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Investigation of a Boeing 747 wing main landing gear trunnion failure

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ABSTRACT

A loud noise was heard from the vicinity of the port wing landing gear during pushback of a Boeing 747-300 from the terminal at Sydney (Australia) airport. Inspection showed that one of the wing landing gear trunnion fork assemblies had failed. Detailed investigation revealed that the trunnion had failed by fatigue cracking. Deep machining grooves were found at the root of an internal radius that had not been shot-peened as required, and a chemical surface process during manufacture had resulted in shallow intergranular attack at the bottom of these grooves. It is probable that the critical cracking started from some of these grooves. In addition, the wall thickness at the failure location was significantly less than the minimum required in the drawings.

Since the deep machining grooves, the lack of peening and the intergranular attack were all consequences of manufacturing, the fatigue cracking probably started shortly after the component entered service. This implies that fatigue cracking was present during all the trunnion overhauls, but was not detected by non-destructive inspections during the overhauls. Quantitative fractography was used to produce a crack growth curve based on fracture surface markings thought to represent the overhaul timings. The crack growth curve suggested that the fatigue cracking was large enough to be detected by inspection during the last overhaul, if not the one before. However, it was probably not easy to detect the cracking. This investigation therefore highlights the difficulties that can be encountered when inspection is the last (or only) line of defence against failure owing to unexpected manufacturing deficiencies.

1. Introduction

A loud noise was heard from the vicinity of the port wing landing gear during pushback of a Boeing 747-300 from the terminal at Sydney (Australia) airport. Inspection showed that the Trunnion Fork Assembly – Wing Landing Gear, hereafter called 'the trunnion' had failed. The Australian Transportation Safety Bureau (ATSB) requested the Defence Science and Technology Organisation (DSTO) to carry out a metallurgical investigation of the failed trunnion. The essential findings of this investigation were used in the final ATSB report [1].

This paper describes the investigation, which established that the trunnion failed by fatigue cracking, and includes Quantitative Fractography (QF) to establish a fatigue crack growth curve from overhaul schedules. Although the validity of such a crack growth curve may be questioned, the results strongly suggest that the cracking was large enough to be detected by inspection during the last overhaul before failure.

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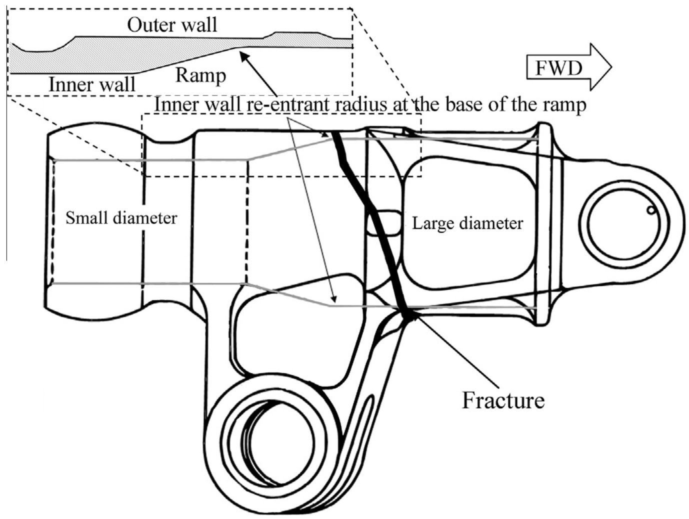

Fig. 1. A schematic of the part is shown, with the internal bore marked by the grey lines and a thick black line indicating the approximate path of the failure. An expanded view of a section of the wall is shown in the dashed box. This indicates several features of interest noted in the investigation.

1.1. Trunnion background information

The trunnion was reported to have been manufactured from the ultra-high strength steel 4340M. The manufacturer's drawings indicated that the trunnion was forged, machined to size, steel-shot-peened all over, and electroplated with a 'Titanium–Cadmium' (TiCad)[1] coating before painting. The trunnion consisted of a round tube with various protrusions on the outer surface, including two lugs for attaching the landing gear drag brace. One end of the tube had an integral fork end fitting that attached to the main strut; the other end had an outer ball shape that fitted into a bearing attached to the wing. The engineering drawing of the trunnion indicated that the inner surface of the tube had a diameter change about halfway along the bore from a diameter of 135.64 mm (+/– 0.25 mm)[2] to 99.06 mm (+/– 0.25 mm). These diameters were connected by a shallow internal ramp with a re-entrant radius to the ramp of 25.40 mm. The outside diameter directly over this radius was 146.56 mm, giving minimum wall thicknesses of 5.33 mm for a concentric bore. The drawing allows a minimum wall thickness of 4.57 mm to allow for some non-concentricity in the bore diameter with the outer surface diameter in this region. This is probably required due to the complicated form of the outer surface. A schematic of the trunnion is shown in Fig. 1 with several of these features indicated.

The manufacturer's design philosophy with regard to fatigue was not known. However, discussions with the aircraft operator suggested that the trunnion life was to be determined from a 'retirement-for-cause' or 'on-condition' approach, whereby repairs (which were allowed in some areas) or retirement depended on the trunnion's condition at overhaul. This approach allows an effectively indefinite life as long as unrepairable damage is not found.

Overhaul was specified to be done regularly with a maximum allowable interval of 12,000 landing cycles or 8 years of service, whichever came first. However, details of the life and period between overhauls in Table 1 indicate that other operational considerations dictated the overhaul schedules. In fact, the trunnion had been fitted to five different aircraft, with overhauls each time. Failure occurred after 25,095 landing cycles, which would have been 6509 cycles, or another 4 years, before the next normally scheduled overhaul.

Table 2 lists the expected manufacturing and overhaul procedures relevant to the present investigation. Note that shot-peening is not part of the standard overhaul procedure. Peening would be required only if an area was blended to repair damage, and then only on the blended area.

2. Investigation

The failure occurred about halfway along the trunnion, severing the entire cross-section. Fig. 1 shows that the failure was between the drag brace attachment lugs and the fork end. Fig. 2 shows the two parts of the trunnion after fracture. The fracture is clearly seen to run through the entire cross-section of the tube at about the middle of the component. The circles in Fig. 2 encompass an area of the fracture that was corroded and appeared to be significantly older than the rest of the fracture.

[1] A cadmium plating process used to provide ambient temperature corrosion resistance for high strength steels in fracture critical applications such as aircraft landing gear and naval arrestor hooks. A typical standard for this process is SAE AMS2419C (2003-05-07).

[2] Since the part was designed in inches and the drawings were only marked in inches, measurements reported here have been converted from the inch values and rounded to two decimal places.