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ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Technical Analysis – 200502231

Inflight Engine Failure
13 km WSW Young, NSW
Piper PA31P-350 – Chieftain, VH-IGW
Lycoming TIO-540-V2AD, s/n L8484-61A
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Released in accordance with section 25 of the *Transport Safety Investigation Act 2003*

Published by: Australian Transport Safety Bureau
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ISBN and formal report title: see ‘Document retrieval information’ on page iii.

DOCUMENT RETRIEVAL INFORMATION

Report No.	Publication date	No. of pages	ISBN
200502231	December 2006	19	1 921164 24 7

Publication title

Inflight Engine Failure, 13 km WSW Young, NSW, Piper PA31P-350, VH-IGW, Lycoming TIO-540-V2AD, s/n L8484-61A, 18 May 2005

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Abstract

During a flight from Essendon to Armidale, the left engine of a Piper PA31P-350 (VH-IGW) failed during cruise at 17,000 feet. Examination of the engine revealed that the crankshaft had fractured in two locations: through the web between the No.4 main bearing journal and the No.4 connecting rod journal; and through the web between the No.3 main bearing journal and No.3 connecting rod journal. It is evident that the event that initiated the multiple fractures of the crankshaft and the subsequent engine failure, was the creation of surface damage in the No.4 main bearing journal fillet radius through rubbing contact between the main bearing insert and the fillet radius. The factors that contribute to this event may be related to the retention of the main bearing insert in its housing and the crankshaft loading conditions that act to displace the bearing insert from its location in the bearing housing.

The movement of main bearing inserts during engine operation is a function of the magnitude of the forces that resist movement (created by establishing an interference fit) and the magnitude of forces acting to move the insert (crankshaft bending moments).

One factor that lowers the resistance of an insert to movement, the inclusion of material between the parting faces of the main bearing housings during engine assembly, was identified. However, other factors that may contribute to bearing insert movement, such as the magnitude of crankshaft bending moments, could not be established from an examination of the physical evidence.

The restoration of the surfaces of the main bearing housings indicated that main bearing insert movement was not an isolated case.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations. Accordingly, the ATSB also conducts investigations and studies of the transport system to identify underlying factors and trends that have the potential to adversely affect safety.

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The ATSB does not have the resources to carry out a full cost-benefit analysis of each safety recommendation. The cost of a recommendation must be balanced against its benefits to safety, and transport safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example, the relevant regulatory authority in aviation, marine or rail in consultation with the industry).

FACTUAL INFORMATION

Introduction

During a flight from Essendon to Armidale the left engine of a Piper PA31P-350 (VH-IGW) failed during cruise at 17,000 ft. The pilot reported that prior to the failure there was a slight variation in the left engine rpm and an increase in left engine vibration. The variation in engine rpm was corrected by adjusting the left propeller speed. The indications on the engine instruments were normal and there were no visible signs of leaking oil. A time period of approximately ten minutes elapsed between the initial observation of engine irregular performance and final failure. The engine shutdown procedure was completed successfully. The aircraft descended to 10,000 ft and diverted to land at Bankstown without further incident.

Initial examination of the Lycoming TIO-540-V2AD engine revealed that the crankshaft had fractured in two places allowing the section containing the No.3 and No.4 connecting rod journals[1] (the section between the two intermediate main bearings) to become displaced, see figure 1.

Figure 1: The fractured section of the crankshaft in the position found during initial engine examination

Physical Evidence

Examination of the engine revealed that the crankshaft had fractured in two locations: through the web between the No.4 main bearing journal and the No.4 connecting rod journal; and through the web between the No.3 main bearing journal and No.3 connecting rod journal, see figure 2.

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[1] Lycoming numbering convention

Figure 2: **The location of both fractures and their orientation with respect to the crankshaft webs**

Crankshaft Web Fracture, No.4 main/No.4 connecting rod

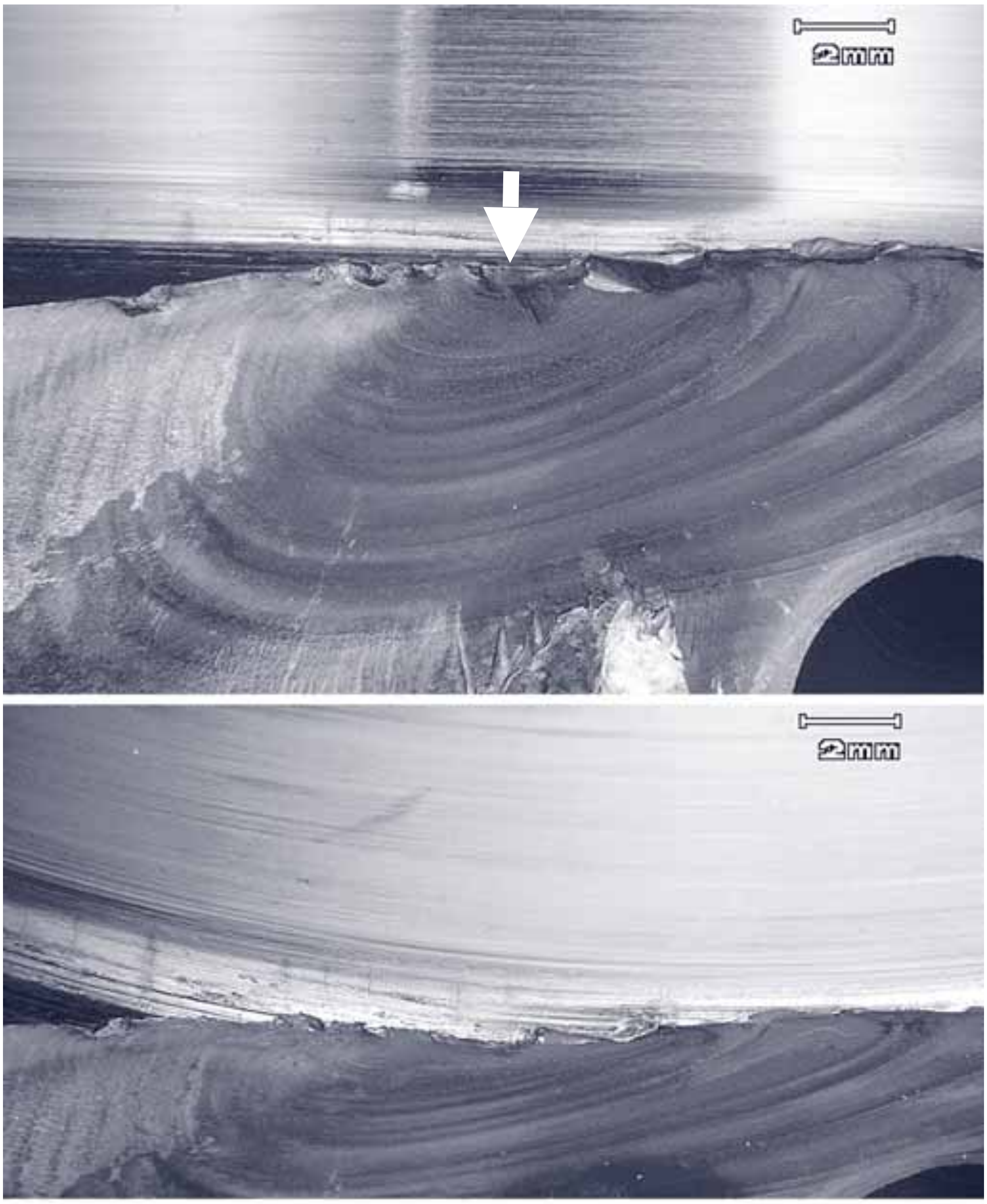
The fracture of the web between the No.4 main and No.4 connecting rod journals occurred as a result of fatigue crack initiation and growth, see figure 3. The fatigue fracture surface features present on the fracture surface indicated that crack growth had occurred over a period of approximately 50 engine start/stop cycles.

Figure 3: Crankshaft Web Fracture, No.4 main/No.4 connecting rod

Fatigue crack initiation No.4 Main Bearing Journal Fillet

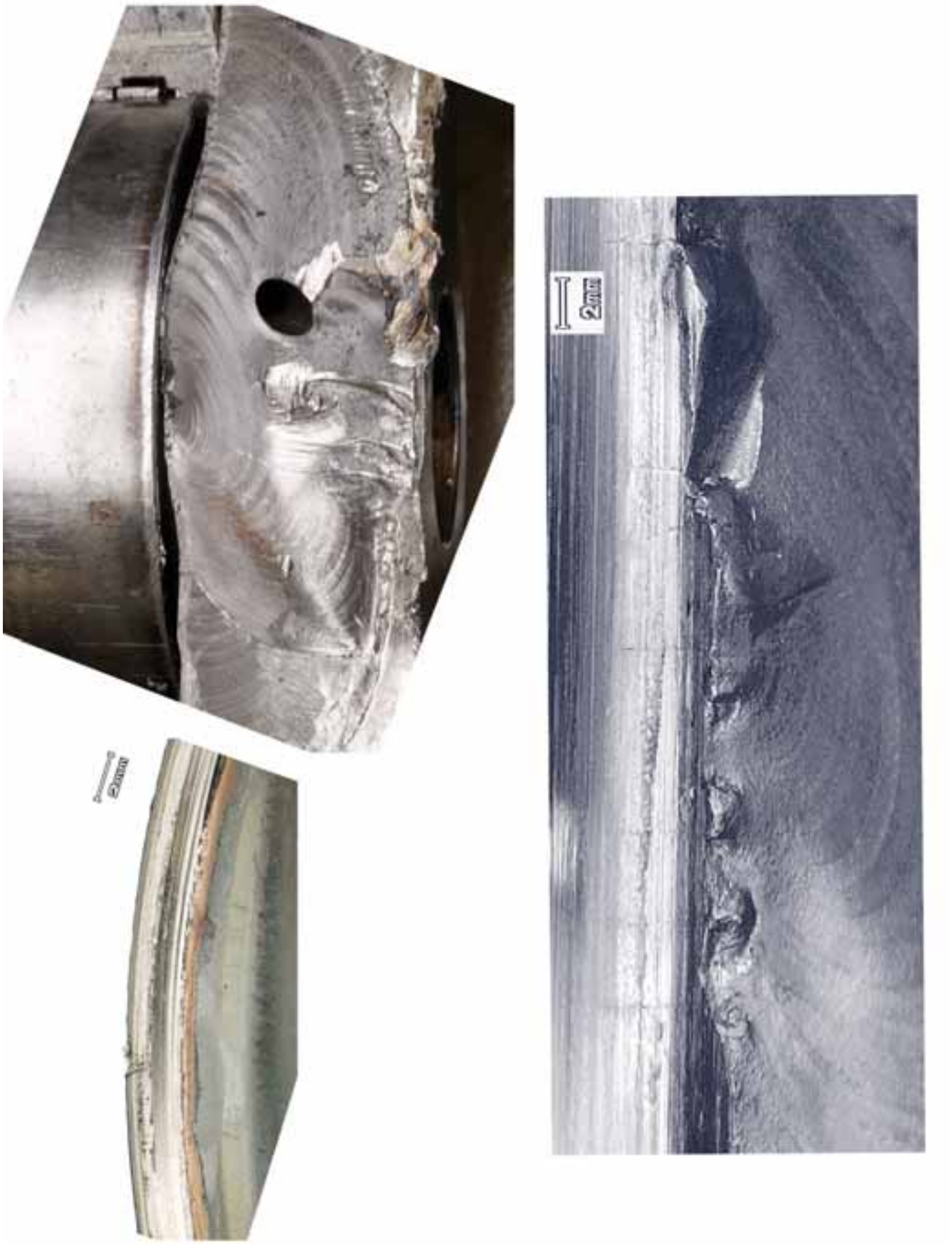
Fatigue cracking in the fillet radius of the No.4 main bearing journal initiated from damage created by rubbing contact between the No.4 main bearing insert and the fillet radius, see figure 4. The axial movement of the No.4 main bearing insert forward in its housing, during engine operation, allowed the bearing insert to come into contact with the rotating crankshaft main bearing journal fillet radius, see figure 5. The contact between the bearing insert edge and the journal fillet radius was sufficient to damage the fillet surface by scoring and localised heating. Localised thermal expansion of the hardened surface of the fillet, from localised heating, results in the formation of a series of short axially-oriented cracks.

Figure 4: The site of fatigue crack initiation, No.4 main bearing journal fillet



The location of the fatigue crack initiation is indicated by the arrow. Circumferential scoring and a series of short axially-oriented cracks in the journal fillet are evident

Figure 5: The relationship between the No.4 main bearing insert and the journal fillet damage



The position of the main bearing insert at crankcase disassembly (top left), the edge of the main bearing insert showing the effects of sliding contact with the journal fillet (bottom left), and the main bearing fillet showing the effects of sliding contact with the bearing insert (right)

An examination of the No.4 main bearing housing revealed that the bearing insert had moved forward under the influence of loading created during engine operation. The wear created by the movement of the bearing insert, in the region of the insert tangs, delineates the extent of axial movement, see figure 6. The bearing insert did not rotate in its housing.

Figure 6: The extent of No.4 main bearing insert displacement

Position of bearing insert at crankcase disassembly (left). The nature and extent of wear created by the bearing insert tangs as the insert has moved in its housing

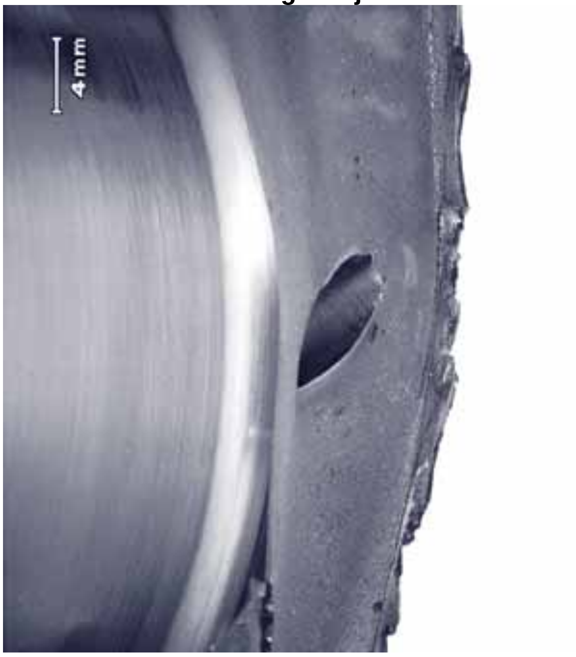
Crankshaft Web Fracture, No.3 main/No.3 connecting rod

The fracture of the crankshaft web, No. 3 main/No. 3 connecting rod journals, also occurred as a result of fatigue crack initiation and growth. However, in this case the fracture surface features indicated that fatigue cracking had occurred over a short operational time period. The nature and site of crack initiation indicated that high bending loads were responsible for crack initiation and growth, see figure 7. Fatigue cracking initiated at the surface of the fillet at the transition between the fillet radius and the web, see figure 7. No abnormal features, such as, damage created through contact with other components, or material discontinuities, contributed to fatigue crack initiation.

It is evident that fatigue crack initiation and propagation in the web between the No.3 main and No.3 connecting rod journals occurred under a condition of repeated high bending loads, created by abnormal crankshaft flexure, following the fracture of the web between the No.4 main and No.4 connecting rod journals. The absence of progression mark fracture surface features, typical of those formed by the engine start/stop cycle, indicated that crack growth occurred over a short period of time during the last flight.

Figure 7: **Crankshaft web fracture, No.3 main bearing journal/No.3 connecting rod journal**

Figure 8: **Detailed view of the No.3 main bearing journal fillet at the site of fatigue crack initiation in the web between the No.3 main and No.3 connecting rod journals**



Recorded Evidence

Engine s/n L8484-61A, had completed 291.3 hours since overhaul. The crankshaft had been installed in the engine prior to overhaul and had been examined for cracks (magnetic particle inspection) prior to engine reassembly.

The crankshaft was identified by a series of hand etched, stamped, and as-forged numbers. The part number of the crankshaft was LW 17740 (letter stamped into propeller flange), the crankshaft serial number was V5311 (hand etched on the propeller flange), see figure 9. Two, as-forged, numbers (17707 and V60) were present on the edges of two crankshaft webs.

Engine logbook entries on the 20 August 2002 and 21 October 2002, indicated that the crankshaft had been assessed for compliance with Lycoming Service Bulletins, SB 552 and SB 553 and associated Airworthiness Directives. On both occasions the Service Bulletins where found to be not applicable. A review of Lycoming Service Bulletins, SB 550, SB 552, SB 553, SB 566, SB 569, SB 569A, that address a material issue with Lycoming crankshafts, found that the engine model, TIO-540-V2AD, engine serial number, L8484-61A, and crankshaft serial number, V5311, were not listed.

Figure 9: Crankshaft part and serial number markings on the propeller flange

Evaluation

Crankshafts are subjected to a complex alternating loading condition during engine operation. During each revolution the crankshaft journals and crankshaft webs are stressed in bending and torsion. Because a crankshaft is subjected to a very large number of alternating stress cycles during its operational life, crankshafts are designed to have a life not limited by the initiation and growth of fatigue cracks.

The control of fatigue fracture is based on ensuring that the magnitude of alternating stresses, developed during engine operation, do not exceed the fatigue endurance strength of the crankshaft. The endurance strength of a crankshaft is a function of the geometry of the shaft (dimensions of journals, webs, and journal fillets), the presence of surface hardening, the presence of residual compressive surface stresses, and the crankshaft material properties. Reductions in the endurance strength of a crankshaft to levels below the design limit may erode safety margins and result in fatigue fracture during engine operation. Similarly, increases in the magnitude of alternating stresses developed during engine operation that exceed the design limit, may erode safety margins and result in fatigue fracture during operation.

ANALYSIS

Fracture sequence

Detailed examination of both fractures revealed that the crankshaft fractured first through the web between the No.4 main bearing journal and the No.4 connecting rod journal as a result of fatigue associated with alternating bending stresses. Fatigue cracking initiated in the fillet of the No.4 main bearing journal and propagated over a period of approximately 50 engine start/stop cycles. The orientation of the plane of fracture through the web allowed both sections of the crankshaft to continue to rotate as one. However, the fracture in the web resulted in increased alternating bending stresses being developed in the fillet of the No.3 main bearing journal, during continued engine operation, with a consequent initiation of fatigue cracking and crack propagation to final fracture over a short period of engine operation.

During the period of engine operation following the first fracture of the crankshaft, continued rotation of the crankshaft is possible. However, during this period of rotation, local deformation of the contacting regions of the fracture surfaces will result in a small circumferential displacement of one half of the crankshaft relative to the other half. This displacement will affect the ignition and valve timing of cylinders forward of the fracture (Numbers 1, 2, 3, 4), and through the effect on timing, reduce the performance of the engine. A reduction in engine performance will, finally, be manifested in propeller synchronisation problems as the power available is no longer sufficient to maintain propeller constant speed operation.

Fatigue initiation, no.4 main journal crankshaft web

It is evident that fatigue cracking in the No.4 main/No. 4 connecting rod crankshaft web initiated as a result of damage created in the fillet of the No.4 main bearing journal. This damage comprised circumferential scoring created through contact between the No.4 main bearing insert and the crankshaft during engine operation. It is also evident that the nature of contact between the journal fillet and bearing insert, was sufficient to create a series of short axially-oriented cracks through the localised heating of the hardened surface of the journal fillet.

The effect of main bearing insert contact with the main bearing journal fillets is known and is managed, in practice, by ensuring that inserts are retained in their housings.

Retention of main bearing inserts

Main bearings in a horizontally-opposed six-cylinder engine are subjected to loads arising from the need to react to crankshaft bending moments.

It is evident that the event that initiated the multiple fractures of the crankshaft and the engine failure was the creation of surface damage in the crankshaft No. 4 main bearing journal fillet radius through rubbing contact between the main bearing insert and the fillet radius. The factors that contribute to this event may be related to the retention of the main bearing insert in its housing and the crankshaft loading conditions that act to displace the bearing insert from its location in the bearing housing.

The forces that act to move main bearing inserts are related to the need to react to crankshaft bending moments, and frictional forces created by crankshaft rotation. The magnitude of crankshaft bending moments is related to the magnitude of inertia forces generated by the reciprocating masses and shaft rotation, and it is related to pressures created by each combustion event, brake mean effective pressures (bmep). The duration of operation at highest bmep for each flight is an important variable.

Operational experience has shown that the rearmost intermediate main bearing (No.4, Lycoming numbering convention) is the most sensitive to increases in the magnitude of crankshaft bending moment. This sensitivity is related to the placement of intermediate main bearings between two connecting rod journals, the distance of the bearing from the propeller, and the successive firing of cylinders on either side of the bearing – features of the layout and firing order of horizontally-opposed six cylinder aircraft engines.

The force that acts to retain the inserts in their housing is friction created by the interference fit of the inserts in the housing. The interference fit of main bearing inserts is created through a difference in the circumference of the inserts and the housing. The outer circumference of the inserts is manufactured to be greater than the circumference of the housing. During engine assembly, the bolts used to join the crankcase halves also compress the main bearing inserts and create a radial force between the inserts and housing. The combination of the radial force and the coefficient of friction between the contacting insert and housing surface creates the friction force that acts to retain the inserts in the housing.

Examination of the main bearing housings revealed that a jointing compound had been placed on the parting faces of each main bearing housing, see figure 10. The inclusion of any material between the parting faces of the main bearing housings will have the effect of reducing the difference in the circumference of the housing and the outer circumference of the bearing inserts, and will reduce the magnitude of the insert retention force.

Figure 10: An example of the nature of material placed between the parting faces of each main bearing housing

Examination of the main bearing housings also revealed that the surfaces had been restored by welding, see figures 11 and 12. Weld restorations of this nature are based on depositing weld metal (a lower strength material compared to the crankcase material) and re-boring the housing.

The need for main-bearing housing weld restoration indicates that insert movement has occurred in the past. However, the magnitude of the factors that contribute to insert movement and their synergy have not resulted in insert movement to the extent that crankshaft fillet damage has occurred in this engine

Figure 11: One half of the No.4 main bearing housing, etched to reveal the extent of weld repair

Figure 12: Weld repair crankcase marking, CG5638

FINDINGS

Contributing factors

1. The left engine of VH-IGW, Lycoming TIO-540-V2AD, failed during flight as the result of the multiple fracture of the crankshaft.
2. The fracture of the crankshaft involved fatigue crack initiation and growth (over a period of approximately fifty flights) to final fracture of the crankshaft web between the No.4 main bearing journal and the No.4 connecting rod journal. Subsequently, the crankshaft web between the No.3 main bearing journal and No.3 connecting rod journal fractured as the result of fatigue crack initiation and growth of a short period of time during the last flight.
3. The fracture sequence was initiated by the damage created through the sliding contact between the No.4 main bearing insert and the fillet region of the No.4 main bearing journal.
4. The movement of main bearing inserts during engine operation is a function of the magnitude of the forces that resist movement (created by establishing an interference fit) and the magnitude of forces acting to move the insert (crankshaft bending moments). One factor that lowers the resistance of an insert to movement, the inclusion of material between the parting faces of the main bearing housings during engine assembly, was identified. However, other factors that may contribute to bearing insert movement, such as the magnitude of crankshaft bending moments could not be established from an examination of the physical evidence.

Other safety factors

1. The restoration of the surfaces of the main bearing housings indicated that main bearing insert movement was not an isolated case.