



Main landing gear failure – Melbourne Aerodrome

20 October 2009

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Abstract

Following landing at Melbourne Aerodrome on 20 October 2009, the crew of a Boeing 737-8FE aircraft, registered VH-VUI, reported that the aircraft was difficult to taxi, requiring more power and steering input than usual. A subsequent visual inspection revealed the number-4 wheel to be oriented at an angle with respect to the axle and, following disassembly, it was discovered that the inner wheel hub and bearing mount had broken away from the wheel assembly.

Examination of the wheel revealed that the inner hub had failed from fatigue cracking that had initiated in the area adjacent to the bearing cup.

Fatigue cracking of the inboard bearing cup bore was an emerging issue for the 737 wheel type at the time of the failure. In May 2009, the wheel manufacturer issued a temporary revision to the *Standard Practices Manual*, with an updated inspection method for the susceptible area, and the aircraft manufacturer had issued a service letter in August 2009 with a periodic inspection requirement. The operator was in the process of reviewing and incorporating the changes into their own maintenance schedules at the time of the incident.

Immediately following the occurrence, the operator performed a fleet-wide examination, identifying those wheels potentially at risk of a similar failure. Subsequently, ten wheels were removed from service for immediate inspection. The operator also implemented an ultrasonic inspection program for wheels with over 4,000 cycles at every tyre change.

The manufacturers of both the aircraft and the wheel released updated information to operators and maintainers in early 2010, which included a revision to the recommended inspection interval.

FACTUAL INFORMATION

History of the flight

On 20 October 2009, a Boeing 737-8FE aircraft, registered VH-VUI, departed Adelaide, South Australia on a scheduled passenger service to Melbourne, Victoria. After arrival at Melbourne Aerodrome at approximately 0900 Australian Eastern Daylight-saving Time (EDT¹), the flight crew reported difficulty in taxiing the aircraft, with more power and steering input required than usual. The aircraft was able to continue to the gate and disembark the passengers in the normal manner.

Post flight examination

A visual inspection of the landing gear, following arrival at the gate, revealed the number-4 main landing gear wheel (right outboard) to be oriented at an unusual angle with respect to the axle. The wheel was subsequently removed, and the inner wheel hub and bearing mount was found to have detached from the wheel assembly (Figure 1).

The operator later reported to the Australian Transport Safety Bureau (ATSB) that some contact and wear damage had been observed on the brake assembly. No damage was observed on the right main landing gear axle. The number-3 wheel assembly was replaced as a precautionary measure and the number-4 brake assembly replaced due to damage sustained during the wheel failure.

1 The 24-hour clock is used in this report to describe the local time of day, Australian Eastern Daylight-saving Time (EDT), as particular events occurred. EDT was Coordinated Universal Time (UTC) + 11 hours

Figure 1: Right main landing gear showing fractured hub after removal of the wheel (image provided by the operator)



Aircraft information

Table 1: Aircraft details

Manufacturer	The Boeing Company
Model	737-8FE
Serial number	34441
Year of manufacture	2006
Date first registered in Australia	1 August 2006
Maximum take-off weight	79,015 kg

Wheel information

General

The 737 aircraft was designed with a tricycle type landing gear with air/oil shock struts. The left and right main landing gear absorb landing forces and support most of the aircraft weight when the aircraft is on the ground. The main landing gear also transmits the braking forces to the aircraft structure. Each main landing gear has two wheel assemblies.

The main landing gear wheels are comprised of inner and outer halves, held together with tie bolts (Figure 2). The internal diameter of each inboard

wheel assembly was shot peened² during manufacture; however, the manufacturing specifications did not require the shot peening to extend beyond the bearing bore to cup intersection tangency.

Figure 2: Schematic diagram showing inboard and outboard wheel halves and the approximate location of the failure origin (circled)

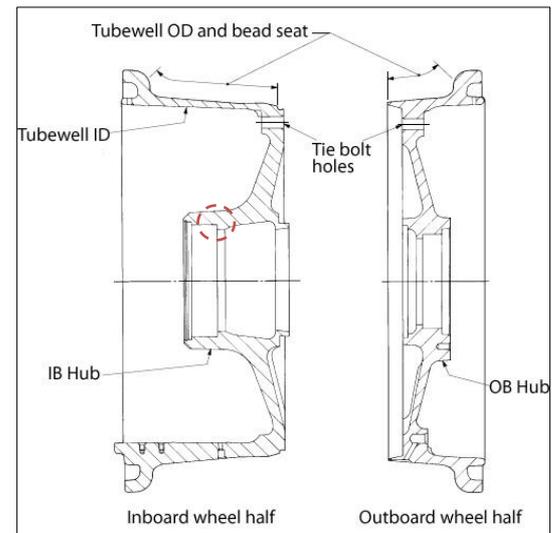


Table 2: Number-4 wheel assembly details

Manufacturer	Honeywell International
Wheel part number	2612311-1
Inboard assembly	2615480
Wheel serial number	B8154
Date of manufacture	April 2005
Total hours/cycles since new	9,853 hrs / 5,711 cycles
Total hours/cycles since overhaul	1,775 hrs / 701 cycles
Date of last overhaul	18 February 2009
Total tyre changes since new	23
Date of last tyre change	14 September 2009

² Shot-peening is a process whereby the surfaces of a component are subject to multiple and repeated light impacts (using steel shot or similar). The process creates a shallow surface layer of compressively-deformed material that can improve the resistance to fatigue crack initiation.

Maintenance history

The wheel was last overhauled on 18 February 2009, at its 21st tyre change. Wheel overhaul was completed in accordance with the component maintenance manual (CMM) and included:

- visual inspection
- eddy current inspections of the bead seat and tube well outer diameter, and the wheel halves at designated areas
- replacement of the tie bolts.

The most recent tyre change (number 23) occurred on 14 September 2009, and included visual examination and eddy current inspection of the bead seat and tube well outer diameters (as shown in Figure 2).

The operator stated that the wheels in its inventory were overhauled in accordance with the schedule provided in the CMM, whereby full overhauls were completed at every 7th tyre change.

The operator was not aware of any repairs to the wheel during its service history.

Examination of the failed wheel

Initial inspection of the wheel showed the hub section to have fractured away from the web of the inboard wheel half, with cracking extending through the transition radius between the two regions (Figure 3).

Figure 3: Inboard wheel segment, showing missing hub area



Examination of the separated hub section revealed that the failure was characterised by two predominantly axial planes of fracture. These transitioned into a circumferential fracture within the hub-to-web transition radius region (Figure 4).

Figure 4: Fractured hub segment



The axial fracture surfaces showed an inclined plane of darker, stained fracture within the hub wall. That location was coincident with the base of the inboard bearing seat. This area was subsequently cleaned and a closer examination showed clear evidence of fatigue fracture.

Several planes of fatigue fracture were evident; each of which were characterised by beach marks. The beach marks radiated outwards from an origin area at the inner bearing seat radius. The fatigue fracture zone extended for approximately 80mm in an inboard direction beneath the bearing seat, and 26mm towards the inner hub end (Figures 5 and 6).

The remainder of the hub fracture surfaces appeared dull grey in colour and exhibited a rough fibrous appearance, considered typical of ductile overstress failure.

Figure 5: Radial fracture surface showing likely origin of failure at the bearing seat.

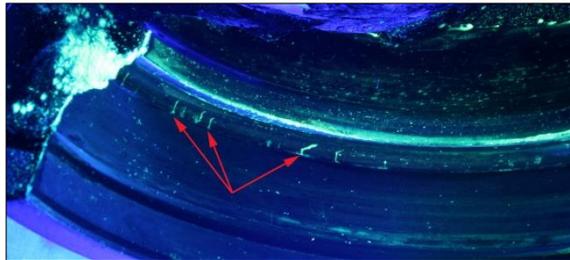


Figure 6: Same as Figure 5 from the opposite side of the segment.



To identify the presence of any further cracking, the remaining sections of inboard hub were examined using a fluorescent penetrant inspection technique. Multiple indications of other radial and circumferential cracks were noted within the region of the bearing bore radius (Figure 7).

Figure 7: Radial cracks identified during fluorescent penetrant inspection



This area was then examined at high magnification and confirmed the existence of additional cracking. The cracks were oriented in the radial direction and were directly adjacent to the shot peened region (Figure 8).

Figure 8: Axial cracks adjacent to the shot peened area.

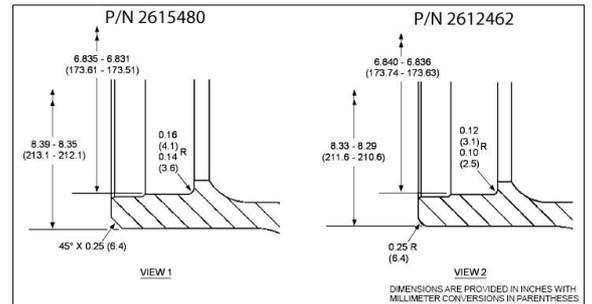


Background to the occurrence

The wheel manufacturer introduced the inboard wheel half (P/N 2615480) in 2005, as a revision to wheel assemblies P/N 2612311-1, to address a prior issue of bearing cups working loose. Loose bearing cups could result in mechanical damage,

which may allow the hub to fracture or the bearing to fail. The revised inboard wheel half incorporated an increased interference fit³ between the wheel bearing bore and bearing cup/sleeve assembly, and slight geometry changes to the hub to make it stiffer (Figure 9). These changes commenced as of wheel serial number B7900.

Figure 9: Comparison of revised (left) and prior (right) inboard wheel half assemblies (from CMM 32-40-14 Rev 7)

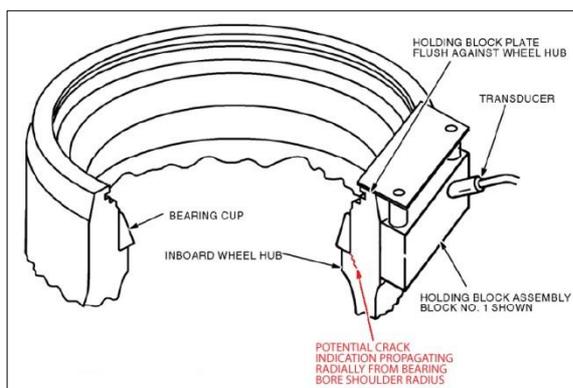


In 2008, the wheel manufacturer began receiving reports of hub fractures and cracking on the post-2005 inboard wheel halves. Analysis of these failures found that the hubs were fracturing from fatigue cracking that had developed in the transition between the bearing bore and the thrust shoulder radius. The affected wheels typically had about 4,000 flights cycles (20 tyre changes) when the cracks were found.

Following this, the wheel manufacturer developed an ultrasonic inspection method to check for cracks in the bearing bore (Figure 10). This improved inspection method was released as a temporary revision to their Standard Practices Manual (SPM Temporary Revision 32-1) on 1 May 2009. The Service Information Letter, (Publication Number D200904000037), accompanying the change to the SPM stated that inboard wheel halves that exhibited a service history of fatigue cracking at this location should be inspected using this procedure. Of note however, was that there were no corresponding amendments to the updated wheel CMM released in June 2009.

³ An interference fit is achieved when the male component dimensions slightly exceed the female component dimensions - the resultant friction providing a force to retain the components together.

Figure 10: Potential location of crack and ultrasonic test method (SPM).



In addition to the SPM revision, the wheel manufacturer implemented a design/manufacturing change, to extend the shot peening to cover the entire bearing bore. The changes were due to commence at the production of wheel serial number B15419.

In August 2009, the aircraft manufacturer issued Service Letter 737-SL-32-162, recommending that operators perform periodic ultrasonic checks of the post-2005 wheels, in accordance with the revised SPM-TR-32-1, and to the following schedule:

- new to 10 tyre changes: ultrasonic inspection not required
- 11 to 20 tyre changes: ultrasonic inspection every other tyre change
- 21 and beyond tyre changes: ultrasonic inspection every tyre change.

Prior to the temporary SPM revision and the Service Letter, examination of the wheel halves could be performed using either eddy current, ultrasonic or fluorescent penetrant inspection methods (at the maintainer's discretion). The nature of eddy current and fluorescent penetrant inspection methods meant that inspection of the susceptible bearing bore areas was only possible after the bearing cups were removed.

Maintenance procedures

The operator reported to the ATSB that it had assessed the May 2009 changes to the wheel manufacturer's SPM using their internal engineering change evaluation (ECE) system. In view of the absence of any supporting changes to the wheel CMM, and the lack of any recorded history of cracking in the affected area, the

operator determined that no further assessment or work was required.

After the later release of the August 2009 Service Letter by the aircraft manufacturer, the operator re-assessed the situation in accordance with its risk management procedures⁴ and subsequently commenced preparations to implement the ultrasonic inspection method. This included discussions with the wheel manufacturer and non-destructive testing (NDT) provider seeking information in relation to implementation of the new procedure. The NDT provider had indicated that the new procedures would require the acquisition of new and specialised inspection hardware.

The last tyre change on wheel SN B8154 occurred during this period. Maintenance records for the subject wheel showed that at tyre change number 23 on 14 September 2009, specific ultrasonic inspection of the bearing bore shoulder radius had not been carried out.

Similar occurrences

During the course of the investigation, the ATSB became aware of a similar main landing gear hub failure on a Boeing 737NG aircraft operated by another Australian operator. A photograph supplied by the operator indicated that the failure mechanism was similar to the one involving VH-VUI. The failure occurred on 30 April 2010, and was discovered during a post-flight walk-around inspection.

This operator has since implemented ultrasonic inspection of the affected wheel hubs at each tyre change after the 11th tyre change.

ANALYSIS

Component failure

Failure of the right outboard main landing gear wheel (serial number B8154) of VH-VUI occurred as a result of the initiation and growth of fatigue cracking through the inboard hub. The ATSB investigation identified the initiation of cracking at the bearing bore shoulder radius; the cracking propagating radially until final fracture occurred

⁴ Internal procedures for the assessment of non-mandatory service information to determine priorities for recommended/suggested action.

via overstress. Hub fracture resulted in the complete separation of the inner hub from the wheel and produced the aircraft steering difficulties reported by the flight crew.

The hub examination also revealed the presence of multiple smaller cracks around the entire circumference of the bearing bore shoulder radius. Those cracks appeared to have initiated at the region adjacent to the shot peened surface.

The part and serial numbers of the subject wheel identified the component as one of the post-2005 wheels that had a previously-identified susceptibility to fatigue cracking at the bearing bore shoulder radius.

Wheel inspection

The aircraft and wheel manufacturers' were aware of an emerging issue relating to the propensity for the post-2005 wheel design to initiate fatigue cracks at the bearing bore shoulder radius of the inboard wheel hub. The wheel manufacturer had implemented a number of changes to address the problem, including the use of a through-thickness test method (ultrasonic testing) and a design/manufacturing change to extend the shot peening into the susceptible area.

While the update to the Standard Practices Manual (SPM Temporary Revision 32-1) detailed the ultrasonic inspection; the accompanying service information letter advised that wheel halves *with a history of fatigue cracks in the transition between the bearing bore and thrust shoulder radius* should be inspected using this procedure or equivalent. Considering that at the time that this information was released, the operator had no experience or history of cracking being detected in the bearing bore area of the wheels within its inventory, the decision not to introduce the additional ultrasonic inspection was reasonable.

Upon the August 2009 introduction of service letter 737-SL-32-162, the operator had commenced preparations for the implementation of the recommended schedule of inspections, and had discussed the issue with the wheel manufacturer and NDT service provider. The last opportunity to detect the cracking before it resulted in wheel failure was during the 23rd tyre change on 14 September 2009. While that occurred some 4 weeks after receipt of the service letter, the logistics involved in sourcing the

necessary test equipment and training operators meant that the technique was not yet brought to an operational status at the time of that last tyre change.

FINDINGS

From the evidence available, the following findings are made with respect to the failure of the right outboard main wheel assembly involving VH-VUI and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The post-2005 main landing gear wheel design had shown a susceptibility to fatigue cracking at the inner hub bearing bore shoulder radius. [*Minor safety issue*]
- A fatigue crack had initiated at the shoulder radius at the bottom of the bore for the bearing cup and propagated into the inner wheel hub and bearing mount.
- The fatigue cracks developing within the wheel hub were not detected during the tyre change inspection carried out in September 2009.
- At the time of the last tyre change, crack initiation at the bearing bore shoulder radius was an emerging issue with no requirement for mandatory inspection of this area during a tyre change. [*Minor safety issue*]
- The fatigue cracking within the wheel hub propagated to critical size, whereupon the inboard bearing hub fractured away from the flange – rendering the wheel unserviceable and damaging the associated brake componentry.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal

safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Wheel assembly manufacturer

Susceptibility of wheel design to fatigue cracking

Minor Safety Issue

The post-2005 main landing gear wheel design had shown a susceptibility to fatigue cracking at the inner hub bearing bore shoulder radius.

Action taken by the wheel manufacturer

The wheel manufacturer made a change to the design of new production wheel components, incorporating shot peening of the entire bearing bore area to help prevent the fatigue cracks from developing. This change was introduced at wheel assembly serial number B15419. The improved wheels were intended for delivery on new aircraft at line number 3099; scheduled for November 2009.

No mandatory requirement for wheel inspection

Minor Safety Issue

At the time of the last tyre change, crack initiation at the bearing bore shoulder radius was an emerging issue with no requirement for mandatory inspection of this area during a tyre change.

Action taken by the wheel manufacturer

Following the occurrence, the wheel manufacturer released Service Bulletin 2612311-32-003 in February 2010, which provided specific non-destructive inspection requirements for wheel part number 2615480. The Service Bulletin required mandatory non-destructive inspection of wheel halves SN B7900-B15418 to be performed on a yearly basis or every fifth tyre change.

ATSB assessment of response/action

The ATSB is satisfied that the action taken by the wheel assembly manufacturer adequately addresses the safety issue.

Aircraft manufacturer

No mandatory requirement for wheel inspection

Minor Safety Issue

At the time of the last tyre change, crack initiation at the bearing bore shoulder radius was an emerging issue with no requirement for mandatory inspection of this area during a tyre change.

Action taken by the aircraft manufacturer

In November 2009, the aircraft manufacturer updated the inboard hub fracture issue to a safety service related problem (safety-SRP) and advised operators to incorporate the recommended inspections and inspection intervals as soon as practical.

The aircraft manufacturer released a further Service Bulletin (SB-737-32-1444, issued 8 April 2010) and an update to its previous Service Letter (737-SL-32-162-A, issued 4 May 2010) that summarised the issue, and contained the recommended non-destructive checks and intervals. The service bulletin urged operators to perform inspections as per the Honeywell Service Bulletin and standard practices manual mentioned previously.

ATSB assessment of response/action

The ATSB is satisfied that the action taken by the aircraft manufacturer adequately addresses the safety issue.

Aircraft operator

No mandatory requirement for wheel inspection

Minor Safety Issue

At the time of the last tyre change, crack initiation at the bearing bore shoulder radius was an emerging issue with no requirement for mandatory inspection of this area during a tyre change.

Action taken by operator

Immediately following the occurrence, the operator reviewed the information supplied by the wheel and aircraft manufacturers and assessed the wheels on their fleet. Subsequently, the operator elected to remove ten wheels from service that fell within an identified risk profile

The operator has further reported to the ATSB that since this occurrence, it has altered its non-destructive wheel inspection procedure to include an ultrasonic inspection in accordance with Honeywell Standard Practices Manual, ATS Number 32-49, Temporary Revision No 32-1, dated 1 May 2009. Initially, the operator performed the inspection at each tyre change after the 11th change. However, following the results of a number of inspections, and in conjunction with the Honeywell Service Bulletin (2612311-32-003), the operator has since altered the inspection in line with the Service Bulletin and performs an ultrasonic inspection of the bearing bore at every fifth tyre change.

As a result of the occurrence, the operator also performed a review of its engineering change evaluation procedure which resulted in changes to the process flow chart to include additional steps and a more structured risk assessment.

ATSB assessment of response/action

The ATSB is satisfied that the action taken by the aircraft operator adequately addresses the safety issue.

SOURCES AND SUBMISSIONS

Sources of Information

- Aircraft operator
- Maintenance provider
- The Boeing Company
- Honeywell Aerospace

References

- Fleet team digest article (FTD), 737NG-FTD-32-08008, "Inboard Hub Fractures on Honeywell Main Gear Wheels", last revision 20 April 2010.
- Boeing Service Bulletin 737-32-1444, "LANDING GEAR – Tires and Wheels – Main

Landing Gear Inboard Wheel Half Inspection", April 08, 2010.

- Boeing Service Letter (SL), 737-SL-32-162-A, "Inboard Hub Fractures on Honeywell Main Gear Wheels", 4 May 2010.
- Honeywell service information letter (SIL) D200904000037, "Inboard Wheel Half Ultrasonic Inspection," 01 May 2009.
- Honeywell Standard Practices Manual, "Temporary Revision No. 32-1", 1 May 2009.
- Honeywell Component Maintenance Manual (CMM) 32-40-14, "737-600/700/800/900/BBJ Main Wheel Assembly, Part Number 2612311-1, Revision 7", 5 June 2009.
- Honeywell Service Bulletin 2612311-32-003, "Landing Gear – Main wheel assembly – Non destructive Testing (NDT) Inspection of Inboard Wheel Half, PN 2615480 and PN 2612462, Hub for Crack Indications in the Bearing Bore Area", issued 5 February 2010.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the Civil Aviation Safety Authority, the aircraft operator, the component manufacturer and the aircraft manufacturer.

Submissions were received from all parties. The submissions were reviewed, and where considered appropriate, the text of the report was amended accordingly.