% |
| Jun 99 | 4 | 0 | 0% | 0 | 0 | N/A |
| Jul 99 | 1 | 0 | 0% | 0 | 0 | N/A |
| Aug 99 | 8* | 2 (*7) | 25% (*87.5%) | 0 | 0 | N/A |
| Sep 99 | 1 | 0 | 0% | 0 | 0 | N/A |
| Oct 99 | 3 | 1 | 33% | 7 | 7 | 100% |
| Nov 99 | 0 | 0 | N/A | 0 | 0 | N/A |
| Dec 99 | 3 | 0 | 0% | 0 | 0 | N/A |
| Jan 00 | 1 | 0 | 0% | 0 | 0 | N/A |
| Feb 00 | 6 | 0 | 0% | 0 | 0 | N/A |
| Mar 00 | 0 | 0 | N/A | 0 | 0 | N/A |
| Apr 00 | 6 | 0 | 0% | 3 | 3 | 100% |
| May 00 | 1 | 0 | 0% | 0 | 0 | N/A |
| **Total** | **38** | **4 (*12)** | **10.5% (*31.6%)** | **13** | **10** | **76.9%** |

* CASA advised that an ASSP 175/176 Periodic Inspection conducted in May 1999 covered three of the programmed ASSP tasks for May 1999 and five of the programmed ASSP tasks for August 1999.

The formulae for programming ASSP detailed in the manual took no account of staffing levels which would have been required to complete the program or which were available in the various offices. Indeed, in many cases Area Offices would not have been able to complete their surveillance programs, prepared in this way, even if they were fully staffed. In 1999 and 2000, however, the Adelaide Office had fewer than 50% of its complement of flying operations staff and so the program of surveillance set down for flying operations in general, and for the Whyalla Airlines AOC in particular, was never capable of completion. As a result, in order to manage the process as effectively as possible, tasks that were scheduled for Whyalla Airlines for a particular month were commonly done in conjunction with other tasks at a different time.

Problems in achieving surveillance targets at the time of the accident were not restricted to Whyalla Airlines or to the Adelaide district office. Deficiencies in CASA's surveillance planning and achievement during the same period are already documented in two audit reports compiled in 1999; one by the Australian National Audit Office and the other by the International Civil Aviation Organisation.

### Surveillance outcomes

In addition to the en-route inspection conducted in May 1999 (ASSP 125), the surveillance records also showed that a comprehensive periodic inspection (ASSP 175/176) was undertaken. CASA advised that the ASSP Manual current at the time did not require a single periodic inspection (ASSP 175/176) for low capacity RPT operators such as Whyalla Airlines. Instead, the various elements of a periodic inspection were set out in separate ASSP tasks such as the Operator Port Inspection (ASSP 140), Operations Records Inspection (ASSP 150), Operations Manual Inspection (ASSP 155), Operations Library Inspection (ASSP 156), and Training and Checking Manual Inspection (ASSP 157). These inspections were programmed individually and usually at different times. However, because of the surveillance resource limitations existing at the time, the working practice was to combine all or most of these inspections into a single exercise which was most appropriately conducted and recorded as the periodic inspection (ASSP 175/176). The en-route inspection revealed that Whyalla Airlines operations were conducted in an overall satisfactory manner. The periodic inspection revealed a number of errors and oversights in record keeping. The inspection also led to discussion between CASA inspectors and airline management on the quality of internal audit processes. The outcomes of the inspection were not formally recorded in ASSP because of staffing problems but were known to the team leaders and the Area Manager.

The results of ASSP 125 (en-route check) and ASSP 165 (ramp check) conducted in August 1999 were satisfactory. An ASSP 165 check conducted on 26 October 1999 noted a minor discrepancy regarding the recording of a defect. The airworthiness inspections conducted in October 1999 revealed a number of minor deficiencies relating to three Whyalla Airlines aircraft, including MZK (see section 1.19.2). However, none of those were likely to have contributed to the accident, and all were satisfactorily acquitted on 7 December 1999. The airworthiness surveillance conducted in April 2000 identified a number of minor deficiencies with two of Whyalla Airlines' Chieftain aircraft (not MZK) (see section 1.19.2). None of those deficiencies were indicative of broader problems that may have contributed to the accident.

Whyalla Airlines' AOC was reviewed and re-issued in September 1999. No specific inspections were undertaken for the re-issue process. Assessments were made on the basis of CASA's knowledge and experience with the operator gained during previous surveillance and general dealings with the company. CASA had advised the airline of its intention to conduct an annual periodic inspection in May 2000. However, other urgent tasks diverted staff resources within CASA and the inspection was postponed.

### CASA's new approach to surveillance

In mid-1998 following a period of developmental work, CASA began introducing a systems-based auditing process to replace the product–based approach which was being applied at the time. In early 2000, district offices were required to complete a safety trend indicator (STI) questionnaire as an initial step towards the introduction of the new surveillance system. The STI was designed to systematically assess the functioning of all certificate holders throughout the country. That initiative was seen as necessary, not only to fulfil CASA's obligation to monitor safety, but also to enable surveillance resources to be more efficiently targeted. The only evidence that an STI was carried out on Whyalla Airlines prior to the accident was an undated STI sheet which, based on its chronological position on a file, suggested that it was completed some time prior to mid May 2000. The data from this sheet was not entered into CASA's IT system.

The surveillance planned for a low capacity RPT operator like Whyalla Airlines under CASA's new program is now a three yearly re-certification audit (in line with the 3-year AOC cycle) and an annual visit. Other (risk-based) audits may be conducted as a result of an identified risk. The new program also focuses on system/organisation based auditing rather than product/task based audits (as in the past).

### 1.19.4 Safety culture

Human and organisational factors play a vital role in the safety of flying operations. As improvements in technology have led to significant decreases in accidents and incidents caused by mechanical or equipment failure, attention has shifted to the role of human error and systemic or organisational deficiencies in accidents and incidents.

One description that encapsulates much of the combined effect of the human and organisational aspects of a particular organisation is the concept of 'safety culture'.

In simple terms, safety culture can be described as 'the way we do things around here'. It is reflected in the set of shared beliefs held by people in the organisation that are borne out by the actions of management and staff at all levels. Safety culture can have a very significant effect on the safety of flight operations. In fact, differences in safety culture are recognised by the international aviation community as contributing significantly to the variation in accident rates between different air transport operators[31].

A good safety culture is fostered by an environment in which:

- Senior management demonstrates a strong commitment to safety and sets high standards,
- Standards are maintained throughout the company,
- Potential hazards and actual occurrences are reported in a timely manner, and
- The company acts on information from hazard and occurrence reports in a constructive way.

The role of company senior management, both formally and informally, is crucial in promoting a good safety culture. Employees gain an awareness of the standards expected of them not only by the words, but also by the deeds, of company management. If employees see management condoning or indirectly promoting unsafe practices, then they will tend to act in the same way.

A good safety culture depends on people knowing the risks of their operation, and expecting that when they report hazards to management, appropriate action will be taken by the company. Ideally, all accidents and incidents will be seen as an opportunity for the organisation to learn from mistakes in the past to ensure a safer operation in the future.

When organisations with a poor safety culture respond to an accident or incident, they are likely to focus on the individual, rather than considering that the occurrence may indicate a more general problem within the company. However, focussing on more general human and organisational factors does not mean that breaking the rules is

31 Reason J, 1997. *Managing the Risks of Organizational Accidents*, Ashgate:UK.

condoned. Instead, it denotes a 'just culture', where an atmosphere of trust is developed and people are encouraged, even rewarded, for providing essential safety-related information. At the same time, a clear line is drawn between acceptable and unacceptable practices.

Best practice in the air transport industry today, even for small operators, is for the philosophy, policies and procedures underlying a good safety culture to be formalised in a flight safety program. The importance of such programs is recognised throughout the aviation industry world–wide.

In May 2000, the Civil Aviation Safety Authority (CASA) issued a Discussion Paper, *Proposed Civil Aviation Safety Regulation (CASR) Part 119, Air Operator Certification – Commercial Air Transport*. The document summarised, from a safety perspective, the most significant rule enhancements proposed. One of the requirements was that 'all operators must introduce a flight safety program'. The paper stated that 'imposing these new requirements will inculcate a safety ethos throughout an operator's organisation, enhance aviation safety management and give effect to the... [relevant ICAO requirement].'

#### Management and safety culture

In any airline operation, even a small regional airline, there are a number of distinct roles and responsibilities essential for the safe and efficient operation of the company. At the highest level, the Company Board or Owner/Director(s) is crucial in determining the overall ethos and operational culture of the company. A Board or an Owner/Director can exert a significant influence on the day to day operations of the company. This can occur directly, through the development of policy and procedures, as well as indirectly, through the company culture that management promotes.

The important role that company management plays in the safety of aviation operations is recognised in the *Civil Aviation Act 1988*. Section 28BE places the responsibility for safety management on the holder of the Air Operator Certificate (AOC), associated directors and managers.

Under the direction of the Board or Owner/Director, the senior management personnel of the company who implement company policy and procedures are the next link in the chain of responsibility. These key personnel usually include:

- The senior executive (general manager/manager), responsible for the overall management of the company, including operations, administration and finance.
- The Chief Pilot, responsible for flying operations.
- The Maintenance Controller, responsible for aircraft maintenance.
- The Check and Training Captain, responsible for training and checking company line pilots.

It is essential that these senior personnel have the appropriate background, experience, training, and personal qualities necessary for them to successfully discharge their duties. The roles and responsibilities of these positions were addressed in the CAOs and included in the company operations manual.

In an ideal situation, each of these senior positions should be held by a different individual. This would ensure that there was sufficient breadth and depth of experience among senior management to provide the safeguards necessary for safe operations. In contrast, if one person has control of most, or all, or the critical functions of the organisation, then the checks and balances that follow from having more than one point of view as part of the decision making process, can be lost.

In some small air transport companies, one person may largely be responsible for all aspects of day to day operations. For example, the Owner/Manager may also be the Chief Pilot and the Check and Training Captain, and the remainder of the staff mainly young and inexperienced line pilots. In such an environment, the safety of flying operations will rest largely in the hands of one individual. That is not a robust or resilient system as it can be more easily influenced by factors such as a dominant personality, commercial pressures, or excessive workload.

The problem can also be exacerbated in some small organisations that do not have good systems in place. To a certain extent, people and systems act as simultaneous and mutually reinforcing defences. Adequate experienced staff, with good personal qualities and following good work systems and practices, will mitigate the risks that the organisation faces.

Lower pilot experience levels and high turnover rates are, to a large extent, inherent characteristics of low capacity RPT operations. The most appropriate means of maximising the standard of safety within their operations is to have systems in place to maintain appropriate standards and practices across the organisation. The establishment of a good safety culture is an important component of this process.

### NTSB Commuter Airline Safety Study (1994)

In a 1994 study of Commuter Airlines Safety, the US National Transportation Safety Board made the following relevant comments regarding organisational structure and management responsibility in commuter airlines:

> The Safety Board's survey of commuter air carriers conducted for the present study revealed a wide variation in management structure and responsibility across the airlines, and all 21 air carriers surveyed had their director of operations and chief pilot performing duties necessary for the day-to-day operation of the airline in addition to those listed in the flight operations manuals. For example, most of the chief pilots who were interviewed for the survey reported that they flew the line, at least on a part-time basis, and had managerial duties in other areas, including duties related to pilot training, scheduling flight checks and maintenance, resolving issues among the pilots, updating and distributing manuals, safety meetings, ramp coordination, and promoting operational standardization.
>
> The Safety Board acknowledges that the director of operations and chief pilot should maintain flight currency to be effective in their positions. However, airline managers should be given sufficient time and support to perform their critical tasks related to the company's flight safety program.
>
> Management's role in air carrier safety was also a topic of discussion at the 1994 public forum. Participants commented that management positions of director of operations, chief pilot, and director of maintenance are vital to the safe operation of a commuter airline, and participants expressed concern regarding the multiple responsibilities of the positions. In addition, a representative of a major airline reported that management functions of the commuter airline and how the functions are apportioned are examined during the major airline's audit of its code-sharing partner[32].

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32 NTSB, 1994. NTSB Commuter Airline Safety Study. National Transportation Safety Board: Arlington, VA.

### 1.19.5 The safety culture of Whyalla Airlines

#### Company safety program

One of the conditions imposed on Whyalla Airlines by CASA in May 1998 was that the company establish a safety program (see section 1.19.2). The Whyalla Airlines safety program was outlined in the company operations manual (see Attachment E), and included the designated position of 'Safety Officer'. The manual stated that the Safety Officer was not to hold positions such as Chief Pilot or Maintenance Controller, and that the person 'display previous external experience that would benefit the role'. The Operations Manual also stated that safety meetings were to be held each month.

Although safety meetings had been held regularly when the program was first introduced, meetings had become less frequent, with only three held in the 18 months preceding the accident. The last meeting prior to the accident on 31 May was held on 8 March 2000. Because of the high pilot turnover rate within the company, there had been four different safety officers since the program began.

The ATSB obtained copies of the minutes from safety meetings held from the beginning of the program through to the last meeting, held shortly after the accident on 31 May 2000. A review of the meeting minutes suggested that over time, the focus of the meetings had moved from discussing safety issues only, to discussing more general company issues. According to the minutes of the meeting held on 8 March 2000 (the last meeting prior to MZK's accident), the issues discussed were:

- Provision of a baggage trolley at Wudinna 'to assist pilots with efficient movement of baggage'.
- Installation of a park brake on the baggage trolley at Whyalla to reduce the likelihood of aircraft damage when loading in strong winds.
- Removal of sharp edges from the Adelaide baggage trolley.
- Providing a passenger questionnaire to target areas of service that require improvement.
- Installing a radio in the Chief Pilot/Manager's office to enable efficient communication between pilots and management during flight.
- A requirement that all pilots obtain through the Chief Pilot/Manager an embroidered shirt and tie that must be worn on RPT flights.
- The appointment of a new safety officer.
- A reminder that safety reports should be handed in on time.
- Discussion of the engine failure incident involving MZK on 7 January 2000.

During the investigation, discussions were held with management and pilots regarding the company safety program. The Managing Director and the Manager said that they were 'absolutely committed' to the safety program: 'Whyalla Airlines was committed to a high standard of safety as evidenced by its commitment to an expensive maintenance program to a standard well beyond other operators'. They added that the importance the Manager placed on correct fuel management to achieve a safe flight was also indicative of the company's attitude to safety. The Manager said that the company program was loosely based on the BASI 'INDICATE' Program. The original INDICATE database software had been installed on a computer but the company considered it to be clumsy and not very pilot friendly and it had been replaced by a paper–file system[33].

The Manager reported that minutes should have been produced for all of the safety meetings and held on file by the safety officer. The Manager said that the safety program had stagnated and that this was due in part to the high turnover of pilots within the company. He said that it was not always possible to find a pilot who wanted the role. He expressed the view that the time and resources necessary to sustain a safety program could be significant compared with the benefits it provided.

The Manager indicated that he dealt with all air safety incidents that were reported by company pilots and the safety officer also held a copy of each report. The reports were also sent to the ATSB and CASA. The Manager did not believe that company pilots should have felt any concern about a negative reaction from management when they reported an incident.

With regard to specific issues, he made the following comments:

- At times it was difficult to adhere to flight schedules in the company's RPT operations. The late arrival of passengers was an ongoing problem. He considered that turn-around times were adequate and said that pilots had been told that it was acceptable if they were unable to maintain flight schedules.
- There was not, in his opinion, a significant problem regarding flight and duty times. He considered that the line pilots did not appear to have concerns in that area.
- Pilots worked for the company under a loose agreement where they were paid a set amount per day. They were usually paid for working 6 days per week even though they may work only 5 days on occasions. There was no formal employment contract for the pilots and none of those interviewed raised employment contracts as an area of concern.

The views of company pilots regarding the company safety culture and the effectiveness of the company safety program varied. Positive comments included:

- Most pilots felt that for the most part, air safety incidents were reported to the company and the ATSB.
- Most pilots considered that the company's aircraft were always well maintained.
- One pilot said that the company was 'really big' on safety.
- New information relevant to the company's operations was circulated to pilots under a cover sheet containing all pilots names.
- One pilot said that the Managing Director was very committed to the safety program and had stated that it should be run 'seriously'.

Other comments about the company safety culture and safety program included:

- Most pilots felt that the Managing Director was much more committed to the safety officer role than the Manager, who they said considered that safety meetings were 'a waste of time'.
- Most pilots thought that if CASA did not require a company safety program, there was unlikely to have been one established.

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33 A revised version of INDICATE was developed by the ATSB in January 2001 and is available free on the ATSB website.

- Most pilots considered that turn-around times was the most significant matter discussed at safety meetings, but said that management never addressed the issue.
- The amount of feedback that pilots received from the Manager regarding air safety incidents that involved the company was poor in many instances, and inconsistent overall.
- It was reported that the current safety officer was not paid any additional sum for occupying the position, whereas a previous safety officer had been paid for those duties.
- There was no training provided for the safety officer, although it had been intended that this would occur, high workload and other issues resulted in no formal training taking place.
- One pilot indicated that any incumbent of the safety officer position would require a strong personality to institute changes to company operations.
- It was suggested that while the Manager attended safety meetings, he did not actively participate in the discussions.
- There were no formal procedures or guidelines provided regarding the handover of the safety officer's role from one individual to another.

#### Operational safety concerns

A number of Whyalla Airlines pilots expressed concerns about operational safety issues that they felt had not been addressed by management, even though some of the issues had been raised at safety meetings:

- One pilot claimed that in some instances, if he was to maintain the flight schedule, he did not have sufficient time to properly conduct the pre-flight checks. Another pilot also believed that the turn-around times could easily cause an important check to be overlooked.
- Some pilots stated that the Manager had tried to influence the way that they operated in a manner that was potentially detrimental to flight safety. Examples included:
  - One pilot claimed that he was told by the Manager to depart from Whyalla twenty minutes before first light in an aircraft that did not have a fully serviceable artificial horizon. The pilot delayed his departure until daylight because he was not willing to risk flying the aircraft without a primary flight instrument.
  - Some pilots claimed that the Manager became abusive to pilots who were running late for an RPT flight departure.
  - The Manager's attitude appeared to be that the best pilots were those who used the least amount of fuel.

#### Pilot turnover

Whyalla Airlines had experienced an ongoing turnover of pilots in the twelve to eighteen months preceding the accident. During that time five of the usual complement of six pilots had left the company and been replaced. The accident pilot, and another pilot who had started with Whyalla Airlines at the same time, had been with the company for seventeen months and were the longest serving line pilots at the time of the accident.

Most company pilots felt that flying for Whyalla Airlines was a good stepping stone towards employment with one of the larger RPT operators, which was commonly regarded as their career goal. This was not an unusual situation in the aviation industry. Many low capacity RPT operators experience high pilot turnover rates.

The Manager said that the company had identified this high turnover as a potential problem and was concerned that it had too many junior pilots, particularly after the departure of the previous Chief Pilot. The Manager indicated that he had been planning to restructure the company in an attempt to employ more experienced pilots.

#### Management duties and responsibilities – Whyalla Airlines

The Whyalla Airlines organisational structure, and the duties and responsibilities of the Chief Pilot, supervisory pilots, training pilots, and check pilots are shown at Attachment F.

### 1.19.6 Relationship between the manager and the pilot of MZK

Following the accident there were reports from within and outside the company suggesting that the actions of the pilot of MZK may have been adversely influenced by the Manager/Chief Pilot of Whyalla Airlines. As a normal part of the investigation those reports were examined.

The Manager said that he had been critical of the pilot during his initial training with the company. He said that this was the way he treated all pilots new to the company and was aimed at achieving improvement in areas where deficiencies had been noted. Some individuals accepted criticism better than others did and there may have been a conflict between his personality and that of the pilot of MZK. However, the Manager believed that the pilot was the type who would stand up for his own opinion. He also believed that, on the accident flight, the pilot would have returned to Adelaide if he had encountered engine problems.

On 11 June 1999, the pilot was in command of Chieftain VH-XMC when it had a landing gear problem on approach to Adelaide Airport. The pilot landed the aircraft without damage but was subsequently 'grounded' by the Manager following a complaint from a passenger to the airline that the pilot had not briefed the passengers on the emergency. The Manager said that he had taken the pilot off RPT flying for one month and told him that his employment might be terminated. (Others reported that the Manager had told the pilot he was sacked and had one month to find another job.) During that period, the pilot continued work as a company charter pilot and satisfactorily completed emergency procedures training and a comprehensive instrument rating renewal. The Manager then reinstated the pilot to RPT flight duties. The only specific issues regarding the pilot's handling of the incident that the Manager had been able to identify was that the pilot had apparently not briefed the passengers properly about the emergency and had not given sufficient consideration to fuel management in the event that he had to divert. The failure of some passengers to hear the emergency briefing was reportedly due to a speaker in the rear of the cabin not operating.

On 7 January 2000, the pilot was in command of MZK on a scheduled flight from Cleve to Adelaide when the left engine sustained a catastrophic mechanical failure. The pilot diverted to Maitland, SA, and made a successful emergency landing. The Manager said that he had initially asked the pilot why he had not continued on to Adelaide, where maintenance was available, but the pilot had said that the aircraft was too badly damaged. There were reports that the Manager/Chief Pilot had been aggressive and abusive towards the pilot for landing at Maitland instead of continuing to Adelaide. However, the Manager reported that when he saw the damage that had been caused, he had complimented the pilot on his decision to land at Maitland. The Manager/Chief Pilot said that, because there had been no complaints from any of the passengers (in fact, passengers had praised the pilot's handling of the situation), there was no specific action taken by the company against the pilot. The incident was discussed at a safety meeting and the company agreed that the pilot had acted appropriately in the circumstances.

It was reported that activities were rushed during the turn-around of MZK at Adelaide before departure for Whyalla on the accident flight. The Manager of Whyalla Airlines was assisting the pilot of MZK with checking passengers and baggage. He then loaded the aircraft while the pilot completed the aircraft weight and balance calculations. The Manager said that the pilot appeared in good spirits before the flight. Others who were there did not report any unusual activity between the Manager and the pilot although one individual thought there were some signs of tension present.

**Observation:**

Information concerning Whyalla Airline's safety program, and the views of management and line pilots, allowed a number of conclusions to be drawn concerning the company's safety culture:

- The small size of Whyalla Airlines and the low experience level of line pilots placed great importance on the role of owner/managers in the company's safety culture.
- The size and organisational structure of the company resulted in one or two persons performing most key functions, thus increasing the risk of decisions being made without proper consideration of all aspects.
- The standard of maintenance of company aircraft and the standard of endorsement training given to pilots enhanced the safety culture of the company.
- The 'shoot the messenger' type response of the Manager to at least some air safety incidents was a negative aspect of the safety culture.
- The experience level of line pilots made it difficult for Whyalla Airlines to always appoint an appropriately qualified and experienced pilot as safety officer.
- The lack of recognition by the company of the safety officer position, either by additional pay or some other means, detracted from the importance of the position within the company.
- The decreasing frequency of safety meetings and the failure of the company to address what some pilots considered to be important safety issues, such as turnaround times, detracted from the safety culture of the company.
- Some of the NTSB Commuter Airlines Safety Study comments regarding organisational structure and multiple responsibilities for management personnel were applicable to and reflected in Whyalla Airlines.

## 1.20 Flight and duty times

To minimise the likelihood of fatigue influencing crew performance CASA prescribes limits on the flight and duty times for pilots. CAO 48 provided the following requirements:

> 1.13 – An operator shall not roster a pilot to fly when completion of the flight will result in the pilot exceeding 90 hours of duty of any nature associated with his employment in each fortnight standing alone. For the purposes of this paragraph, duties associated with a pilot's employment include reserve time at the airport, tours of duty, dead head transportation, administrative duties and all forms of ground training. The operator shall designate the day on which the first of the fortnightly periods shall start.

The Manager of Whyalla Airlines indicated that dead head transportation had not always been included in the calculations of pilots' flight and duty times. Also, the periods that pilots assisted with tasks such as baggage and ticketing during aircraft turn-arounds was also not recorded as flight and duty time. In its audit of the company after the accident (see 1.19.2) CASA found inaccuracies in flight and duty records.

The question of which activities should be included in the calculation of flight and duty times was identified in ATSB Investigation Report 199904538 and resulted in a safety recommendation (R20000235) being issued to CASA concerning the types of duties that should be included in flight and duty time calculations.

The flight and duty times for the pilot of MZK are detailed in section 1.5.3.

# 2 ANALYSIS

## 2.1 Engine reliability

The engine failures in MZK were dependent failures. That is, the failure of the right engine was a consequence of the change in engine operating conditions of that engine created by the response to the initial (left) engine failure. Of the other engine failure events examined as part of the investigation, in each case, the flight was safely completed on the other engine. On that basis, the risk of two engines experiencing independent mechanical failure during flight does not appear to have increased.

A significant aspect of the engine failure analysis was that the accumulation of lead oxybromide deposits in the left engine of MZK was also a feature in at least eight other Lycoming IO-540 or TIO-540 engines that had failed, and in two Teledyne Continental Motors TIO-520 engines that had experienced defects. Of further significance was the strong association between engine fuel leaning practices and the creation of lead oxybromide deposits. Historical material indicated that the issues of engine reliability and the formation and management of deposits were not new. However, the wide variation in fuel leaning techniques among Australian operators of the engines, along with the incidence of lead oxybromide deposits observed in the engines that were examined, indicated a deficiency in combustion chamber deposit management, at least among some of the operators of high–powered piston engine aircraft in Australia. It raises the question as to whether the level of reliability of these engines is meeting the expectations expressed in the airworthiness standards (see section 4, safety recommendation R20010257).

## 2.2 The accident involving VH-MZK

With the exception of the engines, there were no faults apparent in the aircraft or its systems that might have contributed to the accident.

The reasons for the two engine failures were presented in section 1.17.

The absence of any flight data or cockpit voice recording from the flight inhibited efforts to accurately reconstruct the sequence of events and flight path that led to the accident. Substantial investigation effort was directed towards analysing recorded radar and voice transmission data. Information regarding the aircraft's altitude, track and groundspeed was obtained from radar data for the period the aircraft was within radar coverage. Audio analysis of voice transmissions from MZK provided snapshots of engine operation during climb from Adelaide (2,400 RPM), initial cruise (2,200 RPM), and at commencement of descent (2,400 RPM). As a result of the limited data available, only some events relating to the accident sequence could be determined.

The failure of the left engine was, in effect, pre-determined by the initiation of the thermal cracks some 50 plus flights before the accident. The malfunction of the right engine developed over a brief period of detonation at an engine power setting well above the normal cruise setting. (The RPM and manifold pressure setting used by Whyalla Airlines during normal cruise was not within the envelope of engine operation where detonation could occur.) The fact that there was oil remaining in the engine when it ceased operating indicated that the piston was holed late in the accident flight. It follows, therefore, that the failure of the right engine was a function of the response to the failure of the left engine. That is, the double engine failure was a dependent failure.

Combining the engine failure analysis with information obtained from recorded radar and audio data provided a likely sequence of events (see table 7 and fig. 53). Other alternatives considered did not fit the known data.

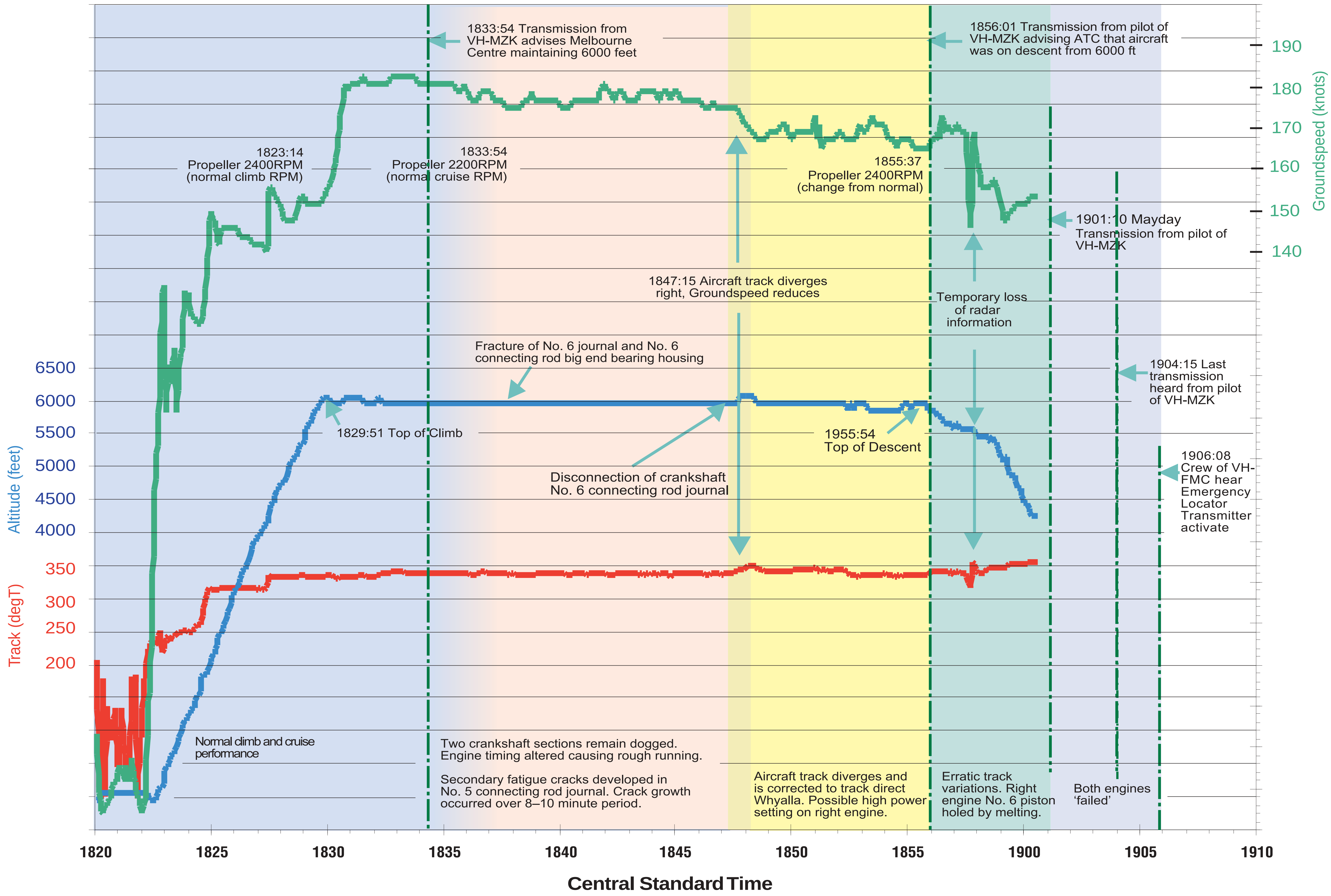
**Table 7:**
**Likely sequence of events**

| *Time* | *VH-MZK* | *Left engine* | *Right engine* |
|---|---|---|---|
| Approximately 50 flights before the accident flight | | Thermal cracks created in No. 6 connecting rod crankshaft journal. | |
| 31 May 2000<br>1823:14 CST | Aircraft on climb after departing Adelaide on accident flight | Analysis of audio signal from MZK indicated propeller RPM of 2,400 (normal climb setting).<br>• The aircraft's rate of climb (approximately 850 ft per minute) was consistent with normal two-engine operation. | |
| 1833:54 | Aircraft stabilised in cruise flight at 6,000 ft, 181 kts groundspeed. | Analysis of audio signal from MZK indicated propeller RPM of 2,200 (normal cruise setting).<br>• The estimated cruise TAS (161 kts) was consistent with normal two-engine operation for Whyalla Airline's cruise power settings. | |
| 1837:41 | Initial indication of aircraft speed and track variations. | Possible time of fracture of No.6 connecting rod crankshaft journal.<br>• The two crankshaft sections remained dogged and continued to rotate.<br>• Relative movement between the journal fracture surfaces would have altered engine timing, causing rough running and loss of performance. | |
| 1837:41 to 1847:15 | | Secondary fatigue cracks develop in No.5 connecting rod crankshaft journal and No.3 main bearing journal.<br>• Resulted from increased flexing of crankshaft following fracture of No 6 journal.<br>• Crack growth occurred over a period of 8 to 10 minutes after No 6 connecting rod crank-shaft journal fractured. | Likely pilot response at some time during this period was to increase power on right engine to compensate for decrease in performance.<br>• No audio information available regarding propeller RPM at this time.<br>• Aircraft maintained altitude and achieved an average groundspeed of about 167 kts.<br>• This would have required signfi cant power increase on right engine. |

| | | | |
|---|---|---|---|
| 1847:15 – 1855.54 (top of descent) | Aircraft diverged right of the direct track to Whyalla.<br>• Possible consequence of pilot reaction to left engine failure | Possible time of fracture of No.6 connecting rod big end housing.<br>• Fracture occurred while engine was rotating at speed.<br>• Engine ceased operating immediately. | Higher power operation led to combustion chamber overheating, affecting detonation limits for power setting.<br>• Possible that some level of detonation was occurring in all cylinders.<br>• Heavy detonation has been noted to cause rapid heating of components.<br>• Rate has exceeded 1 deg F per sec. Heating from 400˚F to 1,000˚F could take less than 10 minutes. |
| 1852:30 | Apparent aircraft track correction back towards GIBON | | |
| 1855:43 | Pilot acknowledged ATC advice that radar services were terminated. | | Analysis of audio signal from MZK indicated propeller RPM of 2,400.<br>• Normal cruise RPM was 2,200 |
| 1855:54 | Aircraft commenced descent. Pilot reported on descent at 1856:01 | | |
| 1855:43 – 1901:10 | Erratic track variations evident from radar data.<br>Initial rate of descent approx. 400 ft per minute. Groundspeed varied between 165 and 172 kts. | | No.6 piston holed by melting. Engine operation restricted to 5 cylinders.<br>• Piston damage resulted in crankcase pressurisation.<br>• Some, but not all, engine lubricating oil vented overboard.<br>• Indicates piston was holed late in accident flight.<br>• Piston hole likely to affect the intake pressures and turbocharger operation in a cyclic manner.<br>• Likely engine power surging over which the pilot would have no control. |
| 1858:30 | Rate of descent increased to approx. 650 ft per minute | | |

| Time | VH-MZK | Left engine | Right engine |
|---|---|---|---|
| 1900:19 | Last valid radar data. Aircraft at 4,260 ft, ground-speed 153 kts. | | |
| 1901:10 | MAYDAY transmission.<br><br>Landing gear unsafe horn had activated.<br><br>• Indicated one or both throttle levers at/below 12 inches MAP position. | | |
| 1902:49 | Stall warning horn had activated.<br><br>• Aircraft speed between 77 and 83 kts (zero flaps) | | |
| 1904:15 | Last recorded radio transmission | | |
| Approx 1906:38 | Crew of FMC hear ELT<br><br>• ELT activated by impact forces. | | |

**Figure 53:**
**VH-MZK sequence of events based on recorded radar and audio data and engine failure analysis**



In explanation and amplification of the likely sequence of events, the following points are relevant:

- A change in wind speed and/or direction could have contributed to the deterioration in the aircraft's groundspeed that occurred about 23 minutes after departure. However, wind information from the Bureau of Meteorology plus radar data for various flights before and after the accident flight indicated that there was no significant variation in wind speed and/or direction. Engine malfunction was, therefore, a far more likely explanation for the groundspeed deterioration.
- Radar data suggested that altitude hold was engaged for the majority of the cruise segment. It is likely that at some stage during the sequence the autopilot became (or was deliberately) disengaged and that, consequently, the pilot was manually flying the aircraft. In asymmetric flight, at night, with changing engine operating conditions and indications, the pilot's workload in flying the aircraft would have been very high.
- The left engine would probably have exhibited rough running and elevated operating temperatures. The open position of the engine cowl flaps may indicate that the pilot was responding to the malfunction. The pilot may have deliberately shut down the engine and feathered the propeller when vibration and other signs became severe enough. Alternatively, the engine would have ceased operating of its own accord when the dogging between the fracture surfaces was lost completely. The propeller then would have automatically feathered.
- Other than the audio indication of 2,400 RPM just before the descent was initiated, and in the absence of conclusive information regarding the time the left engine ceased operating, there was no other information available regarding the conditions under which the right engine was operated. Additional information regarding issues such as:
  - the maximum power that was set on the right engine and the timeframe over which that applied,
  - whether the power increase was made incrementally or as a single step, and
  - the operating temperatures reached and their rate of increase, would have enabled a better understanding of the pilot's actions and responses regarding the right engine operation. The open cowl flaps may indicate an attempt by the pilot to respond to the right engine overheating and malfunction.
- The location at the top of the centre instrument panel in the cockpit of the engine RPM, MAP, EGT and fuel flow gauges meant that they were comparatively easily scanned by the pilot as he flew the aircraft by reference to the primary flight instruments. The combined cylinder head temperature, oil temperature, and oil pressure gauges (fig. 3, page 13), however, were located in the lower right instrument panel (fig. 6, page 14). The pilot would have had to turn his head to monitor these gauges. Accurate reading may have required him to lean to his right. The right engine gauges, being further away from the pilot, would have been more difficult to see and read accurately. It is likely that any change in gauge indication would not be easily detected in the pilot's peripheral vision if his attention was focused on the flight or engine performance instruments and/or possible passenger concerns after the problem with the left engine became apparent. It is possible, also, that vibration caused by the left engine before it ceased operating would have made interpretation of instrument indications difficult. The difference in

presentation of the left and right triplex gauges (see fig. 6) may have added to difficulties with interpretation of instrument indications.

- The aircraft manufacturer advised that the optimum glide speed (the best lift/drag ratio) at 4,200ft and an aircraft weight of 6,750 lb, with two engines feathered, was 126 kts. This would result in a descent rate of about 1,000 ft per minute. With one propeller feathered and one windmilling, the descent rate would be substantially greater. The last recorded groundspeed of the aircraft was 153 kts (approximately 133 kts TAS). The rate of descent of the aircraft just before radar contact was lost was approximately 650 ft per minute. This suggests that the right engine was operating and providing thrust at that time. The unfeathered position of the propeller blades at impact suggests that the right engine may have continued to operate at reduced power until the aircraft struck the water.
- The MAYDAY transmission was the first indication from the pilot that the flight was not progressing normally. While it might be expected for the pilot to have reported the problem with the left engine, it is not unknown for pilots of multi-engine aircraft not to report single engine failures. The pilot had recently experienced an engine failure and had successfully managed the aircraft on one engine. However, the reason why the pilot did not report the first engine failure in this instance could not be determined.
- When the right engine malfunction became evident, the pilot's workload and stress levels would have increased enormously. The likely similarity in symptoms between the left and right engine problems evident to the pilot may have led him to report that both engines had failed even though the right engine may have been still operating, albeit at greatly reduced power.
- The pilot's comment in the MAYDAY transmission that he was 'trying to make Whyalla', while also saying that he was going to have to ditch the aircraft could have been a result of the stress of the moment. It could also have indicated that there was some power from the right engine but that it was not clear that the aircraft could reach Whyalla. The pilot might also have been indicating that he was continuing along the track to Whyalla, an appropriate technique in the event of later search and rescue action being activated.
- The radio transmissions from the pilot represent only very short segments of time. Therefore, it is difficult to draw firm conclusions regarding the operation of the engines from the activation or otherwise of the landing gear unsafe warning horn during the radio transmissions from the aircraft. A similar comment applies to the presence of the stall warning in a subsequent transmission.

### Apparent decision to continue to Whyalla

The nature of the left engine failure suggested that it became apparent gradually and subtly although increasing levels of vibration and rough running would probably have been evident at some stage. As the performance of the left engine deteriorated, it is likely that the pilot would have given consideration to shutting down the engine and feathering the propeller. He may, concurrently, have adjusted the right engine settings to maintain aircraft performance. At this stage, (and this is borne out by the absence of any radio transmission from the pilot) the pilot was unlikely to have been overly concerned regarding the ongoing safety of the flight as the right engine would (apparently at least) have been operating normally.

The company operations manual listed procedures to be followed in the event of an engine failure in a twin engine aircraft. Factors that may have influenced the pilot's decision making process included:

- **The availability of a suitable diversion aerodrome.** Port Pirie and Kadina were equipped with runway lighting but there was no published instrument approach procedures for either of these locations. The forecast weather conditions and the prevailing conditions (primarily cloud) visible from the aircraft may have led the pilot to conclude that neither Port Pirie nor Kadina were suitable destinations.
- **Aerodrome where repairs could be undertaken.** Comprehensive engine repair facilities for the aircraft were available in Adelaide and Port Lincoln, while limited repair facilities were available in Whyalla.
- **Company and passenger expectation.** The pilot may have been influenced by a perception (real or otherwise) that the passengers and the company expected the aircraft to continue to Whyalla.
- **Single engine performance of the aircraft.** In the absence of any indication from the pilot that the flight was not progressing satisfactorily, it is likely that aircraft performance was not a major concern until after the descent was initiated. At this time, the aircraft was about 35 NM from Whyalla. When the right engine malfunction became evident, the aircraft was on descent towards Whyalla and the pilot, in many respects, was probably committed to this course.

### Ditching

In the dark night conditions that prevailed at the time, and with the landing gear retracted, there was little prospect of the pilot being able to see the water surface. Lowering the landing gear and switching on the landing lights may have provided some surface definition. However, the pilot would have had to weigh any potential advantage provided by the landing lights against the possible disadvantages of ditching with the gear extended (necessary for the landing lights to be used). (There was likely to have been sufficient hydraulic pressure available from the right engine to lower the landing gear.)

Reports of other ditching occurrences indicated that successful night ditchings occurred in better light and weather conditions than confronted the pilot of MZK. Under the most difficult circumstances, he demonstrated a high level of skill in ditching the aircraft. As indicated by the relatively minor impact injuries suffered by most occupants, the ditching itself provided a good chance for their survival.

## 2.3 Other issues

Some other issues were identified as having the capacity to influence the performance of the pilot during the engine failure/aircraft ditching sequence.

### Stress and workload

The situation confronting the pilot would have developed into one of very high workload and stress. Throughout, the pilot was solely responsible for concurrently flying the aircraft, dealing with the engine problems, managing the passengers (who would also have been experiencing increasing levels of stress), and planning the remainder of the flight. As the situation deteriorated, each of these tasks would have become much more demanding and stress levels greatly magnified. Together, they might have exceeded the capacity of one individual. However, there were signs such as the operation of the cowl flaps, and the outcome of the ditching itself, which indicated that the pilot retained a level of self control throughout the sequence.

#### Relationship between the Manager/Chief Pilot and the pilot of MZK

While there appeared to have been some difficulties in the relationship between the Manager and the accident pilot during 1999, these appeared to subside in the latter part of that year after the landing gear incident at Adelaide had been resolved. The manner in which the pilot handled the engine failure occurrence in January 2000 appeared to have gained the respect of the Manager. Nevertheless, the Manager did acknowledge that there had been a 'personality conflict' between himself and the pilot of MZK. Information from others reinforced the Manager's acknowledgment in this regard. It is possible that the actions of the pilot in responding to the developing emergency were influenced by his relationship with the Manager. However, there was insufficient information available to support any conclusion regarding the effect the pilot's relationship with the Manager might have had on the eventual outcome.

#### Company safety culture

The notion of safety culture did not appear to be well understood by the management of Whyalla Airlines. While the company recognized the importance for safe operations of material aspects such as good maintenance practices and correct fuel management, the equal importance of other less tangible aspects was not well recognized. For example, line pilots' concerns about short turn-around times, and the way in which the company treated pilots who were involved in air safety incidents, may have lead line pilots to believe that management did not always put safety first.

There was evidence that Whyalla Airlines did not always promote a good safety culture and appeared, in some respects, to place commercial interests ahead of safety. It is likely that the company's priorities and expectations, that is the company culture, influenced the actions of its pilots, not only during normal operations, but also during their response to emergency situations. In this context, it is possible that the decisions taken by the pilot of MZK during and following the engine failure sequence were also influenced by the company culture. However, there was insufficient information available to draw any conclusion regarding the effect company culture might have had on the eventual outcome of the occurrence.

## 2.4 CASA audit activities

The under-achievement of surveillance targets by CASA was not restricted to Whyalla Airlines and has been highlighted in previous investigation reports. The shortcomings of product–based audits have also been reported on previously (see ATSB Investigation Reports 199904538 and 199802830). CASA is in the process of adopting a systems–based audit approach.

With respect to the accident involving MZK, the issue is whether the level of CASA surveillance had any influence on the engine failure or engine handling issues that contributed to the accident.

#### Left engine failure

Notwithstanding the information obtained during the investigation regarding lean of peak operations within the company, there was no indication that company pilots operated engines outside the limits set in the POH (and which permitted operations to 50°F lean of peak EGT). Thus, additional flying operations audit activities by CASA, even if lean of peak operations were observed, would not have provided reason for action regarding company engine operating techniques. In an airworthiness sense, aside from an engine teardown and inspection of the crankshaft for cracks, there was no method by which the impending crankshaft failure could have been detected. Regulatory surveillance activities do not normally include inspections to this detail unless specific grounds exist. There was no such reason in this instance. The left engine had only operated for 262 hours since overhaul by the engine manufacturer and there were no special maintenance, inspection, or other requirements in force regarding the crankshaft.

#### Right engine failure

The Manager of Whyalla Airlines was fairly well regarded by CASA and company pilots for the standard of his training and checking. No deficiencies were noted by CASA concerning his methods of training or checking pilots in handling engine failures during cruise (or any other phase of flight), or of company pilots' actions in conducting these drills in training situations. The fact that the pilot of MZK had properly handled an engine failure in MZK in January 2000 supports this conclusion not only in a general sense, but also with respect to his individual training to take the appropriate actions in the event of an engine failure.

In the periodic inspection it conducted shortly after the accident, CASA identified a number of deficiencies. One of these concerned safety culture. It is possible that, had CASA achieved a higher level of surveillance of Whyalla Airlines, then the deficiency regarding safety culture may have been highlighted. However, since there was insufficient information available to draw any conclusion regarding the effect company safety culture might have had on the eventual outcome of the occurrence, it could not be determined whether prior highlighting of the safety culture deficiency by CASA would have had any bearing on the accident itself.

# 3 CONTRIBUTORY FACTORS

## 3.1 Engine operating practices

- High power piston engine operating practices of leaning at climb power, and leaning to near 'best economy' during cruise, may result in the formation of deposits on cylinder and piston surfaces that could cause preignition.
- The engine operating practices of Whyalla Airlines included leaning at climb power and leaning to near 'best economy' during cruise.

## 3.2 Left engine

The factors that resulted in the failure of the left engine were:

- The accumulation of lead oxybromide compounds on the crowns of pistons and cylinder head surfaces.
- Deposit induced preignition resulted in the increase of combustion chamber pressures and increased loading on connecting rod bearings.
- The connecting rod big end bearing insert retention forces were reduced by the inclusion, during engine assembly, of a copper–based anti-galling compound.
- The combination of increased bearing loads and decreased bearing insert retention forces resulted in the movement, deformation and subsequent destruction of the bearing inserts.
- Contact between the edge of the damaged Number 6 connecting rod bearing insert and the Number 6 crankshaft journal fillet resulted in localised heating and consequent cracking of the nitrided surface zone.
- Fatigue cracking in the Number 6 journal initiated at the site of a thermal crack and propagated over a period of approximately 50 flights.
- Disconnection of the two sections of the journal following the completion of fatigue cracking in the journal and the fracture of the Number 6 connecting rod big end housing most likely resulted in the sudden stoppage of the left engine.

## 3.3 Right engine

The factors that were involved in the damage/malfunction of the right engine following the left engine malfunction/failure were:

- Detonation of combustion end-gas.
- Disruption of the gas boundary layers on the piston crowns and cylinder head surface increasing the rate of heat transfer to these components.
- Increased heat transfer to the Number 6 piston and cylinder head resulted in localised melting.
- The melting of the Number 6 piston allowed combustion gases to bypass the piston rings.

## 3.4 The flight

The factors that contributed to the flight outcome were:

- The pilot responded to the failed left engine by increasing power to the right engine.
- The resultant change in operating conditions of the right engine led to loss of power from, and erratic operation of, that engine.
- The pilot was forced to ditch the aircraft into a 0.5m to 1m swell in the waters of Spencer Gulf, in dark, moonless conditions.
- The absence of upper body restraints, and life jackets or flotation devices, reduced the chances of survival of the occupants.
- The Emergency Locator Transmitter functioned briefly on impact but ceased operating when the aircraft sank.

# 4. SAFETY ACTION

## 4.1 Engine reliability

High power variants of horizontally opposed, six-cylinder, air-cooled reciprocating engines power many aircraft employed in low capacity public transport operations in Australia. At the time of publication of this report, there were 107 Piper Chieftains on the Australian aircraft register and a much greater number in operation worldwide. Many other single and multi engine aircraft are equipped with high–powered reciprocating engines. The engine failure analysis presented in this report highlighted a number of issues that affect the reliability of these engines. Accordingly, the following recommendations are issued:

### Combustion deposits

#### Safety recommendation R20010254

The Australian Transport Safety Bureau recommends that the Federal Aviation Administration (Piston Engine Certification Directorate) review the certification requirements of piston engines with respect to the operating conditions under which combustion chamber deposits that may cause preignition are formed.

### Use of anti-galling compounds

#### Safety recommendation R20010255

The Australian Transport Safety Bureau recommends that the Federal Aviation Administration FAA (Piston Engine Certification Directorate) review the practice during assembly of applying anti-galling compounds to the backs of connecting rod bearing inserts with respect to its affect on the safety margin for engine operation of the bearing insert retention forces achieved.

#### Safety recommendation R20010256

The Australian Transport Safety Bureau recommends that Textron Lycoming review the practice during assembly of applying anti-galling compounds to the backs of connecting rod bearing inserts with respect to its affect on the safety margin for engine operation of the bearing insert retention forces achieved during assembly.

### Reliability of aircraft propulsion systems within Australia

#### Safety recommendation R20010257

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority review the operating and maintenance procedures for high–powered piston engines fitted to Australian registered aircraft to ensure adequate management and control of combustion chamber deposits, preignition and detonation.

## 4.2 Fuel mixture leaning practices

On 30 October 2000, the ATSB issued the following recommendation:

### Safety recommendation R20000250

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority alert operators of aircraft equipped with turbo-charged engines to the potential risks of engine damage associated with detonation, and encourage the adoption of conservative fuel mixture leaning practices.

### CASA response

The following response was received from the Civil Aviation Safety Authority on 22 March 2001:

> CASA also accepts Recommendations [sic] R20000250 and has published an article in the January/February aviation safety magazine Flight Safety Australia. Furthermore, CASA is considering further action on this matter and is consulting the aeroplane and engine manufacturers with a view to them improving their engine leaning procedure.

Response status: CLOSED – ACCEPTED

## 4.3 Ditching

### Safety recommendation R20010258

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority educate industry on procedures and techniques that may maximise the chances of survival of a ditching event. Part of that education program should include the development of formal guidance material of the type contained in the UK CAA General Aviation Safety Senses leaflet 21A Ditching.

## 4.4 Carriage of life jackets

On 30 October 2000, the ATSB issued the following recommendation:

### Safety recommendation R20000248

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority amend Civil Aviation Order Section 20.11 paragraph 5.1.2 to remove the restriction that it only applies to aircraft authorised to carry more than nine passengers.

### CASA response

The following response was received from the Civil Aviation Safety Authority on 22 March 2001:

> CASA accepts Recommendations [sic] R20000248 and is in the process of amending Civil Aviation Order 20.11 to comply.

Response status: CLOSED – ACCEPTED

#### Safety recommendation R20000249

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority ensure that Civil Aviation Orders provide for adequate emergency and life saving equipment for the protection of fare-paying passengers during over-water flights where an aircraft is operating beyond the distance from which it could reach the shore with all engines inoperative.

#### CASA response

The following response was received from the Civil Aviation Safety Authority on 22 March 2001:

> CASA is sympathetic to recommendation R20000249 but wishes to consult more widely with the aviation community and other stakeholders including ATSB before taking further action.

Response status: OPEN

## 4.5 Upper body restraint

The issue of upper body restraint also arose during the Bureau's investigation of the accident involving Cessna Floatplane VH-HTS at Calabash Bay, NSW, on 26 July 1998 (Investigation Report 199802830). On 31 March 1999, BASI (now the ATSB) issued the following recommendation:

#### Safety recommendation R19980281

The Bureau of Air Safety Investigation recommends that the Civil Aviation Safety Authority mandate the compliance of all manufacturers' service bulletins relating to the provision of upper body restraint to occupants of FAR part 23 certified aircraft engaged in fare-paying passenger operations, and emphasise compliance with their instructions on the correct use of the restraint systems.

#### CASA response

The following response was received from the Civil Aviation Safety Authority on 4 August 1999:

> The value of upper body restraint in improving the chances of occupant survival following an aircraft impact is supported by both accident analysis and research testing. Australia has long been in the forefront of advocating the use of shoulder harnesses in both aircraft and road vehicles.
>
> Any requirement for retrospective installation of shoulder harnesses in older small aircraft would be an Australian unique requirement, and as such CASA would need to conduct formal consultation with the industry. However, there are standard modification kits available for the most common types, but some design effort will be required for some aircraft types. Mandating the installation of upper body restraint in small aircraft would require substantiation to support the proposed rule. CASA therefore intends to gather the appropriate accident, research data and cost data to determine if the requirement can be justified in an NPRM.
>
> CASA Airworthiness Branch, will be researching this issue.

On 8 October 2001, CASA advised that a draft Discussion Paper (DP 0109CS) had been prepared that was proposing a requirement that all small aircraft that carry fare-paying passengers be fitted with a shoulder restraint in all seats occupied for take-off or landing. The DP was being processed through the Standards Coordination Branch of the Aviation Standards Division.

## 4.6 Refuelling procedures

A short time after the accident, as the investigation was progressing, the refuelling organisation introduced revised procedures nationally for communicating fuel grade and volume between refueller and pilot, especially if the pilot is not in attendance during the refuelling. The revised procedures also ensure appropriate contemporaneous documentary evidence of the refuelling details.

## 4.7 Report distribution

Upon its release, a copy of this report was sent to all owners of Piper Chieftain and other high–powered piston engine aircraft on the Australian register.

# ATTACHMENTS

## Attachment A: Abbreviations

| | |
|---|---|
| AAT | Administrative Appeals Tribunal |
| AC | Advisory circular |
| AD | Airworthiness directive |
| Altitude | Height above mean sea level in feet |
| ANO | Air Navigation Order |
| AOC | Air Operator's Certificate |
| ASSP | Aviation Safety Surveillance Program |
| ATC | Air Traffic Control |
| ATSB | Australian Transport Safety Bureau |
| BASI | Bureau of Air Safety Investigation |
| bhp | Brake horsepower |
| broken | When used to describe cloud cover, means 5 to 7 OKTAS |
| C | Celsius |
| CAA | Civil Aviation Authority |
| CAO | Civil Aviation Order |
| CAR | Civil Aviation Regulation |
| CASA | Civil Aviation Safety Authority |
| CASR | Civil Aviation Safety Regulations |
| CB | Circuit breaker |
| CESM | Cold Exposure Survival Model |
| CHT | Cylinder head temperature |
| CST | Central Standard Time |
| EGT | Exhaust gas temperature |
| F | Fahrenheit |
| FAA | Federal Aviation Administration (USA) |
| FAR | Federal Aviation Regulations |
| FIS | Flight Information Service |
| FOI | Flying Operations Inspector |
| FS | Flight Service |
| ft | Feet |
| g | Gravitational constant |
| GPH | Gallons (US) per hour |
| GPS | Global Positioning System |
| hPa | Hectopascals |
| ICAO | International Civil Aviation Organisation |
| IFR | Instrument Flight Rules |
| IT | Information technology |
| kHz | Kilohertz |

| | |
|---|---|
| KIAS | Indicated airspeed expressed in knots |
| KTAS | True airspeed expressed in knots |
| kts | Knots |
| L | Litres |
| LCRPT | Low Capacity Regular Public Transport |
| LL | Low lead |
| m | Metres |
| MHz | Megahertz |
| mL | Millilitres |
| MP | Manifold pressure |
| NM | Nautical mile |
| NPRM | Notice of proposed rule making |
| NSW | New South Wales |
| NTSB | National Transportation Safety Board |
| OKTAS | Cloud amount expressed in eighths |
| POH | Pilot's Operating Handbook |
| QNH | An altimeter sub-scale setting to show height above mean sea level |
| ROP | Rich of peak |
| RPM | Revolutions per minute |
| RPT | Regular public transport |
| RSR | Route surveillance radar |
| SA | South Australia |
| scattered | When used to describe cloud cover, means 3 to 4 OKTAS |
| SI | Service instruction |
| SSAPCO | Safety Systems Assessment of Passenger Carrying Operation |
| SSR | Secondary surveillance radar |
| STI | Safety trend indicator |
| T | Degrees True |
| TAAATS | The Australian Advanced Air Traffic System |
| TAR | Terminal area radar |
| TCU | Terminal control unit |
| TIT | Turbine inlet temperature (regarded as equivalent to EGT for the purposes of this report) |
| TMA | Terminal area |
| TSO | Technical Standing Order |
| UK | United Kingdom |
| UK CAA | Civil Aviation Authority of the United Kingdom |
| USA | United States of America |
| WA | Western Australia |
| WW | Flight number designator for Whyalla Airlines Pty Ltd |
| VHF | Very high frequency |

Note 1. All bearings are in degrees magnetic unless otherwise indicated.

Note 2. All times are Australian Central Standard Time (Co-ordinated Universal Time (UTC) + 9:30 hours) unless otherwise stated.

## Attachment B: Whyalla Airlines' system of maintenance

The Whyalla Airlines' approved system of maintenance for their Piper Chieftain aircraft required that a Check 2, Check 3, Check 2A and Radio Check be conducted at appropriate intervals. The Check 2 and 3 schedule was to be completed every 100 hours (maximum) time in service or 12 months (whichever was the earlier). The Check 2A was to be completed 50 +/- 5 hours time in service after the Check 2 and 3 was completed. The Radio Check was to be conducted within 10 hours of the Check 2 and 3.

The items included in each check are detailed below.

**Check 2**

| | |
|---|---|
| Propeller – | Spinner, blades, lubricate, propeller air pressure (monthly), feathering of the propeller. |
| Engine – | General inspection, oil strainer, oil filter change and inspection, replace oil, spark plugs clean and adjust, cylinder compression, ignition harness and insulators for high tension leakage and continuity, magnetos points and timing, clean air screen, clean fuel injectors, tension alternator belt, compressor oil level and tension of belt. |
| Turbocharger – | Turbine wheel inspection in accordance with Lycoming SB 452, induction and exhaust components (Piper SB 644), alternate air door operation, operation of compressor bypass door. |

**Check 2A**

Engine group: Cowls inspection, replace engine oil and oil filter, inspect oil filter element, AD/PA31/96 engine baffles inspection.

**Check 3**

Airframe: Cabin, fuselage and empennage, wing, landing gear, electrical and instrument groups.

**Radio Check**

Accessible interwiring, plugs and sockets

Microphones, headsets and cords

Fuses

Antenna

ELT battery

Switches and controllers

Lighting

Communication systems – HF, VHF and audio.

Navigation systems – ADF, VOR, localiser, glideslope, marker, GPS and transponder.

## Attachment C: Piper Navajo and Chieftain ditching occurrences

A search of Australian and overseas aircraft accident databases revealed at least 13 Piper Navajo and Chieftain ditching occurrences in addition to the occurrence involving MZK. Of these, two resulted in fatalities. A brief summary of each of these occurrences follows:

**6 September 1984.** Two men were retrieved from a liferaft off the coast of Florida, close to the wreckage of a Chieftain aircraft (and 27 bales of marijuana). *NTSB MIA84LA250*

**14 February 1989.** Following a loss of oil pressure, the pilot shut down the right engine of the aircraft. The aircraft was heavy and could not maintain altitude on the remaining engine. The pilot ditched the aircraft and was subsequently rescued. He received minor injuries. *NTSB LAX89LA119*

**2 August 1990.** The left engine of the aircraft failed and the pilot ditched the aircraft. The pilot was not injured. *NTSB ANC90LA129*

**10 July 1993.** During a day flight, the aircraft ran out of fuel and the pilot ditched the aircraft. The two occupants were rescued about 7 hours later. *NTSB MIA93LA152*

**13 October 1993.** The pilot and his passenger were ferrying the aircraft from Christmas Island to Hawaii. Approximately 3.5 hours after departing Christmas Island, at 1406 Hawaii Standard Time, the right engine failed. The left engine subsequently overheated and the pilot elected to ditch the aircraft. Both occupants were rescued, with minor injuries. *NTSB LAX94LA012*

**27 July 1995.** During cruise in daylight, the left engine failed. The aircraft did not maintain altitude on the remaining engine, and the pilot subsequently ditched in the St Lawrence River. The seven occupants of the aircraft exited through the rear door, shortly after which the aircraft sank. The occupants were not injured and were retrieved from the water about 40 minutes after the ditching. The aircraft was not equipped with lifejackets. *TSB Canada A95Q0142*

**18 October 1995.** During a night flight in visual meteorological conditions while on descent from 5000 ft, the left engine failed. The aircraft was unable to maintain altitude on the remaining engine and the pilot subsequently ditched the aircraft 6 NM south of JFK Airport New York. All occupants exited through the pilot's seat window exit. The occupants were retrieved from the water approximately 30 minutes after the ditching. Four occupants were not injured, one received minor injuries and one was in cardiac arrest and did not survive. The intact aircraft was recovered and had incurred very little damage. The flaps and landing gear were found in the retracted position. *NTSB NYC96FA012*

**10 April 1997.** During a daytime authorised overweight ferry flight from Hawaii to California, the right engine of the Chieftain failed. The pilot headed the aircraft back towards Hawaii, but the aircraft could not maintain level flight on the remaining engine. The pilot attempted to maintain flight in ground-effect at approximately 116 kts however the aircraft clipped the top of a wave. The pilot then closed the throttle of the operating engine and ditched the aircraft 28 NM offshore. The swell was approximately 2 m and the other occupant of the aircraft described the deceleration as violent, and that he was flung forcibly against his seatbelt. The two occupants were not injured, and were recovered from liferafts about 2 hours after the ditching. *NTSB LAX97LA154*

**12 June 1998.** Towards the end of a daylight ferry flight, the pilot, who was the sole occupant of the aircraft, advised air traffic control that the engines were spluttering. The pilot subsequently ditched the aircraft near the island of Jersey in the English Channel. Radar information indicated that the aircraft impacted the water at a groundspeed of about 100 kts. The flaps and landing gear were retracted, and the pilot's seat was not equipped with a shoulder harness. The sea-state in the area was between 1 and 2.5 m. The aircraft was substantially damaged, with significant disruption to the forward fuselage and flight deck areas. The pilot did not survive, and was found strapped into the pilot's seat in the wreckage. *AAIB Aircraft Accident Report No: 2/99*

**7 September 1998.** Shortly after a daylight take-off from Homer, Alaska, the pilot reported that one engine had failed. He subsequently ditched the aircraft, with flap and landing gear retracted, at a speed at which the stall warning had activated. The aircraft sank within one minute. The pilot was not injured and was retrieved from the water 47 minutes after the accident. *NTSB ANC98LA143*

**14 April 1999.** The pilot was conducting a day ferry flight from Hawaii to California and reported higher than expected fuel consumption. Subsequently, the aircraft's engines failed due to fuel exhaustion and the pilot ditched the aircraft approximately 20 NM off the coast of California. The pilot sustained minor injuries during the ditching and was rescued from a liferaft approximately 30 minutes later. *NTSB LAX99LA149*

**25 August 2000.** During a daylight sightseeing flight near Hilo, Hawaii, the right engine failed and the aircraft did not maintain altitude on the remaining engine. The pilot instructed the eight passengers to don their lifejackets and briefed them to prepare for ditching. The pilot subsequently configured the aircraft with full flap, landing gear retracted and full power on the left engine. The tail of the aircraft touched the water first, followed by a jolt that momentarily stunned the pilot. When he fully regained awareness, the water in the cockpit was chest high. One passenger reported that right emergency window exit was unusable due to water pressure. The pilot and seven passengers exited the aircraft through the pilot's seat window exit and the rear main door. One passenger did not exit the aircraft and did not survive. The eight survivors sustained minor injuries. The aircraft sank nose-first, gradually rolling to the right, and disappeared within 60 seconds. Rescue personnel were on-scene in approximately 15 minutes. *NTSB LAX00FA310*

**6 May 2001.** During a night flight, both of the Chieftain's engines failed. The pilot subsequently ditched the aircraft in Massachusetts Bay, 3 NM south-east of Nahant, Massachusetts, USA. The NTSB advised that the pilot was careful not to stall the aircraft, maintaining an airspeed of about 85 kts. The pilot was able to see the surface of the water by moonlight and the aircraft touched down in a flat attitude. The landing gear and flaps were retracted. The NTSB also advised that the deceleration had been described as strong and the aircraft immediately began to fill with water. All nine occupants exited via the pilot's seat window exit and six fitted into a small raft. The aircraft sank within 40–45 seconds. Each of the nine occupants sustained minor injuries during the ditching. *NTSB NYC01LA116*

An internet search for information related to aircraft ditching identified a number of useful sites. One site, http://www.equipped.com/ provided a number of articles discussing various aspects of ditching, in addition to related issues such as life jackets, life rafts and water survival.

## Attachment D: Extracts from Piper Chieftain Pilot's Operating Handbook, Emergency Procedures

The following extracts were taken from Piper Chieftain POH Report: 2046 dated 1 November 1976.

**3.3 EMERGENCY CHECKLIST**

**ENGINE INOPERATIVE PROCEDURES**

ENGINE SECURING PROCEDURE
(FEATHERING PROCEDURE)

Throttle ………………………………………….…. lose
Propeller …………………. FEATHER (1000 rpm MIN.)
Mixture …………………………………IDLE CUT-OFF
Cowl flaps ………………………………………….. close
Air conditioner …………………………………….…...OFF
Magneto switch ……………………………….……..OFF
Emergency fuel pump …………………………….……OFF
Fuel selector ………………………………. OFF (detent)
Fuel boost pump CB [circuit breaker]……………….…pulled
Alternator CB switch ………………………………..OFF
Prop.Sync. [propeller synchrophaser] ……….…….. OFF
Electrical load …………………………….……..reduced
Crossfeed …………………………………… Considered

ENGINE FAILURE DURING FLIGHT
(Above 76 KIAS)
Inop. Eng. [inoperative engine]………………….identify
Operative eng. ……………………….. adjust as required
Airspeed ………………….attain and maintain 106 KIAS

Before securing inop. Engine:
Fuel flow …………………………… check (if deficient – Emergency fuel pump ON)
Fuel quantity ……………………………………….check
Fuel selector (inop.eng.) ………………….switch to other tank containing fuel
Oil pressure and temp. ……………………………..check
Magneto switches …………………………………. check
Air start ……………………………………………..attempt

If engine does not start, complete Engine Securing Procedure.

Power (operative engine) ……………………..as required
Mixture (operative engine) ……………. adjust for power
Fuel quantity (operative eng. Tank) …………… sufficient
Emergency fuel pump (operative eng.) ………as required

**ENGINE ROUGHNESS**

Emergency fuel pumps …………………………….. ON
Engine instruments ……………………… scan for cause
Mixture ………………………………..adjust as required
Alternate air …………………………………. as required
Cowl flaps ……………………….. adjust for proper CHT
Fuel ………………….. switch tanks if fuel in second tank
Magnetos ………………………………………… check

**ENGINE OVERHEAT**

Cowl flaps ……………………………………….. OPEN
Mixture ……………………………………………richen
Power …………………………………………….. reduce
Airspeed ………….……… increase (if altitude permits)

**3.5 AMPLIFIED EMERGENCY PROCEDURES (GENERAL)**

The following paragraphs are presented to supply additional information for the purpose providing the pilot with a more complete understanding of the recommended course of action and probable cause of an emergency situation.

**3.7 ENGINE INOPERATIVE PROCEDURES**

ENGINE SECURING PROCEDURE (FEATHERING PROCEDURE)

The engine securing procedure should always be accomplished in a sequential order according to the nature of the engine failure (ie., practice, engine failure during takeoff, engine failure during climb etc).

Begin the securing procedure by closing the throttle of the inoperative engine and moving its propeller control to 'FEATHER' (fully aft) before the propeller speed drops below 1000 rpm. The inoperative engine mixture control should be moved fully aft to the 'IDLE CUT-OFF' position. 'CLOSE' its cowl flap to reduce drag and turn 'OFF' the air conditioning (if installed). Turn 'OFF' the magneto switch, the emergency fuel pump switch and the fuel selector. Pull out the fuel boost pump circuit breaker and turn 'OFF' the alternator circuit breaker switch of the inoperative engine. The propeller synchrophaser (if installed) should be OFF. Complete the procedure by reducing the electrical load and considering the use of the fuel crossfeed if the fuel quantity dictates.

**ENGINE FAILURE DURING FLIGHT (Above 76 KIAS)**

If an engine fails at an airspeed above 76 KIAS during flight, begin corrective response by identifying the inoperative engine. The operative engine should be adjusted as required after the loss of power has been verified. Attain and maintain an airspeed of 106 KIAS. Once the inoperative engine has been identified and the operating engine adjusted properly, an engine restart may be attempted if altitude permits.

Prior to securing the inoperative engine, check to make sure the fuel flow to the engine is sufficient. If the fuel flow is deficient, turn ON the emergency fuel pump. Check the fuel quantity on the inoperative engine side and switch the fuel selector to the other tank if a sufficient supply is indicated. Check the oil pressure and oil temperature and ensure that the magneto switches are ON.

If the engine fails to start it should be secured using the "Engine Securing Procedure."

After the inoperative engine has been secured, the operative engine can be adjusted. Power should be maintained as required and the mixture control should be adjusted for power. Check the fuel supply and turn ON the emergency fuel pump if necessary. The cowl flaps on the operative engine should be adjusted as required to maintain engine temperatures within allowable limits. Trim five degrees toward the operating engine. The electrical load should be decreased to a required minimum. Land as soon as practical at the nearest suitable airport.

### 3.9 ENGINE ROUGHNESS

If an engine falters or runs erratically, the cause may be fuel flow interruption, fuel contamination, icing or air starvation, or ignition problems. If roughness occurs, turn the emergency fuel pumps ON. Scan the engine instruments to see if the cause can be determined. Adjust the mixture controls for maximum smoothness; if the mixture is too rich or too lean, engine roughness may result. Open the alternate air control; a blocked induction system can cause roughness. If cylinder head temperatures are too high or too low, adjust the cowl flaps as required.

If the problem is in the fuel system, selecting another tank containing fuel may remedy the situation. A check of the magnetos will determine if they are operating properly.

### 3.11 ENGINE OVERHEAT

If engine temperatures become excessive, open the cowl flaps. Enriching the mixture and reducing power will also reduce engine temperature. If a more rapid reduction of engine temperature is desired, increase the airspeed by establishing a shallow dive.

## Attachment E: Whyalla Airlines' Safety Program

The following extracts were taken from Whyalla Airlines' Operations Manual Part A, issued 31 August 1998.

**A1.20 Safety Program**

Whyalla Airlines Safety Program

Relying on the approach discussed in the CASA publication "Aviation Safety Management: An Operator's Guide to Building a Safety Program", Whyalla Airlines has elected to implement the BASI – INDICATE Safety Program. Essentially, this Program shall be undertaken in a manner that satisfies all specified guidelines, as appropriate to the size of the company and number of employees.

The Operational Safety Officer is selected in accordance with the following:

It is required that the Safety Officer not hold current positions such as Chief Pilot, or Maintenance Controller, and also display previous external experience that would benefit the role. It is considered necessary that the Safety Officer be exposed to operations on all sectors, charter work and also be able to spend a reasonable amount of time in the various base's used by the Whyalla Airlines flights.

The Safety Officer reports directly to [name provided], the Managing Director, with formal communication to the Chief Pilot, which is the preferred option in the INDICATE PROGRAM. The position is part time, with assistance as required by other specified Line Pilots. It was not considered necessary for each base to require a Safety Officer.

As per BASI – INDICATE guidelines for companies with fewer than 20 employees, Whyalla Airlines will not run a stand-alone Confidential Reporting System. Staff wishing to report a hazard can contact the Safety Officer direct and send a written memo specifying their concern, with appropriate details and any recommendations. The Safety Officer must acknowledge this and give feedback. All reports shall be kept on file. The Safety Officer is responsible for investigation, and ensuring that it is recorded in the BASI – INDICATE PROGRAM.

Discussion will be facilitated at the Focus Groups as to what Hazards should be reported, with examples, as well as what is considered to be more appropriately directed towards the Chief Pilot. It will be pointed out that the BASI C.A.I.R. (Confidential Aviation Incident Report) system is always available if required, and that the requirements for reporting Incidents and Accidents to BASI still exist. Results of reporting system will be published in Minutes of Focus Group meetings, and Monthly Safety Meetings, as well as any urgent matters prior to these times by Safety Memos. Anonymous reports will not be accepted. Personal Attacks or grievances will be handled by [name provided], with the safe operation of the Airline being the prime objective.

Regular Safety Meetings will be held each month on a day and time to be specified by the Safety Officer. The Safety Officer will chair the meetings and the agenda will be as per the INDICATE guidelines. Participation in Focus Groups will include [names provided], Chief Pilot, Maintenance Controller, all Line Pilots, and a representative from our Maintenance organisation, [name provided].

Monthly meetings will be open to all of the above, with the exception that only operational commitments that cannot be altered would preclude attendance. Minutes will be typed and sent to all participants, BASI INDICATE data will be loaded, with copies sent to any additional persons as required by the Hazard.

The meetings have the authority to identify any Safety Hazards to all Management levels within the Airline, and to document their history and management, so that items of a critical nature are dealt with quickly at the highest level, in a transparent fashion.

The program will be documented both on computer (with backup), as well as a print out of monthly status and kept on file. Backup users nominated are [name provided] and [name provided], who, along with [name provided], constitute those with access to operate the program. The program is on a computer in a secure environment.

Vital safety information will be distributed by the Safety Officer in the form of minutes, memos as directed by the Chief Pilot, or Maintenance Controller, and literature of operational or safety interest. To determine the effectiveness of this system, direct feedback to the Chief Pilot and/or Safety Officer will be sought, with a record of all distributed material.

Additionally, Whyalla Airlines has become a Corporate Member of the Aviation Safety Foundation Australia (ASFA), which enables us to tap into an established forum for information and services. The BASI – INDICATE program will be evaluated after being in operation for a period of six months and thence annually, as part of an overall Safety Audit process.

# Attachment F: Training and checking organisation responsibilities

The following extracts were taken from the Whyalla Airlines' Operations Manual Part C Training and Checking, issued 30 August 1998.

### C1.1 Functions of the organisation

The training and checking organisation has the responsibility of ensuring that only appropriately trained pilots with the necessary experience and proficiency are released to act as pilot in command on line operations.

The training and checking organisation is directly responsible to the operator (Whyalla Airlines Pty Ltd) for the standard of flight operations.

CAO 82.3 appendix 2 1.1 (b)

The organisation is to perform the training and checking of Whyalla Airlines pilots in accordance with the applicable regulatory requirements.

### C1.2 Structure of the organisation

The Chief Pilot shall seek approval from the Authority for at least one of its pilots to be approved as a check pilot.

When only one company pilot holds approval as a check pilot, then approval shall be obtained from the Authority for a check pilot from another organisation to be approved under the Whyalla Airlines Pty Ltd training and checking organisation.

Organisational Structure

Chief Pilot

Training and Checking Organisation

Supervisory Pilots Training Pilots Check Pilots

Line Pilots

### C1.3 Duties and responsibilities

Company Directors, Management, Chief pilot, Check pilots, Supervisory pilots, Training pilots, Line pilots and Trainee pilots are all responsible for ensuring that training and checking is done correctly, safely, and in accordance with the manual.

#### C1.3.1

The Chief Pilot is wholly responsible for,

- The effective management of the training and checking organisation CAO 82.3 appendix 2 2.1
- Standard of the company's flight operations
- Training and checking course contents and completion standards
- Recording of all training and checking activities conducted
- Planning when checks are due
- Ensuring checks occur at the required periodicity
- Monitoring the conduct of supervisory, training and checking pilots

**C1.3.2**

Supervisory Pilots are responsible to the Chief Pilot for,

- Standard of a trainee pilot's line training
- Supervision of trainee pilots in all normal procedures associated with line flying
- Conducting parts 1 and 2 of conversion training syllabus for new pilots already type endorsed
- Completion of all documentation associated with the training undertaken

**C1.3.3**

Training Pilots are responsible to the Chief Pilot for,

- All of the supervisory pilot responsibilities and duties
- Standard of endorsement or conversion training provided to company pilots
- Training pilots to become supervisory pilots
- Training of pilots for recency or checks due
- Retraining pilots after a failure to reach the required standard during a check
- Completion of all documentation associated with the training undertaken.

**C1.3.4**

Check Pilots are responsible to the Chief Pilot for,

- All of the supervisory and training pilot responsibilities and duties
- Where approved by the Authority renewal of command instrument ratings CAO 40.2.1
- Where approved by the Authority conducting the crew member emergency procedures proficiency test in CAO 20.11
- Conducting initial and recurrent base proficiency checks, line checks and night checks
- Conducting checks of competency in accordance with CAR 217
- Checking and certifying new pilots to line. CAO 82.3.3.3
- Training of pilots to become training or check pilots
- Conduct of any other training or checking contained in this manual or required by the Chief Pilot
- Completion of all documentation associated with the training undertaken.

**Piper PA31-350 Chieftain VH-MZK  Spencer Gulf SA**

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