Australian Government
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ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation AO-2009-047
Final

Nose landing gear axle fracture VH-VBA, Boeing 737-7Q8 Melbourne aerodrome, Victoria 25 July 2009

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Nose landing gear axle fracture - VH-VBA - Boeing 737-7Q8 - Melbourne aerodrome, Victoria - 25 July 2009

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Abstract

On 25 July 2009, a Boeing 737-7Q8 aircraft, registered VH-VBA, was taxiing toward the runway for departure at Melbourne aerodrome, Victoria, when the crew reported hearing a loud thud from the airframe. The crew of a passing company aircraft advised the crew of VH-VBA that they had lost a nose wheel tyre. It was subsequently discovered that the right wheel had detached from the nose landing gear (NLG) as a result of a fracture of the axle.

An Australian Transport Safety Bureau investigation of the NLG failure determined that the nose wheel had separated as a result of the initiation and propagation of a fatigue crack through the right, inboard bearing journal. The fatigue crack had originated under the influence of residual stresses in the steel surface associated with grinding damage during manufacture, and its initiation was probably hydrogen-assisted from plating processes applied to the journal bearing surfaces.

As a result of the occurrence, the aircraft operator conducted an immediate, fleet-wide inspection of axles with similar service history. To reduce the likelihood of future possible axle failures, the aircraft manufacturer conducted an audit of the landing gear supplier’s processes and production records, in an attempt to establish the extent of the grinding problem. The aircraft manufacturer also released a communication to 737 operators and maintenance providers, detailing enhanced inspection recommendations for the identification of grinding damage.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

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

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB’s investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

FACTUAL INFORMATION

Occurrence brief

On 25 July 2009 at approximately 0825 Eastern Standard Time[1], a Boeing 737-7Q8 aircraft, registered VH-VBA, was taxiing for departure at Melbourne aerodrome, Victoria, when the crew reported hearing a loud thud from the airframe. The crew of a passing company aircraft subsequently advised that VH-VBA had lost a nose wheel tyre.

The aircraft was stopped on the taxiway to allow company engineers to inspect the nose landing gear. It was found that the right nose landing gear (NLG) axle had fractured and the entire right nose wheel had separated. The aircraft was taxied back to the gate and passengers disembarked. There were no injuries to passengers or crew and no further damage sustained by the aircraft.

Aircraft information

- Manufacturer: The Boeing Company
- Model: 737-7Q8
- Serial number: 28238
- Registration: VH-VBA
- Year of manufacture: 2001
- Date first registered in Australia: 4 April 2001

Nose landing gear description

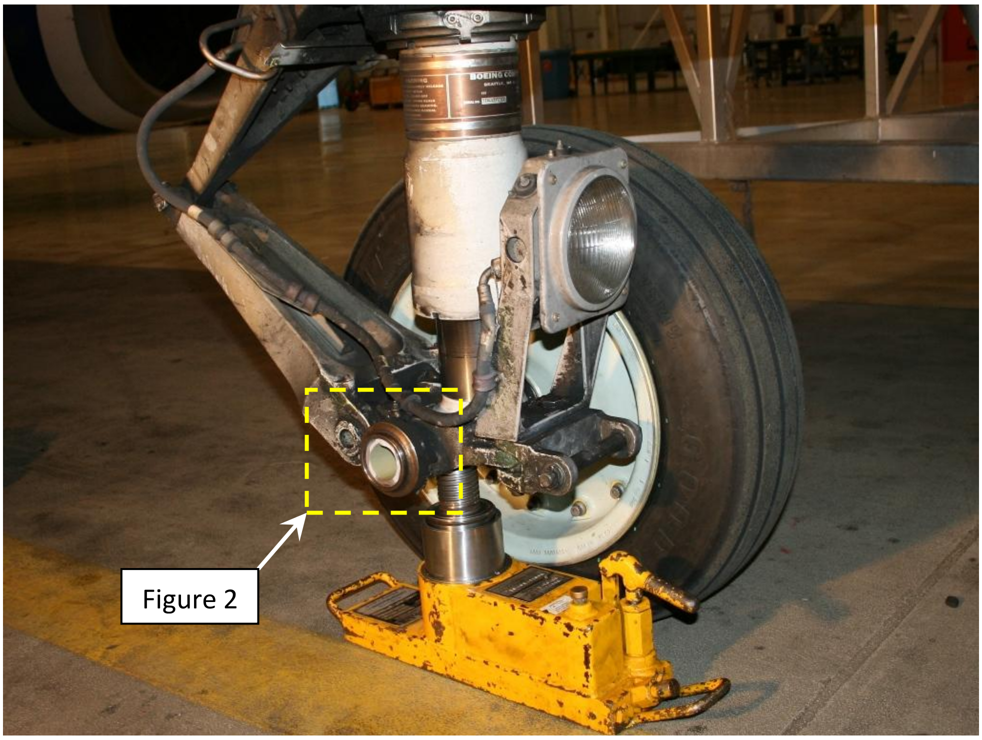
The 737 nose landing gear (Figure 1) was a telescopic oleo arrangement, comprised of:

- an airframe-mounted outer cylinder assembly
- an inner cylinder assembly that slid vertically within the outer cylinder
- a torsion link unit joining the two.

Sliding movement of the cylinders was resisted and damped by compressed nitrogen and oil, which provided the shock absorption properties of the gear. The two nose gear axles were part of an integral forged assembly at the base of the inner cylinder. Each axle consisted of an inner and outer hard chromium plated journal surface, upon which the corresponding wheel bearings were supported.

1 The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST) as particular events occurred. EST was Coordinated Universal Time (UTC) +10 hours.

Figure 1: Nose landing gear with fractured axle indicated



Nose landing gear maintenance information

- Nose landing gear part number: 001A6200-5
- Nose landing gear serial number: T11433Y0858
- Inner cylinder assembly part number: 162A1120-2
- Inner cylinder assembly serial number: BFG 1705
- Inner cylinder cycles since new: 18355
- Inner cylinder cycles since last overhaul: 1751

A review of maintenance records showed that all required maintenance procedures had been carried out on the landing gear assembly. The last overhaul was conducted on the inner cylinder in 2008, and as part of that overhaul, the assembly had been inspected using magnetic particle inspection (MPI), with no reported defect or crack indications. Measurements of the chromium plated bearing journal surfaces were within tolerance and there was no evidence of rework to these areas. There was, however, a re-application of cadmium plating in the axle flange area, (separate from the bearing journals) along with associated post-plate baking.

In response to previous NLG axle fractures on 737 aircraft, the manufacturer released a service letter in July 2008 regarding the implementation of additional inspections for corrosion of the axle underneath the bearing spacer. Maintenance records showed that the aircraft operator had carried out this inspection on the subject NLG in November 2008, with no defects reported.

Nose landing gear axle examination

The NLG inner cylinder right axle had fractured through the chromium plated inner-bearing journal surface, underneath the area covered by the wheel bearing spacer (Figure 2). The outboard section of axle remained in, and was subsequently recovered with the right wheel. Both wheel bearings were in good condition and the wheel nut was lock-wired in place.

Figure 2: Axle fracture with bearing spacer in situ

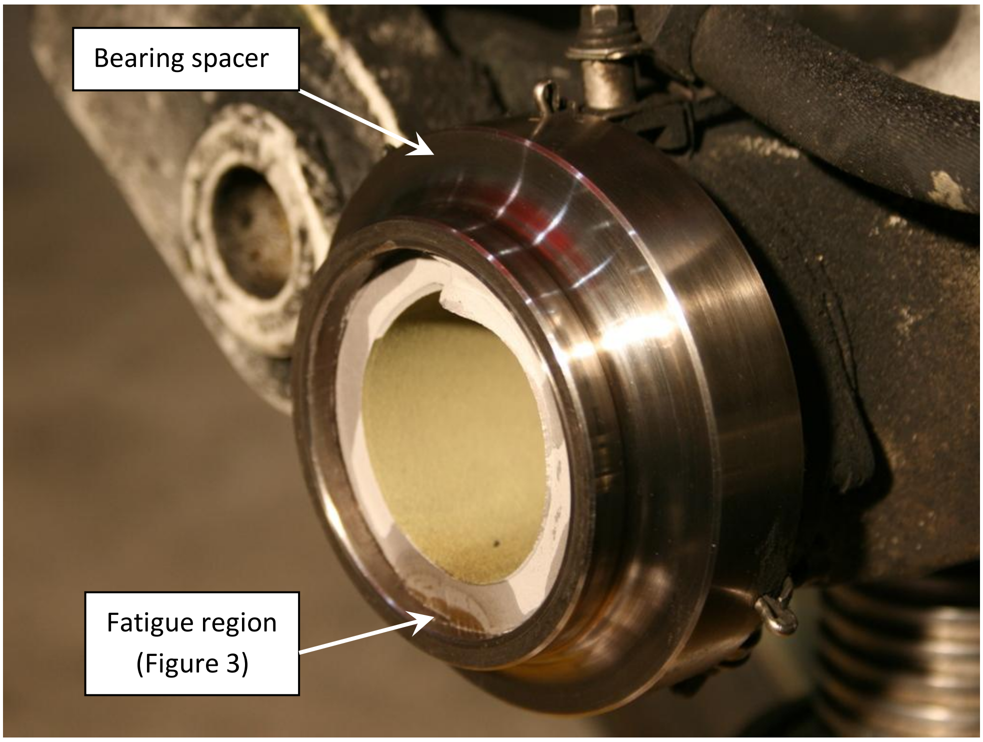


Figure 3 shows the fatigue portion of the axle fracture in detail. A series of clear crack progression (beach) marks were observed radiating outward from the 6 o'clock position (underside) of the axle, consistent with a fatigue fracture originating from the exterior surface. Several ratchet marks[2] were also present, which indicated multiple crack initiation sites. The final fracture had occurred by ductile overstress after the fatigue cracking had extended through approximately 15 to 20% of the total axle cross-sectional area.

The initial portion of the fatigue crack showed a brown discolouration/staining that was diffusely bounded by one of the more prominent crack progression marks (Figure 3). The discolouration was easily removed utilising an ultrasonic bath with anionic detergent.

There was no evidence of corrosion at the crack initiation site. There was also no significant scoring, abrasion or other defects observed on the bearing journal surface. Axle dimensions, including the wall and chromium plate thicknesses were measured and found to be within drawing tolerances.

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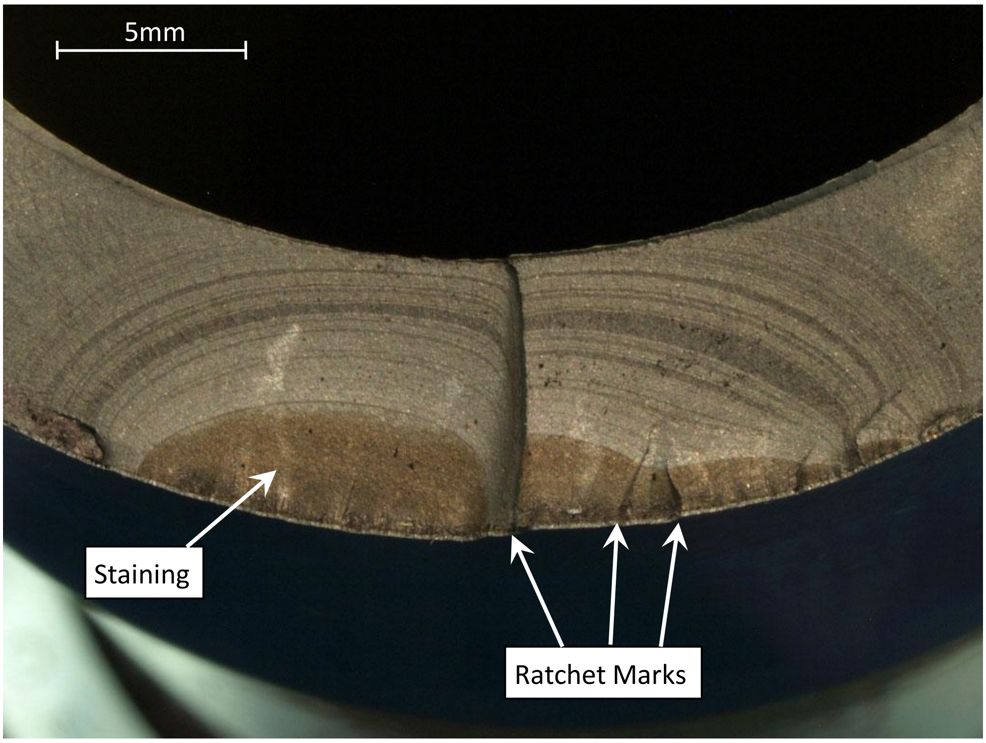
[2] Ratchet marks represent the boundary between cracks in different failure planes.

Figure 3: Fatigue region of fracture surface



Microscopy

Electron microscopy of the chromium plate/steel interface (Figures 4 and 5) at the crack origins showed areas of mixed-mode intergranular and transgranular fracture immediately below the plated surface. Those features had progressed to a depth of approximately 0.1 mm before transitioning to fatigue crack progression.

A cross section was taken through the fracture surface, polished and Nital[3] etched for microstructural analysis. The structure was uniform in appearance through the section and was consistent with a high strength, low-alloy steel in the hardened and tempered condition. No microstructural anomalies were observed; however, several small cracks were noted, originating at the steel/plating interface (Figure 6).

A small section of chromium plating was electrolytically stripped from the cylinder surface adjacent to the fracture. The underlying steel surface exhibited a dimpled appearance, typical of the shot peening process required at manufacture.

Examination of the region adjacent to the primary fracture surface revealed an extensive network of randomly oriented cracks or ‘mud-flat’ cracking (Figure 7). A Nital etch test[3] was performed on the steel surface, revealing evidence of a slightly darker etching band adjacent to the fracture.

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[3] The application of Nital etchant (a solution of alcohol and nitric acid) to a steel surface can reveal microstructural changes, often associated with localised heating as a result of grinding processes.

Figure 4: SEM image showing crack origin and progression marks

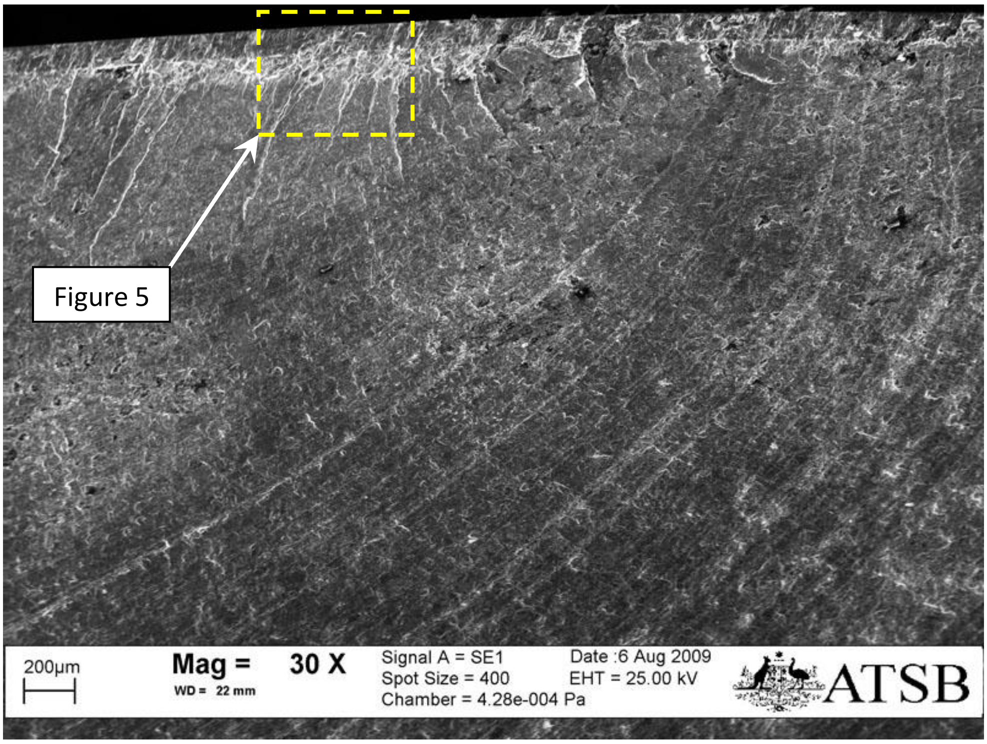


Figure 5: Detail of crack origin

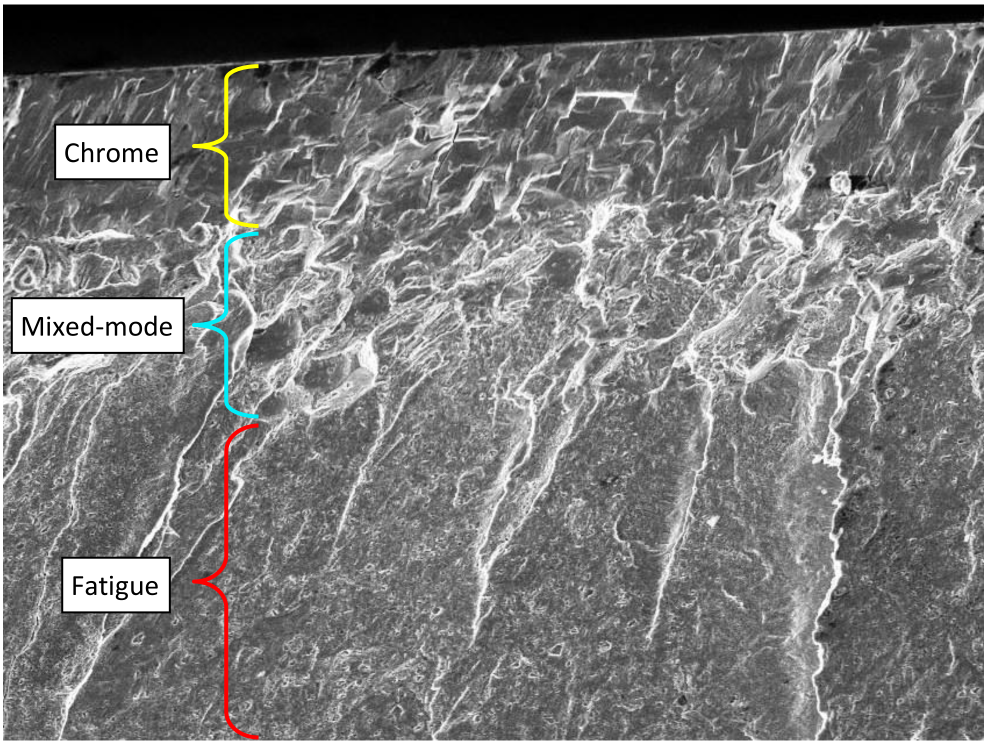


Figure 6: Cracks at steel/chrome interface

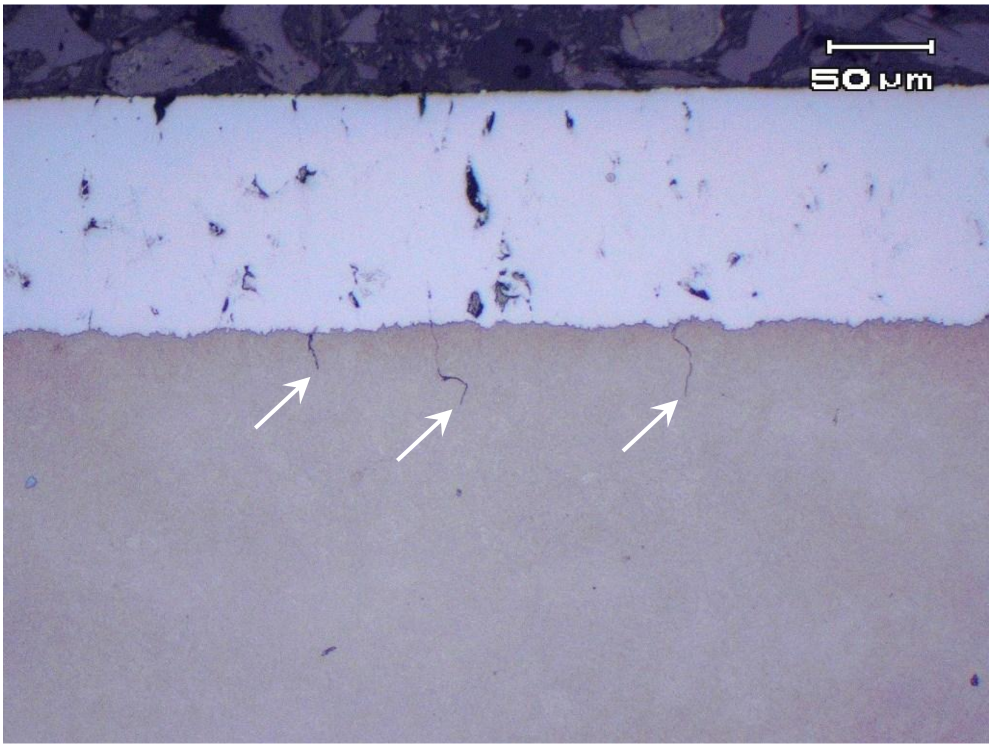
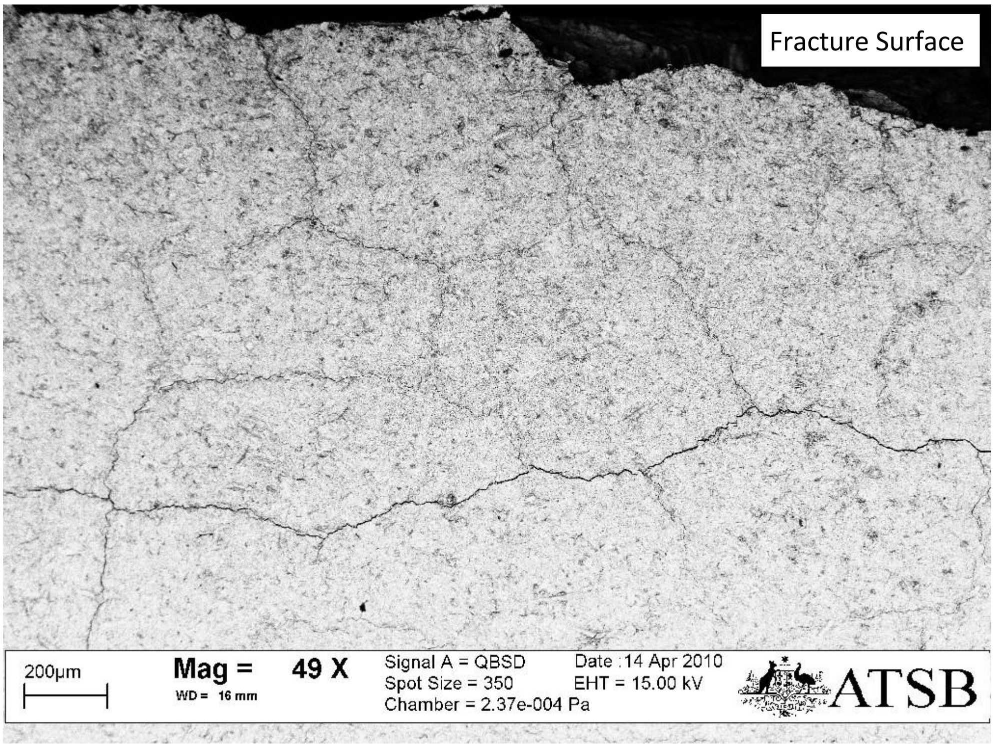


Figure 7: Steel surface cracks adjacent to fracture surface



Hardness

Hardness of the bulk steel was measured at 590 HV_{20} (approximately 55 HRC), which was within the specification range of 51 to 56 HRC.

A microhardness traverse was conducted in the steel section from immediately adjacent to the plated surface to a depth of approximately 3mm. There was no significant variation in the measured hardness.

Chemical Analysis

Chemical analysis by optical emission spectroscopy was conducted on a sample from the axle. The results (Table 1) were found to be consistent with a modified AISI 4340 (300M) grade steel, as specified.

Table 1: Chemical analysis of axle (weight percent)

	C	Mn	Si	P	S	Cr	Ni	Mo
Axle	0.42	0.80	1.72	0.01	0.01	0.78	1.80	0.36
Modified 4340 (300M)	0.38-0.43	0.60-0.80	1.45-1.80	0.035*	0.040	0.70 - 0.90	1.65-2.00	0.20-0.30

*Single values are maximums

Aircraft manufacturer's analysis

At the conclusion of the ATSB's principal examination, the inner cylinder (with inboard fracture surface intact) and associated miscellaneous components were returned to the aircraft operator. The fractured right axle stub was retained by the ATSB for follow-up study if required. The returned components were subsequently forwarded to the aircraft manufacturer, who conducted its own examination of the axle fracture and condition.

As part of the manufacturer's analysis, the intact left axle was examined for comparative purposes. Barkhausen[4] inspection was conducted, followed by stripping of the chromium plating and magnetic particle inspection / Nital etch examination. A network of cracks was subsequently identified on the left inboard journal, with the Barkhausen and Nital etch inspections showing indications that were characterised as overtempered martensite, consistent with surface grinding damage.

The predominantly intergranular fracture region immediately under the chromium plating was attributed to a hydrogen assisted cracking mechanism. The multiple plating processes carried out during the manufacturing process were likely to have provided opportunity for hydrogen generation and damage, arising from the preparatory pickling / cleaning stages prior to plating.

4 Magnetic Barkhausen noise can be used as a non-destructive inspection method that can detect changes in crystal lattice defects and dislocations, and can be utilised for determining the presence of metallurgical defects such as those caused by grinding burns.

Previous occurrences

At the time of the VH-VBA axle failure, there had been several other instances of axle fractures resulting in wheel loss involving 737 Classic and Next Generation[5] (NG) aircraft in the worldwide fleet. Those occurrences were attributed to a variety of factors including, but not limited to:

- bearing failure resulting in heat on the journal
- corrosion pitting between the axle flange and chromium plate
- damage related to grinding and/or rework of the bearing journals.

As previously noted, and as a result of fractures attributed to corrosion pitting, the aircraft manufacturer had released a service letter in July 2008, introducing a maintenance task for routine visual inspections for corrosion underneath the bearing spacer.

5 737 Classic aircraft encompasses the -300, -400 and -500 models and the 737 Next Generation the -600, -700, -800 and -900 models.

ANALYSIS

Axle fracture

The nose landing gear (NLG) right axle from VH-VBA fractured through the inner bearing journal as a result of fatigue cracking, originating from multiple surface cracks on the underside of the axle – an area of maximum tensile stress under normal loading.

The multiple crack origins and mud flat surface cracking observed was consistent with the effects of residual tensile surface stress. The additional identification of localised areas of overtempered martensite was evidence that the area had sustained thermal damage; most likely generated from frictional effects during a surface grinding or dressing process. The overtempered surface areas are typically associated with a reduction in strength and hardness, as well as a significant reduction in fatigue strength. There was no significant, detected variation in microhardness, which indicated that the grinding damage under the chromium plating was predominantly superficial. The bearing journal had not been reworked during the life of the inner cylinder and therefore the damage had most likely originated during original manufacture.

High-strength, low-alloy steels such as modified 4340 (300M) are also susceptible to hydrogen embrittlement, wherein hydrogen atoms can diffuse into the metal, often during pickling (cleaning) operations prior to plating. Affected areas exhibit markedly reduced ductility and are susceptible to cracking under sustained loads. The intergranular nature of the crack origins was characteristic of hydrogen assisted cracking.

The ATSB considered that the discolouration of the fatigue fracture surface corresponded to a particular event in the history of the inner cylinder and was not a contributing factor in the initiation of the fatigue cracking. The diffuse boundary of the discoloured area suggested that it may have formed from the introduction of a fluid or contaminant into the crack during cleaning of the axle, during non-destructive testing procedures, and/or as a result of heating effects during post-plate baking. Maintenance records indicated there were no such procedures performed on the axle subsequent to overhaul in 2008, and as such, it was considered probable that the crack was present at that overhaul (at the size illustrated by the discoloured area shown in Figure 3), but was not detected during the associated visual and non-destructive inspections.

A crack the size of the discoloured area on the fracture was considered to be detectable using magnetic particle inspection (MPI). The reasons for non-detection of the crack at that time could not be determined; however it should be recognised that successful detection of defects by MPI can be operator-dependant and reliant on many variables, including the characteristics of the defect, surface preparation, part condition and viewing conditions.

FINDINGS

From the evidence available, the following findings are made with respect to the nose landing gear axle fracture from the Boeing 737-7Q8 aircraft registered VH-VBA, and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- Fatigue cracking originated within the aircraft nose landing gear (NLG) right axle as the result of surface damage associated with grinding during manufacture, and was probably assisted in its initiation by hydrogen evolved during plating processes. *[Minor safety issue]*
- Growth of the fatigue cracking to critical size resulted in the fracture of the NLG right axle and the separation of the right nose wheel from the aircraft.
- It was probable that the fatigue crack was present during the last overhaul of the inner cylinder, but was not detected during non-destructive (magnetic particle) inspection.

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.

Aircraft manufacturer

Nose landing gear manufacturing process

Safety issue

Fatigue cracking originated within the aircraft nose landing gear (NLG) right axle as the result of surface damage associated with grinding during manufacture, and was probably assisted in its initiation by hydrogen evolved during plating processes.

Action taken by aircraft manufacturer

As a result of their own internal and ongoing investigations into the axle failure, the aircraft manufacturer was working with the landing gear supplier to determine the extent of the problem.

The aircraft manufacturer also released a communication to designated 737 stakeholders informing of three (including the subject) recent NLG inner cylinder fractures and their likely origin being related to grinding operations. To reduce the likelihood of future possible NLG axle failures, the manufacturer recommended that inspections for thermal damage be undertaken during overhaul of the NLG inner cylinder. This was to be achieved by Nital etch inspection after stripping the plating from the bearing journals, or by Barkhausen inspection in lieu of stripping the chrome plate.

ATSB assessment of action

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

Aircraft operator

Action taken by aircraft operator

Immediately following the occurrence, the aircraft operator conducted a detailed visual and non-destructive inspection of all axles in their 737 fleet with similar service history. Particular attention was paid to the area underneath the bearing spacer. No defect indications were found.

APPENDIX A: SOURCES AND SUBMISSIONS

Sources of Information

- Operator of VH-VBA
- The aircraft manufacturer
- The overhaul facility
- The Civil Aviation Safety Authority

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 aircraft operator, the aircraft manufacturer, the landing gear overhaul facility, the Civil Aviation Safety Authority and the National Transportation Safety Board..

Submissions were received from the aircraft operator, the aircraft manufacturer, the landing gear overhaul facility, and the National Transportation Safety Board . The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

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Nose landing gear axle fracture, VH-VBA, Boeing 737-7Q8
Melbourne aerodrome, Victoria, 25 July 2009