SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-8K5, G-TAWG
No & Type of Engines:	2 CFM CFM56-7B27E turbofan engines
Year of Manufacture:	2012 (Serial no: 37266)
Date & Time (UTC):	24 December 2019 at 0048 hrs
Location:	Manchester Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 181
Injuries:	Crew - None Passengers - None
Nature of Damage:	Bearing failure, separation of No 4 (right outer) mainwheel and severe damage to the associated brake unit
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	41 years
Commander's Flying Experience:	6,709 hours (of which 246 were on type) Last 90 days - 68 hours Last 28 days - 27 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly after a normal touchdown, the right outer (No 4) mainwheel separated from its axle and was seen, by the pilots, to pass down the right side of the aircraft. The aircraft vacated the runway and was safely brought to a halt on the taxiway. The wheel separated as a result of a failure of the inboard wheel bearing which led to the failure of the outer bearing. The exact cause of the initial failure to the inboard bearing could not be determined.

History of the flight

The aircraft landed on Runway 23R at Manchester Airport after an uneventful flight from Al Massira Airport (Morocco). The co-pilot was PF and as the aircraft slowed to approximately 80 kt he handed control to the commander. At approximately 60 kt the pilots became aware of an object overtaking them at high speed, on the right, along the edge of the runway. ATC informed the pilots that the aircraft may have suffered a tyre problem. The aircraft was slowed to 10 kt, before it vacated the runway onto a taxiway. The pilots reported no handling abnormalities other than a slight judder as the aircraft vacated the runway.

The Airport Fire and Rescue Service attended the aircraft and informed the commander that the right outboard wheel (No 4) and tyre had completely detached, with significant damage to the brake pack. The aircraft was shut down and after consulting with the operator's engineers, it was decided to disembark the passengers prior to any further movement of the aircraft. The passengers disembarked onto the taxiway and were taken by bus to the terminal.

The aircraft was towed to the parking area where a detailed examination was carried out by the operator's engineers.

Debris trail

Marks and debris on the runway indicated that the wheel detached approximately 1,800 m from the threshold and continued for a further 700 m before coming to rest on the grass to the right of Runway 23R, between Taxiway AF and AG. A runway inspection carried out immediately after the landing found metallic debris from the wheel hub, bearings and brake pack strewn along the runway from point P to an area where most of the debris was found, abeam Taxiway BD (Figure 1).

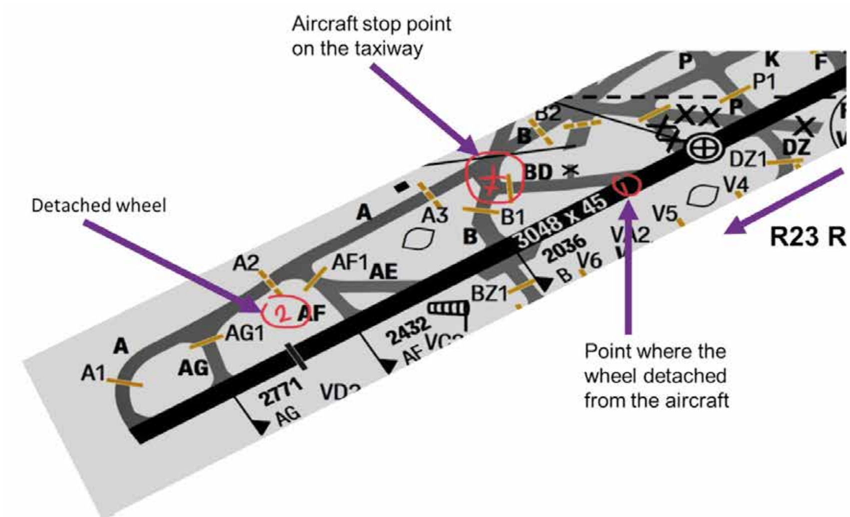


Figure 1

Final location of aircraft, debris and wheel as plotted by airport authorities

Recorded information

The CVR and FDR were downloaded but held no relevant information to help determine why the mainwheel separated from the aircraft.

Aircraft details

G-TAWG is a Boeing 737-8K5, passenger aircraft. It was built in 2012 and had accrued approximately 29,000 flight hours and had a valid airworthiness review certificate.

The aircraft is fitted with tricycle retractable landing gear with two wheels fitted to each landing gear leg. All the wheels can rotate independently of each other. The right mainwheel assembly was fitted to the aircraft on 14 November 2019 and had accrued 130 cycles.

Landing gear, wheels and brakes

Main wheels

The main wheels, which are designed to allow easy replacement, are fitted to fixed stub axles and are held in place by a single wheel nut and washer. The wheel nut is secured by locking bolts.

The wheels are of a split hub design with the hubs containing the inboard and outboard tapered roller bearings (Figure 2). The outer bearing component is known as the cup and the inner bearing component as the cone. The cup bearing raceway is an interference fit within the hub, and the cone is a sliding fit on the stub axle. The rollers run on tracks in the cone and cup. The track on the cone is defined by a rib around its edges; there are no ribs on the cup. The inboard and outboard bearing assemblies are fitted with external grease seals which are held in place by spring steel retaining rings located in grooves in the wheel hub. The general arrangement of the inboard and outboard bearings is shown in Figure 3.

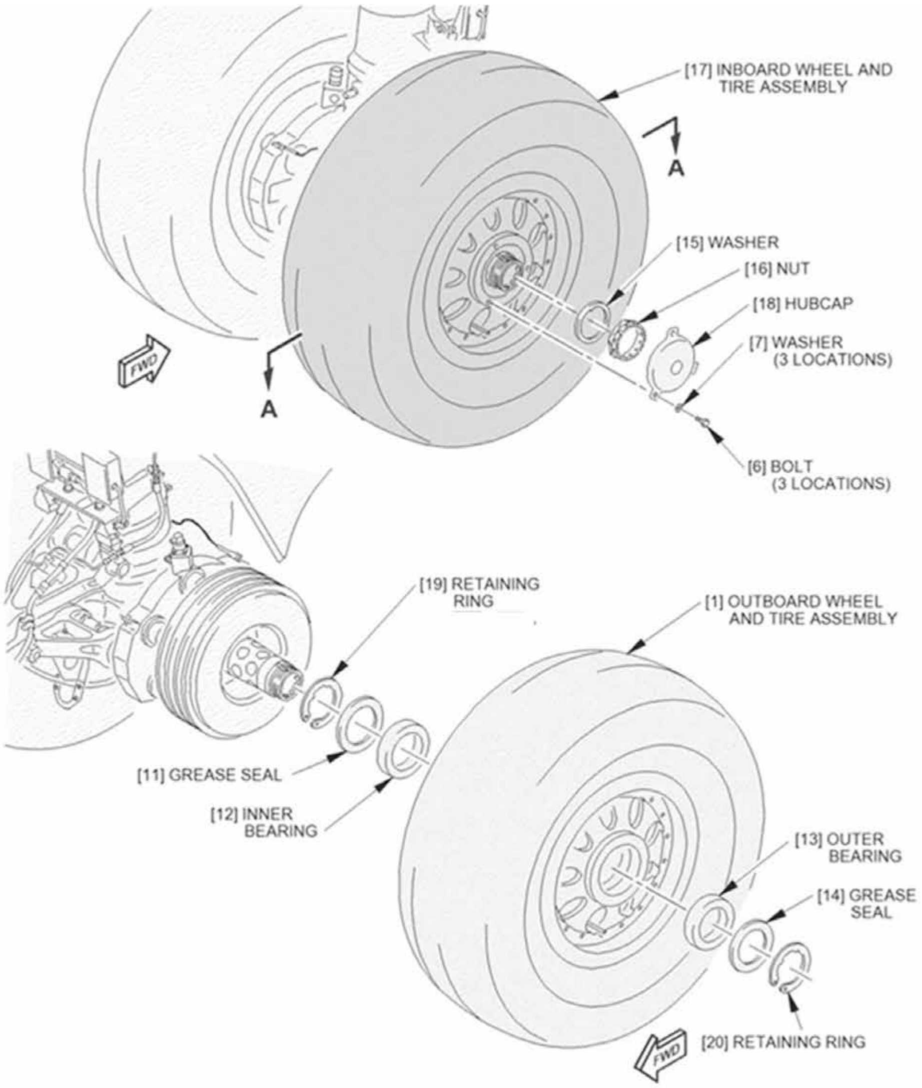


Figure 2

Landing gear mainwheel general arrangement (courtesy of Boeing)

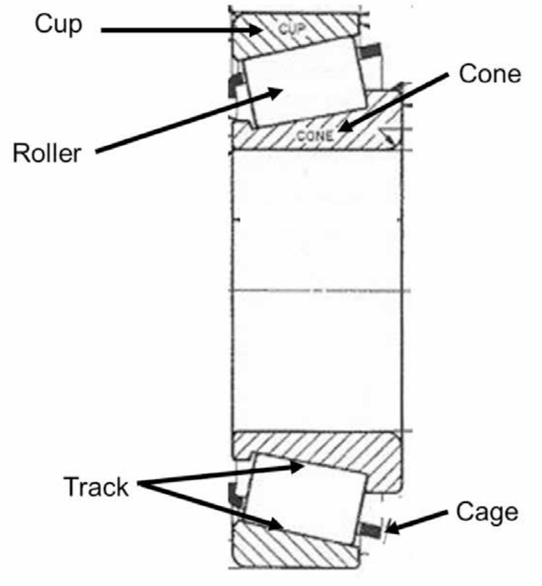


Figure 3
Bearing general arrangement (courtesy of Timken)

Standard wheel bearing assembly practice

The bearings are provided as part of the wheel assembly. When fitted to the axle, a nut and washer are used to apply pressure to the bearings, which is known as the preload. The preload ensures the bearing cups and cones are correctly seated, and the rollers correctly aligned. This is achieved by applying a torque to the nut using a suitable torque wrench. Once the bearing assembly has been preloaded, the nut is loosened slightly, whilst maintaining a tight contact between the cup, cone and rollers, then retightened to its service torque, which is usually about 20-25% of the preload torque. Both these procedures are done whilst slowly rotating the wheel clockwise to ensure that the large roller ends are seated against the cone rib.

Brake units

All four main wheels are fitted with multiple rotor and stator brake packs. The rotors are single piece carbon ceramic discs with equally spaced radial key slots which engage with a set of bars, known as rotor drive keys, rigidly mounted on the inner surface of the wheel hub.

The torque tube and reaction plate, which constitute the main frame of the brake pack, are fixed to the lower part of the landing gear axle boss (Figure 4). A set of friction stators are positioned on the outside and between each of the rotors and are prevented from rotating by locking in ridges radially spaced around the torque tube.

When hydraulic pressure is applied to the brake pack, a set of six pistons, equally spaced around the brake housing, impart a compressive force against the reaction plate on the end of the torque tube. This creates a braking effect between the rotors and stators. The brake reaction loads are imparted into the landing gear structure via the torque reaction recesses.

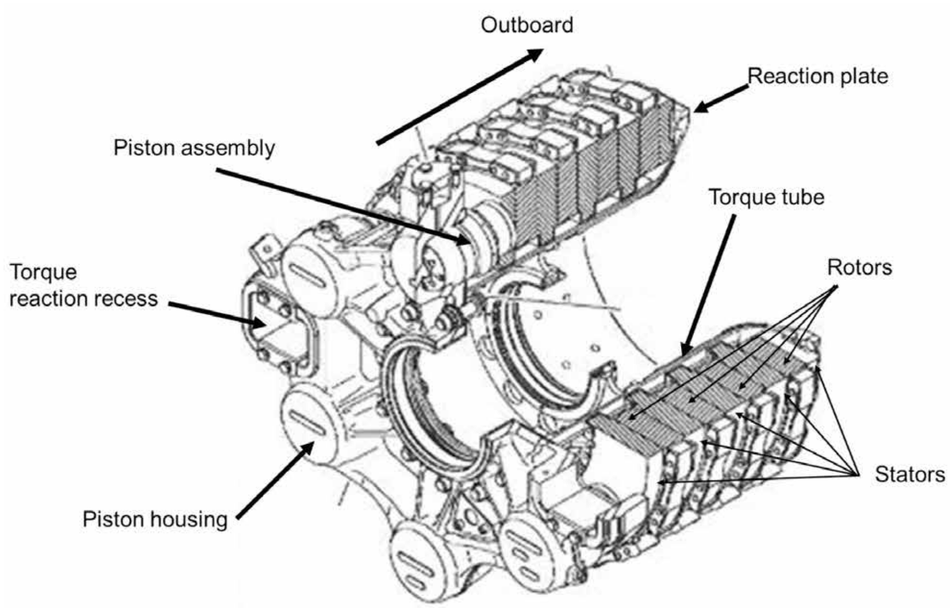
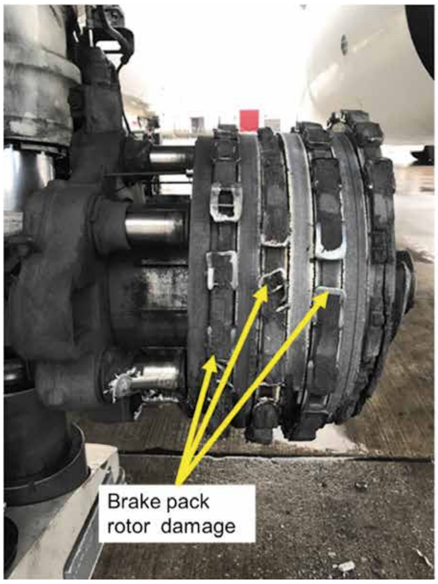
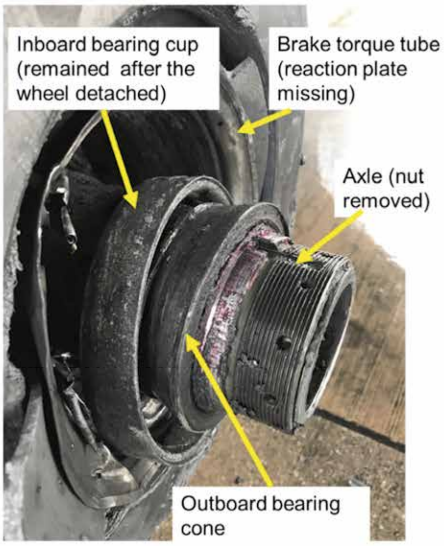


Figure 4
Brake assembly components

Initial examination

Prior to moving the aircraft, an inspection was carried out by the operator's engineers who found significant damage on the brake pack and to the wheel bearing cones, which were still attached to the axle. The tracks were heavily scored, exhibited heat damage and the remains of some of the rollers were smeared onto the bearing tracks. The inboard bearing cup had detached from the hub and was loosely hanging on the axle (Figures 5 and 6). The nut and washer were still in place on the axle and were relatively undamaged. The brake pack reaction plate was found on the runway.





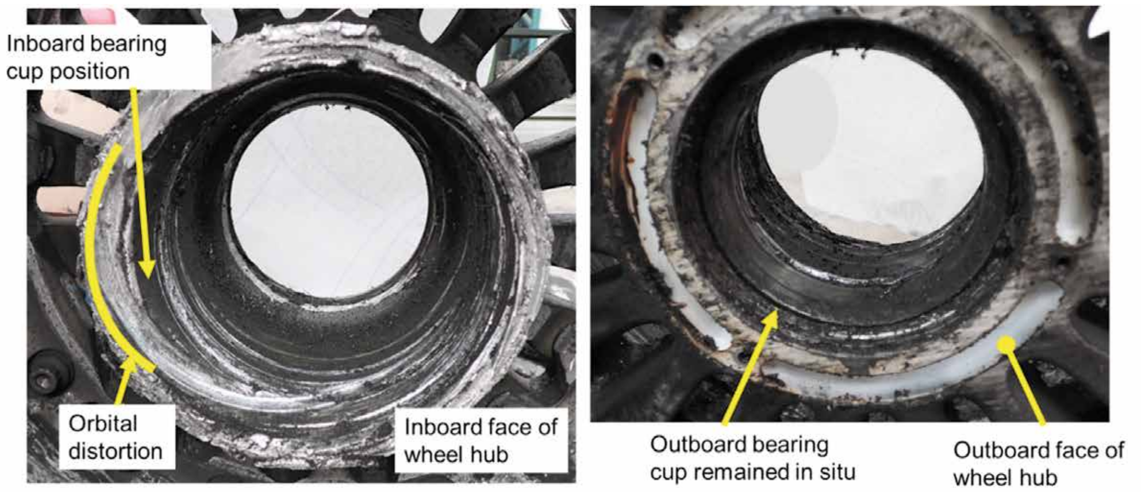
Figures 5 and 6
Brake pack and bearing damage

Detailed examination

A detailed examination of the wheel and brake components was carried out at the AAIB premises by the AAIB and a representative from the bearing manufacturer.

Wheel hub

All but one of the brake rotor drive keys had detached and the inner face of the hub was heavily scored over its entire surface. The outboard bearing cup was in place, but the inboard bearing cup had detached. The hub, where the inboard cup had been fitted, was badly distorted and had taken on an offset elliptical shape (Figures 7 and 8).



Figures 7 and 8

Hub damage around the inboard and outboard bearing cup area

Brake pack

The brake pack rotors and stators were all present, although they had been pushed outwards by the brake pistons which had travelled to their full extension. There was no evidence of hydraulic fluid leakage. The outer reaction plate had detached along with a large portion of the brake torque tube. Some of the lower-most pistons had deep gouges in their outer surfaces. Most of the rotors and stators were distorted and had various cracks and fissures across their surfaces. Figure 9 shows the damage to the brake pack torque tube and pistons.

Axle, wheel nut and spacer

Apart from debris and light scratch marks, the axle appeared to be undamaged. The wheel nut and washer remained in place and were removed by the operator after the event. Examination found the washer to be in relatively good condition and there was some scoring and indentation on the nut flats.

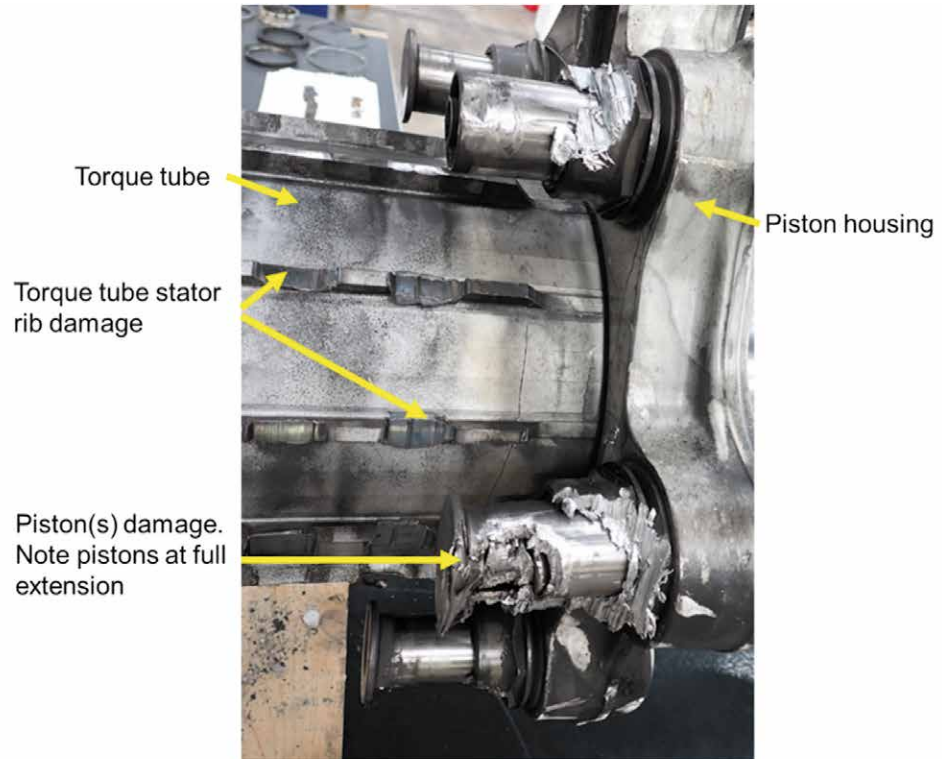


Figure 9
Damage to the torque tube and pistons

Bearings

Only 20% of the outboard and 50% of the inboard bearings were recognisable. The outboard bearing cone, which was still fitted to the axle, was scored and showed evidence of metallic smearing on its bearing track. None of the rollers or the cage were in place. The remains of the rollers were found on the runway and showed signs of skidding welding and overheating. The outboard bearing cup remained within the wheel hub and exhibited similar damage to the bearing cone.

The damage to the inboard bearing was far worse than on the outboard bearing components. The inboard cone was severely overheated, its bearing track was worn and misshapen and the remains of several rollers were smeared and welded to its surface. The inboard bearing cup exhibited very similar damage to the cup on its bearing track. Figures 10 and 11 show the condition of the outboard and inboard bearing cones.

The cages from both bearings had been reduced to deformed fragments which showed similar extreme levels of heating and distress as the rollers. There were minute quantities of grease present on the remains of the grease seals and significant carbonised grease deposits on some of the bearing debris.

Figure 10
Outboard bearing cone

Figure 11
Inboard bearing cone

Aircraft maintenance history

Fitment of the wheel assembly

The wheel was overhauled on 11 November 2019, released to service on 14 November 2019 and fitted to G-TAWG on 25 November 2019. The following entry was made in the maintenance work order:

> *'G-TAWG WO 1200 1621*
> *No 4 m/wheel worn to limits*
> *No 4 m/wheel assy replaced iaw AMM 32-45-11, final TQ 150ft/lbs #8007'*

The number #8007 identifies the torque wrench used to apply the service torque. The licenced engineer who replaced the wheel reported that there was nothing abnormal about the task and that the replacement wheel was serviceable. He was satisfied that the bearings had been correctly fitted and were properly greased. Regarding the application of the torque, the engineer said he always set the torque wrench to 550 lbf-ft, which was in the middle of the required range. Similarly, he would set the service torque to 150 lbf-ft and that a small clockwise, movement of the nut, as specified in the Aircraft Maintenance Manual (AMM), was only ever required to align the locking bolt holes between the nut and the axle.

Torque wrench

The torque wrench used by the engineer for the preload, #WS3045, has a range of 480 to 940 Nm, equivalent to 354 to 693 lbf-ft, and the required torque is set using a small retractable crank handle located at the hand-grip end of the wrench. It is known as a 'break-out' torque wrench because an unmistakable audible 'click' is heard and a 'jolt' felt through the handle when the required torque is reached.

On 8 January 2020, just over two weeks after the event, the torque wrench used to apply the preload torque on G-TAWG underwent its annual calibration[1]. It was found to be under reading by 11% to 12% on each of the test settings: the allowable tolerance is ±4%. As a result of this finding, the torque wrench was withdrawn from service. No issues have been reported with the torque wrench used to apply the service torque of 150 lbf-ft. It is common practice for a torque wrench to be set and tested using a test gauge; however, when the wheel was fitted to G-TAWG there did not appear to be a test gauge readily available.

Clamping force

The outside diameter of the axle thread is 3.78 inches (96 mm) and the preload torque range results in a clamping force exerted by the nut on the bearings of 8,800 lbs to 10,600 lbs (4,000 kg to 4,800 kg). The effect of the torque wrench under reading would have reduced the force exerted by the engineer on the nut to 8,600 lbs (3,900 kg) which equates to 97.5% of the required minimum force.

Second occurrence of bearing failure

On 15 February 2020 another Boeing 737 in the operator's fleet, G-FDZB, suffered a mainwheel bearing failure, which was detected during the pre-flight inspection when it was observed that the wheel and brake assembly were covered in "silver glitter". The inboard bearing was subsequently found to have seized and there was severe damage to the wheel hub and brake assembly.

Due to the restrictions of the Coronavirus pandemic, at the time of writing the operator had not completed their investigation into the cause of this bearing failure, but once the situation allowed would take the following safety action:

> As a result of the No 4 inner wheel bearing failure found on Boeing 737-800, G-FDZB, and its similarities with a preceding bearing failure on Boeing 737-800, G-TAWG, a component failure investigation will be carried out to ascertain if there is a common cause for both failures.

Footnote

1 Calibration Report Number 3209160001 issued to the operator on 25 February 2020.

Analysis

The right outer mainwheel (No 4) detached from its axle as a result of a failure of its wheel bearings.

Bearing operating conditions

During start up, pushback and taxi, the loaded bearing rotates slowly and gradually increases speed during the takeoff until eventually it slows and stops as the landing gear is retracted. During this period, the bearing gently warms and settles into running surrounded by a compliant lubricant.

The conditions during the landing are very different. The bearing hub and wheel assembly will have been 'cold soaked' at altitude and at touchdown the wheels and bearings will accelerate to landing speed with increasing load as the aircraft's aerodynamic lift reduces. These conditions do not normally present a problem; however, the landing conditions can exacerbate any faults or wear and lead to premature failure of the bearing assembly.

Sequence of events leading to the wheel detaching

The inboard bearing was more severely damaged than the outboard bearing indicating that the inboard bearing failed first, causing secondary damage to the outboard bearing. The severity of the damage to the inboard bearing indicates that it may have been running for a period of time in a distressed condition during which large amounts of heat were generated.

The elliptical damage to the hub, and the area where the inboard bearing cup is located, is consistent with the inboard bearing becoming loose allowing the wheel to wobble about its axle.

With a loss of wheel alignment, the outboard bearing would have deteriorated until the rollers and cage were released. Damage to the brake components show that as the bearings failed, the wheel loads were imparted into the brake components leading to the torque tube failure. The brake pistons then had nothing to react against, so fully extended under hydraulic brake system pressure. The damage to the hub and bearings was such that the wheel was able to move outwards over the outboard bearing cone, washer and nut until the wheel eventually came off the axle.

Possible causes

The bearings were too badly damaged to determine why they failed, but damage can be caused by:

- Insufficient or poorly applied grease
- Incorrect handling
- Incorrect type of grease
- Break down of the grease properties
- Excessive grease (not a common occurrence)
- Ingress of water, debris or other contaminants

- Incorrect assembly, by misalignment or by incorrect preload
- Sudden shock loading whilst stationary
- Overload during rotation
- Wear and gradual degradation of the rolling surfaces over time

The following aspects were considered during this investigation.

Damaged during the landing

The aircraft had not been subjected to a heavy landing since the wheel had last been fitted. Therefore, the possibility that the bearing assembly failed as a result of excessive landing loads was discounted.

Poorly prepared bearing

Pre-installation inspection of the wheel and bearing assembly, prior to being fitted to the aircraft, was carried out by the engineer. The engineer identified nothing abnormal and reported that the bearings had been greased correctly.

Pre-existing faults

The severity of the damage to the bearing components make it impossible to identify any pre-existing faults, or damage, or the presence of excessive moisture in the grease. Water ingress is known to cause a rapid degradation of bearings of this type.

Debris

The inboard and outboard bearing assembly was too badly damaged to establish if any debris (metallic, grit or dust) had initiated their failure.

Insufficient preload

The importance of applying the correct preload while rotating the wheel is emphasised by the bearing and aircraft manufacturer. There was no evidence that the correct preload procedure was not applied when the wheel was fitted.

The torque wrench used (#WS3045) was calibrated and certified by the manufacturer and was required to be tested annually. It was last calibrated in January 2019 and was found to be out of calibration five weeks after the event. It is good practice to check the torque set on the torque wrench prior to use, but this is not a mandatory requirement and, as in this case, it may not always be possible to ensure that a suitable test set is readily available.

It is not known how long the torque wrench was over reading or the likely error when the wheel was fitted. If it was over reading by 11% to 12% then the actual torque applied could have been as low as 484 to 489 lbf-ft, which is slightly below the minimum requirement of 500 lbf-ft. Consequently, the compressive force applied to seat the bearings might have been 3,900 kg, which is 100 kg below the minimum requirement of 4,000 kg. However, this relatively small reduction in force is not considered sufficient on its own to have caused the bearing to fail.

Conclusion

Bearing failure investigations such as this are often inconclusive due the severity of the material damage within the bearing destroying evidence of the initiation. Therefore, it was not possible to determine the cause of the bearing failure, or to discount the possibility that there was a pre-existing fault, or the bearing had become damaged as a result of the ingress of debris or moisture.

It is possible that preload torque applied was slightly below the minimum required; however, it was still considered enough to ensure that the bearing assembly was correctly seated and makes it unlikely to have affected the bearing running condition. However, a combination of the possible causes set out in this report cannot be ruled out.

The AAIB will review the findings of the operator's investigation into the bearing failure on G-FDZB and will provide an update to this report if it provides further clarification on the cause of the bearing failure on G-TAWG.

Published: 1 October 2020.