Boeing 737-81Q, G-XLAD

AAIB Bulletin No: 5/2004	Ref: EW/C2002/12/04	Category: 1.1
Aircraft Type and Registration:	Boeing 737-81Q, G-XLAD	
No & Type of Engines:	2 CFM56-7B26 turbofan engines	
Year of Manufacture:	2000	
Date & Time (UTC):	23 December 2002 at 0030 hrs	
Location:	Gatwick Airport, West Sussex	
Persons on Board:	Crew - 8	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	37 years	
Commander's Flying Experience:	4,980 (of which 2,950 were on type)	
	Last 90 days - 216 hours	
	Last 28 days - 85 hours	
Information Source:	AAIB Field Investigation	

History of the Flight

The flight during which this incident occurred was the last in a series of flights that originated in Manchester on 20 December 2002. On that day the crew had reported for duty at 1855 hrs for a return flight to Tenerife-South. The allocated aircraft, G-XLAD, had just been returned to service after engineering work to investigate an airframe vibration experienced during the previous flight. An inspection had revealed no faults and the aircraft's flight from Manchester was uneventful until the descent into Tenerife. When descending through about FL150 a smell of burning plastic had become apparent on the flight deck. No immediate cause could be found and the crew requested a priority landing at Tenerife-South, which was by now about 30 nm away. The commander decided that the situation did not warrant a distress call. When established on the final approach at about 12 nm, in VMC, the data on the Commander's Primary Flight Display (PFD) became intermittent, shortly followed by that on the First Officer's (FO) and the standby PFDs. The autopilot then disengaged without the aural disconnect warning sounding. The FO, who was the handling pilot for the sector, continued to fly manually for an otherwise uneventful landing.

After shutdown on the allocated stand the Commander checked the electronics and equipment bay for signs of burning, but could find none. He reported the matter to his company who dispatched their own engineer since there was no appropriate engineering support at the airport. The engineer arrived at Tenerife-South on the evening of 21 December 2002. He commenced work on the aircraft the following morning but could find no signs of burning or any obvious cause of the problems encountered during the previous flight. However, during inspection of the recorded in-flight faults it

was indicated that both navigation multi-mode receivers had tripped out on the previous approach, which he thought might have accounted for the loss of ILS information on the PFDs. As he could find no existing faults the engineer cleared the aircraft for flight, believing that it would be positioning empty back to Manchester. On this basis he agreed with the Commander that after departure they should conduct a visual approach back into Tenerife to ensure that the ILS was working properly prior to the onward flight.

However, just before departure the company instructed the Commander to position the aircraft to Las Palmas where a sub-charter had been arranged for 76 passengers to be flown to Brussels. The aircraft left Tenerife-South at 1500 hrs on the afternoon of 22 December 2002 and, after a short and uneventful flight, carried out a successful ILS approach and landing at Las Palmas. After boarding the passengers the aircraft departed for Brussels at 1630 hrs.

The flight was uneventful until the burning smell previously encountered on the flight deck became apparent briefly whilst descending through about FL120. There were no other problems indicated and after landing it was agreed with the company that the aircraft should be flown to Gatwick, the company's main engineering base, for further investigation. The aircraft then departed Brussels at 2300 hrs with only the crew and the engineer on board.

When established in the cruise at FL240 both pilots and the engineer became aware of the aircraft repeatedly yawing gently to one side and then returning quickly to a normal attitude. Descriptions differed between the crew as to the duration of each event, varying from 20 seconds to two minutes. Their description of how often the events occurred also varied, ranging from continuous to once every four minutes. The Commander recalls the indications during each disturbance in the cruise showing a slip to the right requiring about 2.5 units of right aileron to keep the aircraft straight. There was no asymmetric power and the yaw damper indicator showed a central position. The rudder trim was slightly displaced to the left, which was not considered unusual for this phase of flight. On attempting to apply right rudder the Commander found that his rudder pedals could not be moved, although between each disturbance the pedals could be moved again normally.

The pilots and engineer checked the flight deck for any abnormal switch selections or popped circuit breakers but could find none. The engineer then went to the rear of the passenger cabin where he turned to look forward towards the flight deck. He described the aircraft seeming to drift to the right before kicking back abruptly to the left. The kick was pronounced but was such that he was able to stand without support. These deviations, each of which lasted for about 20 seconds, continued throughout the few minutes that the engineer remained in the cabin and were consistent in their direction. He reported this to the Commander who, convinced of the seriousness of the situation, briefed the purser for a possible emergency landing.

The aircraft commenced its descent for Gatwick during which the divergences seemed to be more pronounced. As a result of this, and whilst on a closing heading for the localiser at FL080, the crew transmitted a PAN call to Gatwick approach advising they had problems with the rudder. The Commander described the divergences at this point showing the slip indicator displaced just over half way with the aircraft yawing to the left through about 20°. Gatwick approach acknowledged the PAN call and shortly afterwards asked the aircraft to slow to 230 kt. The commander reported that at this stage he disconnected both the autopilot and autothrust since the divergences were now more extreme, however, he decided to leave the YAW DAMPER engaged since it appeared to be behaving normally.

The non-normal checklist for UNCOMMANDED YAW OR ROLL requires that the autopilot and autothrottle be disengaged (if engaged) and verification that symmetric thrust is applied; the YAW DAMPER should then have been selected to OFF.

ATC cleared the aircraft to descend to 3,000 feet where the Commander recalls at one point having to apply 5 units of left aileron to keep it tracking straight. The aircraft was then established on the ILS with the intention of completing a flap 25 landing, in VMC, with a surface wind reported as light.

When passing 300 feet AGL the Commander reported that the aircraft progressively yawed left, to the extent that the slip indictor was displaced three-quarters to the right and full right aileron was required

to keep the aircraft straight. As on the other occasions his rudder pedals could not be moved despite him now applying full force to the right pedal. Simultaneously with the automated 30 foot radio altimeter call the uncontrolled divergences suddenly stopped. However, the extreme control inputs necessary to control the aircraft up to this point could not be corrected quickly enough to prevent the aircraft yawing and rolling to the right. The crew reported that the aircraft landed about 30° off the runway track touching down first on its right main gear.

The Commander attempted to regain the centre line by use of the rudder, but although he could now move the pedals they appeared to be ineffective. He therefore used the nosewheel steering to control the aircraft. The aircraft cleared the runway and was brought to a halt on the taxiway whilst the crew spoke to the fire service, on their discrete frequency of 121.6 MHz, to confirm their services would not be required.

The commander then taxied the aircraft to the allocated parking stand during which time he attempted to move his rudder pedals again, only to find that they would not move. When finally parked and with the engines still running he tried once more and this time found they had become free again. After shutdown an engineer from the maintenance organisation used by the Company was briefed on the control problems that had been encountered.

Engineering investigation

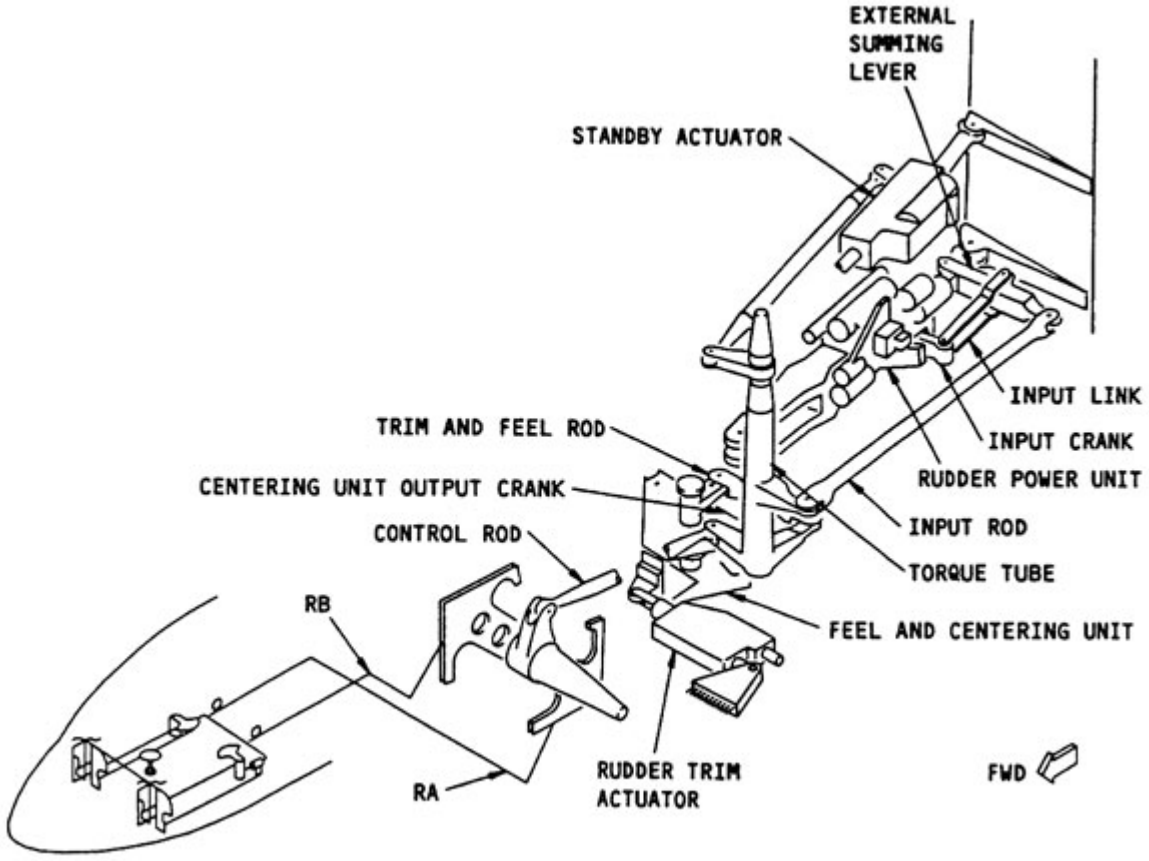
After the flight from Brussels to Gatwick the aircraft was taken out of service and subjected to a series of inspections agreed between the operator's engineering representative, the contracted maintenance organisation and Boeing's product support organisation. These checks included a thorough inspection of the pedal mechanisms, the rudder cable system and the rudder system's mechanical components at the rear of the aircraft. There was no evidence found of any restriction within the system and the measurements taken, which included the rudder cable tensions and rudder pedal forces, were within limits. Both stall management yaw damper units were sent to an overhaul agency in the UK for testing; under test these units performed their yaw damper functions normally and without any apparent defect.

As a further precautionary and investigative step the rudder hydraulic actuator was replaced with another unit and the aircraft was then returned to service. The operator's engineering quality department continued to monitor the aircraft in service and there have been no further reports of problems with the rudder control system. The rudder hydraulic actuator removed from G-XLAD was returned to its manufacturer in the USA. A full programme of testing, agreed by the AAIB and NTSB, was overseen by a representative from the FAA and the tests found the actuator to be behaving normally.

System description - rudder

Figure 1 shows the main elements of the 737-800 rudder control system, which is similar to earlier 737 models. The pilot inputs are made through two pairs of conventional rudder pedals, connected in series through forward quadrants and a single cable loop to an aft quadrant. This aft quadrant is connected to a control rod, which is directly connected to the rudder torque tube. The rudder feel and centering unit, which is biased by the electrically-powered rudder trim actuator, is also connected to the rudder torque tube and this torque tube is directly linked to provide mechanical inputs to the rudder hydraulic actuator and to the standby rudder actuator.

Figure 1: B737-800 Rudder control system



Within the rudder control system there are three main inputs to the Flight Data Recorder (FDR). The rudder pedal position sensor is mounted at one of the forward quadrants, close to the pilots' pedals, and the rudder position sensor is mechanically linked directly to the rudder. However, the rudder pedal force transducer is a load transducer mounted on the control rod connected to the rudder torque tube in the rear of the aircraft. This transducer is therefore remote from the pedals and measures the sum of the loads within the rudder control circuit rather than the actual loads at the rudder pedals.

Recorded data

The aircraft was fitted with a 30 minute Cockpit Voice Recorder (CVR) and a 25 hour FDR. The AAIB was not notified of the incident for several days, consequently the CVR had been over-written. All of the available FDR information was, however, recovered successfully.

Analysis of the recorded data

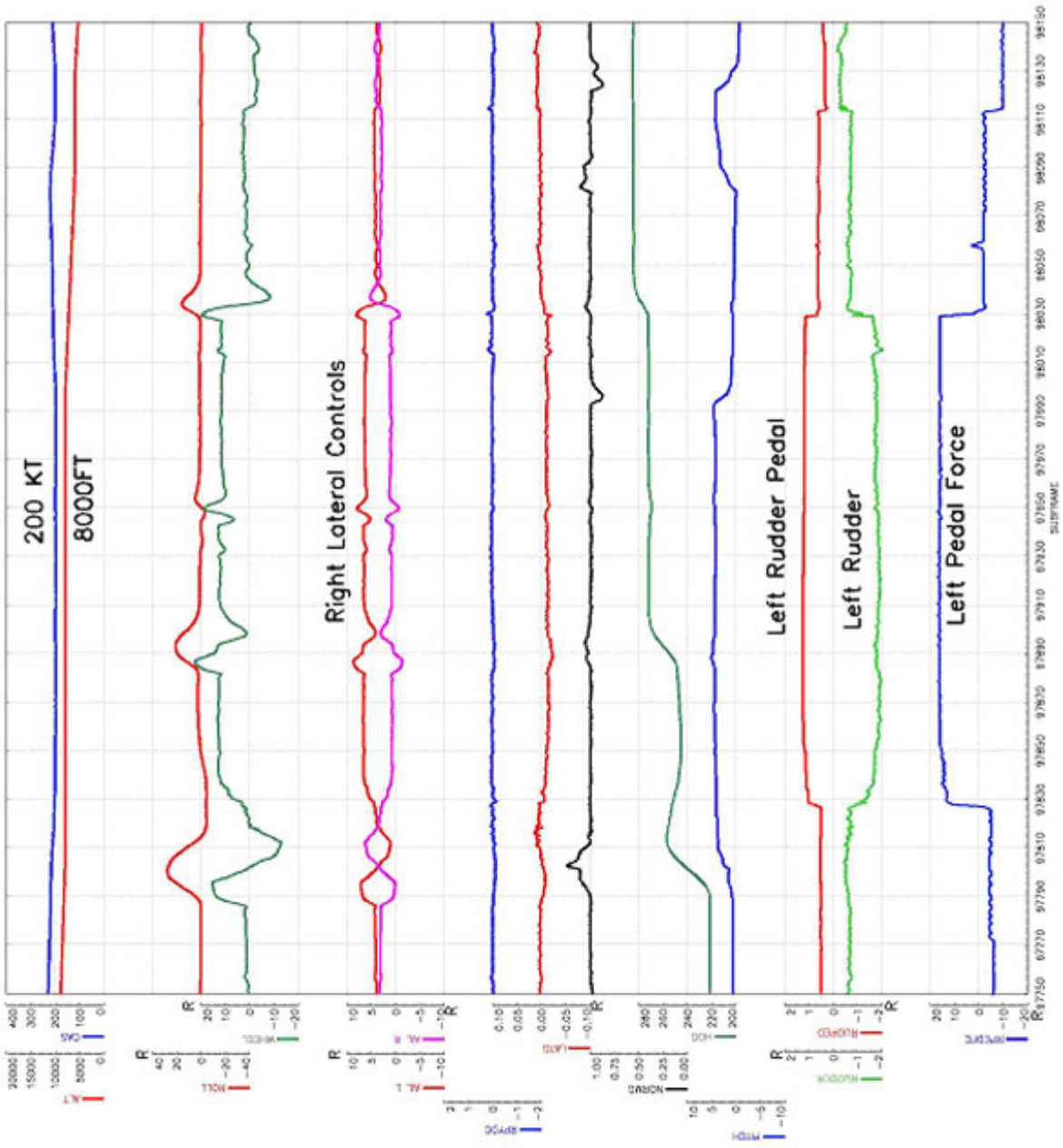
All sectors recorded on the FDR were examined for unusual rudder control activity, particularly the incident sector from Brussels to Gatwick. The full and free rudder control check prior to the incident flight indicates that the rudder angle, rudder pedal and rudder pedal force parameters are consistent, and operating in the correct sense. The breakout force was about 15 lb in each direction, which was in broad agreement with the manufacturer's data.

During the sector from Brussels to Gatwick the crew reported a number of instances of yaw divergence coupled with an inability to move the rudder pedals. Examination of the whole flight showed that the indicated FDR rudder pedal force was always less than 20 lb (ie close to the breakout force inferred from the full and free check), and the indicated rudder angle was always less than 2°. Throughout the flight the yaw damper appeared to be operating normally and in the correct sense. Salient FDR parameters from the most obvious of the rudder inputs and reversals are shown in Figure

2, when the aircraft was at about 8,000 feet and 200 kt. It can be seen that at an FDR time of about 97830 seconds the rudder pedal was deflected to the left by about 1° (from its initial position of 1° to the left), and remained essentially unchanged from this value for about 3 minutes, even during the turn to the right at time 97890 seconds. Throughout this period the indicated rudder pedal force to the left was about 16 lb. It can also be seen that throughout this period the ailerons were deflected to the right, suggesting that the aircraft was in a slight but prolonged side slip. This is an unusual manoeuvre for a large commercial aircraft, especially with the autopilot engaged.

Figure 2: Salient FDR Parameters Incident to B737-81Q en-route to Gatwick on 22 December 2002

Figure 2

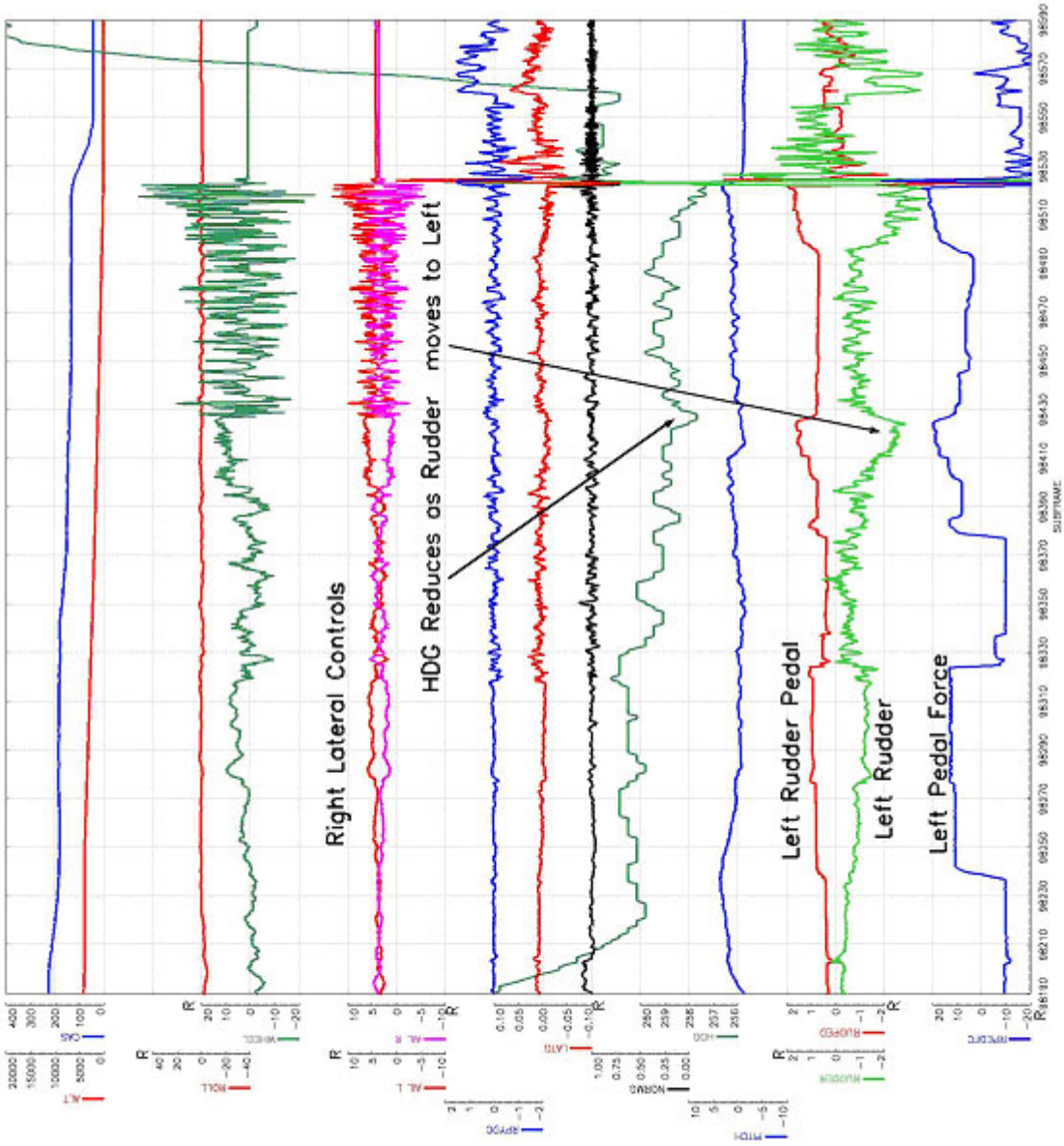


Salient FDR Parameters
Incident to B737-81Q en-route to Gatwick on 22 December 2002

The same parameters are displayed in Figure 3 for the landing at Gatwick. Here it can be seen that there were a number of reversals of both the rudder inputs and forces during the approach (eg at FDR time 98323 seconds and at 98378 seconds). However, these force levels are within the breakout and friction bands and result in very small rudder movements.

Figure 3: Salient FDR Parameters during Landing at Gatwick Incident to B737-81Q en-route to Gatwick on 22 December 2002

Figure 3

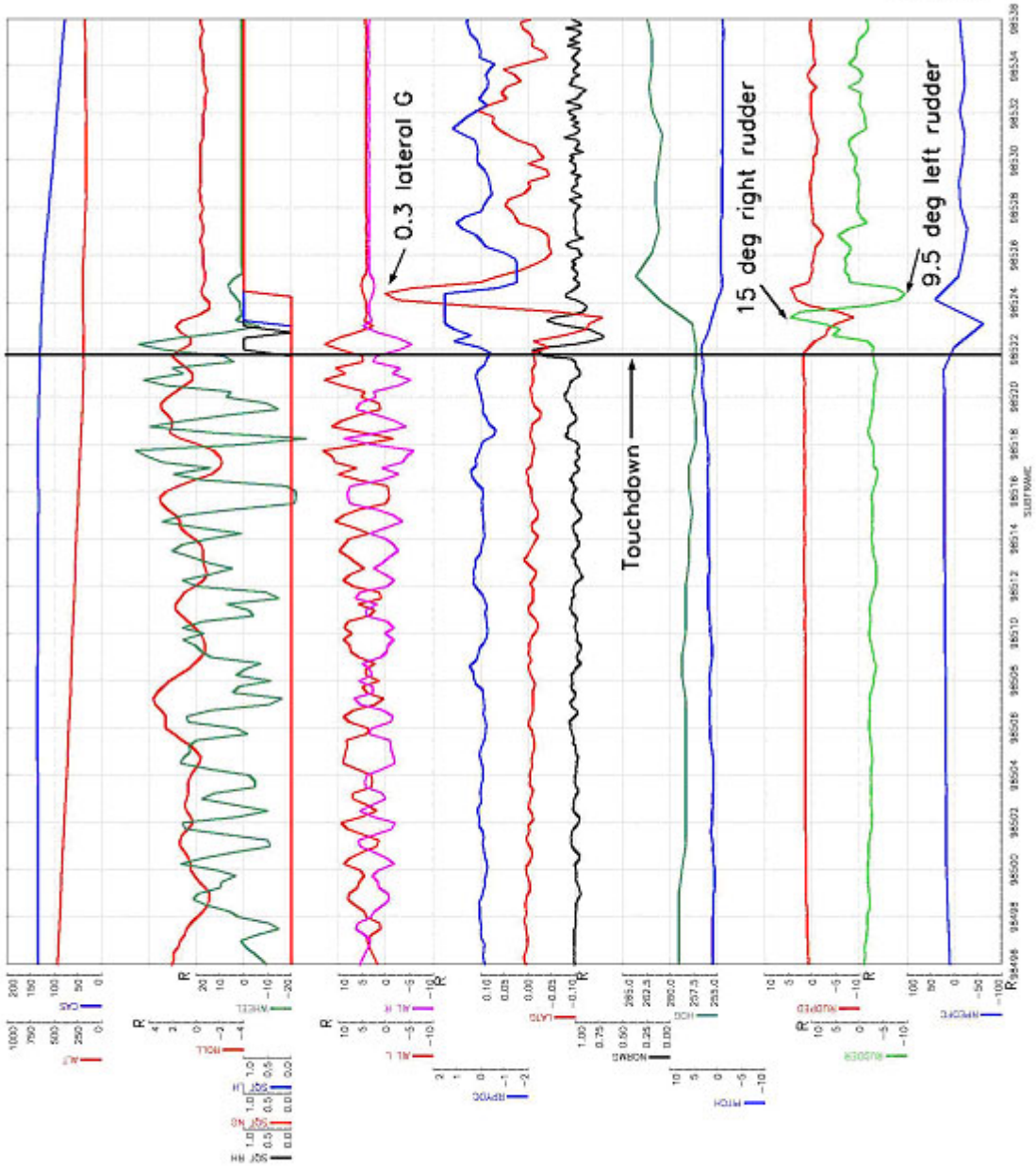


Salient FDR Parameters during Landing at Gatwick
Incident to B737-81Q en-route to Gatwick on 22 December 2002

Figure 4 shows the recorded data from 500 feet on the approach to touchdown. During this period the maximum control wheel usage was about 50° which was similar to that used on previous landings. The aircraft appears to have landed with about 2° of right bank. The magnetic heading on the approach was an average of about 258°. About 15° of right rudder was applied just after touchdown (FDR time 98522 secs) and the aircraft appears to have responded with the heading increasing from 257° to 263°. A left rudder input was then applied at FDR time 98524 secs which resulted in a lateral acceleration to the left of about 0·3 'g'. The magnetic heading then remained at about 261° for the remainder of the roll-out. The FDR data does not show any evidence of yaw divergence or use of full lateral controls during the final approach.

Figure 4: Salient Parameters from 500 Feet to Touchdown Incident to B737-81Q en-route to Gatwick on 22 December

Figure 4



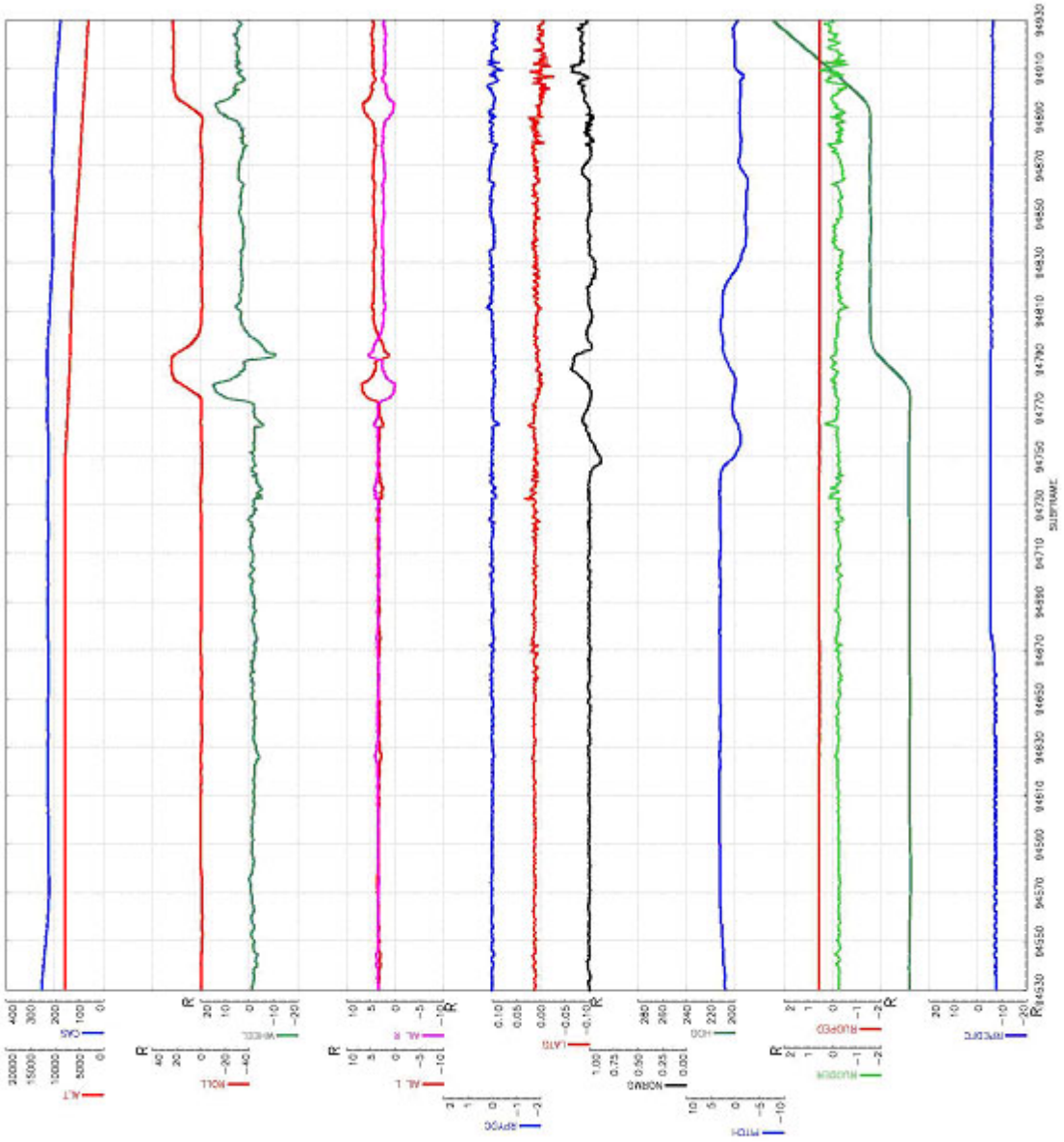
Salient Parameters from 500 Feet to Touchdown
Incident to B737-81Q en-route to Gatwick on 22 December 2002

With regard to the non normal checklist for UNCOMMANDED YAW OR ROLL the recorded data indicates that the autopilot was engaged during the climb and was not disengaged until an altitude of 1,300 feet on the approach into Gatwick, at an airspeed of 145 kt. The data also indicates that the autothrottle and the yaw damper remained engaged until after touchdown.

Figure 5 shows the parameters in cruising flight, extracted from the previous sector from Las Palmas to Brussels.

Figure 5: Salient FDR Parameters Las Palmas to Brussels Incident to B737-81Q en-route to Gatwick on 22 December

Figure 5

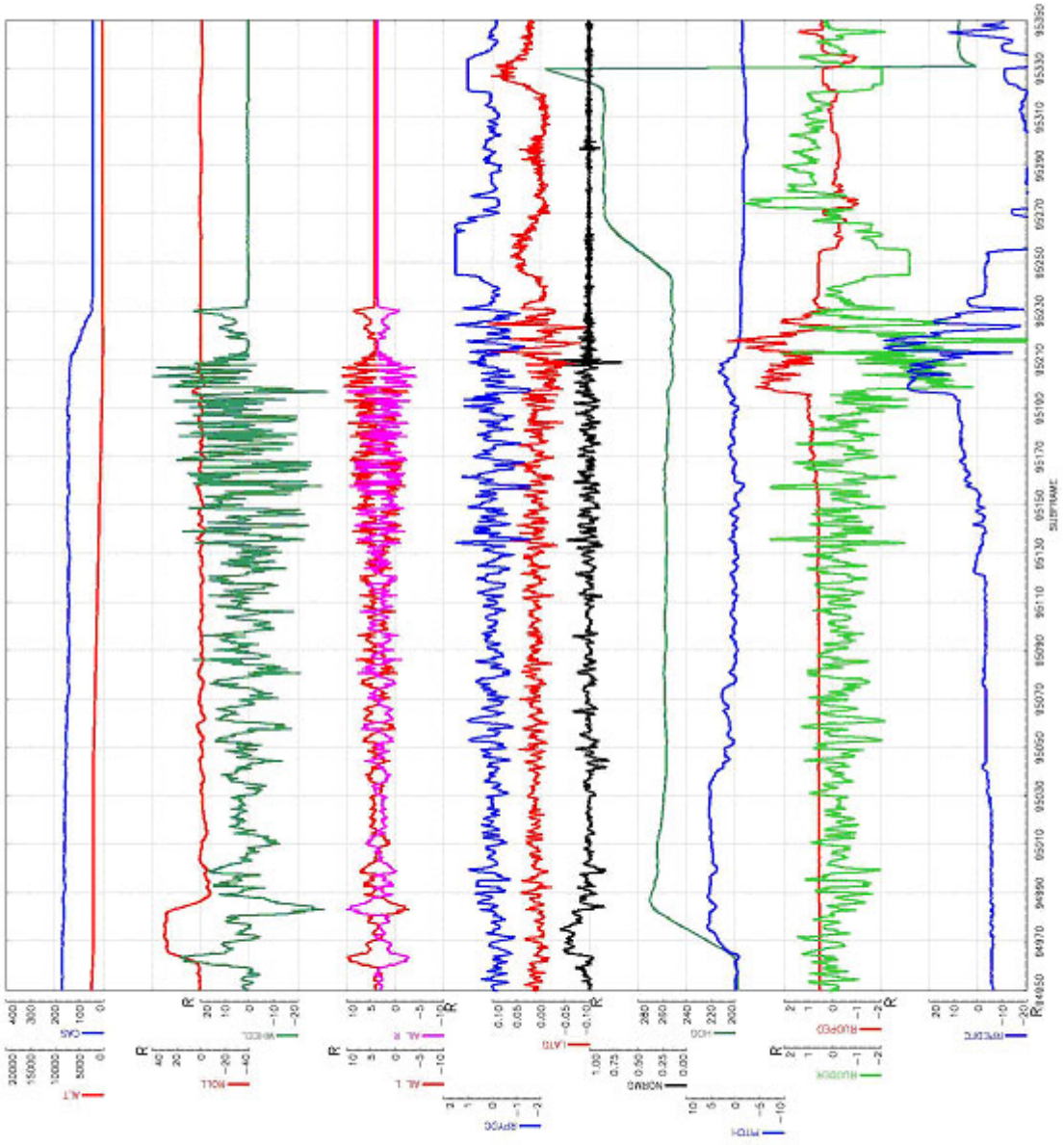


Salient FDR Parameters Las Palmas to Brussels
Incident to B737-81Q en-route to Gatwick on 22 December 2002

It can be seen that, in contrast to the Brussels-Gatwick sector, the rudder pedal and rudder pedal force remain essentially neutral, and the rudder responds normally to inputs from the yaw damper. Similarly, the approach and landing at Brussels (Figure 6), which covers the same period of flight as Figure 3, has no apparent rudder pedal inputs until the aircraft has touched down.

Figure 6: Salient FDR Parameters Landing at Brussels Incident to B737-81Q en-route to Gatwick on 22 December

Figure 6



Salient FDR Parameters Landing at Brussels
Incident to B737-81Q en-route to Gatwick on 22 December 2002

From the FDR data alone, the rudder pedal position, rudder pedal force and rudder angle parameters appear to be consistent. The yaw damper appears to be operating normally, and in the correct sense, and the aircraft appears to respond normally to other control inputs. Examination of all other sectors recorded on the FDR show that, once airborne, the rudder pedal parameter remains sensibly neutral. The reasons for the unusual control inputs in the incident sector cannot be inferred from the FDR data.

Analysis by the aircraft manufacturer

Despite the lack of any mechanical or electrical defect identified in G-XLAD there remained the anomaly, on the flight from Brussels to Gatwick, of the repeated, small, rudder pedal displacements over sustained periods. This behaviour had not appeared previous to this sector and the aircraft's

technical records showed no evidence of it later. The AAIB requested the manufacturer's assistance in determining whether there might be mechanical ways in which these inputs could be made, apart from extraneous or inadvertent crew inputs.

In response to this request, the manufacturer conducted a study, reviewing the FDR data and then analysing a number of scenarios to identify a possible source of the input into the rudder system. These scenarios included a 'sticky' pedal assembly (which might be generated by the higher friction of a failed bearing), ice build-up within the rudder control circuit and foreign object intrusion. There were also a number of other scenarios studied which involved faults in the nose gear steering system and faults in the wheel brake system.

The analysis was hampered by the location of the 'rudder pedal force' load transducer at the input rod to the rudder torque tube at the rear of the aircraft. This meant that only the sum of the loads within the rudder control circuit was being measured, rather than the actual loads at the rudder pedals.

Within the study the scenarios involving faults within the nose gear steering and wheel brake systems did not match the FDR data, principally because of the apparently normal movement of the steering tiller at each end of the flight and the presence of pedal movements in both directions in flight. With regard to the rudder system, all three of the fault cases analysed ('sticky' pedal assembly, ice build-up and foreign object intrusion) still required some form of pilot input, since the system is not powered forward of the load transducer. The ice and foreign object cases did not match the FDR data, specifically because of the pattern of pedal movements. This left the 'sticky' pedal scenario which could be made to match the FDR data, although the likely mechanical causes would be expected to persist and thus would have been found during the subsequent aircraft inspections or been reported on later flights.

In summary, therefore, the manufacturer's study suggested that the FDR data could only be matched with the scenario of higher friction in that portion of the control circuit forward of the load transducer. However, in order to generate the observed behaviour some form of input at the pedals would still be required, albeit inadvertent, and this characteristic of the rudder flight control system would be expected to persist for the subsequent flights.

Discussion

On previous flights there had been reports associated with airframe vibration, smells of burning, display irregularities and an unannounced autopilot disconnect. No faults had been identified to account for these reports. During the flight from Brussels to Gatwick the crew reported disturbances in yaw which concerned them sufficiently to warrant a distress message. These divergences occurred in both directions, for varying periods of time, at irregular intervals and were accompanied by an inability to move the rudder pedals. The flight crew did not complete the non-normal checklist for UNCOMMANDED YAW OR ROLL. Unusual but small rudder displacements were recorded by the FDR but the large amplitude excursions reported by the flight crew were not evident

The rudder flight control system and its components were subjected to a series of inspections agreed between the operator, its maintenance organisation and the aircraft manufacturer. No faults were found and the aircraft has since operated without further problems of this nature. A detailed study by the aircraft manufacturer considered the FDR data and analysed a number of mechanical scenarios in an attempt to identify a possible source of the input into the rudder flight control system. This study concluded that the FDR data could only be matched with the scenario for higher friction in that portion of the control circuit forward of the load transducer. However, in order to generate the observed aircraft behaviour some form of input at the pedals would still be required and this characteristic of the rudder flight control system would then be expected to persist for subsequent flights. There have been no further reports of problems with the rudder control system. This investigation has therefore been unable to explain the aircraft behaviour that was reported by the flight crew.