McDonnell-Douglas DC10-30ER, C-GCPH

AAIB Bulletin No: 12/2001	**Ref: EW/C99/1/1**	**Category: 1.1**
Aircraft Type and Registration:	McDonnell-Douglas DC10-30ER, C-GCPH	
No & Type of Engines:	3 General Electric CF6-50C2 turbofans	
Year of Manufacture:	Not known	
Date & Time (UTC):	6 January 1999 at 0700 hrs	
Location:	London Heathrow Airport, Block 91	
Type of Flight:	Scheduled passenger	
Persons on Board:	Crew - 11	Passengers - 255
Injuries:	Crew - nil	Passengers - nil
Nature of Damage:	Damage to turbine section of No 1 engine	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	Not known	
Commander's Flying Experience:	15,000 hrs total (of which 4,000 were on type)	
	Last 90 days - 180 hrs	
	Last 28 days - 60 hrs	
Information Source:	AAIB Field Investigation	

History of the flight

Following an uneventful flight from Calgary to London, the aircraft landed on Runway 27L and taxied off the runway to the right, onto the outer taxiway. After taxiing east towards Block 85, the aircraft held awaiting clearance to cross Runway 27L from the north side to Terminal 4. After a short wait, the aircraft was cleared to cross the runway via Block 85 and the commander was asked to expedite the crossing. The commander reported that he had used slightly more thrust than normal, to comply with the request, and shortly afterwards he became aware of a vibration through the airframe.

All three crew members initially suspected that a tyre might have deflated during a tight taxiing turn in Block 91 (just south of their crossing block), but the aircraft's taxiing characteristics remained unchanged and so the commander continued for the short distance (less than 200 metres) to the allocated stand (stand 12) at Terminal 4. However, as the aircraft approached the stand the vibration amplitude increased and so the commander asked the flight engineer to scan the systems panel whilst he manoeuvred the aircraft onto the stand. As the aircraft reached the stand, the flight engineer reported that the only abnormal indication was the No 1 engine N1 (fan) RPM which was reading 17% instead of the expected 34%. The commander advanced the No 1 engine thrust lever but there was no N1 response and so he shut the No 1 engine down, before completing the remainder of the normal arrival and aircraft shut down procedures.

Some 30 minutes later, the ATC staff in the Heathrow Control Tower were contacted by Terminal 4 Operations Control and informed that C-GCPH had suffered a mechanical failure of an engine whilst taxiing. A search of the aircraft's taxying route was then carried out and scattered engine debris was found in the northern half of Block 91, indicating that the engine had probably failed after the aircraft had crossed Runway 27L.

Initial inspection of the No 1 engine

An immediate visual inspection of the engine, on the ramp, revealed the presence of metallic debris in the jetpipe and considerable damage to the 4th (rearmost) stage of the low pressure turbine (LPT). There were also several tears, bulges and small holes in the LPT casing, in the plane of 1st stage LPT rotor. The engine cowlings, however, appeared undamaged and the small amount of engine hardware which had passed through the LPT casing holes was found lying in the cowling. The debris collected from the taxiway consisted of LP turbine blade sections, including at least 7 sections of LP turbine blades with their dovetail roots, in addition to fragments of nozzle guide vane. These parts, together with the debris found in the cowling, were retained with the No 1 engine for later investigation.

Following this initial inspection it was decided to dispatch the engine to the nearest approved overhaul facility, at Hanover, for strip examination.

Strip examination of engine at MTU, Hanover

A cross-section of the CF6-50 turbofan engine layout is shown in the diagram at Figure 1.

Before disassembly of the engine the oil filters, fuel filters and chip detectors were checked; no evidence of debris resulting from bearing or oil seal failure was observed. A borescope inspection of the LP turbine was then conducted through the LP turbine case borescope port, but during this examination the LP shaft was not rotated in order to prevent additional damage. This inspection revealed severe damage to those nozzle guide vanes and turbine blades which could be seen. In addition, several of the 1st stage LP turbine (LPT 1) blade root end dovetails were no longer installed in the disc. Further borescope inspections, conducted through the turbine mid-frame and high pressure (HP) turbine ports, indicated that there was no significant damage upstream of the HP turbine nozzle guide vanes. As a result of this inspection it was decided that the investigation would be focussed on the LP turbine module (Figure 1).

Before separating the LP turbine module from the engine, the dimension 'CU' was measured (ie from the rear face of the turbine rear frame to the aft end of the LP shaft assembly). This dimension was found to be 1.812 inches, which was within the required limits of 1.75 to 1.85 inches. The coupling nut (see Figure 1a), which secured the LP turbine rotor to the LP shaft, was removed and visually inspected. The breakaway torque for the nut was measured during removal and found to be approximately 20,000 ft-lbs, which indicated that no looseness had developed in the LP rotor/shaft joint; no damage was observed on the nut. The LP turbine module was then separated from the rest of the engine at the joint between the turbine mid-frame and the rear of the HP turbine case (Figure 1a).

This exposed the rear of the stage 2 HP turbine, which exhibited no significant damage. The freedom of the HP rotor system to rotate was checked and found satisfactory, with no evidence of blade rubbing in either the turbine or compressor sections. Some minor scratches were apparent on the suction face of the HP turbine blades, and the blade tip distortion which was present was within limits, although shroud filler material was missing at several places.

The LP turbine rotor positioning shim (Figure 1a), positioned between the turbine rotor and the shoulder on the LP shaft (dimension 'CU' adjustment), was examined; it was found to be undistorted and within the permitted dimension range at 0.163 inch thick. After removing the turbine rear frame, which exhibited only minor signs of distress, the LP turbine case halves were separated from each other and the turbine mid-frame, and removed from around the rotor with considerable difficulty. Severe damage was then revealed throughout all 4 stages of the LP turbine. There had been damage to the casing, which had caused the penetrations apparent before strip, and secondary damage to the nozzle guide vanes and shrouds of all stages, but the degree of damage diminished towards the aft end of the turbine.

The four LP turbine rotor discs were then separated. Examination of these revealed that the blades of the 2nd, 3rd and 4th stages had suffered secondary damage as a result of debris travelling aftwards, but no evidence of primary failure was observed on any of these blades. The severity of the damage reduced from the 2nd stage aft, there being 2 complete blades missing from this stage but only aerofoil damage to the turbine blades of the 3rd and 4th stages, with stage 4 blades less damaged than stage 3. The LPT 1 rotor, however, was very severely damaged. A large proportion (75 out of 128) of the blade roots were missing from their slots in the LP 1 disc and several of the remaining blade roots had moved aft from their normal position, to varying extents. The aerofoil of every blade root remaining in the disc had been sheared off at the level of the blade platform.

Examination of the stage 1 LP turbine blade retainers showed that all of those remaining in position exhibited varying degrees of abrasion damage to their forward 'upstand', as illustrated in the photograph at Figure 2, and depicted in the diagram at Figure 2a. The shape of this abrasion damage to the forward faces of these retainer upstands was consistent with it having been made by circumferential rubbing contact against the aft corner of the LPT1 nozzle air seal 'discourager leg' (see Figure 2a). In those cases where the forward upstand had not been completely worn through and was still in its intended position, the turbine blade roots had been retained in their correct positions. However, where the forward upstand of retainers had been abraded right through, approximately 0.175 inch of the upstand height had been lost in every case and, as a result, the residual height of the upstands had become short enough to allow the associated blade roots and retainers to slide axially aft. However, this reduced height of the upstands had been sufficiently long to restrain affected blades from moving forward relative to the retainer. The majority of those turbine blades, where the forward upstand of the retainers had abraded through, had moved aft by varying amounts and carried the remainder of their retainers with them. However, in no circumferential position had the interference between the seal and the LPT1 disc assembly been sufficiently severe as to affect the forward face of the turbine disc.

It was noted that there were two standards of stage 1 LP turbine blades with different thickness 'Angel wings' (Figure 2a). It was also observed on the blade roots remaining in the disc that those with the thicker Angel wings had evidence of rubs on the underside of their platforms; this rubbing was consistent with it having been made by the outer rim ('R' in Figure 2a) of the stage 1 nozzle air seal discourager leg.

The LPT 1 nozzle guide vane assembly was removed from the turbine mid-frame. During removal it was noted that all of the vane attachment fasteners were undamaged and that their measured release torques indicated that all of them had been secure. Examination of the assembly showed that although all of the LPT1 nozzle vanes were still in place and complete, they all had suffered damage in the direction of rotation to the trailing edge of their aerofoils, over their full height. It was observed, by contrast, that their leading edges were undamaged. There was no evidence of the passage of hard particles forward through the turbine mid-frame.

The stage 1 nozzle air seal was visually inspected while still attached to the turbine mid-frame. The internal diameter surface of the seal was observed to have two areas where the seal honeycomb material had been rubbed away by the LP 1 turbine disc 'Shark tooth' knife seal edge (see Figure 2a). The more clearly defined rub was across an arc at the bottom of the engine and the second, lighter, rub was at the top of the engine, just to the left of the centreline. The lower rub was 0.75 inch wide and 0.030 inch deep, but the upper rub had minimal depth, about 0.003 inch, and was the same width as the lower rub. No evidence of hard particle impact damage was observed on either the internal diameter surface of the honeycomb or the knife seal.

The discourager leg of the stage 1 nozzle air seal was observed to have two circumferential segments of missing material over approximately the same arcs as the rubs on the honeycomb seal. The sectors of missing material had detached due to cracking in the fillet radius of the vertical leg, and all of these crack surfaces were oxidised. There was a 4.50 inches long arc of missing material in the upper left segment of the discourager leg and in the lower segment there was a 6.65 inches arc of material missing. There were cracks in the fillet radius which extended from both ends of the gap in the lower sector; that on the left side was 2.36 inches long and that on the right was 1.30 inches in length. The edges of the crack over the lower sector were found to be eroded and there was evidence of light rubs on the aft face of the discourager seal, due to contact with the stage 1 turbine blade retainer forward faces, which had caused thinning of the remaining ends of the discourager leg due to 'feathering' as a result of the rubbing contact.

Cause of engine failure

Examination of the engine therefore revealed no evidence of any significant damage forward of the stage 1 LP turbine nozzle guide vanes. Since the damage to these nozzle vanes was only on their downstream face trailing edges, this indicated that the primary failure had been aft of this section. The condition of the stage 1 LP turbine, as found, indicated that the major damage to the gas-path components through the remainder of the LP turbine module was as a direct result of the loss of a considerable number of intact stage 1 LP turbine blades, together with the aerofoils of all the other stage 1 LP turbine blades, and the subsequent passage of this blading debris through the aft stages of the LP turbine. The condition of the blade roots which had remained in their disc slots was consistent with secondary damage and loss of their aerofoils as a result of contact with those stage 1 turbine blades which had disengaged from their disc dovetail slot locations. There had been no failure of any dovetail slot.

The presence of a considerable number of stage 1 LP turbine blade roots which had displaced aft from their normal position in the disc, by varying amounts, showed that there had been a failure of the mechanism by which the blades were retained axially in their dovetail slots. It was observed that those roots which had moved aftwards in their slots all had retainers with forward upstands which had been substantially shortened and that in this condition the retainers had become ineffective in preventing aftwards movement of the blade roots, the direction in which the gas forces on the turbine blades would tend to drive them.

It was therefore apparent that the primary cause of the aft displacement and release of stage 1 LP turbine blades had been the loss of a critical portion of the forward upstands on a large number of their blade retainers. This loss had been caused by rotational rubbing contact and erosive wear between the forward faces of the retainer upstands and the aft face of the stage 1 LP turbine nozzle seal assembly. This had worn a groove part way up the upstands, thereby weakening them and, in many cases, causing the upper part of the upstand to separate completely (see Figure 2a).

Recent engine overhaul history

At the time of this failure, the LPT module had run for a total time of 51,215 hrs over 10,677 running cycles since new, and 16,063 hrs over 2,473 cycles since the LPT module had been overhauled by the operator. This most recent overhaul had included work to modify the discourager leg of the LPT1 nozzle seal in accordance with Service Bulletin SB 72-863. This modification was intended to reduce the likelihood of the rim (R in Figure 2a) of the discourager leg from rubbing on the inboard sides of the Angel wings on the LPT1 blades.

It was reported by the engine manufacturer that there were no significant anomalies found in the records of this overhaul and that all of the recorded dimensions, which could have been significant in relation to the axial positioning of the LPT1 disc relative to the engine case, were within the specified limits. The dimension 'CU' (measured as 1.812 inches during disassembly) was recorded as being 1.80 inches, which was at mid-limits.

Contact between the LPT1 nozzle seal and LPT1 blade retainers

The purpose of the LP turbine stage 1 nozzle seal is to prevent the passage of the hot gasses from the gas path to the inside of the LP shaft assembly. The main seal consists of the single knife edge, cantilevered forward from the LPT1 disc, which runs inside the steel honeycomb bore attached to the LPT1 nozzle ring (Figure 1a). To assist the seal in its function, there is a secondary part of the seal system known as the discourager, which functions by creating a restriction between the vertical leg on the aft face of the honeycomb seal carrier and the Angel wings which project forward from the LPT1 blade roots.

The design of the seal has to allow for changes of relative axial position between the honeycomb seal, which is attached to turbine mid-frame and is effectively part of the engine case, and the LPT1 rotor disc, which is part of the LP shaft. These changes in relative position arise from alterations in engine power which are accompanied by temperature changes throughout the engine, and resultant expansion or contraction of assemblies. In general, the engine case temperature tends to react more quickly to power changes than the rotors, and the LP rotor is probably significantly slower to react since it is the innermost shaft within the engine. Furthermore, its position relative to the case is fixed at the LP shaft thrust bearing, some 11 feet forward of the LP turbine (see Figure1), giving rise to the potential for relatively large expansion differentials between the case and the position of the LPT1 disc.

The design of the seal has, therefore, to take into consideration the calculated range of axial differential movement, together with the worst tolerance stacks within the LP turbine module which could affect the position of the LPT1 disc relative to the shoulder on the LP shaft. With reference to Figure 2a, it can be seen that the relative axial positioning of everything within the LP module, when fitted to the engine, is dependant on the dimension 'X', the position of the LP shaft shoulder aft of the HP turbine case rear face. The two relevant tolerance stacks are the case, from the HP turbine case rear flange to the discourager leg (ie A-B+C), and the LPT spool, from the shaft shoulder abutment face on the forward diaphragm to the forward face of the LPT1 disc rim (ie Y-Z). The primary control of the axial relationship of the seal to the LPT1 disc is made by the thickness of the shim positioned between the shaft shoulder and the LPT spool forward diaphragm, which is finally established when the LPT module is fitted to the engine and the dimension 'CU' measured. There is no lower limit on the thickness of this shim, but it must not be greater than 0.275 inch.

It appears that, in this case, the position of the LP turbine rotor was further forward, relative to the LPT1 Nozzle assembly, than the design allowed for and as a consequence contact occurred between the LPT1 blade retainers and the base of the discourager lip at corner S in Figure 2a. This abrasion resulted in the loss of a critical portion of the blade retainer upstands of a large proportion of the LPT1 blades, which allowed those blades to displace aft and disengage from their dovetail retaining slots in the disc. These liberated blades then destroyed the LP turbine module.

Conclusions

The manufacturer had no record of a previous instance of abrasion of the blade retainers by the LPT1 seal which had led to the rearward migration of turbine blades out of the disc. This indicated that the design clearances and tolerances had proved correct in practice. The presence of contact abrasion in this case, therefore, suggested either that the LPT1 disc had been axially further forward than its normal limits allowed, or that the LPT1 stator seal had been aft of its limits. Since the abrasion of the blade retainers was relatively even around the LPT1 disc, the disc run-out would appear to have been satisfactory. It is possible, however, that the run-out on the seal was excessive, although the damage suffered during the failure precluded any reasonable assessment of this.

The damage to both the LP turbine module and to the seal assembly precluded any accurate assessment of the pre-failure relative positions of the LPT1 disk and the seal, and consequently the axial clearance between them or their run-outs.

It was, therefore, not possible to establish whether this seal / blade retainer contact situation arose as the result of a singular adverse tolerance stack having occurred within the build up of the forward part of the LP turbine spool, or as a result of an error of measurement during the reassembly of the module at the last overhaul, or possibly because the seal assembly had become critically distorted after reassembly and running of the engine

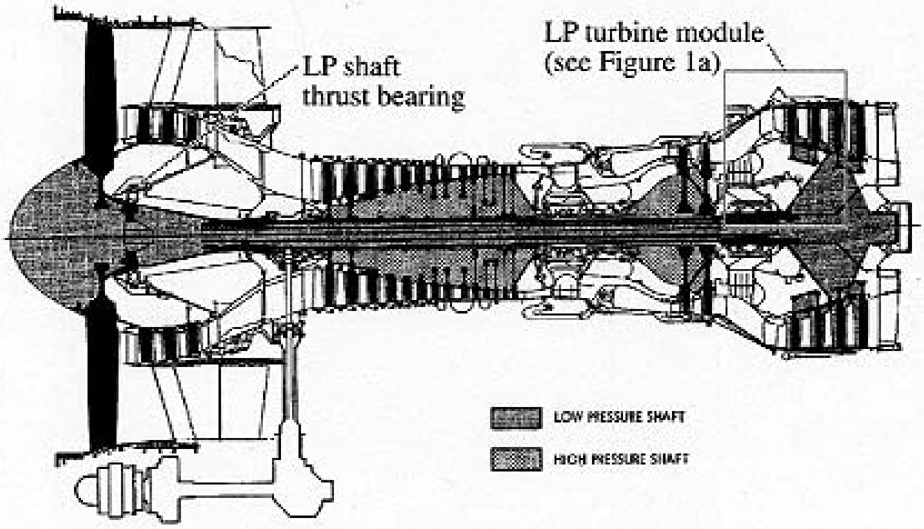

Figure 1 General arrangement of CF6-50 Turbofan

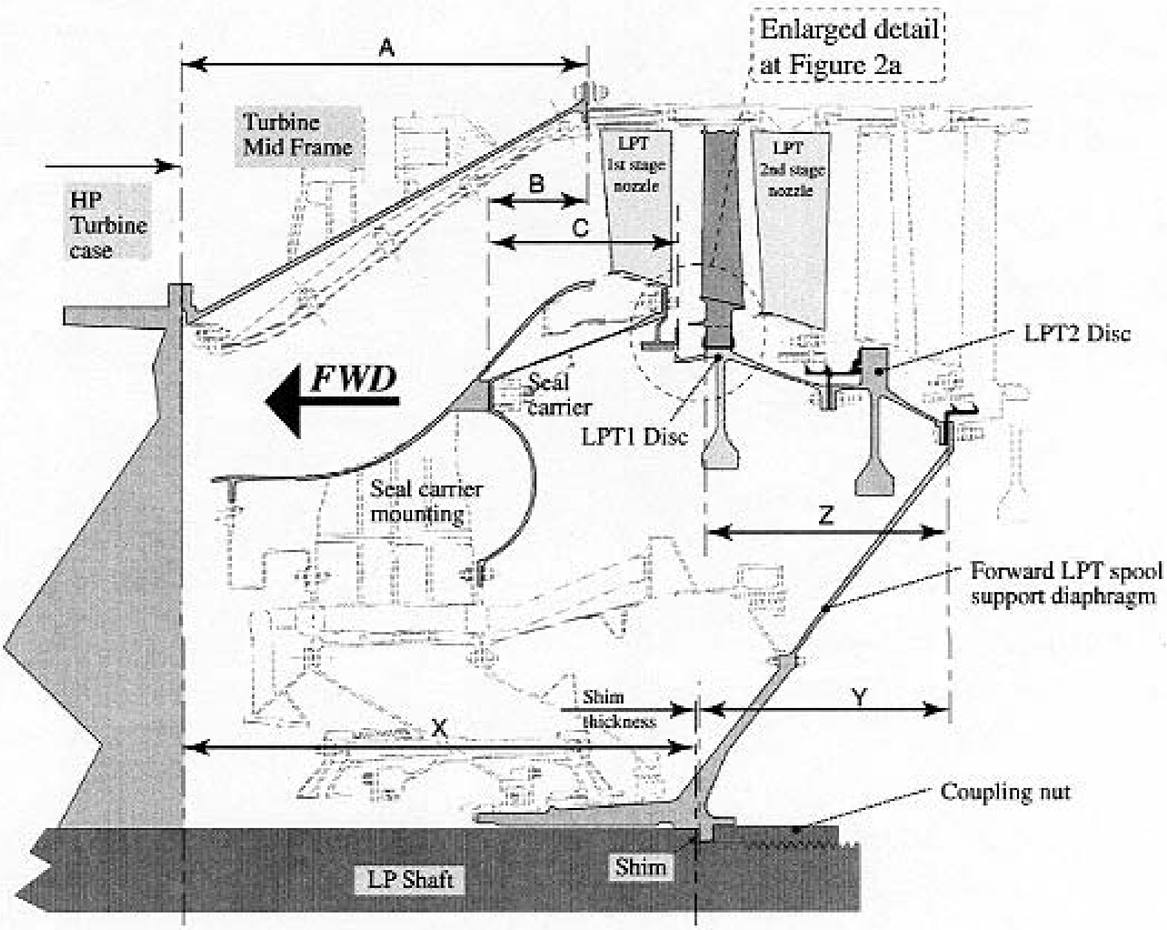

Figure 1a Half section showing general build arrangement of the Turbine Mid-frame and the forward part of LP Turbine Module

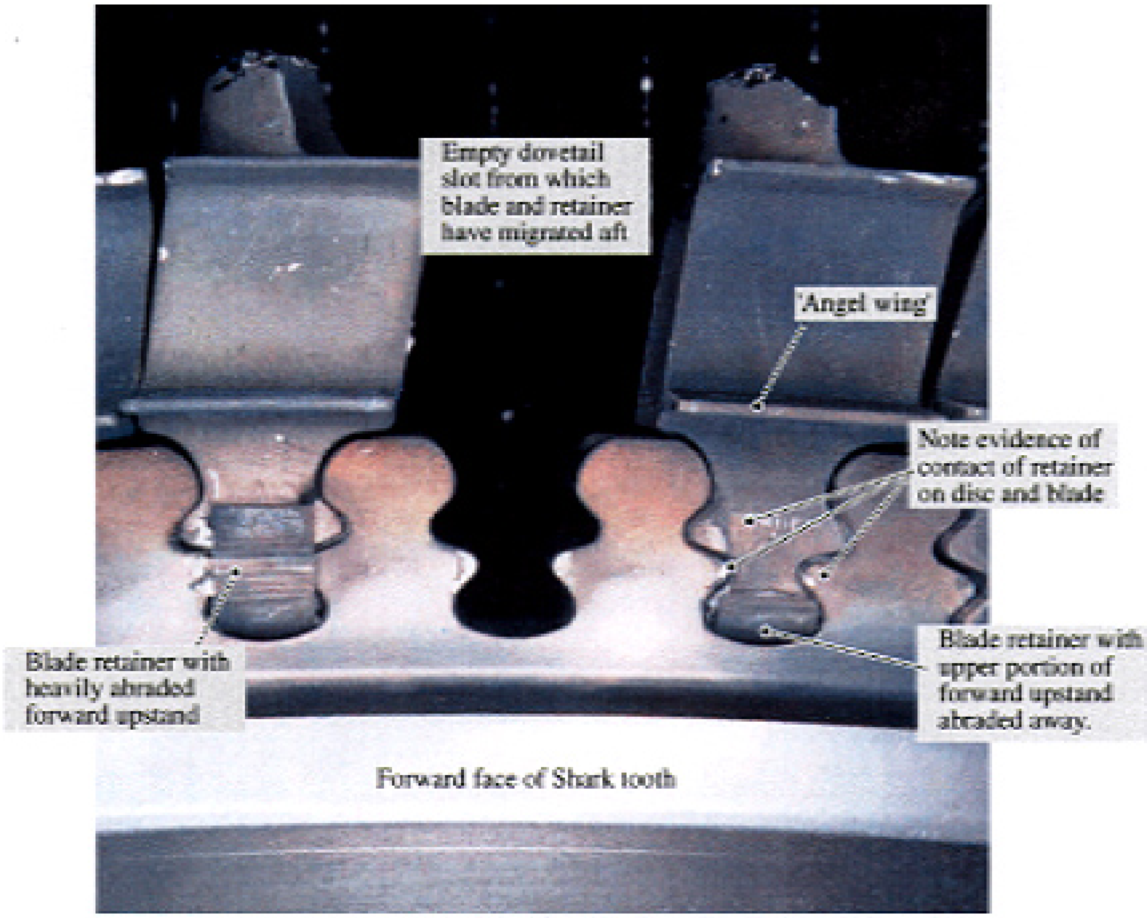

Figure 2 Sector of LPT1 disc rim as found during strip examination

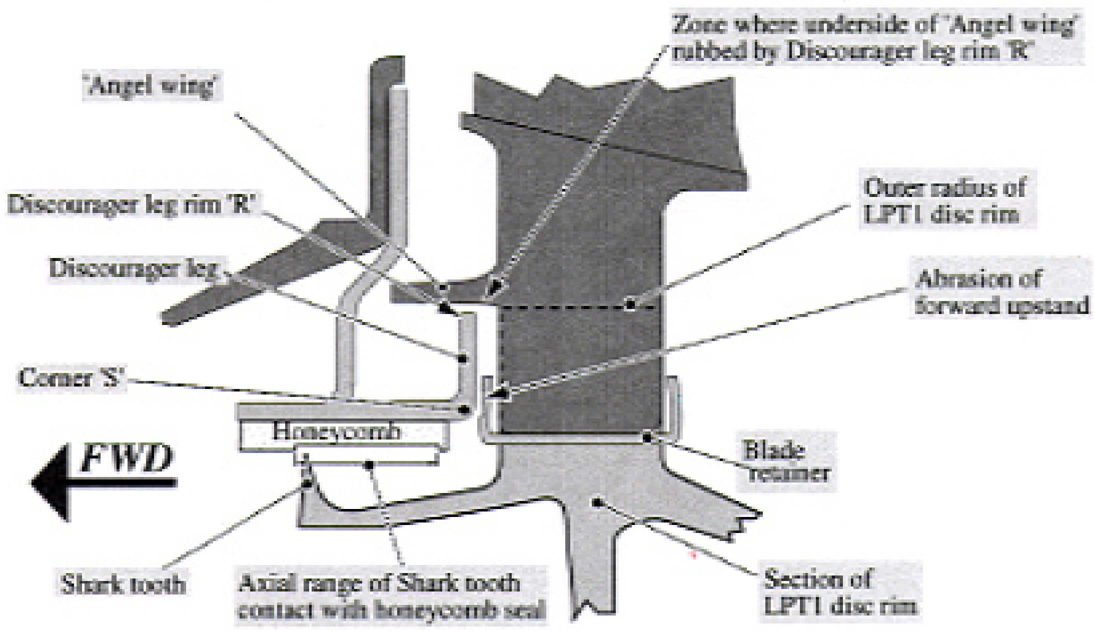

Figure 2a Detail cross section showing arrangement of LPT 1st stage nozzle seal