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Examination of Variable Stator Vane Control Levers

Rolls Royce Ltd. RB.211-Trent 800 Turbofan Engine

Boeing 777-212ER, 9V-SRE

EXAMINATION OF A FRACTURED VARIABLE STATOR VANE CONTROL LEVER

Rolls Royce Ltd RB.211-Trent 800 Engine, Boeing 777-212ER, 9V-SRE

1. FACTUAL INFORMATION

1.1 Introduction

During a flight from Brisbane to Singapore, the crew of the Boeing 777-212ER aircraft noticed the onset of abnormal vibration levels and several 'thumps' from the right engine. While continuing to monitor the engine, the vibration and thumps recurred and the engine was subsequently shut down after the oil and exhaust gas temperatures rapidly increased. Following a diversion to Darwin, the crew conducted an uneventful single engine landing.

On initial inspection, maintenance personnel found a single fractured first-stage variable stator vane (VSV) control lever (figure 1). Later internal boroscopic inspection of the engine found significant levels of mechanical damage within the intermediate and high-pressure compressor stages.

The fractured lever and a selection of other levers from the first-stage VSV assembly were removed from the engine for examination by the ATSB.

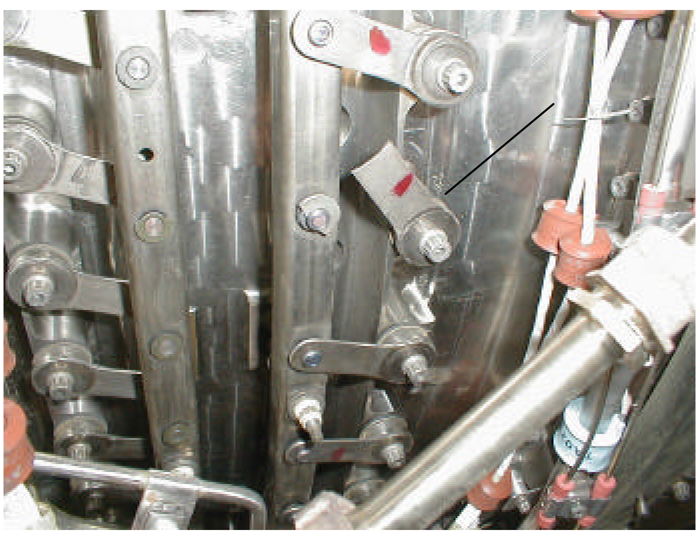

Fig. 1 External view of the stage-one variable stator vane actuator ring and the single fractured lever (arrowed).

1.2 Visual examination and fractography (failed lever)

Initial inspection in the ATSB laboratory found the VSV lever had fractured transversely through the end of the arm section (figure 2), at a location coincident with the riveted connection to the actuator pin. The fracture path followed a uniform arc, extending from one side of the arm to the opposite and intersecting the pin connection at the centre (figure 3).

Fig. 2 Underside of the VSV lever removed from the engine.

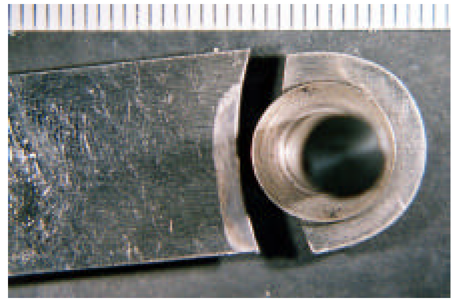

Fig. 3 Underside of the VSV lever showing the curved fracture path and the wear mark produced by in-service movement after failure.

A prominent track mark had developed on the underside of the arm where the relative movement between the separated arm and the pin flange had produced appreciable wear. The effects of wear extended to the fracture surfaces themselves, which were heavily eroded and all fracture surface detail obliterated (figures 4 & 5). Apart from the fracture, the arm had sustained little other mechanical damage and showed no evidence of deformation or distortion associated with the failure.

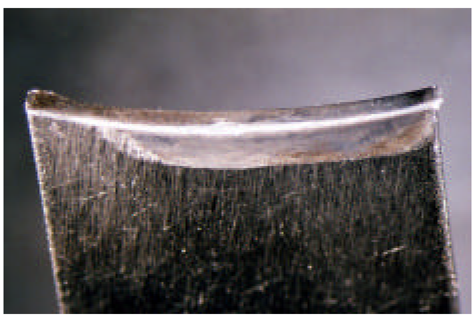

Fig. 4 Arm section fracture surface showing degree of wear and loss of detail.

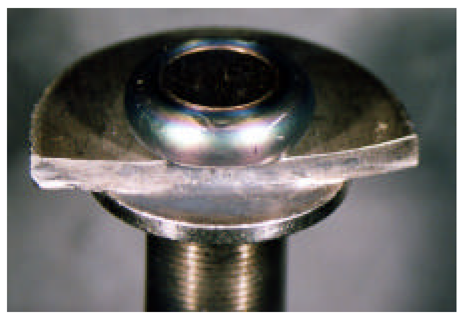

Fig. 5 Pin section fracture – adjoins the surface shown in figure 4.

On close inspection, the fracture path appeared to intersect the bore of the rivet hole, with slight upward 'dishing' of the arm section beneath the rivet head (figure 6). A clearance or gap was not evident between the pin shaft and the bore of the arm hole through which the pin shaft was riveted.

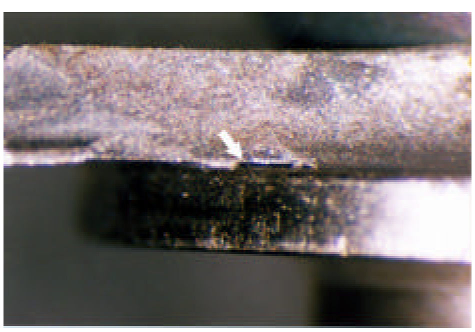

Fig. 6 Gap between the pin flange and the control arm produced by upward 'dishing' of the arm beneath the rivet head.

The examination did not show any evidence of binding or excessive friction between the actuator pin and the mating bushing, nor did any other component show significant indications of miss-installation or anomalous operation.

1.3 Examination of the riveted connection (intact levers)

1.3.1 Sampling and preparation

Initially, a single VSV lever from assembly number 235837 (same as the failed lever) was selected for metallographic examination of the riveted connection between actuator pin and the lever arm. The lever was number 31 from the first-stage VSV (the failed lever was number 28). To enable the examination of the full circumference of the joint, a specimen was prepared by grinding the rivet head away to flush with the upper surface of the lever arm. That region was subsequently removed from the arm and mounted to present the upper surface for preparation and metallographic study. Following observations made on lever 31, three further levers were selected and prepared for examination in a similar way. These were item numbers 26, 46 and 62 from assembly numbers 235837, 235347 and 238137 respectively.

1.3.2 Observations

The riveted joint from lever number 31 presented a single, shallow transgranular crack extending from the joint interface into the arm section (figure 7). The crack measured 0.6mm total length and extended away from the pin by around 0.3mm. Close examination showed the crack to have initiated from the end of an area of fusion or 'welding' between the lever arm and pin materials (figure 8). The fused region extended for approximately twenty percent of the joint interface length. Indications of the initiation of a similar crack-like defect were also found at the opposing end of the fused region.

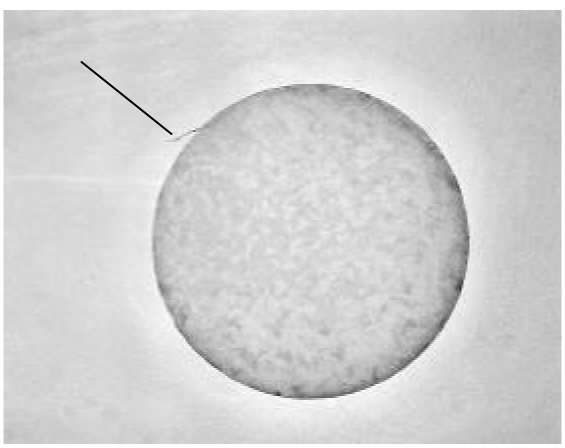

Fig. 7 (Left) Planar section through the rivet shank of lever 31, showing a crack extending into the arm material (arrowed). Magnification X 7.5

Fig. 8 (Left below) Closer view of the cracking shown in figure 7. Note the initiation from the end of a fused area around the pin circumference. Magnification X 115

Of the three VSV levers subsequently examined after the findings from lever 31, one item (number 46) showed extensive cracking in the arm material adjacent to the arm-pin interface (figure 9). This cracking was also associated with an area of fusion between the pin and arm alloys (figure 10). Many of the cracks showed a preferential orientation, extending tangentially away from the pin. Several smaller cracks were noted within the pin material; also adjacent to the fused interface (figure 11). The metallographic study did not show any evidence of cracking or related damage in the areas that were not fused between the pin and arm sections.

Lever number 26, while not exhibiting cracking of the extent shown by lever 46, did show an extended area of fusion around the pin circumference (figure 12), in much the same way as the other items. Interfacial flow and crack-like lap features were noted in several areas within the fused regions.

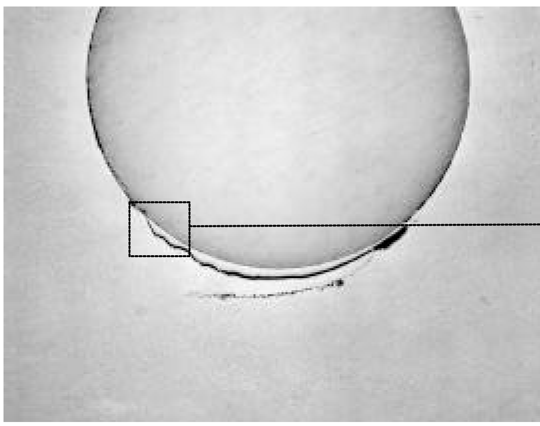

Fig. 9 Cracking and separation alongside the fused interface of lever 46. Magnification X 9

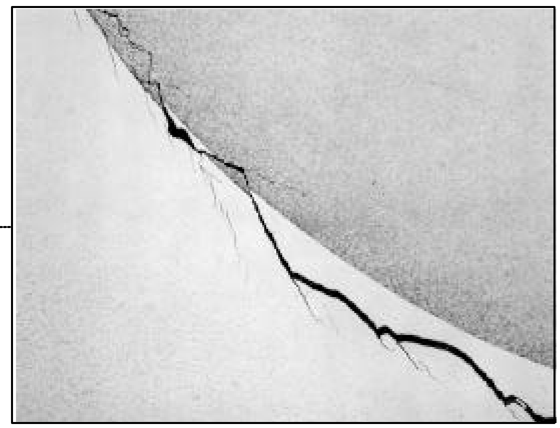

Fig. 10 Closer view of the cracking shown in the boxed area of figure 9. Note the many fine cracks extending tangentially into the arm section. Magnification X 46

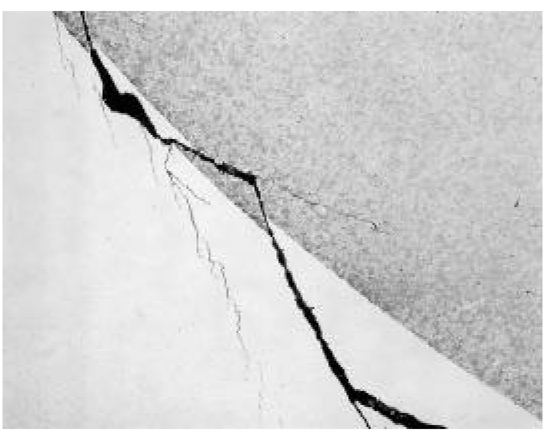

Fig. 11 Closer view again of the cracking within lever 46, showing cracks developing within both the pin and arm materials. Magnification X 92

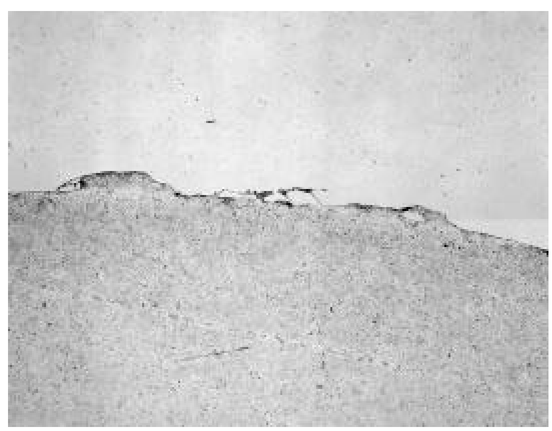

Fig. 12 Irregular interface observed within lever 26 containing many lap-like defects. Magnification X 92

2. ANALYSIS

2.1 Failure mechanism

While the repeated post-failure movement of the fracture surfaces against one another had destroyed any fracture surface detail, the absence of any associated physical deformation suggested the failure was probably a product of a progressive fatigue cracking mechanism. The observed fracture features suggested that the crack initiation occurred from the pin hole.

The examination found evidence of distortion of the arm section by the forces used to rivet the control pin to the arm body. During riveting, the expansion of the rivet shaft could induce tensile stresses within the bore of the rivet hole if the diameter was insufficient to allow for the expansion. Tensile stresses of this nature would be expected to predispose the lever arm to the initiation and propagation of fatigue cracking.

2.2 Cracking of the riveted connection

It was understood that the riveted joint between the actuator pin and the arm of the VSV levers was intended to be a fully mechanical joint and not reliant upon metallurgical bonds of any nature. The development of welding and partial fusion between the pin body and the arm section of the levers examined was therefore considered to be anomalous and most likely a result of the forces and temperatures associated with the riveting operation. Partial fusion between the pin and arm produced inherent notch-like defects at the ends of the fused areas and it was from these regions that cracking was observed.

Titanium and titanium alloys have a strong reactivity with oxygen at temperatures above 550ºC and can become embrittled. As a result, special precautions must be taken to avoid the exposure of the heated alloys to air. The distinct bluish colouration of the forged rivet heads is an indication of elevated temperature oxidation of the alloy and indicates that shielding may have been inadequate during the riveting operation. Embrittlement of the heated material at the rivet interface may have been a contributing factor in the cracking observed.

The nature of the cracking damage within the VSV levers examined was consistent with the initial in-service failure of the first VSV lever. The presence of cracking and crack-like defects at the pin interface provides ideal stress-raising conditions for the subsequent initiation of fatigue cracking, leading to eventual component failure.

2.2 Post-failure arm movement

Marks and wear at the VSV control lever fracture indicated an extended period of independent movement between the two halves of the component before the final engine shutdown. The bias in the wear marks to one side of the arm (figure 2) suggests that during operation, the vane remained at the limit of its travel, while the actuator ring and pin continued to move laterally in response to throttle movements.