Boeing 747-236B, G-BDXH, 9 August 1996

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Aircraft Type and Registration:	Boeing 747-236B, G-BDXH
No & Type of Engines:	4 Rolls Royce RB211-524D4 turbofan engines
Year of Manufacture:	1979
Date & Time (UTC):	9 August 1996
Location:	London Airport - Gatwick
Type of Flight:	Scheduled Passenger
Persons on Board:	Crew - N/K - Passengers - N/K
Injuries:	Crew - Nil - Passengers - Nil
Nature of Damage:	Lower rudder hydraulic actuator body fractured, control linkage broken
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	N/A
Commander's Flying Experience:	N/A
Information Source:	AAIB Field Investigation

Whilst the aircraft was being taxied out to the runway for take off, the crew carried out the pre-flight checks for full-and-free movement of the controls. During their rudder movement check, the lower section of the rudder jammed at a deflection of 14° to the right and, shortly afterwards, a loss of No 2 hydraulic system fluid contents was observed. The aircraft was returned to the terminal gate where initial inspection revealed damage to the lower rudder Power Control Unit (PCU) and its input linkage. The aircraft was taken out of service.

The PCU was removed and inspection showed that the casing had cracked circumferentially, near to the ram end, and the crack had extended in an axial direction to the free edge of the casing. This had permitted the externally threaded locking ring, and the power cylinder end seal block which it secured, to move outwards along the ram towards the eye end. As found, the ram was retracted as far as it was possible with the displaced locking ring and end seal block. The end of the input feedback lever, which attached to the power ram eye end fitting, had broken open. The PCU had been fitted to this aircraft at manufacture and had accumulated approximately 70,500 hours and 12,000 flights.

Metallurgical examination revealed that high cycle fatigue had originated in the runout radius of the cylinder thread undercut (see Figures 2a & b) and propagated to a critical length over 3,000 cycles, with evidence of four overload events having occurred within the propagation period. There were no deficiencies in the material specification and no defects were found in the casing which would have contributed to the initiation of the failure. The damage to the end of the input feedback lever had been caused by the actuator ram end retracting into the displaced locking ring and end block. The loss of the hydraulic system fluid was also a result of the displacement of the seal block.

There had been two previously recorded cracks in this area of this type of PCU and a fourth occurred shortly after this event. The first event, in 1976, involved an aircraft which had flown 22,000 hours/6,200 flight cycles, the second in 1992 on an aircraft which had flown 60,000 hours/15,000 cycles and the most recent in an aircraft which had flown 30,000 cycles, mainly in shorthaul operations.

The first of the cylinder casing thread failures occurred on an upper rudder PCU, during a take off; the aircraft suffered the loss of one hydraulic system and the upper rudder jammed at full right deflection. That failure had resulted from fatigue cracking originating in the root of the innermost thread in the casing, which was found to have very sharp radius corners. As a result of this failure, the manufacturer introduced an inspection of the threads at overhaul. In addition, a controlled root radius on the thread was incorporated into subsequent manufacture, as a product improvement. Later, an increase of the radius in the thread undercut was also introduced as a further product improvement. The need to ensure that the locking ring was properly tightened was also emphasised.

The second and fourth failures of this area of the PCU casing both initiated in the thread undercut zone and were similar to the failure on 'XH', but without any overload events.

The original design of the PCU was for an aircraft life of 60,000 flight hours/18,000 flight cycles. Endurance testing with an accepted load spectrum was successfully performed on a single PCU and accepted for Type Certification. The overall design philosophy of the rudder system to meet the requirements of FAR/JAR 25.671 resulted in the rudder being made up of two, independently actuated, control surfaces either of which could malfunction within the limits of its actuator's power and authority, in any phase of flight, without loss of adequate rudder control.

The design of the PCU incorporated a 'snubbing' action over the last 12% of its stroke (see Figure 2b) which worked by restricting the hydraulic fluid return flow. The purpose of this was to reduce the actuator ram speed as it approached the end of its stroke; the pressure developed in the snubbed volume was greater, the higher the ram speed as the piston entered the snubbing zone. It was considered most likely that the cyclic loads responsible for initiating the fatigue cracking in the thread root and undercut zones had been generated by high snubbing pressures. It was recognised that the situation in which high ram speeds were most likely to be achieved near the limit of travel was during the pre-take-off rudder control check when, in the absence of flight loads, there was no appreciable damping of rudder movement.

As a result of the first failure in 1976, the manufacturer had issued an Operations Manual Bulletin and a revision to the Maintenance Manual, both to the effect that all rudder flight controls checks should be performed slowly and smoothly (not less than 8 seconds for a full cycle) to avoid generating high snubbing loads. Examination of the Flight Recorder data from 'XH' showed that there had been two full travel checks of the rudder during taxi, the first of which was performed in 3.5 seconds and the second in 7.5 seconds. Whilst these last applications of rudder had induced the final failure of the PCU, the crack had then existed for some 3,000 cycles.

As a result of this failure on 'XH', the operator instigated a special check of high cycle PCUs; no defects were revealed by these checks. The operator also issued a notice to flight crews, later incorporated into the Flying Manual, reminding crews of the requirement to perform the rudder travel check slowly and smoothly. A programme to monitor rudder application rates at high angles of travel was also introduced and the results of this showed that about 70% of such events occurred during the pre-flight control checks.