SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 777-236, G-YMMP
No & Type of Engines:	2 Rolls-Royce RB211 Trent 895-17 turbofan engines
Year of Manufacture:	2001
Date & Time (UTC):	14 June 2010 at 1617 hrs
Location:	Singapore International Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 12 Passengers - 202
Injuries:	Crew - None Passengers - None
Nature of Damage:	Extensive damage at rear of right engine nacelle and further airframe damage
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	44 years
Commander's Flying Experience:	14,770 hours (of which 4,934 were on type) Last 90 days - 192 hours Last 28 days - 79 hours
Information Source:	AAIB Field Investigation

Synopsis

On departure from Singapore International Airport to London a number of EICAS (Engine Indicating and Crew Alerting System) messages were displayed for the right engine. During the climb the crew interrogated the system and established that the event had been transient and that it was safe to continue en route. During the flight there were further events associated with the right engine, showing increased fuel consumption and the crew elected to divert to Amsterdam, Netherlands, transmitting a PAN. After the aircraft landed safely it was found that the right aft inner nacelle was severely damaged and largely missing, with further minor airframe damage and this matched items of nacelle recovered from the runway at Singapore, but not yet identified. Examination indicated that the nacelle damage was due to thermal disbond originating from the HP3 duct area. There have been a number of separate but similar events in other airlines and the airframe manufacturer has issued a series of Service Bulletins to reduce the rate of occurrence.

History of the flight

The aircraft was on a scheduled flight from Singapore International Airport to London Heathrow Airport. Due to the length of the sector four flight crew operated the flight: a commander and co-pilot, and a 'heavy' captain and co-pilot. The commander was the handling pilot for the takeoff and climb to cruise.

The commander and both co-pilots were on the flight deck for the start up, takeoff and climb to cruising altitude. The start up was uneventful, however due to a high takeoff weight, with a minimal derate to the engines' thrust, high EGTs were expected during the takeoff and briefed by the commander. At this time it was dark.

The aircraft took off from Runway 02L at 1617 hrs on 14 June 2010. At approx 500 ft aal the right engine's EGT fluctuated by approximately ± 100°C and the ENG THRUST R caution message momentarily illuminated on the Engine Indication and Crew Alerting System (EICAS), along with the ENG RPM LIMITED R advisory message. At this point the flight crew also noted that the right engine's N1 was at its maximum of 100.5%. As no recall items were required from the QRH the autopilot was engaged and the departure continued while the situation was monitored. At acceleration altitude the thrust was reduced to 'climb thrust' on both engines; the ENG RPM LIMITED R message cleared and both engines' parameters settled in their normal range.

At a suitable point in the climb the STATUS page and Maintenance Access Terminal (MAT) were accessed by the co-pilots; an EEC C1 R status message remained but this required no crew action. The MAT showed several discrete failures, including a 'short' on the fire loop for the right engine core. Interrogation of the maintenance pages produced an automatic snapshot of the engine event after takeoff. This showed that the right engine's N1 had reached its limit, with fuel flow, EPR, EGT, N2 and N3 all depressed during the event.

With both engines apparently running normally, as the aircraft climbed through 10,000 ft the commander disconnected the autothrottle and selected full thrust as a 'confidence and troubleshooting' check. Full rated thrust was achieved, although N1 was higher on the right engine. Climb thrust was re-selected and the autothrottle re-engaged. The crew elected to continue en route while evaluating the situation. Possible causes were considered to be a birdstrike, fan damage, spurious indications or a failure within the EEC or associated systems. At this stage the only unusual indication was that the right engine N1 was approximately 3.5% higher than the left engine. At this point the 'heavy' co-pilot went into the cabin for his rest.

Once the aircraft had reached its initial cruising altitude the only technical discrepancy was that for a given EPR, the right engine's N2, N3, fuel flow and EGT were depressed compared with the left, while the N1 was higher. The crew considered possible fan damage, but the vibration indicator showed only 0.8 units[1], with N2 being the dominant item. Maintenance control in London was contacted to discuss the possibility of erroneous N1 indications, as this seemed a likely cause of the displayed symptoms; they suggested it was unlikely. A higher noise level reported from the cabin was also discussed, and the likely cause of this was deemed to be an ongoing issue with the wing root fairing, which had been recently subject to a tape repair due to previous reports of cabin noise.

Approximately 4 hours into the flight an ENG EEC MODE R advisory message was displayed on the EICAS and the QRH checklist actioned. The EEC has two control modes, 'Normal' and 'Alternate' and this message was advising that the right engine had switched to 'Alternate'

Footnote

1 The engine vibration monitoring system is primarily intended for engine condition monitoring, but it is also a useful tool for isolating and determining corrective action for engine anomalies. There is no certified vibration limit, but when a high vibration level is reached, the secondary engine parameters are automatically displayed. Since there are no operating limitations for the airborne vibration monitoring system, there are no specific flight crew actions (or procedures) based solely on vibration indication.

mode; as part of the QRH actions, the crew also switched the left engine to 'Alternate' mode . Given the MAT indication of several failures in this area and the EEC C1 R status message this was not a cause for alarm for the crew as they had suspected EEC issues. Following this action, the discrepancy between left and right N2, N3, and fuel flow increased, as would be the case if the right N1 was over-reading; vibration remained normal.

The crew consulted the "*Performance In Flight*" section of the FCOM 1 relating to Alternate Mode EEC. This suggested a 20 tonne decrement to 'primary mode' performance limit weight for climb and net level-off weight. The crew decided that climb decisions would be based on this higher assumed weight.

Approximately 5 hours into flight the Flight Management System's 'fuel remaining' calculations at London Heathrow started reducing. While the required thrust and fuel flow were high they were not entirely inconsistent with a 20 tonne performance decrement, although the fuel flow was higher than would be expected. As a result, reaching London Heathrow with the minimum required fuel of 5,400 kg was becoming unlikely, and the trend was worsening. At this point the aircraft was over Afghanistan and the route ahead had few suitable alternates for several hours. The crew considered that if a turnback were attempted it would still be several hours before the aircraft would reach an acceptable alternate airport. As the fuel on board was about 52,000 kg of fuel and total fuel flow was about 8,000 kg/hr the crew felt it was prudent to continue towards better alternates, with several less suitable, but usable, places to go if conditions worsened. A crew handover took place and it was agreed the 'heavy' crew would continue to monitor the situation closely, liaise with operations, and advise the operating crew if conditions deteriorated.

Approximately 8 hours 45 mins into the flight the commander was woken in his rest bunk by what he believed was an engine compressor stall. As the engines continued running, with no change in thrust, he decided it had been imagined. The relief crew heard a "thud" and felt a slight movement of the aircraft. They then noticed that the required thrust setting and fuel flow had reduced, and that the fuel state, although now showing insufficient for London, had stopped deteriorating. They then began planning what options were available, given the remaining fuel state, and contacted the operator to see which alternates were preferable. The 'heavy' crew suspected that a panel had become loose, creating drag for several hours, and suddenly detached. As it was now daytime the 'heavy' captain examined the aircraft exterior as far as possible but could find no evidence of missing panels or other damage. The rear of the engine was not visible from the cabin. The possibility of reverser blocker or cascade doors detaching was considered, although engine parameters remained unchanged.

The crew elected to divert to Amsterdam International Airport, Netherlands, primarily because the weather was excellent, multiple runways were available and the aircraft would arrive with about 2,000 kg above minimum reserve fuel, thus allowing for contingencies. Having established that rated thrust was available from the right engine, a standard Flap 25 landing was planned. As the crew did not know how many track miles remained or which runway to expect prior to establishing contact with Amsterdam ATC, and any delay caused by ATC or a latent technical problem might have resulted in landing below reserve fuel, they transmitted a PAN on initial contact. The aircraft landed without further incident, using idle thrust reverse, at 0511 hrs on 15 June 2010. Having vacated the runway near the AFRS, who were on standby, the commander elected to get visual inspection from them; this was inconclusive.

After shutdown and passenger disembarkation the crew vacated the aircraft to see if there were signs of damage. They discovered that the aft inner nacelle on the right engine was severely damaged, and much of it missing, and that there was further airframe damage.

Engine debris at Singapore International Airport

Aircraft parts were found by a Singapore International Airport Airside Operations vehicle on the edge of Runway 02L during a scheduled maintenance closure of Runway 01 on 14 June at 1715 hrs (0115 hrs Singapore time). Attempts were made to identify the parts, but without success. At 0843 hrs (1643 hours Singapore time) on 15 June 2010 the airport authorities received a call from the operator of G-YMMP, saying that parts of an engine nacelle were missing on arrival in Amsterdam. The operator's representative in Singapore subsequently identified the parts as belonging to G-YMMP.

Initial examination

The operator and the airframe manufacturer made initial assessments at Amsterdam of the damage to the aircraft. It was clear that the left inner wall 'D-duct' on the right engine thrust reverser had separated from its engine and that a large portion of the turbine exhaust nozzle was missing (Figure 1). There was also damage to the inboard flap fairing and flaperon, consistent with the separation of the items from the engine, with scraping and gouge damage on the right lower wing skin and the right horizontal stabiliser.

The manufacturer's initial examination indicated that buckling damage to the inner wall D-duct was consistent with a:

> *'typical of loss of stability due to disbond of inner facesheet'*

and that this form of failure had been seen on a number of previous occasions. It appeared likely that

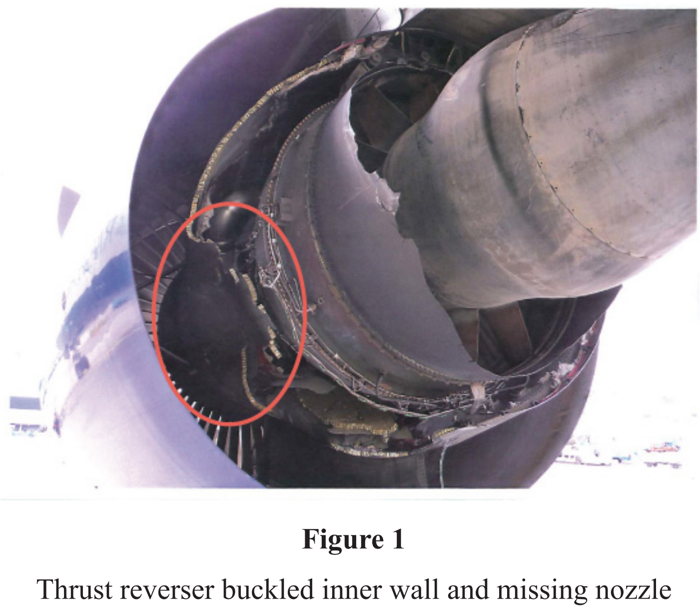

Figure 1

Thrust reverser buckled inner wall and missing nozzle the separation of the turbine exhaust nozzle had been caused by the failure of the duct structure as the inward collapse of the inner wall applied bending loads to the nozzle supporting structure.

This initial examination by the manufacturer also indicated areas in which there did not appear to be sufficient sealant to preserve firewalls, such as on the leading edges of the insulation blankets, around cooling tube penetrations and around the interface between the left HP3 duct and the insulation blankets, without evidence as to how much this had contributed to the failures. The airframe manufacturer reported that:

'preliminary results of hardware and engine fault codes and QAR data are consistent with the loss of the nozzle being secondary to the loss of the inner wall.'

Thrust reverser thermal barrier system - description

The affected parts of the thrust reverser system and engine cowlings are within the design responsibility of the airframe manufacturer, not the engine manufacturer. The maintenance manual for the aircraft describes the function of the thermal barrier protection applied to the thrust reverser as being to keep it:

'structurally serviceable'

and to prevent:

'parts separating from the airplane in flight.'

The inner wall of the fan duct cowl (Figures 2 and 3) is a composite material susceptible to;

'radiant heat damage from fires and [normal] engine operation'

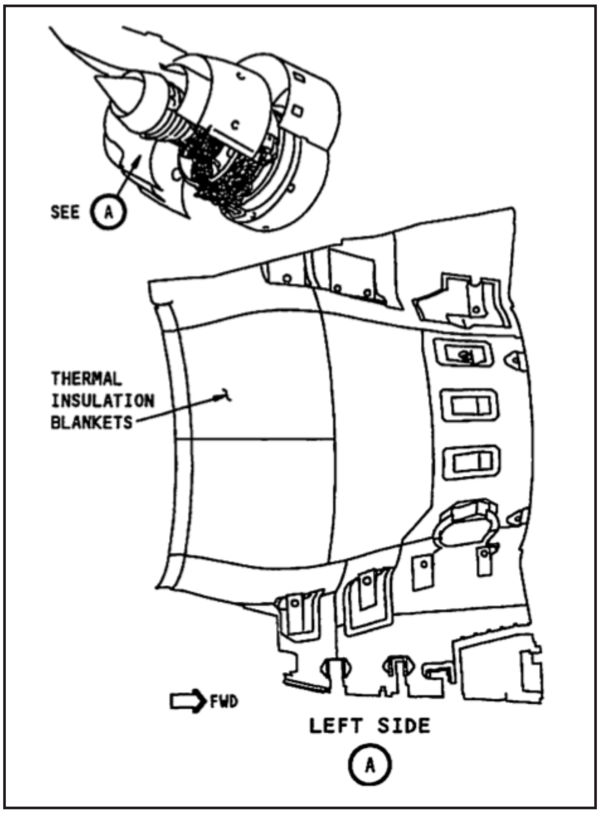

Figure 2

Thrust reverser thermal barrier in fan duct cowl
(courtesy Boeing)

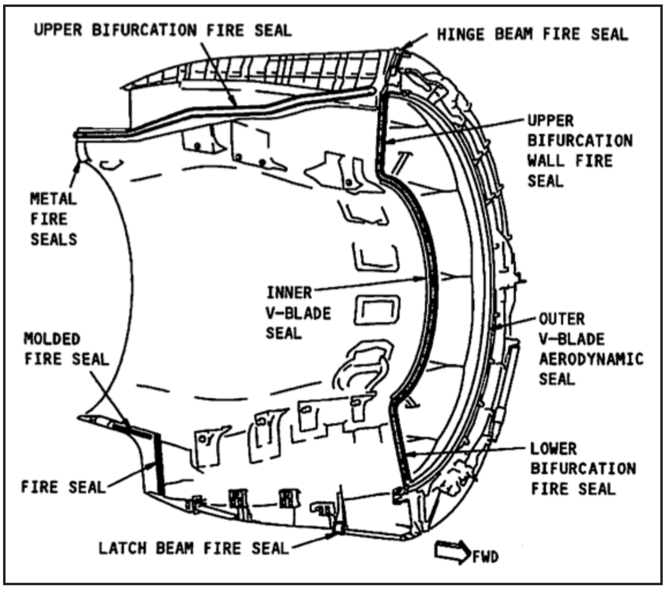

Figure 3

Location of thermal blanket seals in fan duct cowl
(*courtesy Boeing*)

without the thermal barrier. The barrier consists of thermal insulation blankets installed in the area bounded by the fire seals in Figure 3.

The integrity of the blanket-to-blanket seal, the blanket penetration seals and the blanket edge seals is critical to the success of the thermal barrier protection and to the preservation of the structural integrity of the thrust reverser inner wall. The maintenance manual states that large amounts of hot (leaked) compressor air:

> *'can penetrate through the gaps between the overlapped blankets to cause convective heat damage to the T/R inner wall'*

and that it is:

> *'important to find any holes in the bleed offtake pneumatic ducts, or gaps at pneumatic duct connections, or damaged kiss seals and kiss seal mating surfaces during engine visual inspections.'*

Flight data recorders

Data downloaded from the flight data recorder (FDR) for the incident flight is presented in Figures 4 & 5. Figure 4 shows the takeoff and climb to 7,000 ft amsl from Singapore International Airport. At 1618:35 hrs, as the aircraft climbed through 500 ft, the right engine

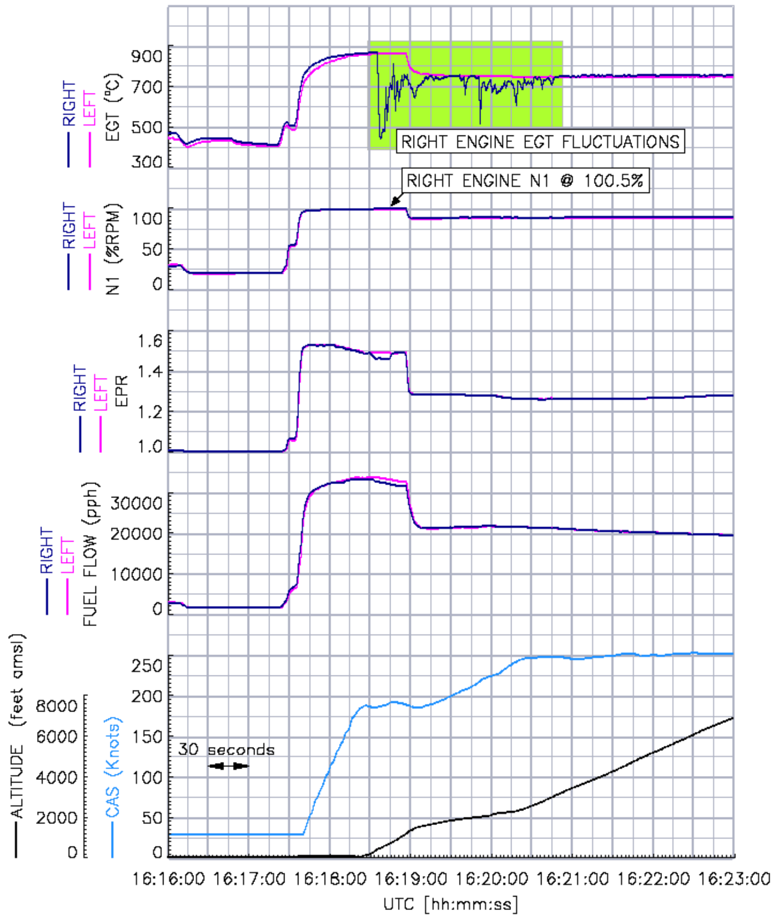

Figure 4

FDR data for the takeoff, showing right engine fluctuations

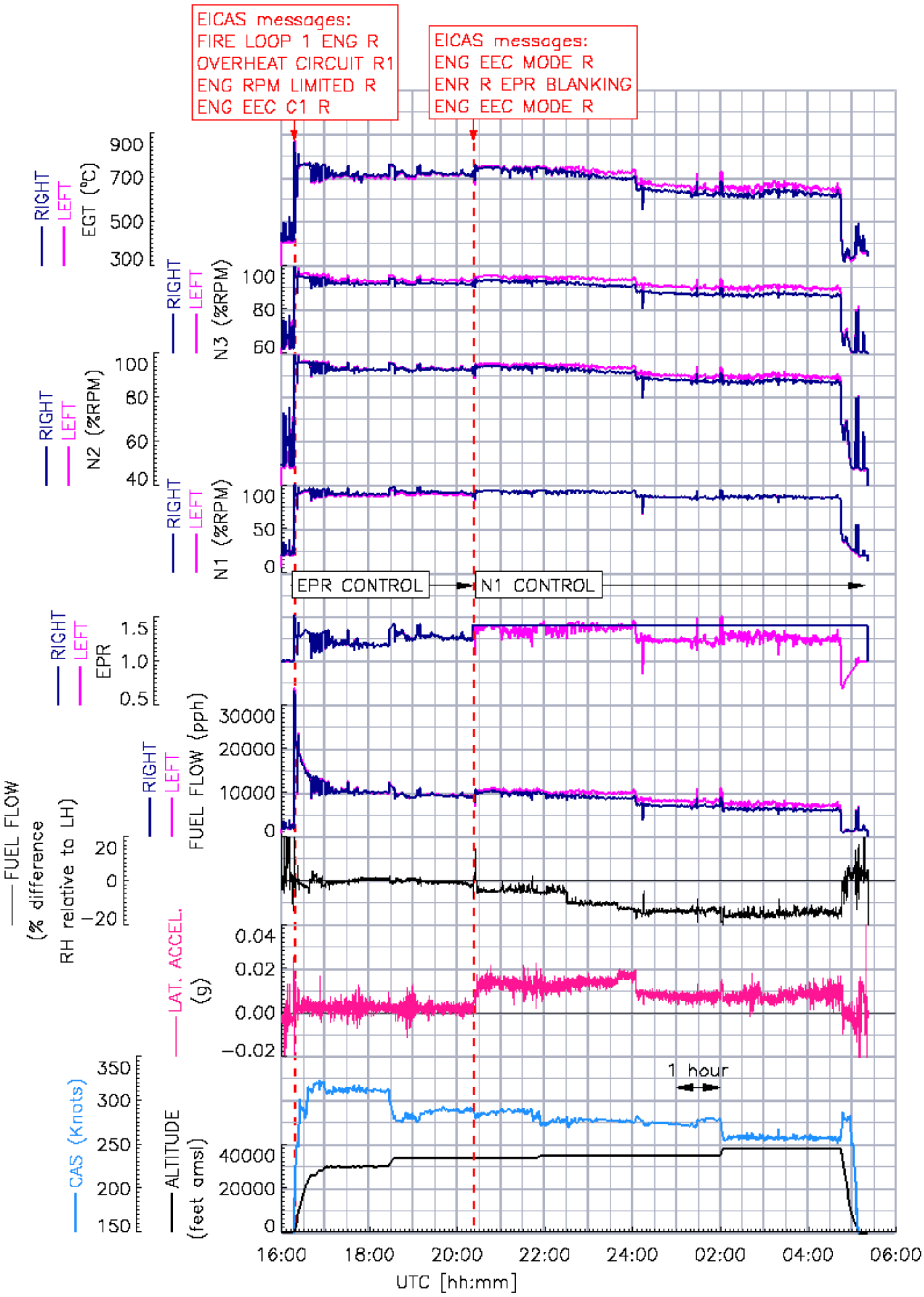

Figure 5

Salient FDR parameters of incident flight

N1 increased from a nominal 99% to 100.5% and the left engine remained at 99%. At the same time, the right engine EGT dropped from 867ºC to 448ºC and then fluctuated around 700ºC for about 130 seconds, before rising to 750ºC; the left engine EGT remained steady at 865ºC, dropping smoothly to 750ºC as the engine thrust was reduced to climb thrust.

Figure 5 shows data for the complete flight to London Heathrow Airport. Also indicated on Figure 5 are the EICAS messages displayed to the crew. These messages were recorded on the Maintenance Message Data Report, downloaded from the EICAS after the flight. The first set of messages were at 1618 hrs during the time of the right engine EGT fluctuations. However, the report only records the time for each message as hours and minutes so the exact timing is unknown. For the next four hours the EPRs and fuel flow for both engines were matched but small discrepancies between the engines were recorded for N1 (1 to 3.5%RPM), N2 (0 to 1%RPM), N3 (1 to 2%RPM), and EGT (0 ºC to 8ºC).

The second set of EICAS messages occurred at 2023 hrs, approximately four hours into the flight, as the right engine EPR signal was lost. It was at this point the engines switched from Normal EEC mode (‘EPR’) to Alternate EEC mode (‘N1’). From this point onwards the engine N1s were matched but discrepancies between the engines (left greater than right) were recorded for fuel flow, N2, N3 and EGT. In particular, a 5% difference in fuel flow was measured, increasing in steps to 15% by the end of the cruise portion of the flight. Also recorded was a lateral asymmetry to the right: rudder trim (not shown) was only used between 0254 and 0320 hrs, when 0.05 inches of left rudder trim actuator movement was recorded.

Engine performance review

During the investigation, the engine manufacturer conducted an analysis of the performance of both engines during the flight, primarily using data from the EHM (engine health monitoring) and QAR (quick access recorder).

This analysis reflected the account of the flight given by the flight crew and by the FDR data. In particular, it identified the anomalies between N1 and EPR during the initial event at takeoff and the relatively high power settings on both engines during the first four hours of flight, reflecting, and compensating for, some degree of exhaust nozzle area change on the right engine.

Following the event at about four hours, and the switching to ‘Alternate’ EEC mode (controlled by N1, rather than EPR), the higher power settings continued, with the left engine reflecting scheduled performance but the right engine performance degraded by the changes in effective nozzle areas. The total fuel consumption by the engines, resulting in the PAN diversion into Amsterdam, matched the aircraft tank quantities.

Detailed examination

Following the initial investigations at Amsterdam and in the United Kingdom, the significant items from the failed duct on G-YMMP were despatched to the USA for more detailed investigation at the airframe manufacturer.

During this examination the manufacturer identified several locations with clear indications of thermal exposure and disbond. Of those, the location of greatest interest was around the drag link fitting, immediately above the HP3 cutout (Figure 6). This was among the more discoloured areas, and it was clearly included in the disbonded region of the panel. The discolouration of other areas of the inner wall was evidence of overheating at those locations, but the manufacturer reported that discolourations outside the disbond region associated with the panel collapse were '*unlikely to be implicated in the failure*' of the panel. This was consistent with the manufacturer's initial assessment at Amsterdam.

The manufacturer further noted significant characteristics of the disbonded surface. These included areas with low bond strength, as evidenced by small fillet scars and/or adhesive failure between the honeycomb core and the facesheet, and a region of significantly overheated adhesive between the drag links next to the HP3 cutout.

Service history and safety actions

This was the first event of this type experienced by the operator of G-YMMP but it followed approximately 10 other events on 777 aircraft with this airframe-engine combination. A further two events have been recorded since that to G-YMMP.

As a result of the initial incidents, in February 2005 the aircraft manufacturer issued Service Bulletins 777-78A0059 and 777-78-0060. These SBs principally involved one-time inspections of the thrust reverser inner wall, insulation blankets, compression pads, and drag link fittings (-059), and the application of sealants (-060).

Following further events at other operators, one of which was on an airframe which had SBs -059 and -060 correctly completed, an additional Service Bulletin, 777A78-0065 was issued in June 2008, requiring recurring inspections. Initial inspection of the blanket sealing on G-YMMP was carried out on 5 February 2010 and a repeat inspection was carried out on 14 May 2010, with no significant damage reported.

Figure 6

HP3 duct disbond location

However, a full NDT inspection of the inner wall with all the thermal blankets removed had not yet been completed on G-YMMP at the time of this incident, as the inspection was not yet due.

The airframe manufacturer issued a further, and extensive, Service Bulletin in late 2009, 777-78-0071, stating that the existing thermal protection system was insufficient to prevent damage to the inner wall of the thrust reverser and incorporating a new thermal protection system to reduce the temperatures experienced by the inner wall during flight. There was some initial delay in the approval by the EASA of the design change included within this Service Bulletin, as EASA was requesting further data and design substantiation from the airframe manufacturer, and the design change had not been fully approved at the time of this event to G-YMMP (14 June 2011). However, the operator of G-YMMP commented that, even with earlier EASA approval, the scope of the work and the number of aircraft to be covered leaves it uncertain whether G-YMMP would have been modified by the date of this incident.