Department of Transport and Regional Services

Australian Transport Safety Bureau

TECHNICAL ANALYSIS REPORT

Report No. 33/02

Task No. BE/200200019

Occurrence No: BO/200204836

Examination of the Main Landing Gear Wheel Bearings

Boeing 727, VH-TXH

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1. FACTUAL INFORMATION

1.1. Examination brief

During a routine departure from Melbourne aerodrome, the inner left main landing gear wheel separated from a B727 aircraft (registration VH-TXH) and was later recovered near the aerodrome perimeter fence. Preliminary examination showed that the outer axle bearing had failed, allowing the wheel hub to move axially outward – over the retaining nut and off the stub axle (figure 1).

Fig. 1. Left main landing gear from VH-TXH after the loss of the inboard (position-2) wheel was discovered.

The remnants of the failed bearing, the wheel hub and all other wheel bearings from both main landing gear assemblies were subsequently received by the ATSB's Canberra laboratories for examination and analysis of the failure and to identify any significant contributory factors.

1.2. Samples received

From the failed wheel assembly (position two), the ATSB received the wheel hub and tyre, the damaged stub axle, the inner bearing with its rear sealing cap and remnants of the outer bearing races, cage and rolling elements.

Both inner and outer bearings (excluding the outer races) were received from the other main landing gear wheel positions one, three and four. In all positions, the wheel bearings fitted were 'Timken' tapered roller units, arranged in an inwardly facing configuration. The bearing units carried the identification:

Outer: 'Timken LM522546'
Inner: 'Timken M224749 *2-629'

1.3. Visual examination

1.3.1. Failed bearing

The outer bearing from position two had sustained very extensive damage that was consistent with the breakdown and collapse of the roller assembly during rapid wheel rotation (take-off and landing). The inner race (figure 2) showed gross frictional overheating and metal flow (figure 3), with evidence of the localised melting of the underlying axle material (an aluminium alloy, figure 4). The bearing outer race remained within the wheel hub (figure 5) and had sustained similar damage, with heavy rotational scoring and galling of the race surface and the surrounding housing (figure 6). Any existing evidence of the initial mechanism/s that lead to the bearing's breakdown had been destroyed during the final stages of the failure.

Fig. 2. Inner race of the position-two outer bearing as it was removed from the axle.

Fig. 3. Inner race of the position-two outer bearing illustrating the degree of metal flow sustained.

Fig. 4. Top Left. Inside surface of the inner race showing evidence of the partial melting of the axle material.

Fig. 5. Top Right. Appearance of the bearing outer race that remained within the wheel hub.

Fig. 6. Left. Rolling contact surface of the outer bearing race showing the extreme distress and damage produced to the race and the adjacent housing surfaces.

1.3.2. Inner bearing

The inboard bearing from the number-two wheel position was examined closely for any evidence of the problem that had afflicted the outboard unit. Before cleaning, samples of the adherent grease were taken for particle content analysis. In numerous areas, the grease appeared visibly discoloured and contaminated, particularly around the edges of the rear cap (figure 7). In areas, the contaminant had encroached into the bearing space (figure 8). Where it was heavily contaminated, the grease appeared dry and congealed.

Fig. 7. End cap from the position-two inboard bearing, showing discolouration and contamination of the grease.

Fig. 8. Contaminated grease accumulated around the rolling elements of the position-two inboard bearing.

Comments received from maintenance personnel indicated that it was possible for the bearings to become contaminated during the removal process, however much of the contaminant found was intermixed with the lubricant and unlikely to have been introduced in this manner.

The outer race (remaining in the wheel hub) was in comparatively good condition and showed no significant contact surface breakdown or overheating. A single spiral score mark around the surface (figure 9) was suspected as damage produced during the wheel separation event. Several small areas of light corrosion on the race surface were also of post-failure origin, given that they had a raised profile and did not show any signs of over-rolling by the bearing elements.

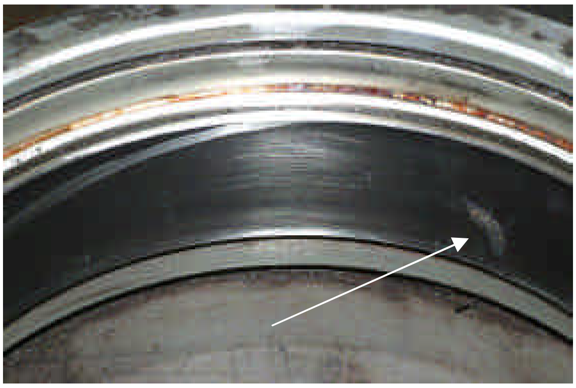


Fig. 9. Outside race from the position-two inboard bearing. The scoring evident on the left side is suspected to have occurred on separation of the wheel. The area arrowed to the right is surface corrosion developing after the wheel loss.

The inner race presented a single small area of spalling at the inner edge of the raceway (figure 10), with characteristic trailing bruising and indentation damage from the liberated metal. The remainder of the race surface was undamaged. Light circumferential scuffing and polishing was present over the majority of the rolling element surfaces, although no spalling or more advanced damage was noted. Most rollers showed an increase in the level of general surface abrasion toward the smaller (inside) ends (figure 11). The roller cage was undamaged.

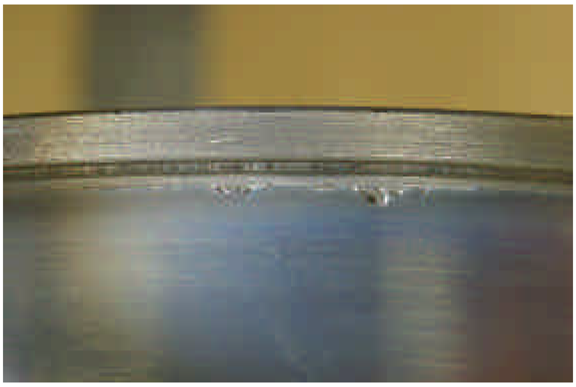


Fig. 10. Inner race from the inboard position-two wheel bearing, showing a small area of surface spalling suspected as originating from misalignment after failure of the outboard bearing.

Fig. 11. Rolling element from the inboard position-two bearing, showing increased abrasion and scuffing toward the inside edge.

1.3.3. Other bearings

Each of the six other bearings fitted to the other main landing gear wheels was examined in turn, with notes made of the grease appearance and particle content, as well as the physical condition of the races and rolling elements. In general, all of the bearings showed a visible level of grease discolouration - most clearly evident inside the rear caps of the inboard bearings (figure 12) and on the end faces of the outboard bearings (figure 13). Samples of the grease were also taken for particle analysis.

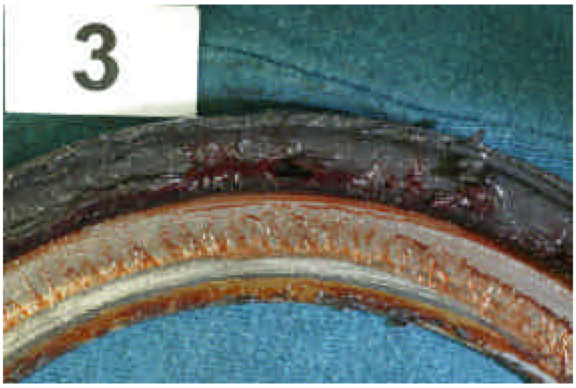


Fig. 12. End cap from the position-three inboard bearing, showing discolouration and contamination of the grease.

Fig. 13. Position-three outboard bearing showing heavily contaminated grease.

After degreasing, the cage of each bearing was split to release the rollers and all surfaces were closely examined. The inner race surfaces of the position-three inboard bearing and position-four outboard bearing both showed the development of incipient spalling damage (figure 14), with the position-four bearing also showing clear evidence of static corrosion damage (figure 15). The corrosion or 'water marks' was present in parallel transverse bands, with a spacing that equalled the roller separation. Several corroded areas showed the clear development of associated spalling bands (figure 16). Light corrosion staining was also noted on the outside flange of the position-one outside bearing (figure 17).

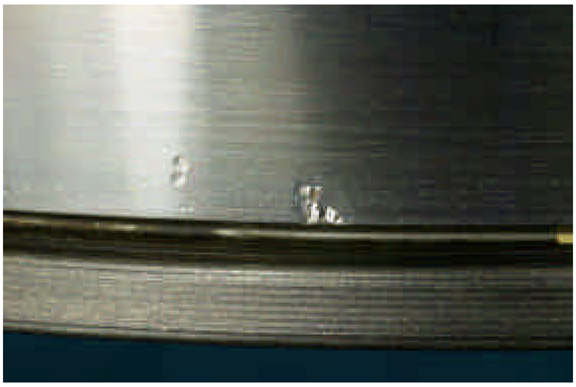


Fig. 14. Surface spalling found on the inner race of the position-three inboard bearing.

Fig. 15. Surfaces of the position-four outboard bearing inner race, showing the static corrosion damage sustained.

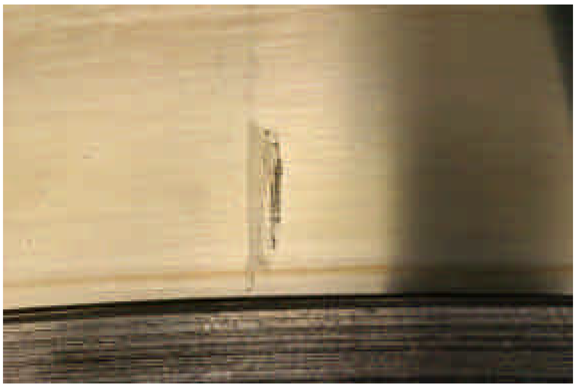


Fig. 16. Corrosion and associated spalling damage on the surface of the position-four outboard bearing inner race.

Fig. 17. Corrosion also found on the end face of the position-one outboard bearing inner race.

1.4. Lubricant particle analysis

The samples of grease from the position-two inboard bearing and the other six intact bearings were prepared for particle analysis by dissolving in solvent to remove the lubricant, followed by an ethanol wash and drying in still air. The particles collected were examined optically and by scanning electron microscopy. Energy-dispersive X-ray spectroscopy (EDS) was used to characterise the chemical composition of the representative particle collections.

1.4.1. Wheel two – inboard bearing

Figures 18 and 19 present a typical sample of the coarse debris recovered from this bearing, which was adjacent to the failed unit. As could be seen from the EDS analysis, the debris was made up of a wide variety of materials, including metallic alloys of iron, aluminium and copper, and non-metallic compounds of aluminium, iron and silicon. Morphologically, the materials assumed a mixture of globular spheroids, angular crystalline particles and irregular flakes. Figure 20 has been annotated with the typical composition of each of the primary particle forms.

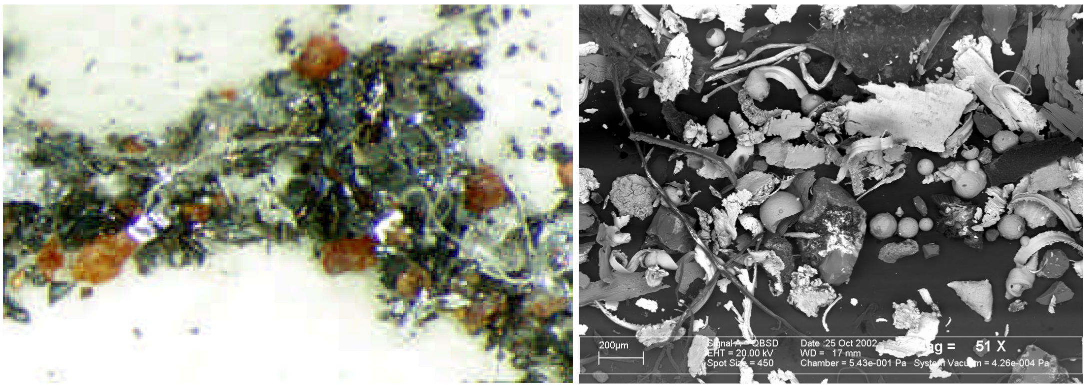


Fig. 18 & 19. Optical and electron micrographic views of a collection of debris from the position-two inboard bearing (adjacent to the failed bearing).

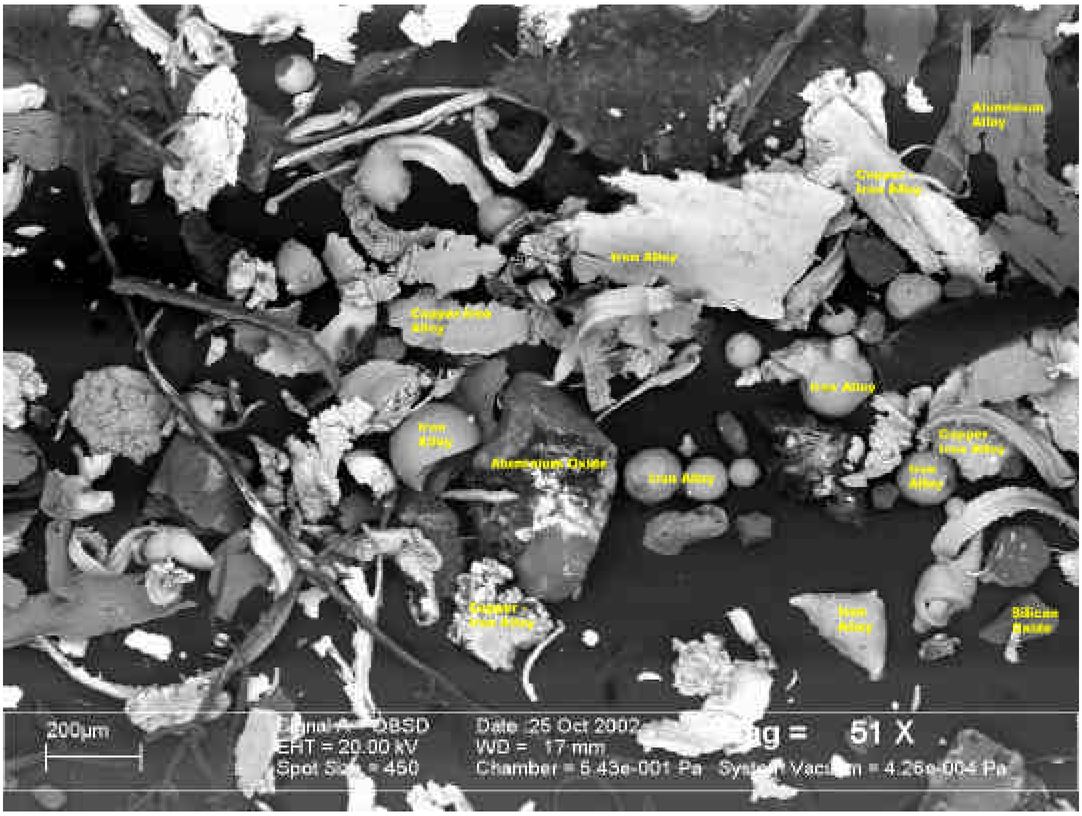
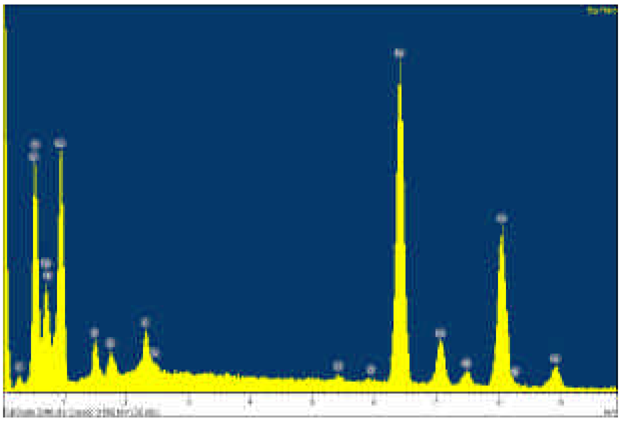


Fig. 20. The electron micrograph shown in Fig. 19, annotated with the material types as determined by X-Ray spectroscopy.

1.4.2. Other bearings

The debris recovered from the grease of the other main landing gear wheel bearings was mainly of flake-type morphology, with a small quantity of angular crystalline particles throughout (figure 21). From the EDS analysis, the flake type particles were characterised as a copper-iron alloy (figure 22), while the angular particles were predominantly aluminium-oxygen-silicon compounds (figure 23).



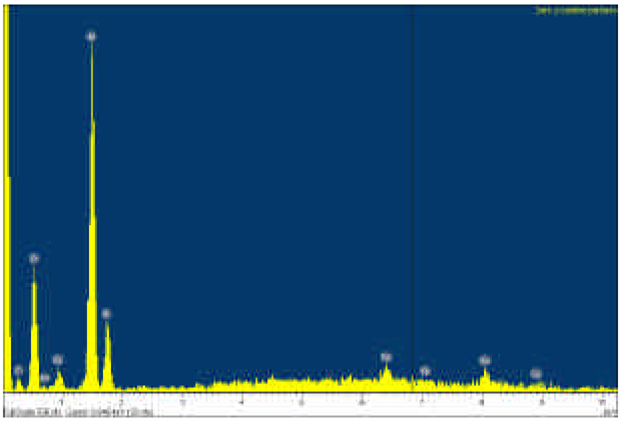


Fig. 21. Above. Electron micrograph of debris collected from the other wheel bearings. Flake and angular crystalline particles can be resolved.

Fig. 22. Centre Left. EDS spectra of the flake-type particles. Predominantly a Fe-Cu composition.

Fig. 23. Lower Left. EDS spectra of the crystalline particles. Predominantly an Al-Si-O composition.

The metallic friction materials commonly used within aircraft braking systems are primarily blends of copper and iron as a base matrix, with the addition of graphite, silicon abrasives and high temperature lubricants such as molybdenum disulphide [Ref. ASM Handbook Vol.18pp582 'Friction and Wear of Aircraft Brakes']

2. ANALYSIS

2.1. Wheel loss

Separation of the position-two main landing gear wheel from the aircraft occurred as a direct result of the gross frictional overheating and subsequent structural failure of the outboard bearing. Without the retaining action of the bearing, the wheel was free to move axially away from its normal position during the last take-off roll. The damage to the races of the inboard bearing was consistent with the axial misalignment that developed as the outer bearing failed and the eventual mechanical contact as the wheel separated from the axle. The light corrosion on the outer race surfaces had developed after the wheel loss.

Because of the damage sustained by the outboard bearing in the final stages of failure it was not possible to directly determine the reasons behind the breakdown.

2.2. Bearing and grease condition

All of the bearings examined showed a degree of grease discolouration, contamination and thickening. The position-two inner bearing (adjacent to the failure) showed contamination with debris produced during the violent breakdown of the outer bearing. More significantly however, the bearings were found to contain appreciable contamination from the wheel brake friction compounds (brake linings). The characteristic copper-iron alloy flakes were found in the lubricant around the edges of all bearings, suggesting that sealing against the ingress of this material had been ineffective. Bearing contamination can lead to a lubricant efficacy loss and an increase in the susceptibility to premature breakdown. If the contaminant is abrasive in any way, the degradation may be more pronounced.

Bearing sealing and overhaul frequency was also brought into question by the discovery of internal corrosion within several of the bearing inner races. The corrosion had formed around several roller-to-race contact points and left characteristic dark stains, sometimes referred to as ‘water marks’. This type of corrosion damage typically occurs during storage or long periods of inactivity, where the lubricant is not being circulated to maintain adequate surface coverage. During operation, corrosion pits on bearing contact surfaces act to create a localised hydrodynamic pressure ‘pulse’ in the lubricant as the rollers pass over the pits. It is this cyclic stress that provides the environment for rolling-contact fatigue damage (spalling). The development of bearing surface spalling leads to a significant increase in friction, with the associated heating effects. In all cases, there will exist a threshold temperature above which the bearing will experience thermal runaway and the type of rapid breakdown that occurred in the present case.

3. CONCLUSIONS

3.1. Findings

1. Separation of the position-two main landing gear wheel from the aircraft occurred as a result of the catastrophic failure and structural collapse of the outboard wheel bearing.

2. Damage to the failed bearing prevented the determination of the specific factors that contributed to the failure of that particular unit.

3. The grease lubricant from all main landing gear bearings was found contaminated with friction material from the wheel brake assemblies.

4. Several of the bearing races showed surface corrosion damage that was consistent with having formed during storage or a period of bearing inactivity.

5. Incipient contact fatigue spalling damage had initiated from several of the corroded areas.

6. The development of contact fatigue spalling damage can lead to catastrophic bearing failure of the nature sustained by the position-two outboard bearing from VH-TXH.

3.2. Significant factors

Although not directly determined from the failed wheel bearing, the evidence found during this investigation suggested that the development of corrosion damage over the contact surfaces of the wheel bearings was a major factor contributing to the failure.