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Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Aviation Occurrence Report - 200505952

Final

In-flight engine fuel leak

Nadi, Fiji

Boeing Company 747-438, VH-OJD

18 November 2005

Australian Government

Australian Transport Safety Bureau

Aviation Safety Investigation Report
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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
200505952	November 2006	13	1 921164 15 8

Publication title

In-flight Engine Fuel Leak, Nadi Fiji, Boeing Company 747-438, VH-OJD, 18 November 2005

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Abstract

While on a scheduled passenger flight from Brisbane, Australia, to Los Angeles, US, the crew of the Boeing Company 747-438 aircraft, registered VH-OJD, observed excessive fuel use by the number-three engine. After confirmation that the engine had a fuel leak, the flight crew conducted and in-flight engine shut-down and diverted the aircraft to Sydney.

Inspection of the engine found a fuel manifold drain line had fractured. Detailed examination of the drain line revealed that it had been subjected to high cycle fatigue (HCF), which led to its failure. The HCF was attributed to harmonic resonance from a combustor rumble of unknown origin.

As a result of extensive testing of the engine, the manufacturer redesigned the drain line and reviewed its attachment (clipping) arrangements.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations. 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.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and, where applicable, relevant international agreements. The object of a safety investigation is to determine the circumstances to prevent other similar events. The results of these determinations form the basis for safety action, including recommendations where necessary. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

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 findings. 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.

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. While the Bureau issues recommendations to regulatory authorities, industry, or other agencies in order to address safety issues, its preference is for organisations to make safety enhancements during the course of an investigation. The Bureau is pleased to report positive safety action in its final reports rather than make formal recommendations. Recommendations may be issued in conjunction with ATSB reports or independently. A safety issue may lead to a number of similar recommendations, each issued to a different agency.

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

On 18 November 2005, approximately 4 hours into a scheduled flight from Brisbane, Australia, to Los Angeles, US, while overflying Nadi, Fiji, the crew of the Boeing 747- 438 aircraft, registered VH-OJD, noticed excessive fuel usage by the aircraft's number-three engine.

After a visual check of the number-three engine from a cabin window, a fuel leak was confirmed. The flight crew, following the non-normal procedure for engine fuel leak, conducted an in-flight shut down of the number-three engine. Discussion with the operator's maintenance watch resulted in a decision to return the aircraft to Sydney.

Subsequent examination of the number-three engine found that the fuel manifold drain line had fractured adjacent to one of the end connectors (Figure 1). The drain line was attached to the engine fuel manifold by a threaded connector which was welded onto the line. The line was then held in position at three locations along its length with 'P' clips.

The fractured drain line was removed and examined by the engine manufacturer and the Australian Transport Safety Bureau (ATSB).

Figure 1: Fuel manifold drain line[1]

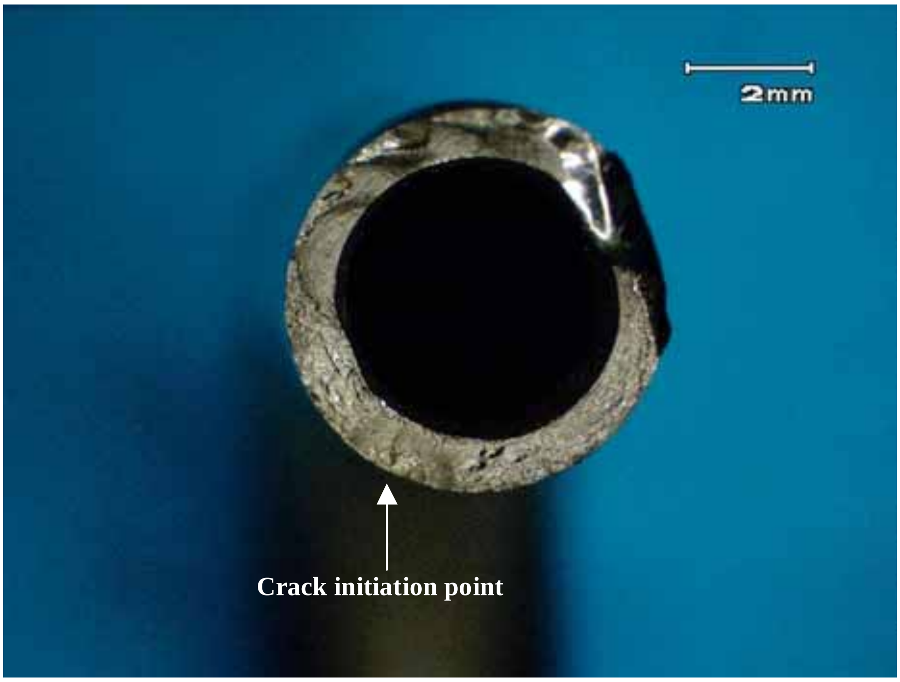
1 Photograph was provided by the operator.

Examination

A detailed examination of the drain line's fracture surface revealed it had occurred within the weld heat affected zone (HAZ)[2] between the connector and the drain line (on the connector side). The fracture had been initiated by a fatigue crack on the outside diameter of the drain line, which progressed until it reached sufficient size for a rapid failure to occur (Figure 2).

Scanning Electron Microscopy was used to characterise the fracture surface, revealing closely spaced striations consistent with high cycle fatigue (HCF). The microstructure of the fractured HAZ was also examined and compared with an intact weld from another location on the drain line. The material was typical of a stainless steel weld deposit, and did not exhibit porosity, cracking or inclusions.

Figure 2: Fracture surface



Teflon tape had been applied to three areas of the line. The tape was applied to help provide a positive grip by the 'P' clips and minimise vibration and chafing during engine operations. The exact location of the clips was detailed by the engine manufacturer and was designed to maximise their effectiveness.

Examination of the drain line found all three Teflon taped areas were worn, with some areas worn through to the drain line surface. The tape edges were frayed and lifting and it was noted that the tape had been wrapped much wider than the clips they were supporting. There was evidence of chafing on the drain line adjacent to two of the taped areas (Figures 3 and 4). The drain line was checked against a build

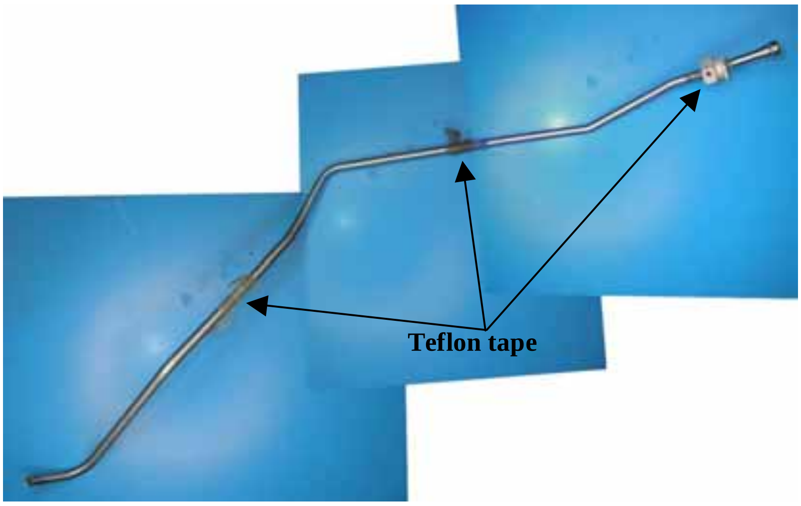
2 The heat-affected Zone (HAZ) is the region of the base material, adjacent to the weld, that may have had its microstructure and properties affected by the heat of the welding process. *Callister, W.D (2000), Materials Science and Engineering: An Introduction 5th edn, John Wiley and Sons, New York.* and *www.enwikipedia.org/wiki/heat-affected_zone*

jig[3] and although it was found to deviate slightly in shape from design specifications, this deviation was not considered to be sufficient to contribute to the failure. It could not be determined whether the deviation was pre-existing (at manufacture) or the result of fitment to the engine.

An examination was made of the 'P' clips for condition, location, clearance and alignment. Some minor discrepancies were found (including spacers incorrectly positioned).

The operator carried out an inspection of the drain line clipping arrangements on the rest of the fleet and some anomalies similar to the occurrence engine were found. Those anomalies however, appeared to have had no adverse effect to the drain lines' serviceability. A fleet-wide inspection of the drain line welds for cracking was also conducted, with no defects found.

Figure 3: Drain line showing Teflon tape



3 A template used for shaping the pipe.

Figure 4: Chafing adjacent to taped areas

Previous occurrence

The operator reported that it had experienced a similar failure of the fuel manifold drain line on the same engine three days prior to this event, during a scheduled flight from Auckland, New Zealand, to Los Angeles, US. On that occasion, the flight crew returned the aircraft to Auckland, where the drain line was replaced and the aircraft returned to service. Maintenance documentation indicated that a new drain line had been fitted and leak tested in accordance with the maintenance manual procedures.

That line was examined by the ATSB and displayed a similar HCF failure mode as the line in this later occurrence. The only variation was that the fatigue crack initiation had occurred from the inside diameter of the drain line.

In addition to the two failures experienced by this operator, one other operator had reported similar failures. That operator had experienced three HCF fractures to fuel manifold drain lines, attributed to two aircraft engines within its fleet.

Engine testing

As a result of the fracture of the two drain lines on the number-three engine, the operator removed the engine from the aircraft, and with the assistance of the engine manufacturer, conducted a number of tests to try to identify the reason for these failures. The tests included vibration/stress testing which found the drain line was being subjected to peak stresses (during certain engine operational phases) of up to 10 times their anticipated levels. These high levels of vibration/stress were attributed to an adverse harmonic resonance created by combustor rumble[4]. The origin of the combustor rumble could not be identified.

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4 (combustor) 'rumble'- An unstable pulsing at low frequency [300-700Hz] in a jet engine. Gunston, B. (2004). *The Cambridge Aerospace Dictionary.* UK: Cambridge University Press.

During the testing, the manufacturer tried various clipping arrangements on the drain line, giving varying degrees of change to the stress levels recorded. Experimentation with different shape drain lines was also trialled until an acceptable vibration/stress level was achieved.

ANALYSIS

The high fuel usage observed on the number-three engine was the result of the fracture of the fuel manifold drain line. Adverse harmonic resonance created by combustor rumble, led to high cycle fatigue and the eventual overload failure of the drain line. The exact origin of the combustor rumble could not be determined.

Examination of the drain line showed evidence of wear to the line's Teflon taped areas, indicating a high level of vibration between the clips and the drain line had occurred, which may have been the result of inadequate tape thickness. The chafing observed adjacent to the taped areas would indicate possible misalignment of the clips or incorrect routing of the drain line on the engine, leading to contact with adjacent parts.

It would be expected that the level of static and dynamic stresses applied to the fuel manifold drain lines would vary from engine to engine, due to variation in the alignment of the fuel lines and engine components. The harmonic resonance created in individual engines would also vary. However, levels of vibration/stress experienced under normal operation should not lead to the failure of components within the system.

The experimentation by the manufacturer with changing the clipping arrangements on the drain line produced limited success in relieving the high stress loads. As a result the manufacturer varied the drain line's shape, until a design was found that reduced the stress loads to an acceptable level. That improvement did not eliminate the combustor rumble, only the effect it had on the system.

The low percentage of engines experiencing this type of problem (only three reported to the manufacturer) would indicate it is unique to a few specific engine/component(s) and not a general design flaw.

SAFETY ACTIONS

Engine manufacturer

As a result of this investigation, the engine manufacturer re-designed the fuel manifold drain line for replacement on all applicable engines under a service bulletin (RB211-SB71-F152) released on 4 August 2006. This service bulletin also provides more detailed information to operators regarding fuel line clipping arrangements on these engines.

Operator

After the incident the operator conducted a fleet-wide inspection of the welded joints on the drain lines for evidence of cracking. No defects were found. The operator also subjected the incident engine to extensive testing with the engine manufacturer to identify the underlying cause of the combustor rumble. However, at the time of releasing this report, no determination had been made. On completion of the testing, the engine was scheduled to undertake a full refurbishment before being returned to service.

The operator also indicated that it would incorporate the manufacturer's service bulletin and replace all drain lines within their fleet on receipt of the new parts.