ACCIDENT

Aircraft Type and Registration:	Boeing 737-800, EI-DLV
No & Type of Engines:	2 CFM56-7B26 turbofan engines
Year of Manufacture:	2006 (Serial no: 33,598)
Date & Time (UTC):	15 September 2017 at 0807 hrs
Location:	London Stansted Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 184
Injuries:	Crew - None Passengers - None
Nature of Damage:	Failure of left nose landing gear axle and separation of left nosewheel
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	33 years
Commander's Flying Experience:	4,500 hours (of which 4,300 were on type) Last 90 days - 255 hours Last 28 days - 85 hours
Information Source:	AAIB Field Investigation

Synopsis

As the aircraft was lining up on the runway to take off, the flight crew heard a noise similar to a nosewheel passing over a runway centre light; they did not consider the noise to be unusual. During the takeoff roll, the flight crew in an aircraft holding near the start of the runway noticed one of the nosewheels depart EI-DLV and be blown off the runway into the area behind the threshold. They informed ATC who informed the crew of EI-DLV, which was now in the climb. A diversion was carried out to East Midlands Airport where an uneventful landing was made.

The nosewheel was found to have separated from the aircraft because the nose landing gear axle had failed at the left inboard journal (the part of the axle that rests on bearings). This was the result of heat-induced cracking and material property changes due to abusive grinding of the chrome plate during the part's last overhaul almost three years earlier. The Maintenance and Repair Organisation that performed the overhaul has introduced a new inspection for detecting abusive grinding.

History of the flight

The following has been compiled using information from crew interviews and downloads from the Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR).

The crew, comprising the commander, co-pilot and four cabin crew, reported for duty at their home base of Kaunas, Lithuania at 0240 hrs on the day of the accident. They operated two sectors, from Kaunas to Copenhagen and then Copenhagen to Stansted, without incident. They then prepared the aircraft for a third sector back to Copenhagen.

The co-pilot completed the walkaround checks and reported seeing nothing abnormal. Nor was anything unusual seen by the ground crew handling the turnaround, including the tug crew which had attached, and subsequently detached, the towbar to the nose gear.

The aircraft pushed back off Stand 43R at 0757 hrs, with the commander acting as pilot flying, and was cleared to taxi via taxiway C to holding point S1 for Runway 22 (Figure 1). The crew reported there was nothing abnormal during the taxi and, on reaching S1, they held in turn before being cleared by ATC to line up and hold. As the aircraft entered the runway, ATC cleared the crew to take off. The commander taxied the nose of the aircraft beyond the centreline to line up on the centre of the runway for a rolling takeoff. As he did so, the flight crew heard a noise similar to the nosewheels passing over a runway centre light. The same noise was heard by the two cabin crew members at the front of the cabin. Neither the pilots nor the two cabin crew members considered the noise to be anything out of the ordinary.

The commander reported that during the takeoff roll, despite there only being a light wind at the time, he used aileron and rudder to keep the aircraft straight on the centreline, as if the aircraft was experiencing a crosswind from the right. The takeoff otherwise appeared normal to the flight crew and, after rotation, the gear was raised with no apparent problems. They continued with the CLN 1E departure given by ATC, before being given a radar heading and climb to FL170.

An aircraft operating on a different radio frequency to EI-DLV and waiting at the S1 hold, informed ATC that, as EI-DLV had started its takeoff roll, they had seen one of the nosewheels depart the aircraft and be blown off the runway into the area behind the threshold. They could also see what appeared to be a part of the aircraft on the runway. ATC ordered a check of the runway and the aircraft parts were recovered.

When ATC notified EI-DLV of what had happened, the aircraft was passing about FL110. The crew entered a hold whilst they assessed the situation. The most appropriate guidance they could find in the aircraft manuals was for '*landing with a flat tyre*' in the Flight Crew Training Manual, which they elected to follow. The crew decided their best option was to return to Stansted, a decision agreed when they contacted the company's engineering base at the airport by radio. The flight crew informed ATC of their intention to return to Stansted and the commander gave the cabin supervisor an emergency brief before advising the passengers of the situation over the PA.

Having prepared the aircraft for the approach, the crew was cleared by ATC to descend and head towards the ABBOT holding and arrival point for Stansted. Shortly afterwards ATC contacted the crew to inform them that the aircraft operator had requested that the aircraft now divert to either East Midlands or Prestwick, rather than Stansted. As this conflicted with the request from the engineering base, on arrival at ABBOT the crew took up the hold in order to contact the company Operations Department by radio via their ground handling agent at Stansted. The Operations Department confirmed the new diversion preferences and the crew determined they had sufficient fuel to divert to East Midlands. The crew then re-briefed and set the aircraft up for a diversion to East Midlands before advising ATC of the new diversion request, at which time they also declared a PAN. The weather report for East Midlands was for light winds, good visibility and a broken cloud base of 3,700 feet aal.

Figure 1

Extract from Aerodrome Chart for London Stansted Airport

ATC gave the crew vectors to establish on the ILS for Runway 27 at East Midlands Airport. When established on the approach, the crew flew a CAT 1 ILS, lowering the gear early; the gear operated normally and gave the normal indications. They elected to use full flaps (FLAPS 40) for landing to give a lower touchdown speed and calculated that AUTOBRAKE 2 was the lowest usable autobrake selection they could use, as advised in the guidance they had consulted earlier. The commander disengaged the autopilot just below 500 feet aal and, on touchdown, lowered the nosewheel as gently as possible onto the runway[1]. He reported the landing appeared normal and that he stopped the aircraft on the runway. The fire service attended quickly; they inspected the aircraft and confirmed that one of the nosewheels was missing. The commander decided against taxiing the aircraft off the runway as the taxiway entrances ahead of them were all at 90° to the runway and he was concerned about putting stress on the remaining wheel. The engines were shut down and the passengers were deplaned onto buses before the aircraft was towed to a stand.

Diversion destination

The operator's preferred choice of diversion destination, relayed to the crew, was based on a desire to avoid closing the busy runway at Stansted Airport and the associated safety and operational implications this would have caused. East Midlands Airport reported that the incident resulted in their runway being closed for about 75 minutes. The closure was promulgated as quickly and as widely as possible, allowing a number of inbound flights to be delayed before they had taken off from their departure airports. It also coincided with a quiet operational period and resulted in only one inbound flight having to divert.

Aircraft examination

The aircraft was examined after it arrived at East Midlands Airport. The left axle of the nose landing gear (NLG) inner cylinder had failed at the inboard journal location (Figure 2). The wheel bearing spacer was still in place and in good condition. On the axle fracture face, near the 6 o'clock position, there were visible bands consistent with fatigue cracking. The separated nosewheel, axle and wheel bearings were recovered from Stansted Airport and, other than the break in the axle, no anomalies were found with these components.

Figure 2

Left nosewheel axle failure at inboard journal.
Bands of fatigue visible near the 6 o'clock position (right image)

Footnote

[1] Maximum de-rotation rate for this landing was -1.4°/sec. Previous landings recorded on the FDR were also reviewed with no hard landings or rapid de-rotations recorded.

Description of the NLG inner cylinder

The nosewheel axles are integral parts of the NLG inner cylinder (Figure 3). Each axle has an inboard and an outboard journal onto which the two bearings from each nosewheel are fitted. The axles are made of a high strength steel alloy and the journals are chrome plated with a minimum chrome thickness of 0.003 inches. The highest stressed area of the axle is at the 6 o'clock position and the highest stress occurs during landing when the nosewheels touch down and load the axles upwards.

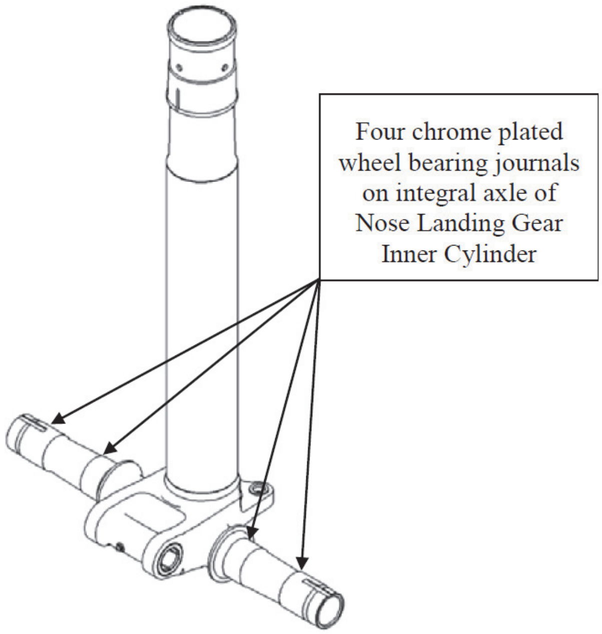

Figure 3

NLG inner cylinder with its four chrome plated wheel bearing journals

Metallurgical examination of the axle failure

The NLG cylinder was taken to a metallurgical lab for detailed examination. This revealed multiple crack initiation points on the lower circumference of the axle around a total length of about 47 mm; however, the dominant crack was near the 6 o'clock position as shown in Figure 2 (right image). A magnified image of this area is shown in Figure 4. Underneath an approximately 80 μm (0.003 inches) layer of chrome plating there was an area of intergranular fracture, about 250 μm thick, which was consistent with either stress corrosion cracking (SCC) or hydrogen embrittlement cracking. Underneath this area was an area characteristic of fatigue cracking, followed by alternating bands of SCC and fatigue. The fracture surfaces outside the banded region were all typical of overload failure.

Visual examination of the chrome plating showed some surface cracking adjacent to the fracture in a direction perpendicular to the axle, but there was no widespread cracking. A fluorescent dye penetrant inspection (FPI) revealed additional cracks, in the same direction, in the area of the main initiation point on both the inboard and outboard surfaces of the axle. A FPI of the left outboard journal and both journals on the right axle did not reveal any cracks.

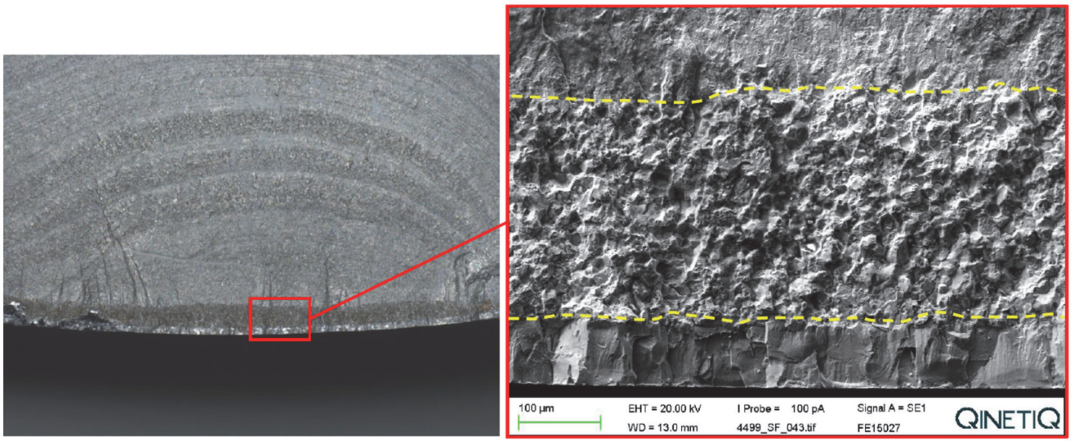

Figure 4

Scanning Electron Microscope image of primary crack initiation site (near 6 o'clock position)

The NLG cylinder was sent to the aircraft manufacturer for a Barkhausen inspection. This is a non-destructive inspection that uses a sensor to measure the material's magnetic properties. It can detect heat damage in steel beneath non-ferromagnetic coatings such as chrome. When applied to the failed journal it detected a raised Barkhausen response, consistent with base metal heat damage in the area around the 6 o'clock position. A similar but smaller area of base metal heat damage was also detected on the outboard journal of the intact right axle, also near the 6 o'clock position. The remaining two journals did not exhibit any heat damage. The base metal heat damage was subsequently confirmed following the removal of the chrome plate. Nital etch[2] revealed characteristic dark patches in the areas with the raised Barkhausen response (Figure 5). The aircraft manufacturer stated that these dark patches indicated that the steel microstructure had changed to overtempered martensite (OTM), also known as a re-tempering burn. This can occur if the part is excessively heated during grinding of the chrome plating and is commonly referred to as 'abusive grinding'.

An examination of the wheel bearings showed that they were in good condition and rotated freely indicating that bearing deterioration did not contribute to the heating of the axle bearing journals. The bearing covers about half the width of the axle bearing journal and yet the heat damage expanded nearly the entire width of the journal. Given this information, the aircraft manufacturer concluded that the only explanation for the base metal heat damage was that it had occurred during post-plating grinding.

Footnote

2 Nital etch is a test for checking machining damage or grinding burn of a hardened steel component. It involves applying a Nital solution, which is a mixture of nitric acid and alcohol commonly used for etching steels, to reveal their microstructure.

Figure 5

Lower face of the failed axle after chrome removal.
The dark areas are evidence of heat damage

When the base metal becomes overtempered from abusive grinding, there is a softening of the material and its strength reduces. The heating also causes a significant change in residual stress from compressive stresses on the surface to tensile stresses which increase the part's susceptibility to cracking. During an abusive grinding event there is rapid localised heating followed by rapid cooling which results in thermal strain that can cause heat-induced cracking. During subsequent cadmium plating of other parts of the inner cylinder, hydrogen can diffuse into areas of tensile stress causing hydrogen embrittlement cracking. This can occur during the period between the cadmium plating and the stress relief bake which removes the hydrogen. These cracks can then propagate in service due to SCC or fatigue or both.

According to the aircraft manufacturer, if OTM is present at the 6 o'clock position then axle fracture is inevitable within about 2 or 3 years, depending on utilisation.

The metallurgical examination also revealed variability in the chrome plating thickness of all four journals. The aircraft manufacturer's measurements are in Table 1. The measurements show that the chrome plating thickness at the failure location was 0.0028 ± 0.0005 inches, which meant that it could have been slightly below or above the 0.003 inches minimum allowable thickness. The right axle inboard journal was measured to be below the minimum thickness at the 6 o'clock position.

	Clock position	Left axle (fractured)	Right axle
Inboard journal	12:00	6.4	6.5
	Forward	4.1	3.1
	6:00	2.8	1.9
	Aft	4.2	4.8
Outboard journal	12:00	5.0	5.8
	Forward	3.6	3.0
	6:00	3.6	3.0
	Aft	4.0	5.0

Table 1

Chrome plate thickness measurements in the centre of the journals
(all values in 1/1000 inches with accuracy of ± 5/10,000 inches).
Minimum thickness 3/1000 inches

Previous Boeing 737NG[3] NLG axle failures due to base metal heat damage

On 7 April 2014, the aircraft manufacturer published Service Letter 737-SL-32-171-A which stated:

> *'Boeing has received reports of four (4) Nose Landing Gear (NLG) Inner Cylinder Axle fractures in the last several years believed to be caused by improper chrome plate grinding during original manufacture. All four fractures occurred at the inboard wheel bearing journal. In three of the cases, the fractured axles were stripped of chrome plate and a Nital etch inspection was performed which indicated severe base metal heat damage (grinding burns) inflicted by poor chrome plate grinding. Since the release of the reference a) multi operator message, 55 other NLG axles which have been subjected to Barkhausen or Nital inspection to look for base metal heat damage have had findings that are indicative of base metal heat damage.'*

The manufacturer had discovered that some issues with the grinding process had been introduced when the manufacture of the NLG inner cylinders was moved to a new facility in February 2001. These manufacturing issues have subsequently been addressed.

The Service Letter recommends that suspect[4] NLG inner cylinders are inspected for heat damage at first overhaul, either by stripping the chrome plating and performing a Nital etch inspection or by performing a Barkhausen inspection. It also states that any suspect NLG inner cylinders that had already been overhauled and not inspected for heat damage should have an on-wing Barkhausen inspection at the next maintenance opportunity.

Footnote

3 Boeing 737NG refers to the newer models of Boeing 737, the -600, -700, -800 and -900.
4 Suspect NLG inner cylinders are identified by serial number in the SL but also include all inner cylinders delivered on aircraft line number 830 and line numbers 858 to 2566.

The Service Letter provides the following background information regarding the chrome plating of the bearing journals:

> *'After application of the chrome plate it is required to grind the chrome plate to obtain the required design dimensions and surface finish. This grinding process has to be very tightly controlled to avoid generation of too much heat as a result of the friction generated between the grinding wheel and the part. Excessive heat can cause the mechanical properties of the high strength steel substrate to change due to stress relief and surface temper effects which can result in cracks forming and subsequent fracture of the axle.'*

Maintenance history of the NLG cylinder on EI-DLV

The NLG cylinder on EI-DLV was previously installed on a different Boeing 737-800 (line number 1642) which was delivered from new in February 2005; therefore, the aforementioned Service Letter was applicable. The cylinder had accumulated 36,238 hours and 22,094 cycles since new. The life limit for the component is 75,000 cycles and an overhaul is required at 10 years or 21,000 cycles, whichever occurs sooner. The cylinder was overhauled by an approved Maintenance and Repair Organisation (MRO) in December 2014 when it had accumulated 17,035 cycles. After overhaul and carrying out the Service Letter instructions, the cylinder was installed on EI-DLV and, other than general visual inspections during wheel changes, there had been no detailed axle inspection since. At the time of the axle failure it had accumulated 9,089 hours and 5,059 cycles since overhaul.

Overhaul of the NLG cylinder on EI-DLV

When the NLG cylinder from EI-DLV was overhauled in December 2014 the MRO had the option of performing either a Nital etch or a Barkhausen inspection in accordance with the Service Letter. The Nital inspection involves removing the chrome plating, performing a visual inspection, re-plating and then grinding the chrome to the required dimensions. The Barkhausen inspection is non-destructive and, if the part passes inspection, there is no requirement to strip the chrome plating.

The operator of EI-DLV had requested that the MRO perform a Nital etch inspection on all its NLG cylinders. The operator stated that this decision was taken at the time because it was thought that Nital etch was a more effective inspection process and that Barkhausen had the potential to miss heat damage or to pass lower levels of heat damage. It was also felt that by re-chroming they would have an axle in an 'as new' condition.

In both the aircraft manufacturer's and the MRO's experience, the Barkhausen inspection did not miss heat damage. All the other operators that had their NLG cylinders overhauled by this MRO had the Barkhausen inspection carried out.

The overhaul record for EI-DLV's NLG inner cylinder was examined. The first two processes involved stripping the cadmium plate from the inner cylinder and the chrome plate from the journals. The records revealed that the Nital etch inspection of the journals was passed, which meant that no evidence of heat damage was found on the base metal. Following shot peening, the journals were re-plated with chrome and then underwent a 6-hour stress relief bake. Chrome plating involves lowering the part into an electrolyte bath of chromic acid and then passing an electric current between two electrodes. The MRO's chrome plating process used non-conforming anodes[5] which resulted in an uneven thickness of chrome being applied.

The grinding was then carried out using a manual grinder. The basic setup of the grinder, grinding wheel and the NLG cylinder is shown in Figure 6. The process is manual and involves the operator turning a wheel to move the grinding wheel towards the cylinder which is rotated by the grinder at a speed of 20 rpm. Before starting the grinding operation, the operator uses a Dial Test Indicator (DTI) gauge to measure any high spots on the journals and then marks them with a chinagraph pen. With the grinding wheel stationary, it is then slowly brought towards the rotating cylinder until first contact, which is the highest spot. The digital reader on the machine is then zeroed and the wheel is brought back by 0.1 inches. During the grinding operation there is a ratchet on the handle which prevents the wheel being moved in by more than 0.0001 inches between movements of the ratchet. Checks are carried out and the grinding wheel is dressed (sharpened) after every 0.003 inches to 0.005 inches of material removal.

A number of different factors can cause a grinding burn which is a consequence of the part getting too hot:

- Not identifying the highest spot correctly which then results in a large slice being removed at first touch.
- Moving the grinding wheel in too quickly (ie not using the ratchet or moving the ratchet too quickly).
- Poor condition of the cooling fluid or inadequate flow.
- Insufficiently dressed grinding wheel which results in heat build-up.
- Machine setup and balance which results in the part rotating non-concentrically.

After grinding, there is a visual inspection of the journals to check for cracks. The parts of the inner cylinder which had the cadmium removed are then re-plated with cadmium. All parts, including the journals, then undergo a magnetic particle inspection (MPI)[6]. Following painting, the final overhaul operation is a 23-hour de-embrittlement bake to remove any hydrogen that was introduced during plating.

Footnote

5 Conforming anodes conform to the shape of the part being plated. Non-conforming anodes do not and typically consist of anode plates on either side of the part.

6 Magnetic particle inspection (MPI) is a non-destructive testing (NDT) process for detecting surface and shallow subsurface discontinuities in ferromagnetic materials such as iron, nickel, cobalt, and some of their alloys. It will not detect cracks in chrome but it may detect cracks in a ferromagnetic material beneath a thin chrome layer.

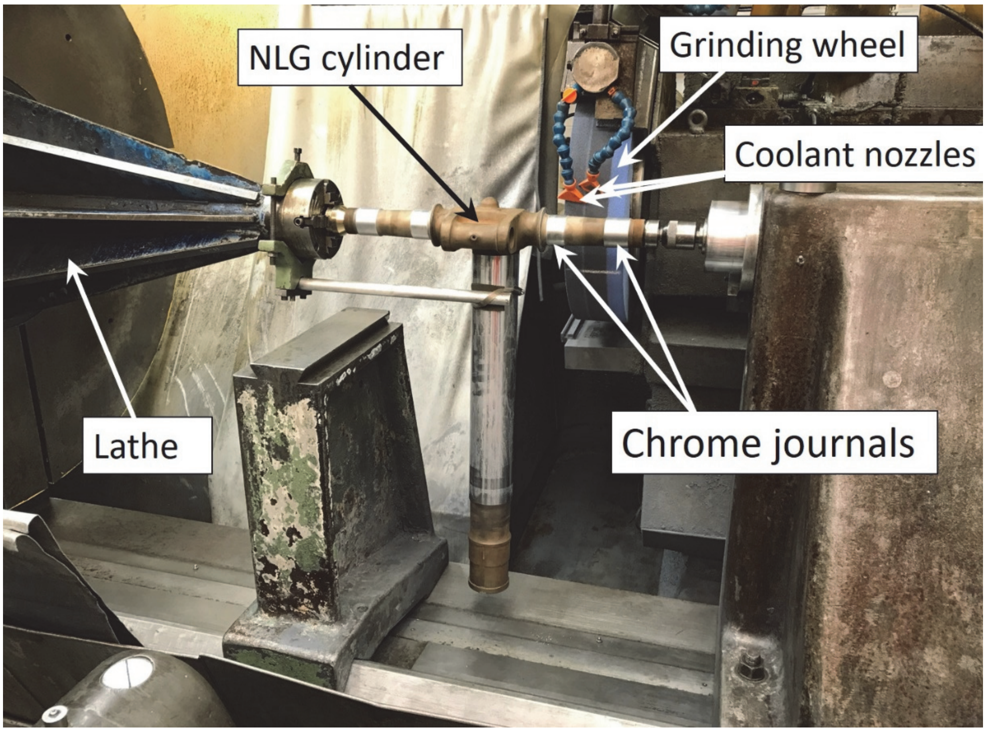

Figure 6
MRO's grinding setup for the NLG cylinder

Investigation by the MRO

Since there was no evidence of grinding burns following the Nital etch carried out at the beginning of the overhaul process, the MRO carried out an internal investigation to determine what might have caused them to occur during overhaul. They reviewed all their processes and interviewed all eight of their grinding operators. The operator who had ground the chrome journals on EI-DLV's cylinder had been carrying out grinding operations for the MRO since March 2006. He had ground 33 NLG inner cylinders during the period leading up to grinding EI-DLV's cylinder and 42 NLG inner cylinders since. None of these other NLG cylinders are known to have suffered from grinding burns. The manufacturer's Standard Overhaul Practices Manual (SOPM) instructions for grinding required a degree of interpretation by the grinding operators. Interviews with the grinding operators revealed some differences in how they performed the grinding process. There was nothing identified in the processes employed by the grinding operator of EI-DLV's cylinder that was particularly unusual.

The grinding of all four journals was completed within one shift. There had not been any significant maintenance on the grinding machine prior to grinding or afterwards. The same machine had been used to grind the journals on about 95[7] Boeing 737NG inner cylinders

Footnote

7 During this period 205 Boeing 737NG NLGs were overhauled; of these, 59 were from the operator of EI-DLV and all required chrome removal. The remainder were from other operators that did not require chrome removal and it was estimated that a quarter of these would have had the chrome removed for defects found.

between 2008 (when the MRO started overhauling 737NG cylinders) and December 2014 (when EI-DLV's cylinder was overhauled); of these, 59 were from the same operator as EI-DLV, and about half of these had been ground by the same operator who worked on EI-DLV. Since December 2014, the MRO has overhauled an additional 90 NLGs, of which 60 were from the operator of EI-DLV.

The MRO concluded from their investigation that all grinding operators were following the aircraft manufacturer's procedures and that they:

> *'understood the implications of making a heavy contact between the wheel and the job when they first touch on. They understood the importance of reporting an incident where this may happen and confirmed good practices to ensure a light touch-on of the wheel to the job when eliminating high spots.'*

The MRO also determined that all the mandatory stress relief bakes had been properly performed.

Grinding tests carried out by the MRO

As part of the investigation, the MRO carried out some grinding tests to see if there were any deflections of the part during spinning due to an imbalance. Because of the long cylinder at right angles to the axle, the part is not balanced about the rotational axis. The aircraft manufacturer stated that a counterweight might need to be added; however, tests at different speeds using a DTI gauge to measure deflection did not reveal any variations, so the benefit of installing a counterweight is not clear. During one of the tests observed by the AAIB, the DTI gauge indicated a fluctuation of 0.001 inches during rotation of the part. This could not be explained and subsequent tests did not reveal the same level of fluctuation. It is possible that differences in the setup could result in the part sometimes not being spun concentrically which could increase the chance of inadvertent contact with the grinding wheel.

Use of non-conforming anodes

The MRO's chrome plating process involves using non-conforming anodes which results in an uneven thickness of chrome being applied. The MRO reported that the chrome is usually thicker at the 3 and 9 o'clock positions. If the chrome is very thick then it prolongs the grinding process, potentially increasing heat build-up. An uneven thickness also means that there will be high spots which increases the risk of abusive grinding from inadvertent contact with the grinding wheel.

The aircraft manufacturer stated that using conforming anodes was best practice as it results in an even chrome thickness, but it was noted that the manufacturer's SOPM did not state which type of anodes should be used. The MRO agreed that using conforming anodes would be best practice but they had been using non-conforming anodes for the previous 10 to 15 years, and the grinding processes they had in place catered for it.

Previous NLG axle failure on a Boeing 737-800 belonging to the operator of EI-DLV

On 3 May 2017 another of the operator's Boeing 737-800 aircraft, registration EI-DHB, experienced an NLG axle failure during taxi at Murcia airport in Spain. The right axle had failed at the inboard journal and there were fatigue cracks which had initiated at the 6 o'clock position. During the investigation of this event, which is ongoing, both a Barkhausen inspection and a Nital etch inspection were performed on the failed journal which did not reveal any base metal heat damage, indicating that no abusive grinding had occurred, and therefore this event was not directly linked to that of EI-DLV.

Aircraft manufacturer's comments

The aircraft manufacturer stated that it was not aware of any other Boeing 737NG NLG axle failures that had occurred due to abusive grinding during overhaul. The only other similar events were due to abusive grinding at manufacture and this issue was addressed by the Service Letter.

The aircraft manufacturer stated that performing a Barkhausen inspection after grinding would help to prevent any parts with abusive grinding damage entering service. However, it does not currently have any plans to mandate such an inspection.

Barkhausen inspection reference standard

To perform a Barkhausen inspection, a reference standard is required to calibrate the equipment. The effectiveness of the equipment is highly dependent on the quality of the calibration which is dependent on the reference standard. The reference standard is made from the same material as the axle and has one or more burns applied to it. Different thickness titanium foils are then applied to the surface to represent the thickness of the chrome plating in the inspection area. The MRO had been using a reference standard with a single burn. In 2015, the aircraft manufacturer produced a new standard for the Barkhausen inspection (BSS 7423) which included a specification for a reference standard with three burns of different intensity on its surface[8]. This reference standard resulted in more accurate Barkhausen tests with fewer false 'fails.' The aircraft manufacturer had four of these new reference standards made for internal purposes, but did not make the details required to manufacture them available to MRO's. Following the EI-DLV axle failure, the aircraft manufacturer loaned one of their reference standards to the MRO of EI-DLV which it used in subsequent Barkhausen inspections.

Analysis

The NLG axle failed as a result of a crack that had initiated near the 6 o'clock position of the left inboard journal and had then propagated over time via fatigue and SCC until the remaining material failed in overload. The final failure occurred as EI-DLV turned onto the runway prior to takeoff.

Footnote

[8] As well as having additional burns, the burns were applied using a controlled induction heating process. The older reference standard with the single burn, had the burn applied using an acetylene flame to produce 'cherry redness'.

The initial cracks had developed because the journal, whilst being overhauled, had experienced a re-tempering burn near the 6 o'clock position during post-chrome plate grinding. This abusive grinding would have resulted in heat-induced cracking in the base metal that probably grew by hydrogen embrittlement cracking during the cadmium plating process, prior to the stress relief bake. If the cracks had extended through the chrome surface from the base metal then they were probably microscopic cracks as they were not detected during the post-grinding visual inspection. The MPI did not detect any cracks but it will not detect cracks in non-ferrous material such as chrome, and it may not detect cracks in steel beneath a chrome layer. There was no requirement to perform an FPI which might have detected cracks in the chrome plating. Because no cracks were detected, the part was returned to service. Over time, in-service axle flexure caused fatigue cracks to initiate from the hydrogen embrittlement region, and propagate through the wall of the axle. This flexure probably also caused through thickness cracks to develop in the chrome plating, at locations coincident with the base metal cracks. These cracks would have allowed moisture to reach the advancing crack tip and cause the fracture to continue to propagate by the observed alternating modes of SCC and fatigue, until final ultimate fracture occurred by ductile separation through the remaining intact axle wall.

This report identifies a number of possible causes of abusive grinding; however, the cause of the two grinding burns on EI-DLV's cylinder could not be determined. Regardless of the cause, there was no effective mechanism for detecting that abusive grinding had occurred. Since the failure, the MRO has introduced a post-grinding Barkhausen inspection. This type of inspection should identify any journals that have suffered abusive grinding and prevent them from being released to service.

The effectiveness of the Barkhausen inspection is dependent on the quality of the reference standard for calibrating the machine. If the aircraft manufacturer were to make and supply more of the new reference standards, or supply MRO's with the detailed instructions to make them, then this could increase the effectiveness of Barkhausen inspections worldwide.

The aircraft manufacturer's Service Letter allows a Barkhausen inspection to be used instead of Nital etch. If a Barkhausen inspection had been carried out on EI-DLV's NLG at the beginning of the overhaul process then there would have been no need to strip the chrome, re-plate and grind the journals, thus removing the opportunity for abusive grinding to occur.

Although the aircraft manufacturer is not aware of any other Boeing 737NG NLG axle failures due to abusive grinding during overhaul, it is considering the issues raised in this report but, at the time of writing, had not initiated any related changes to maintenance, repair or overhaul procedures for 737NG NLG cylinders.

Conclusion

The nosewheel was found to have separated from the aircraft because the NLG axle had failed at the left inboard journal. The failure was caused by a crack that had initiated near the 6 o'clock position of the journal and had then propagated over time via fatigue and SCC until the remaining material failed in overload. The crack was the result of heat-induced cracking and material property changes caused by abusive grinding of the chrome plate during the part's last overhaul.

The cause of the abusive grinding could not be determined, but the abusive grinding would probably have been identified if a post-grinding Barkhausen inspection had been carried out.

Safety action

To ensure that any abusive grinding is detected, the MRO of EI-DLV has introduced a new process to perform a Barkhausen inspection on all journals after grinding. The MRO has also introduced a Barkhausen inspection early in the overhaul process, prior to the Nital etch test.

In addition, the MRO is carrying out Barkhausen inspections on all 12 Boeing 737NG NLGs that were overhauled during the one-year period covering six months before and after the date of EI-DLV's NLG overhaul. These inspections are carried out on the aircraft, on the line, after removing the wheel and bearings. Out of these 12, nine have already been inspected and no evidence of abusive grinding was found.

As some of the manufacturer's SOPM instructions, such as wheel dressing, are open to interpretation, the MRO is developing an internal protocol for grinding so that there is greater consistency among grinding operators.