TECHNICAL ANALYSIS REPORT

Report No. 05/04

Occurrence No. 200305447

Examination of failed Integrated Nozzle Assembly and Thrust Reverser components from a RB211-524 Turbofan Engine

1. FACTUAL INFORMATION

1.1. Examination brief

During the landing at Johannesburg International Airport on 15 March 2003, the flight crew of the Boeing 747-400 aircraft, registered VH-OJO, noted an "ENG 2 REVERSER" message displayed on the engine indication and condition alerting system (EICAS) after the application of reverse thrust. Airport personnel subsequently found debris on the runway and taxiway used by the aircraft.

An engineering examination of the number-2 engine nacelle by the operator’s ground staff established that both panels from the integrated nozzle assembly (INA) drive fairing had been lost, as well as two thrust reverser blocker doors, with a third door substantially damaged. The core assembly of the engine (an RB211-524G/T model) was not damaged.

The operator reported the incident to the South African Civil Aviation Authority, who took the liberated debris into their possession for an engineering investigation of the failures. The components were subsequently sent to the Australian Transport Safety Bureau (ATSB) for further study and engineering analysis. The ATSB commenced a technical analysis investigation into the failure of the components on 1 July 2003. This report presents the findings of the ATSB analysis and conclusions drawn as to the mechanism of failure.

1.2. Other events

The engine manufacturer reported knowledge of approximately 9 fairing release events that had occurred between January 2002 and May 2004, including two additional failures affecting the operator’s aircraft fleet. All known events have occurred during the application of reverse thrust during landing, and all were associated with the RB211-524G and H series engines. The lower thrust RB211-524D engines were not known to have been affected.

1.3. Samples received

The items received by the ATSB included fragments of both INA drive fairing shells (figures 1 & 2), a mostly complete thrust reverser blocker door and pieces of a second blocker door that had broken into multiple sections (figure 3).

Figure 1. Received remnants of the INA drive fairing – side 1.

Figure 2. Received remnants of the INA drive fairing – side 2.

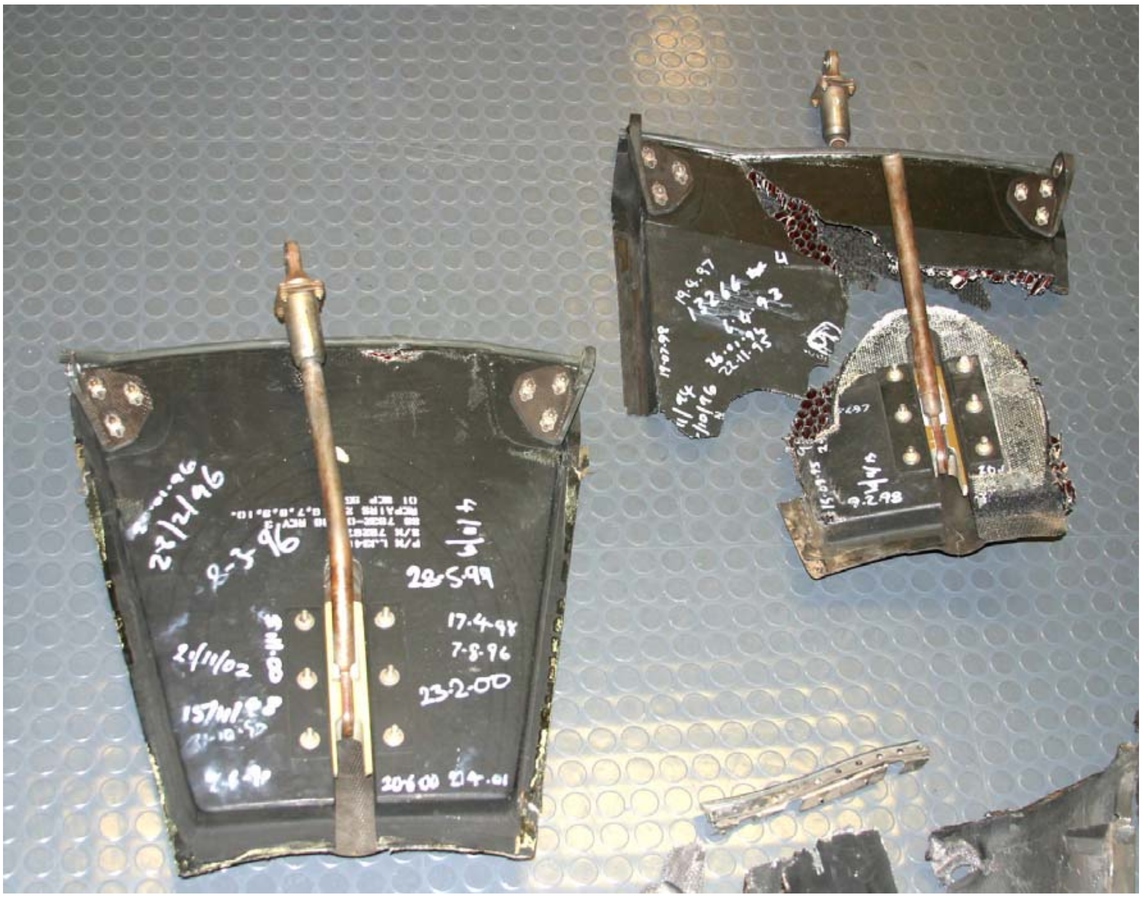

Figure 3. Received remnants of the thrust reverser blocker doors.

1.4. Visual examination

1.4.1. Blocker doors

From their marked identification, the two blocker doors were identified as part number LJ34179. The intact door carried serial number 78267-3, however the fragmented door had lost the panel section that carried its serial number. The doors were predominantly a carbon fibre composite construction, with a bonded honeycomb internal matrix. Both doors showed evidence of multiple impacts on the external surfaces[1] and both had sustained failure at or near to the hinge brackets along the pivoting edge (figures 4, 5). The actuating rod and coupling of both doors had distorted along the length, with the rod from the fragmented door having broken away at the outboard coupling to the actuating mechanism (figure 6).

The impact witness marks left on the external door surfaces were examined closely under directional lighting. Using that technique, it was possible to distinguish an imprint from a reinforcing panel that made up part of the INA fairing shell sections (figures 7, 8).

All of the fractures and disruptions presented by the blocker door sections were consistent with physical overload failures. There was no evidence of progressive cracking, disbonding or other degenerative type failure modes.

---

[1] Surfaces facing into the INA cold-stream duct.

Figure 4. Thrust reverser blocker door showing failure of hinge points.

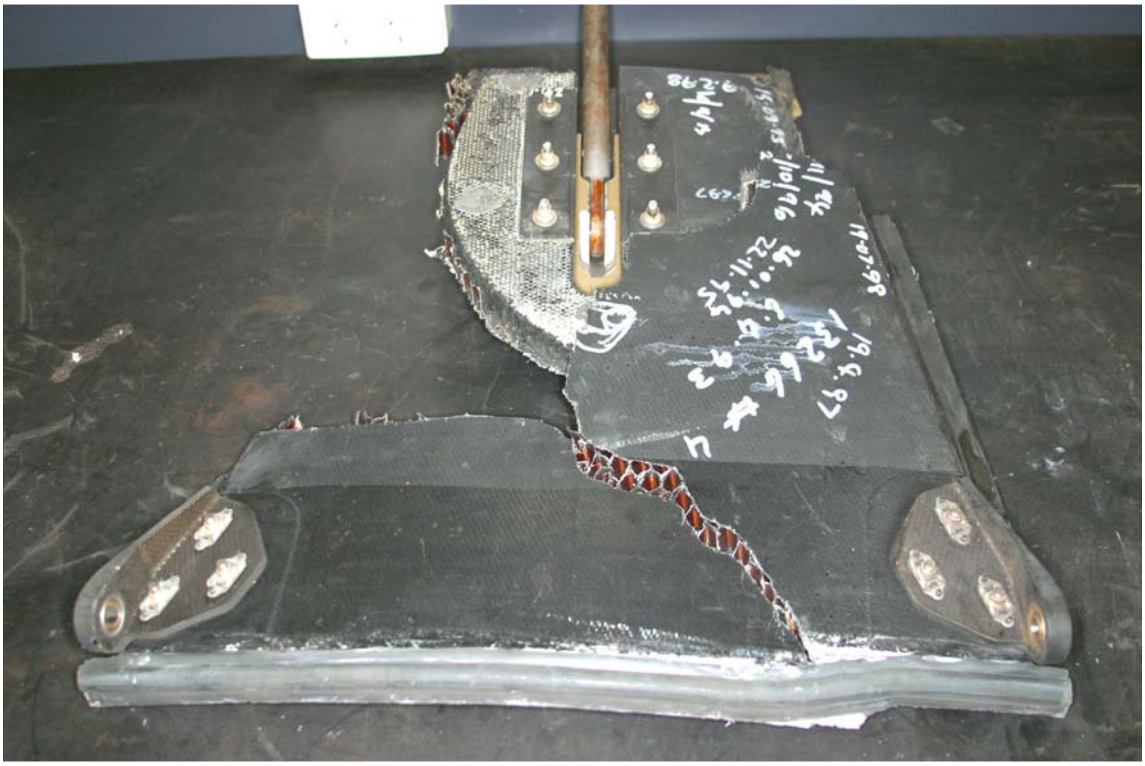

Figure 5. Blocker door major sections illustrating nature of break-up.

Figure 6. Blocker door actuator rod bending failure.

Figure 7. Inward facing surface of blocker door showing impact witness mark from a drive fairing panel (arrowed).

Figure 8. Close view of the impact mark shown in figure 7 above. Compare with figure 14 showing the drive fairing panel.

1.4.2. Drive fairing shells

The RB211-524 accessory transfer drive was faired through the INA cold-stream duct by two symmetrical fibre composite shells, adjoined by two central bolt tower fittings and a number of peripheral tie bolts and bosses (figure 9). The part numbers carried by the two fairing halves were *UL23538* and *UL23537* respectively. Both panels also carried stencilled or written information relating to repair operations conducted by the aircraft operator.

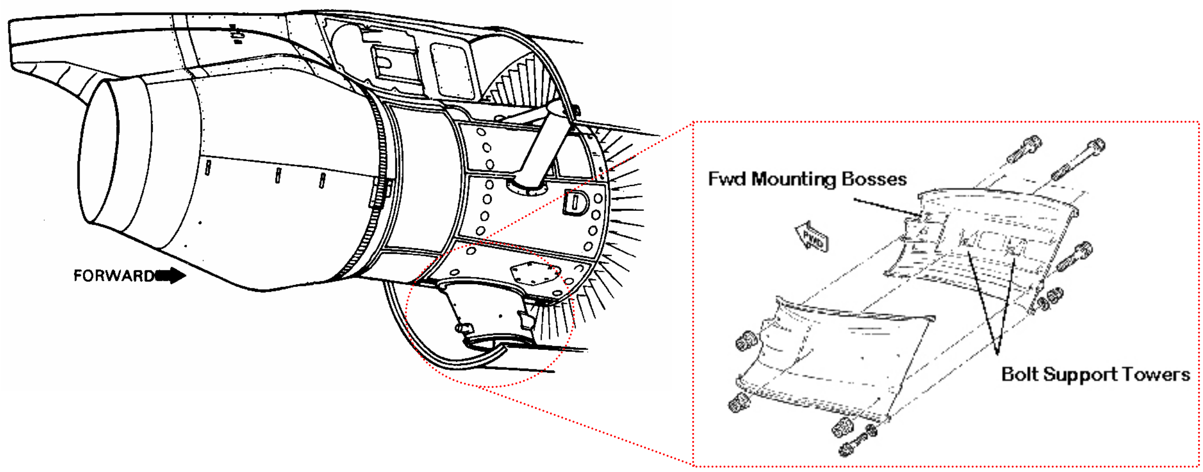

Figure 9. Basic schematic of the drive fairing shells and bolting arrangement. Enlarged diagram courtesy of the operator's Power Plant Engineering department report S-AB1/1.

Destruction of the fairing shells was extensive, with many small fragments produced during the failure sequence. Both central towers had separated from their base flanges on the inside of one panel half (figures 10, 11). Closer inspection revealed evidence of progressive cracking around the separated bases of both towers, with one tower showing evidence of that cracking around the complete circumference (figure 12). The adjacent tower presented mixed areas of ductile overload failure of the riveted connection and cracking around the edges of the base flanges (figure 13). The cracked areas showed minimal associated ductility. The outside faces of the fairing shells where the bolt towers had been affixed were reinforced with a rhomboidal shaped plate through which the fitting had been riveted (figure 14). The impression of one of these plates was found on the external surface of one of the thrust reverser blocker doors (figure 8).

There was no evidence of looseness or inadequate security of the fairing shell connections and no sign of fretting, wear or other characteristics of movement.

Figure 10. Inside surfaces of a drive fairing panel. Note the complete separation of the central bolt towers from their base panels.

Figure 11. Separated drive fairing bolt towers.

Figure 12. Base of a bolt tower illustrating the failure and separation from the flange transition.

Figure 13. Base of the other bolt tower showing a combination of cracking around the flange transition and ductile tearing and pull-through of the riveted connection.

Figure 14. External drive fairing panel showing the reinforcing plate associated with the bolt towers. Compare the appearance of this plate with the impact witness mark found on one of the thrust reverser blocker doors (figures 7 & 8).

1.5. Fractographic examination

Low-power stereomicroscopic examination of the cracked and fractured drive fairing bolt towers found clear evidence of fatigue cracking along the folded transitions between the tower body and the mounting flanges (figures 15, 16).

The bolt towers had been produced as fabricated items from folded and welded stainless steel plate. In some areas, the folding operation used to produce the base flanges had created shallow embossed lines from which fatigue cracking had initiated (figure 17). The weld terminations at the base of the tower corners were also a source of crack initiation (figure 18). Stereomicroscopic examination revealed several regions of crack propagation along the tower bases, extending away from the corner welds.

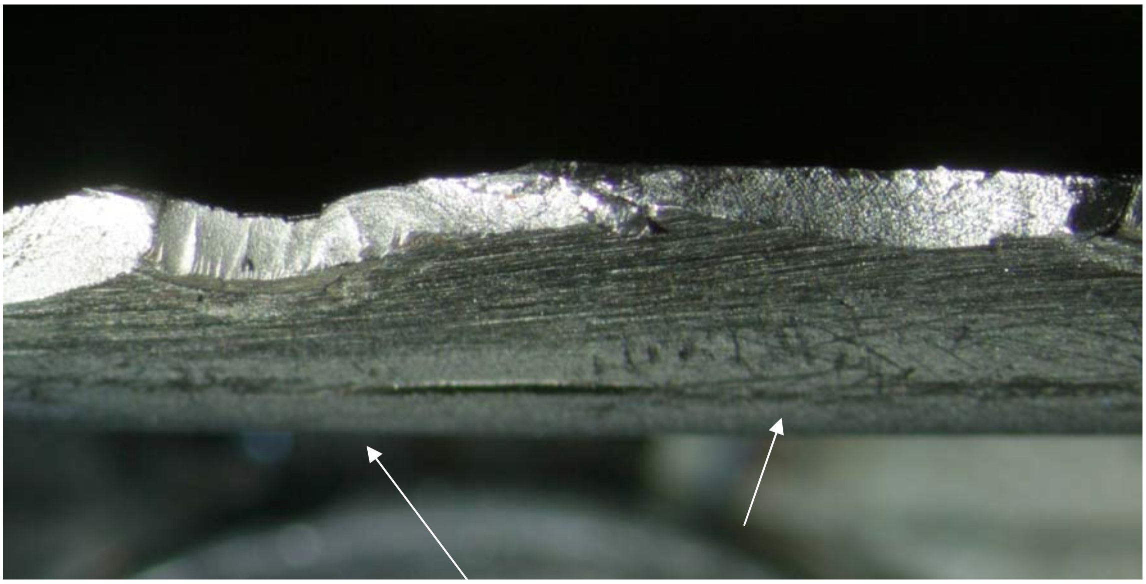

Figure 15. Typical area of cracking / fracture presented along the bolt tower flange transition radius region. Note the clear fatigue crack progression marks and the ratchet marks associated with a crack initiation site.

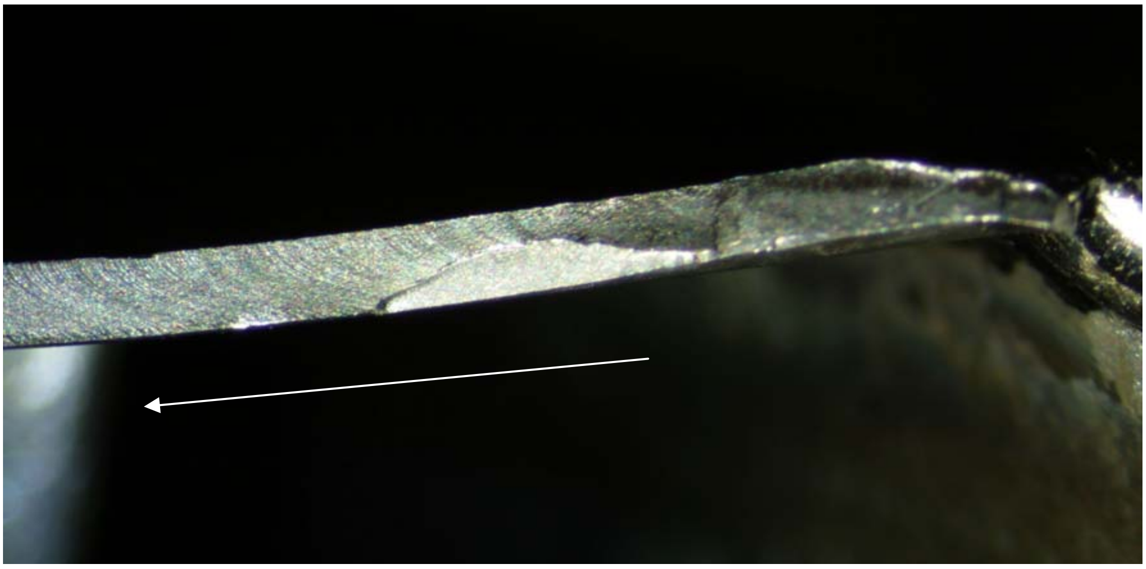

Figure 16. Fatigue crack progression marks extending away from a corner welded region of a fairing bolt tower (arrowed).

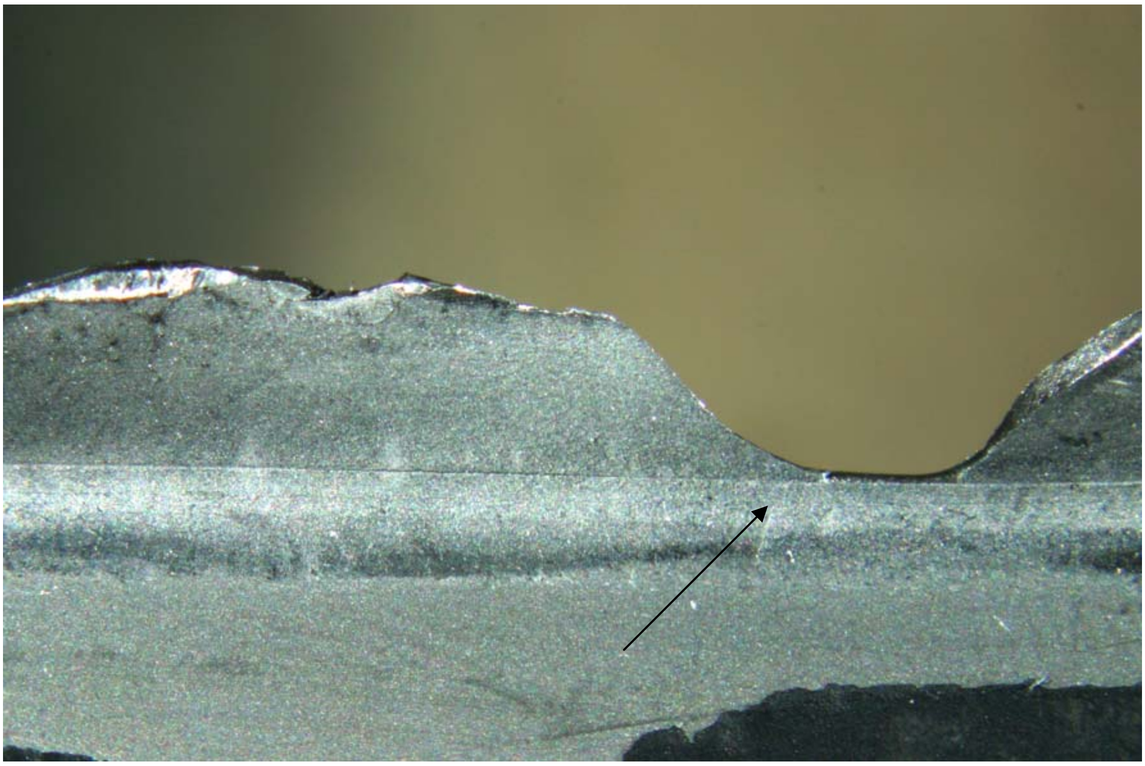

Figure 17. Fracture profile along the transition radius. Note the tooling mark from which fatigue cracking had initiated in some areas.

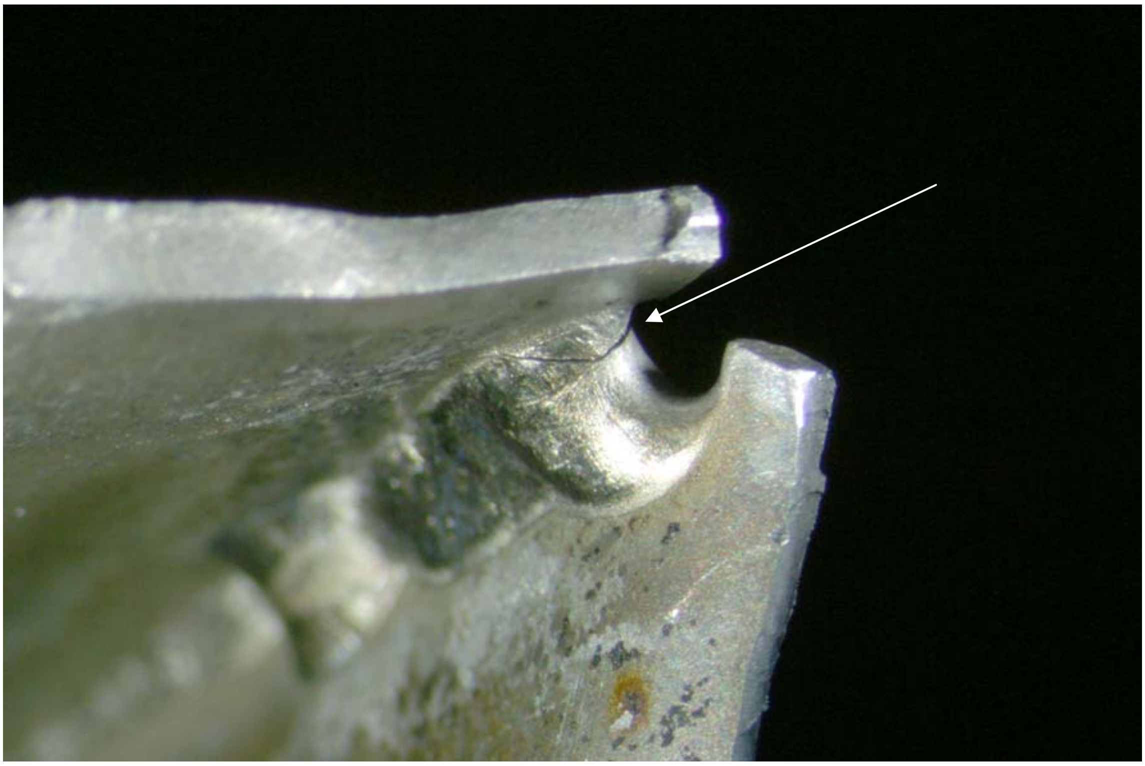

Figure 18. Fatigue cracking associated with a weld termination at the base of a bolt tower corner.

2. ANALYSIS

2.1. Failure event

From the physical evidence associated with the failure of the drive fairings and thrust reverser blocker doors, it was concluded that the initiating event in the failure sequence was the separation and break-away of the drive fairing panels during the application of engine reverse thrust on landing. Characteristic marks on the inward facing surfaces of the blocker doors were witness to the heavy impact of fairing panel sections against the deployed blocker doors, with the door damage and break-up features being typical of the forces induced during such an event.

2.2. Bolt tower cracking

The separation and loss of the drive fairing panels was attributed to the growth of fatigue cracking around the base of both central bolt towers that held the fairing shell halves together. The development and growth of that cracking had resulted in the separation of one tower completely from its base and the partial separation of the other. It was likely that the insecurity resulting from this resulted in the increased flexure and weakening of the remaining structure and the eventual overload failure and separation of the fairings as observed.

Fatigue cracking of the bolt towers was attributed to a vibratory loading environment acting at the local physical stress-raising features inherent to the bolt tower design and fabrication. The welded corners and folded seams associated with the base of the tower components provided ideal sites for the initiation of fatigue cracking. It is noted that the cold stream duct environment in which the drive fairings are located, would inherently expose the fairings to a range of mechanical and aerodynamically induced vibratory loads that potentially could contribute to the fatigue cracking as sustained. Those stresses were likely to be at a maximum during application of reverse thrust, where the extension of the thrust reverser blocker door panels into the air stream would produce turbulence and elevated vibration of the nacelle structures. Also of note was the design of the bolt tower components, which inherently placed the outer flange sections under tensile loads when the two fairing halves were pulled together and bolted. Static tensile loads of that nature would be expected to compound any vibratory induced stresses, thus increasing the potential for fatigue cracking.

The specific identification of any of these sources as being directly contributory to the cracking was outside the scope of this investigation.

3. CONCLUSIONS

3.1. Significant factors

The following factors were found to have contributed to the development of the drive fairing and blocker door failure.

1. The drive fairings were of a design that employed welded sheet metal fabricated fittings to secure the panels within the engine cold stream duct.

2. During engine operation and aircraft flight, the fairing panels were subject to induced vibratory stresses.

3. The design of the securing fittings (bolt towers) rendered the components susceptible to the initiation and growth of fatigue cracking under the influence of vibratory loads.

4. Eventual failure of the bolt towers (from the fatigue cracking) allowed increased flexure of the fairing panels and the eventual premature failure of the composite panel structure.

5. Failure of the panel structure allowed fairing release into the engine cold stream airflow and the subsequent impact with the down-stream thrust reverser blocker doors.

6. The magnitude of the fairing impact with the blocker doors was sufficient to cause structural failure and the ejection of the damaged doors from the engine.

4. SAFETY ACTION

4.1. Aircraft operator

In response to this incident, the aircraft operator instigated a fleet-wide radiographic inspection of fairing panels fitted to RB211-524G-T and RB211-524H-T-36 engines. Numerous instances of cracked bolt towers were detected from those inspections, with the affected components either being replaced, repaired or subject to ongoing repetitive examination.

A modification to the fairing design was developed by the operator’s power plant engineering department, whereby longer bolts and external load bearing washers were used to load the bolt tower bases in compression, rather than tension (figure 19[2]). That modification prevented the further development or propagation of cracking within the bolt towers and was reviewed and accepted by the engine manufacturer for application to the affected engine models. Implementation of the modification was planned at the next engine shop visit for any cracked or previously weld-repaired bolt towers.

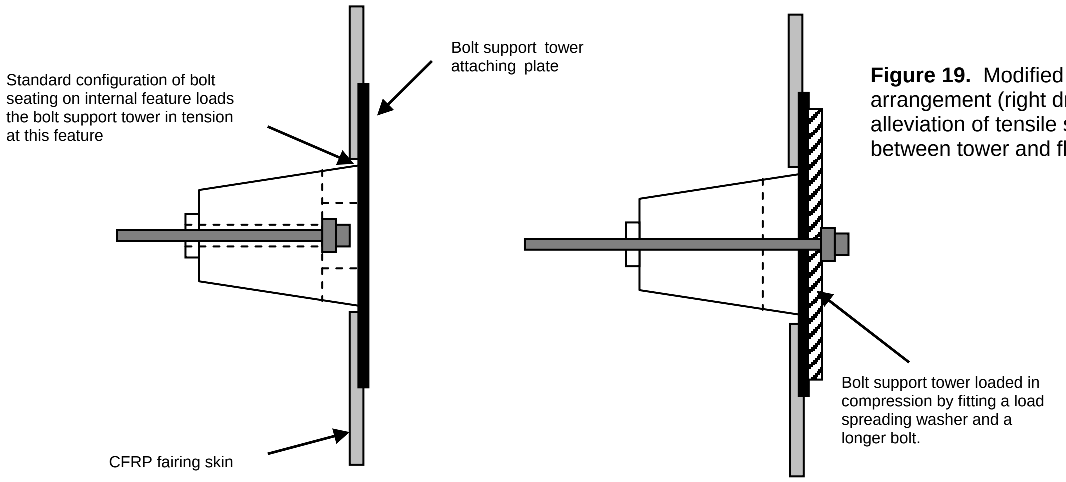

Figure 19. Modified bolt tower arrangement (right drawing) for alleviation of tensile stresses between tower and flange.

4.2. Engine manufacturer

The engine manufacturer has acknowledged the recent history of drive fairing loss from RB211-524 –T series engines. At the time of reporting, a set of partially separated fairings had been returned to the manufacturer and was awaiting laboratory investigation to confirm the failure mechanism. The engine manufacturer advised that the issue of fairing separation is to be investigated through their ‘Resolve Customer Problems’ (RCP) process. Through feedback to the manufacturer, engine operators have indicated that the drive fairings can be difficult to correctly install and may sustain damage during that process. To address that issue, the engine manufacturer issued a world wide bulletin (WW/10140) in May 2003 to highlight the problem and provide recommendations for best practice fitting procedures.

---

2 Drawings courtesy of the aircraft operator’s Power Plant Engineering department, report S-AB1/1