Uncommanded roll, Boeing 737-236 Advanced, G-BGJI

Micro-summary: **During an engineering test flight, a Boeing 737-236 experienced an uncommanded roll.**

Event Date: **1995-10-22 at 1609 UTC**

Investigative Body: **Aircraft Accident Investigation Board (AAIB), United Kingdom**

Investigative Body's Web Site: **http://www.aaib.dft.gov/uk/**

Note: **Reprinted by kind permission of the AAIB.**

Cautions:

1. Accident reports can be and sometimes are revised. Be sure to consult the investigative agency for the latest version before basing anything significant on content (e.g., thesis, research, etc).

2. Readers are advised that each report is a glimpse of events at specific points in time. While broad themes permeate the causal events leading up to crashes, and we can learn from those, the specific regulatory and technological environments can and do change. ***Your company's flight operations manual is the final authority as to the safe operation of your aircraft!***

3. Reports may or may not represent reality. Many many non-scientific factors go into an investigation, including the magnitude of the event, the experience of the investigator, the political climate, relationship with the regulatory authority, technological and recovery capabilities, etc. It is recommended that the reader review all reports analytically. Even a "bad" report can be a very useful launching point for learning.

4. Contact us before reproducing or redistributing a report from this anthology. Individual countries have very differing views on copyright! We can advise you on the steps to follow.

Boeing 737-236 Advanced, G-BGJI: Main document

Aircraft Incident Report No: 1/98 (EW/C95/10/4)

Report on the incident to Boeing 737-236 Advanced, G-BGJI 15 nm north-west of Bournemouth International Airport on 22 October 1995

Contents

Registered Owner:	British Airways PLC
Operator:	British Airways PLC
Aircraft Type:	Boeing 737-236 Advanced
Nationality:	British
Registration:	G-BGJI
Place of Incident:	15 nm north-west of
	Bournemouth International Airport
	Latitude: 50° 55.72' North
	Longitude: 002° 12.55' East
Date and Time:	22 October 1995 at 1609 hrs
	All times in this report are UTC

Synopsis

The incident was notified promptly to the Air Accidents Investigation Branch (AAIB) by the operator and the investigation began that evening. The AAIB team comprised Mr D F King

(Investigator-in-Charge), Mr P D Gilmartin (Operations), Mr C G Pollard (Engineering), Mr S W Moss (Engineering), Mr A N Cable (Engineering) Ms A Evans (Flight Recorders).

The crew reported at 1330 hrs at Gatwick to carry out a post-heavy maintenance check, test flight on the aircraft. The first officer (F/O) completed the external check, while the commander completed the 'Flight Deck Preparation' items of the aircraft checklist. A Standby (STBY) Rudder system check was carried out with no abnormalities noted and during taxi before take-off, the Yaw Damper indicator showed normal response to turns.

When the aircraft was in straight and level flight at FL200 with an indicated airspeed of 290 kt, Autopilot and Autothrottle engaged and Yaw Damper ON, the aircraft experienced roll/yaw oscillations. The Flight Data Recorder (FDR) showed that the Autopilot and Autothrottle were disengaged, and the commander reported that the Yaw Damper was switched OFF but the crew were unable to stop the oscillations. A MAYDAY call was broadcast at 1609 hrs. The crew had the impression that the bank angle would have continued to increase had opposite roll control inputs not been applied.

A descent was made to around FL75 and as the airspeed was allowed to reduce towards 250 kt the oscillations began to decay rapidly and stopped. The total duration of the roll/yaw event was about seven minutes.

A low speed handling check was carried out, and it was found that the aircraft handled well at a speed 150 kt, with Flap 15° selected and with the landing gear down. It was decided to return to London Gatwick Airport in this configuration, and the MAYDAY was downgraded to a PAN. The crew recovered the aircraft to Gatwick without further incident.

The investigation identified the following causal factors:

(i) Contamination of the connector on the Yaw Damper Coupler, in the Electronic and Equipment Bay, by an unidentified fluid had occurred at some time prior to the incident flight and compromised the function of its pin to pin insulation.

(ii) Sufficiently conductive contaminant paths between certain adjacent pins had affected the phase and magnitude of the signals transmitted to the Yaw Damper Actuator, thereby stimulating a forced Dutch Roll mode of the aircraft.

(iii) The location of the Electronic and Equipment (E&E) Bay, beneath the cabin floor in the area of the aircraft doors, galleys and toilets made it vulnerable to fluid ingress from a variety of sources.

(iv) The crew actions immediately following the onset of the Dutch Roll oscillations did not result in the disengagement of the malfunctioning Yaw Damper system.

Four safety recommendations were made.

1 Factual information

1.1 History of the flight

1.1.1 Pre-flight checks

The crew reported at 1330 hrs at Gatwick to carry out a post-P6 maintenance check (§1.6.6.1) test flight on the aircraft. The first officer (F/O) completed the external check, while the commander completed the 'Flight Deck Preparation' items of the aircraft checklist. The fuel load was 10,500 kg, with about 2,000 kg in the centre tank. Neither wing tank was full, with the right wing containing more fuel than the left because of earlier ground running of the engines and the Auxiliary Power Unit (APU).

As the APU was not available, due to the unserviceability of its fire detection system which was damaged during final closure of its cover panels, a ground air start was made on both engines. A Standby (STBY) Rudder system check was carried out with no abnormalities noted. The take-off configuration warning check was carried out which entailed selecting Flap 25°. During this selection there was a momentary double hydraulic 'A' system low pressure warning, indicating failure of the output from both engine driven pumps, but this quickly cleared and did not repeat itself.

During taxi before take-off, the Yaw Damper indicator showed normal response to turns.

1.1.2 Incident flight

The commander was the handling pilot when, at about 1555 hrs, the take-off was made from Runway 26L with full power and Flap 1° selected. After take-off, the aircraft was found to be out of trim laterally, needing left rudder and left aileron trims to achieve wings level flight. The crew assessed this to be due to the fuel imbalance. The crossfeed was opened, and fuel was used from the right wing tank until lateral balance was achieved. The fuel system was then returned to normal and the flight controls then felt normal until the incident occurred. The remainder of the flight until the recovery to Gatwick was conducted in an area between the Southampton VOR and Boscombe Down Airfield.

The pressurisation system was put in Standby (STBY) mode, with a cabin altitude of 4,000 feet set and the rate selector set to high rate. A climb was then carried out in stages to FL200. Handling was transferred to the F/O, Autopilot B was engaged in Command (CMD) mode and the Autothrottle engaged. The STBY cabin altitude was reset to 13,990 feet to check the passenger oxygen mask automatic deployment system, in accordance with the test schedule.

A Spoiler Isolation/upfloat check was also carried out, which involved selecting the Speedbrake to the 'Flight' detent, then operating the Spoiler A and B switches to OFF. The commander went into the cabin to visually check the spoiler upfloat. The left outboard spoiler trailing edge was approximately 3 inches up, all others were about 2 inches up. The ground spoilers were fully retracted. The commander returned to the flight deck, reset the Speedbrake lever to down and reset the Spoiler switches to ON. This was carried out less than two minutes prior to the start of the incident.

The crew attention then turned to the cabin altitude, which was climbing as required by the test schedule. Both pilots donned their oxygen masks as the cabin altitude passed through 10,000 feet and the cabin altitude horn began to sound. (Note: after the incident, it was found that the passenger masks had not deployed, indicating that the cabin altitude had remained below the nominal 14,000 feet activation altitude)

The aircraft was heading 270°M at FL200 with an indicated airspeed of 290 kt, Autopilot B in CMD mode, Autothrottle engaged and Yaw Damper ON. The aircraft started to roll, which was initially countered by the Autopilot applying opposite roll control. The aircraft then began to oscillate in roll, and oscillatory activity was noted on the Yaw Damper indicator. On instructions from the commander the F/O disconnected the Autopilot and Autothrottle and attempted to stop the roll oscillations using control wheel inputs. The timing of these actions was confirmed by the FDR. The commander recalled switching OFF the Yaw Damper at this time in accordance with Flight Crew Notice FCN 38/95, issued in August of 1995. This FCN, issued by the commander in his capacity as Flight Manager Boeing 737 (Technical Projects), reflected the revised Boeing procedure for Uncommanded Yaw or Roll (Appendix 9). The commander then took control and continued to use control wheel inputs in an effort to stop the rolling. He also decided to initiate an immediate descent so that crew oxygen was no longer a consideration and requested the F/O to retard the thrust levers.

A MAYDAY call was broadcast at 1609 hrs. In response, Air Traffic Control (ATC) offered radar vectors to the nearest airport, which was initially a left turn onto 170°M. The commander was reluctant to apply too much bank in order to turn as the roll excursions would have resulted in too steep a bank angle at the extremity of the oscillations. The crew had the impression that the bank angle would have continued to increase had opposite roll control inputs not been applied.

A descent was made to around FL75, with the airspeed maintained at 290 kt or greater. During the descent, control was passed between the pilots, with no change in the oscillations. A further change of handling pilot occurred when the crew oxygen masks were removed, again with no noticeable change in aircraft behaviour. Neither pilot could recall any movement of the rudder pedals and no deliberate rudder pedal inputs were made by the crew. Some power was reapplied once the aircraft had levelled off, and the airspeed was allowed to decay towards 250 kt. As the aircraft approached this speed, the oscillations began to decay rapidly and stopped. The total duration of the roll/yaw event was about seven minutes.

After the oscillations had stopped, the F/O went back into the cabin to check for any abnormalities on the wings but found none. A low speed handling check was carried out, and it was found that the aircraft handled well at a speed 150 kt with Flap 15° selected and with the landing gear down. It was decided to return to London Gatwick Airport in this configuration, and the MAYDAY was downgraded to a PAN. The weather at Gatwick for the landing was surface wind southerly at 5 kt, CAV OK and Runway 08R was in use. The crew considered that the most appropriate checklist for landing in a Flap 15° configuration was the One Engine Inoperative Descent/Approach/Landing checklist, which was actioned.

On checking the Master Caution Recall in the Landing Checklist, the commander noted that the amber FLT CTL caption was illuminated. On checking he saw that the Yaw Damper OFF amber light was illuminated and he switched the system back ON. However, on final approach, at about 3,000 feet, he felt that there may have been a small roll/yaw oscillation commencing. He therefore switched OFF the Yaw Damper, and continued the approach for an uneventful landing at 1644 hrs.

On reaching the maintenance hangar the circuit breaker for the Cockpit Voice Recorder (CVR) was 'pulled', but due to the 30 minute duration of the CVR tape the period of the incident had been erased.

Following the event the crew recalled that, during the initial climb out, a layer of cloud had been encountered between 3,000 and 4,000 feet, thickness about 500 feet, but the total temperature was in excess of °C at that time. There was no cloud above this and no icing was encountered. At the time of the incident, it was daylight, in clear air, no turbulence and with a good horizon above a general overcast.

During debriefing the crew reported that the oscillations were similar to Dutch Roll, with a period of about 2 to 3 seconds. The roll control felt normal to apply, with no signs of any mechanical reversion. There were no indications of any abnormalities associated with the hydraulic systems throughout the flight. The characteristics of the oscillations did not appear to change when the Autopilot was disengaged.

Following an initial examination of the aircraft (§1.12.1-2), a test flight (§1.16.2) was carried out on 10 November 1995. With additional recording equipment installed on the aircraft attempts were made to reproduce the roll/yaw oscillations.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor/None	2	-	-

1.3 Damage to aircraft

A small panel, the left wing fuel booster pump access panel, was found to be missing after the incident flight.

1.4 Other damage

None.

1.5 Personnel information

1.5.1	Commander:	Male, aged 44 years
	Licence:	Airline Transport Pilot's Licence
	Aircraft ratings:	Boeing 737, Viscount, Beech 55/58
	Medical certificate:	Class 1, Renewed 26 September 1995
	Instrument rating:	Renewed 4 May 1995
	Other Ratings:	Instrument Rating Examiner
		Type Rating Examiner - Boeing 737

		CAA Approved C of A Test Pilot
	Last base check:	12 October 1995
	Last line check:	20 October 1995
	Flying experience:	Total all Types: - 8,290 hours
		Total on Boeing 737: - 5,500 hours
	Duty time:	2 hours 39 minutes
	Previous rest:	In excess of 24 hours
1.5.2	First officer:	Male, aged 44 years
	Licence:	Airline Transport Pilot's Licence
	Aircraft ratings:	Boeing 737, Vanguard, Beech 55/58
	Other ratings:	Instrument Rating Examiner
		Type Rating Examiner - Boeing 737
	Medical certificate:	Class 1, Renewed 27 July 1995
	Instrument rating:	Renewed 3 November 1994
	Last base check:	29 March 1995
	Last line check:	18 December 1994
	Flying experience:	Total all Types: - 8,600 hours
		Total on Boeing 737: - 6,000 hours
	Duty time:	2 hours 39 minutes
	Previous rest:	In excess of 24 hours

1.6 Aircraft information

1.6.1	Leading particulars	
	Type:	Boeing 737-236 Advanced
	Constructor's number:	22030
	Date of manufacture:	1980

Certificate of registration:	British Airways, 5 September 1983
Certificate of airworthiness:	issued 3 October 1995
Total airframe hours:	37,871 hours (20,267 landings)
Engines:	2 Pratt & Whitney JT8D-15 turbofan
Maximum weight authorised for take-off:	52,750 kg
Actual take-off weight:	39,376 kg
Estimated weight at time of incident:	38,300 kg
Estimated fuel remaining at time of incident:	9,300 kg
Centre of gravity (CG) at time of incident:	205 inches AoD (Within limits)

1.6.2 Dutch Roll

The Dutch Roll lateral-directional interaction mode is a coupled banking, side slipping and yawing motion. It is often oscillatory, and when lightly damped creates control difficulties for pilots and discomfort for passengers. The Dutch Roll motion can begin with a yawing motion produced by a gust or a rudder input or with a rolling motion, which in turn results in adverse yaw. If the aircraft is designed with positive directional stability the fin tends to re-align the aircraft into the airflow when the temporary yawing moment stops. However, the nose does not return to a position of zero sideslip but tends to overshoot, setting up the cyclic roll/yaw motion of Dutch Roll. The degree of dihedral and wing sweep dictate the lateral qualities and the fin and rudder size influence the directional qualities. If the oscillation is positively stable the roll and yaw amplitudes reduce over successive oscillations and eventually damp out.

The Boeing 737 has natural positive damping in the Dutch Roll mode, (i.e. the motions reduce in amplitude with each cycle), and therefore meets the airworthiness requirements for lateral-directional oscillations without the need for an active Dutch Roll (yaw) damping system. Nevertheless, a Yaw Damper is fitted, which, although not required for flight dispatch, is provided to improve passenger comfort by more quickly damping the Dutch Roll oscillations. To provide active Dutch Roll damping, a rate gyro in the Yaw Damper Coupler senses yaw motion and feeds a signal to the Yaw Damper Actuator in the rudder Power Control Unit (PCU), to oppose the yaw. The period of the basic aircraft Dutch Roll oscillation for the Boeing 737 without Yaw Damping varies with airspeed, reducing from just over 4 seconds at 200 kt to 3 seconds at 280 kt (about 0.25 to 0.33 Hz).

1.6.3 Description of the Yaw Damper system (Appendix 1)

As described in § 1.6.2, the Boeing 737 series of aircraft have positive lateral directional stability but the aircraft still have a tendency to 'Dutch Roll' when disturbed, although the oscillations damp-out over a period of time. The aircraft are fitted with a Yaw Damper system which moves the rudder, with limited authority, to oppose such oscillations. Since it is not essential to the controllability of the aircraft, the system is simplex and powered by the 'B' hydraulic system. It should be noted that the Yaw Damper is independent of the Autopilot, since the latter has no input into the rudder control.

The principal components of the Yaw Damper system are the Yaw Damper Coupler located in the E&E Bay and the Yaw Damper Actuator which is part of the main rudder PCU. The Yaw Damper Coupler contains a rate gyro which senses lateral oscillations and, where these are of a frequency corresponding to the aircraft's natural Dutch Roll, a signal is output to the actuator to oppose the motion.

The Yaw Damper Actuator receives the electrical signals from the Yaw Damper Coupler which modulate an electro-hydraulic valve which ports hydraulic fluid to the appropriate ends of the actuator piston. Movement of this piston is mechanically linked to the input mechanism of the main PCU, which moves to command rudder movement. Rudder response is monitored by a Linear Variable Displacement Transducer (LVDT) and a feedback position signal is transmitted back to the Yaw Damper Coupler. The geometry of the linkage is such that the Yaw Damper authority is limited to 3° of rudder movement on this Boeing 737-200. Yaw Damper motion is not transmitted back to the pilot through the rudder pedals. A small indicator in the cockpit advises the pilot of any Yaw Damper activity.

1.6.4 Activation of the Yaw Damper system

The pilot can select the Yaw Damper ON and OFF using an engage switch on the flight deck overhead panel. Appendix 1 shows the layout of the Flight Control panel in the cockpit overhead (Figure 1) and a highly simplified electrical schematic diagram (Figure 2) which shows only those circuits involved in effecting engagement of the Yaw Damper system. All the major electrical circuits affecting the operation of the Yaw Damper system are supplied from dedicated 28V dc and 115V ac circuit breakers. As depicted in the schematic, the Yaw Damper is switched OFF but the B Flight Control switch is in the normal, guarded, ON position.

For the system to become active, the Yaw Damper Actuator has to be supplied with hydraulic power via a solenoid-controlled hydraulic shut-off valve (SOV). This solenoid opens the valve when it receives a 28V dc supply from the Yaw Damper engage switch on the Flight Controls panel, via contacts in the k12 relay which is in the Autopilot Accessory Unit . The solenoid of relay k12 is supplied with 28V dc from the Yaw Damper Coupler (pin 12 of Connector D295), provided that a logic circuit within the coupler senses that 115V ac is available at pin 2, and that 28V dc has been applied to pin 14 of D295 from the Yaw Damper engage switch. D295 is the connector joining the Yaw Damper Coupler to the aircraft wiring. The solenoid of k12 relay is earthed through the time delay circuits within the Autopilot Accessory Unit, which cause this relay to operate 2 seconds after the engage switch is operated.

When relay k12 is energised, three sets of contacts relevant to the Yaw Damper system, annotated a, b, & c on the schematic, are switched. When switched ON, the contact 'a' supplies 28V dc to a number of additional circuits in the Yaw Damper Coupler; contact 'b' supplies the 28V dc from the

Yaw Damper switch to the SOV solenoid (as above); contact 'c' breaks an earth path for the 'Yaw Damper' light on the Flight Control panel and extinguishes the light which, when illuminated, indicates that the Yaw Damper is not in operation.

The Yaw Damper switch is spring loaded to the OFF position and is held ON electro-magnetically. The hold on solenoid is permanently connected to the 28V dc supply to the switch and takes its earth from the Yaw Damper interrupter circuits in the Autopilot Accessory Unit. This earth is routed via a set of contacts in the B Flight Control switch. When the Yaw Damper switch is in the OFF position, the terminal which supplies 28V dc power to the actuator SOV is earthed.

1.6.5 Description of the E&E Bay

The E&E Bay on the Boeing 737 contains avionics equipment including the Yaw Damper Coupler. It is an area of the lower fuselage below the passenger floor and extends from the nosewheel bay aft bulkhead to the forward face of the forward cargo bay (stations 304.5 to 378.9). On the Boeing 737-200 most of the equipment is mounted in three racks labelled E1, E2 and E3 (Appendix 2) with three or four shelves in each rack. These are labelled -1, -2, -3 etc from the top, so that the upper shelf of rack E1, for example, is designated E1-1. In general, each individual avionic unit is designed for rapid removal from or refitting to its location in the rack. This is achieved by mounting it in a tray equipped with a multi-pin socket so that, as it is slid into engagement in the tray, a mating plug in the back of the unit connects with the socket. The unit is then locked in place with quick-release fasteners at the front.

The trays and racks themselves are commonly removed during major maintenance and thus a further connection is required to interface with the main aircraft wiring looms which are not routinely disturbed for avionics component removal. This is achieved by a series of rack disconnect connectors which are mostly located behind the relevant rack and are sealed against moisture ingress. It should be noted that this is not the case with the unit/tray plug-and-socket arrangement described above.

On the Boeing 737 (and indeed other types of aircraft) the location of the E&E Bay is directly underneath the forward left passenger door vestibule area. With the cabin configuration used on G-BGJI, the galley and forward toilet areas are also above the forward end of the bay, but generally outboard of the equipment racks themselves. G-BGJI was equipped with hydraulically actuated airstairs below the forward left door. As the stairs were retracted, they were stowed in the E&E Bay between racks E1 and E2 and E3 (Appendix 2). Although not directly above the racks, the airstairs are an obvious potential source of moisture ingress into the bay. A fibreglass drip-tray was fitted under the full length of the retracted stairs, with an overboard drain tube to dispose of any water brought into the bay by this route. An early modification further introduced a rubberised fabric 'shroud' which clipped on to the top forward lip of the drip tray and was stretched forward over the E1 rack to attach to the nosewheel bay aft bulkhead, thus forming a moisture barrier over the bay in this area. The fall on the shroud was such that fluid leakage from above should run down the shroud and into the drip tray.

In addition to the shroud, other measures were taken to prevent fluid spilt above the floor from dripping into the E&E Bay area, principally concerned with sealing the floor panels and toilet/galley areas. Procedures are laid-down in the Boeing Maintenance Manual for these measures but many operators adapt them according to their own custom and practice, and to use locally available materials.

1.6.6 Maintenance history

1.6.6.1 P6 inspection

Immediately prior to the incident flight, a major inspection of G-BGJI had been completed, known as a 'P6 Check' in the operator's Maintenance Schedule. It is scheduled every 5 calendar years or 11,200 hours flying time, whichever occurs first, and typically takes about 30 days to accomplish. One of the major objectives of the check is to inspect the structure for corrosion or other defects and to achieve this requires extensive dismantling of the airframe and systems. The individual elements of the check are too numerous to mention in this report, which will concentrate on the activity surrounding the E&E Bay area and the rudder/Yaw Damper system.

Prior to entering the hangar, the aircraft was washed externally and the toilet and potable water systems drained. Early in the check itself, the toilet and galley components were removed from the aircraft. The floor panels were also removed and several required renewal, as is quite usual for an aircraft of this age.

The airstairs and drip-tray were removed from the E&E Bay as were the avionics racks, the individual avionics units being stored on covered shelving alongside the aircraft awaiting refitment. All sound proofing bags were removed and, having gained access to the basic fuselage structure, the area was given a high-pressure wash of water and detergent. To achieve this it was necessary to protect the rack disconnect connectors which, apart from the looms themselves, were the only electrical components of the E&E Bay remaining in the aircraft. Plastic bags were taped around the connectors in an attempt to guard against contamination by the cleaning process.

Visual inspection of the structure was carried out and evidence from the technical records along with the recollections of the individuals involved indicated that the degree of corrosion found and rectified was typical of any aircraft on such a check. There were no indications of any abnormalities which may have indicated heavy fluid contamination. Evidence of dried blue fluid (toilet sanitising fluid) contamination was noted on the floor structure under the toilet but again this was considered commonplace. AAIB examination of several similar aircraft after a few years post-check service confirmed this to be so.

Upon completion of the structural inspection, the E&E Bay was re-assembled and the avionics units re-fitted. The records show that no relevant units required rectification or replacement and thus the ones removed were re-installed. As the aircraft approached completion, when electrical and hydraulic power were reapplied, every system on the aircraft was subjected to a full function test since every system had been disturbed during the check. In the case of the Yaw Damper system this included a Built-in Test Equipment (BITE) check on the Yaw Damper Coupler. No malfunctions were found. The main rudder PCU had been replaced by a unit modified to Boeing SB 737-27-1185 (Rudder PCU - Replacement of the Dual Servo Valve) but in all other respects the rudder/Yaw Damper system components were the same as those fitted prior to the P6 maintenance check.

1.6.6.2 Technical Logs

The Technical Log for the aircraft was examined for evidence of any Yaw Damper problems reported by crews since February 1995 up to the P6 check. Although the Log revealed a very large number of repetitive defects affecting system 'B' Autopilot over the period, there were no entries for the Yaw Damper system. Later, the Technical Log and the Cabin Log were examined for entries which might suggest that significant fluid spillage may have occurred in the forward toilet/galley area over the same period. Only one entry was found, dated 5 March 1995, in which the cabin crew reported:

"Fwd galley floor area wet, no spillages reported. Please check for leaks."

The Action Taken column reported:

"Slight leak traced to toilet sink drain seeping under floor & wetting carpet. Drain fitting tightened, now no leak."

The technical records also showed that the aircraft had departed on the incident flight with the APU inoperative because its fire detection system was unserviceable, the rear toilet servicing panel was 'speed taped' shut and the forward toilet was not serviced. In addition there was some cosmetic furnishing work to complete in the passenger cabin and the airstairs drip-tray access and drain panel was not fitted. All the above was permissible in accordance with the operator's Despatch Deviation Manual.

It had been intended to charge the forward toilet for normal service which involved introducing an initial charge of one gallon of fresh water via the recharging point in the toilet servicing panel. However, it was found that the forward toilet tank would not retain the water due to a misrigged and therefore improperly seated dump valve. As there was some urgency in despatching the aircraft, the decision was taken to rectify the fault after the flight.

Such a fault would allow the water to flow into the 4 inch drain pipe shown in Appendix 2 and, assuming the outboard flap valve was closed, it would stay in the pipe. If the charging process was continued in this situation, the pipe would fill up and, in the presence of the improper sealing described in §1.12.4, fluid could run down the outside of the pipe and into the E&E Bay. However, the leaking dump valve was found early in the charging process and the quantity required to fill the pipe (estimated at about 5 gallons) was never introduced. The toilet system was completely drained prior to the flight.

1.6.6.3 Yaw Damper Coupler history

The Yaw Damper Coupler, part number 4030952-902, serial number 79100850 was manufactured in 1979. Although the recorded history of the unit showed that it had been subject to removals since that time, the records suggested that these were to service other aircraft shortages and not for any unserviceability reasons. Indeed, there was no record of the unit ever having entered workshops since new, nor would there be any requirement for it to do so unless it was defective since the part is operated 'on condition'. Physical inspection internally also showed that the rate gyro, probably the most likely component to cause problems over a period of time, was in original condition and had not been subject to repair or overhaul.

1.7 Meteorological information

1.7.1 Incident flight

At the time of the incident a south to south-westerly airstream was established over the area. The visibility was greater than 20 km, with scattered cloud, base 2,500 feet. The mean sea level pressure was 1022 mb.

The winds/temperatures were:

Surface	180°	10 kt	°C
2,000 feet	240°	17 kt	°C
5,000 feet	220°	15 kt	°C
10,000 feet	230°	15 kt	°C
18,000 feet	230°	15 kt	-16°C
24,000 feet	230°	25 kt	-28°C

1.7.2 Test flight

The weather prevailing at the time of the test flight on 10 November 1995 was significantly worse than that on the day of the incident. A waving warm front was lying across the Boscombe Down area, moving slowly and erratically northwest. Occasional rain and drizzle was associated with the frontal zone, with surface visibility of 3 to 5 km. The mean sea level pressure was 1003 mb and the zero degree isotherm was at 6,300 feet. The cloud was broken, base 1,000 feet, tops 5,000 feet. Higher level overcast prevailed from 6,000 feet, tops 12,000 feet. There were further broken layers between 16,000 and 18,000 feet and between 21,000 and 24,000 feet. The winds/temperatures were:

5,000 feet	160°	11 kt	°C
10,000 feet	195°	21 kt	-05°C
18,000 feet	195°	37 kt	-22°C
24,000 feet	200°	53 kt	-32°C

Moderate icing and moderate turbulence were forecast in cloud.

1.8 Aids to navigation

Not relevant.

1.9 Communications

The crew was being provided with a Radar Advisory Service outside controlled airspace by London Military Radar on VHF frequency 128.7 MHz at the time of the incident. A recording of the radiotelephony transmissions was available for this investigation.

1.10 Aerodrome information

Not applicable

1.11 Flight recorders

1.11.1 Flight Data Recorder

The aircraft was equipped with a Davall 1198 re-cycling wire, accident protected digital Flight Data Recorder (FDR). This had a recording duration of 25 hours and was part of a Teledyne recording system. This system also incorporated a Quick Access Recorder (QAR) which recorded essentially the same information as the mandatory recorder onto a cassette. The FDR was replayed satisfactorily by the AAIB and the data checked with the readout from the QAR performed by the operator. There were some areas of invalid data on the FDR which were not evident on the QAR. A total of 27 analogue parameters plus 73 discrete parameters (events) were recorded.

Among the analogue parameters recorded were Pitch Attitude, Roll Attitude, Rudder Pedal Position (RPP), Control Position Pitch (CPP) and Control Position Roll (CPR). After the incident these parameters were calibrated and a number of anomalies were found. Roll Attitude had a datum error of approximately 4°. The CPP was found to be indicating -4.4° throughout the incident but there were some indications during large movements of the control column, such as during the control checks, or at rotation. CPP was found to have been unserviceable on the flights prior to the incident for which recordings remained on the FDR. Other parameters checked were within calibration limits.

The RPP is measured by a position sensor on the rudder control system forward quadrant situated just below and aft of the pedals. This therefore only detects the pedal movement from the pilots; there is no feedback to the pedals of the Yaw Damper movement. No recording is made on the FDR of the rudder surface position. The engagement of the Autopilot is recorded on the FDR, how ever the Yaw Damper engagement is not recorded.

1.11.2 Data timing

Data is acquired by the Digital Flight Data Acquisition Unit (DFDAU) in 0.125 second time slots, parameters acquired in the same time slot will be synchronised to within 0.125 seconds. Lateral Acceleration, CPR and RPP are all sampled 4 times a second, within the same time slot. Roll Attitude is only sampled twice per second, and is sampled 0.125 seconds after the first and third samples of the previous parameters.

The following table shows the relationship between the parameters:

Timing Offset	0	0.125	0.25	0.375	0.5	0.675	0.75	0.875
Normal Accel	2	10	18	26	34	42	50	58
Lateral Accel		15		31		47		63

Long Accel				28				60
Heading	3							
CPR		16		32		48		64
CPP		13		29		45		61
RPP		14		30		46		62
Roll			20				52	
Pitch	8		24		40		56	

Note: the numbers in the boxes above are the DFDR word slots for the parameters in the 64 word frame.

1.11.3 Cockpit Voice Recorder

The aircraft was equipped with a Fairchild model A100 re-cycling Cockpit Voice Recorder (CVR) which records the latest 30 minutes of audio information on four tracks. In this case aircraft power had been re-applied to the aircraft after landing which allowed the CVR to continue to record, automatically erasing the recording of the incident and thus providing no useful information.

1.11.4 Data interpretation

Pre-flight control checks were carried out and the aircraft took off at 15:53 hrs and climbed normally to 20,000 feet. During the climb there were some small oscillations evident from the lateral acceleration record. These small oscillations occurred between 200 and 260 kt with a frequency of 0.26Hz and varied in both magnitude, up to ±0.03g lateral acceleration, and duration. As such, they went unnoticed by the crew or were regarded as insignificant.

At 16:02:08, as the aircraft approached 20,000 feet at 288 kt on a heading of 270°M, the crew began the spoiler upfloat check, identified from the Speedbrake lever being moved to the 'Flight Detent' position for approximately four minutes. The Autothrottle was already engaged and the 'B' Autopilot was engaged at the top of the climb. Intermittent small oscillations were still evident during the test. Figure 1 at Appendix 3 shows the data throughout the incident, from the movement of the Speedbrake lever to the 'Down' Position; Figure 2 at Appendix 3 shows an expanded plot of the initial part of the incident. Two seconds after the Speedbrake lever was returned to the 'Down' position,at 16:06:28, there was a 2° CPR input to the right and there were coincident small lateral accelerations of ±0.018 g with a frequency of 0.36 Hz at an airspeed of 294 kt. These small oscillations continued with varying amplitude for the next minute, with a slight rise in airspeed to 296 kt and did not cause any detectable roll movement.

At 16:07:35 there was a more significant lateral acceleration oscillation, frequency 0.35 Hz, and up to 0.06g which lasted for three cycles. This was accompanied by a roll of 3° left wing down, and an opposing CPR movement, from the Autopilot of -4.9° to 8.5° right wing down within two seconds. There was no further input of CPR during this initial oscillation. The amplitude of the lateral acceleration cycles increased, by approximately 0.04g per cycle, and reached a maximum in around

20 seconds. The Roll Attitude and CPR began to oscillate in opposition as the Autopilot tried to correct the roll of the aircraft. The Autopilot and Autothrottle were disconnected 15 seconds after the initial left roll, at 16:07:53 with the aircraft at 20,000 feet, 296 kt.

The large oscillations continued, with a frequency of 0.36 Hz, and a magnitude of around ±0.5g lateral acceleration , and ±15° roll around a varying datum with opposing CPR inputs of around ±30° from the pilot. After the Autopilot disconnect the airspeed initially reduced to 277 kt. At 16:07:58 the engine power reduced from 1.48 to 1.11 Engine Pressure Ratio (EPR); the aircraft descended and airspeed increased to a maximum of 313 kt.

Ten seconds after the Autopilot disconnect there were some oscillations evident in the rudder pedal position,however the movement was only ±0.25° with the same frequency as the lateral acceleration. There were also oscillations in other parameters, including Pitch Attitude (up to ±1°) and heading (±5° about a varying datum between 270° and 040°M).

The aircraft levelled at 7,000 feet with an increase in EPR from 1.0 to 1.24/1.19 on Nos 1 and 2 engines respectively; and then decelerated through 275 kt when the oscillations began to damp out. Throughout the oscillations the aircraft was in a left turn, finally reaching a heading of 040°. Figure 3 at Appendix 3 shows this data in expanded form; the oscillations lasted for over 7 minutes and finally disappeared at an airspeed of 250 kt.

After the large oscillations there were some minor, quickly damped oscillations in lateral acceleration of up to ±0.002g. At 16:17:52 flap was selected initially to 1° at a speed of 212 kt and then to 5° and 15° at airspeeds of 200 kt and 165 kt respectively. As the airspeed further reduced, 15 seconds after passing through 170 kt coincident with the scheduled Yaw Damper gain change, there was flight. The a kick of 0.025g in lateral acceleration, followed by small oscillations lasting around 12 cycles. There were then some similar small oscillations with a magnitude of ±0.02g and frequency of 0.2 Hz, which occur periodically during the rest of the flight.The oscillations in lateral acceleration are accompanied by oscillations in roll of up to ±0.5°. Figure 4 at Appendix 3 shows one of these oscillations which lasted for around a minute before damping out. At 16:45 the aircraft landed without incident, with a flap setting of 15° and a touchdown speed of 135 kt.

1.11.5 Quick Access Recorder data

The Quick Access Recorder (QAR) recorded essentially the same information as the mandatory recorder onto a readily removable cassette. The operator routinely removed and replayed the cassettes from the QAR; approximately two weeks of flying data from each aircraft having been kept as an archive. This archived QAR data was analysed for G-BGJI, consisting of 85 flights having taken place prior to the P6 check. On two separate flights on the 8 and 11 September, small oscillations were found; firstly at 36,000 feet between 240 to 245 kt there were intermittent oscillations of ±0.05g with a frequency of 0.35 Hz. On another separate flight one period of small oscillations was observed, damping out in 3 cycles, with a frequency of 0.4 Hz. No other significant oscillations were found on the flights reviewed.

1.12 Aircraft examination

1.12.1 General

Examination of the aircraft began on the evening of the incident flight. It had been impounded in a hangar at Gatwick Airport and had not been disturbed since that flight, other than by those actions necessary to tow it into the hangar.

1.12.2 Non-intrusive tests conducted between incident and test flight

Initial analysis of the recorded aircraft behaviour during the incident flight had indicated that the characteristics were most consistent with erroneous operation of the Yaw Damper system. Therefore, immediately after the incident had occurred, a policy decision was made not to disturb, by disconnection or disassembly, any of the aircraft systems which might have any influence on the operation of the Yaw Damper before a test flight was made. The object of the test flight was to attempt to induce the aberrant behaviour, with additional flight monitoring systems temporarily fitted. It was, however, decided to perform, together with functional tests, such isolation and continuity testing as could be done within this stricture.

It was agreed that the examination would commence by subjecting the aircraft to practically every check in the Maintenance Manual of the flying control, Autopilot and Yaw Damper systems which could be achieved without breaking in to any systems (non-intrusive).

The airframe was inspected visually, including the E&E and landing gear bays, the angle-of-attack sensors and pitot probes. Nothing significant was found with the exception that the hydraulic oil quantity was approximately 1/8" below the FULL line on the sight gauge and the left wing fuel booster pump access panel was found to be missing.

The next stage involved a rigging check on all of the flying control surfaces and cables which could be accessed without extensive removal of panels. Some discrepancies were found relative to the Maintenance Manual requirements for both control surface rigging and cable tensions but there was nothing found which could have been responsible for the aircraft's aberrant behaviour during the incident flight. It was noted that, when the technicians attempted to check cable tensions, they found that nearly all their stock of tensiometers gave different readings. Some instruments were considerably at variance with others despite all being within their calibration dates. There was no system at the operators engineering facility at Gatwick for checking the accuracy of tensiometers upon issue from stores.

The next phase involved full flying control, Autopilot and Yaw Damper function tests and BITE checks where appropriate. Although the Autopilot failed one of its parameter checks on the BITE test, analysis showed this could have had no effect which would explain the aircraft's behaviour. None of the wiring checks performed at this stage revealed any abnormalities.

Since the exhaustive series of checks generally had not revealed any significant defects or abnormalities, it was decided that the aircraft would be left in this condition for the next phase of testing, which was to be a pressurisation test of the aircraft in a simulated flight condition (§1.16.1). The minor defects remained unrectified and no rigging adjustments were made to the flying controls between the incident and test flights (§1.16.2).

In consultation with Boeing and the Civil Aviation Authority (CAA) and after analysis of the DFDR data from the incident flight, a series of structural checks were required, mainly concerned with the fin and rudder attachments, before the aircraft could be allocated a 'B' conditions certificate for the test flight. These checks did not reveal any damage or excessive clearances in the attachment fittings or structure.

1.12.3 Directional control system component examination

Following completion of the test flight and non-intrusive checks which had not revealed any significant abnormalities with the directional control system, the decision was taken to subject the individual components of the system and the associated wiring to function and strip examination as necessary. In addition,the three hydraulic system filter elements were removed from each system and, together with fluid samples, were despatched to an independent laboratory for analysis. The laboratory report did not indicate any abnormalities with either the fluid or filter elements associated with either system. The wiring checks are described in §1.12.5.

The components returned to their respective manufacturers for testing/examination under AAIB supervision were:

a Yaw Damper Coupler

b Rudder PCU

c Standby Rudder PCU

d Rudder Feel and Centring Unit

e Digital Air Data Computer (DADC)

In addition, the Autopilot Accessory Unit was examined in the AAIB laboratories.

1.12.3.1 The Yaw Damper Coupler

This unit was returned to the manufacturer, Honeywell and placed on their Automatic Test Equipment (ATE). Tested repeatedly at ambient conditions, these comprehensive tests did not reveal any significant defects in the unit. The Yaw Damper Coupler was also subjected to the same test regime but manually executed. It was then hot-soaked and tested on the ATE, again performing to specification. There was no facility for performing these checks under humid conditions, so this was not achieved.

The above tests were able to prove the serviceability of all the Yaw Damper Coupler circuitry but could not fully check the rate gyro which is incorporated in the unit. Accordingly, the unit was opened to remove and despatch the rate gyro to another facility for testing as an isolated component. It was at this point that apparent contamination/corrosion deposits were found on the back of the multipin connector inside the unit. This took the form of bluish-white powdery deposits around some of the wire-wrapped connections to the back of the pins (Appendix 4, Figure 1). Closer inspection also showed evidence of light grey deposits on the outside of the connector shell (Figure 2). These observations, which pointed towards moisture impingement on the outside of the connector and subsequent ingress into the unit, were reinforced when the lower cover plate for the unit was examined and signs of dried fluid residue were seen on its inner face (Figure 3). There was, however, no sign of moisture on the outside of the black casing itself.

The decision was made to return the unit (minus the rate gyro) to the UK to embark on humidity and other tests described in §1.16.5. The rate gyro, when tested, proved to be in good serviceable condition.

1.12.3.2 Rudder PCU

The rudder PCU, incorporating the Yaw Damper Actuator, was tested at the unit manufacturer's facility on a rig used for acceptance tests on production and overhauled components. The rig essentially operates the PCU with hydraulic and electrical power connected and plots the response of the unit to mechanical (pilot) and electrical (Yaw Damper) inputs. The performance of the unit was satisfactory in all respects. Measurements were taken of the Yaw Damper solenoid pull-in voltage which were requested in connection with the testing described in §1.16.7.

1.12.3.3 Standby rudder PCU

This was examined at the Boeing Equipment Quality Analysis Laboratory in Seattle, USA under AAIB supervision. It passed an overhaul function test with only minor out-of-limits measurements in two areas. Strip examination showed no abnormalities apart from some scoring of the input lever bearing, the origin of which was not clear but did not appear to affect its operation.

1.12.3.4 Feel and Centring Unit

No evidence was found of failure, defect or malfunction of this unit. Functional testing did not reveal any abnormal behaviour although some excessive backlash in the system was identified, predominantly in the trim actuator. It was uncertain whether this was simply a feature which might be expected on a unit with some considerable time in service but was not considered to have been capable of precipitating the aberrant behaviour of the aircraft during the incident flight.

1.12.3.5 Digital Air Data Computer (DADC)

The DADC was initially tested at the Honeywell facility in Seattle, USA at the same time as the Yaw Damper Coupler. Its interface with the Yaw Damper system is limited to switching the gain of the Yaw Damper Coupler output according to the aircraft's indicated airspeed. In this respect it functioned normally.

1.12.3.6 Autopilot Accessory Unit

Amongst the functions of the Autopilot Accessory Unit is the enabling of the Yaw Damper system. It was tested to establish its conformity with specification with respect to those features which might affect the operation of the Yaw Damper. These tests involved the measurement of contact to contact resistance and the insulation of the terminals of the k12 relay within the unit, in both its switched conditions and testing of the time delay and interrupter circuits. The results of all these tests indicated that the functions under consideration operated correctly and within limits.

It was decided to establish, additionally, the voltages at which the k12 relay engaged and disengaged. This was done by adjusting, in both the rising and falling senses, the voltage applied to the actuating solenoid. Under the test conditions the relay pulled in at 18.7 (Volts) V and dropped out at 18.4V. It was observed, whilst adjusting the voltage very slowly around the changeover voltages, that the relay sounded as if itoperated in two stages, as it emitted a double click. The change of voltage over the double click was very slight and it was established that all contacts operated simultaneously on one of the clicks.

At a later stage of the investigation, studies of the characteristics of the Autopilot Accessory Unit, Yaw Damper Coupler and Shut-off Valve Solenoid as a group showed slightly different operating voltages for the k12 relay with an engage voltage of 18.16V and 17 ma current and a dropout voltage of 17.71V and 9 ma current. (§1.16.7)

1.12.4 The E&E Bay

With the discovery of apparent moisture contamination of the Yaw Damper Coupler connector, described in §1.12.3.1, attention was turned to the E&E Bay in an effort to determine whether there were any obvious sources of such contamination. The P6 check items included washing and so there was little chance of finding evidence of a source of moisture occurring in the past.

Examination commenced with an inspection of the avionics cooling plenum which is situated directly above the E1-1 rack which houses the Yaw Damper Coupler. This had clearly been washed and bore numerous watermarks on its polished aluminium alloy surface. One of these marks, however, was of particular interest since it ran directly above the Yaw Damper Coupler in the rack. The fluid appeared to run forwards from about the mid-point of the plenum on the top surface and then run rearwards to about the same point on the lower surface. A search for a corresponding leak in the rubberised shroud above this apparent path proved negative.

The shroud itself was then removed and examined. Although it had evidently been partially cleaned during the P6 check it was still heavily stained on its upper surface and bore heavy deposits of a waxy substance similar to that used during the floor panel sealing operation. When tested for leakage, the shroud proved water-tight apart from a small area of porosity which had resulted from chafing where it was folded and fastened over the lip of the airstairs drip-tray. This area was fairly remote from the E1-1 rack and it was difficult to conceive any situation whereby fluid entering the bay by this route could contaminate the rack. Doubts were expressed concerning the installation status of the shroud during the incident flight. This arose because, initially, it was not suspected that fluid contamination of the Yaw Damper Coupler was responsible for the incident and investigation was centred on the key components of the directional control system. At an early stage the airstairs drip-tray was removed to greatly facilitate access in the E&E Bay requiring the shroud to be unclipped and rolled back. There is no doubt that it was in the aircraft, attached to the nosewheel bay bulkhead but the inspection team could not recall with absolute certainty that it had been fully fitted. The technician involved with preparing the aircraft for the incident flight had, however, stated that it was completely and correctly installed prior to the flight.

The large-diameter toilet drain pipe, routed laterally across the E&E Bay (Appendix 2), was a potential source of contamination in precisely the area to affect the back of the E1-1 rack components, although such a scenario would still require penetration of the shroud before fluid could reach this location. The pipe is normally empty of fluid except during the toilet drain operation on the ground, although any improper seating of the toilet dump valve in the tank would result in the pipe starting to fill-up. The operator indicated that this was a commonly reported defect and just such a condition was present immediately before the incident flight (see §1.6.6.2). In this case, however, the leaking dump valve was detected and the aircraft despatched with the forward toilet empty.

Externally, the pipe had a number of dried fluid residue paths visible, some of which were probably by-products of the cleaning and corrosion protection processes during the P6 check. Tests on the pipe itself showed that it did not leak but the potential for leakage did exist because of faulty assembly at the interface of the pipe with the tank. Essentially, a screw had been trapped between two mating flanges such that, if the pipe filled up as described above to the level of the aircraft floor, fluid could have escaped and run down the exterior of the pipe into the E&E Bay. As described in §1.6.6.2, there should not have been sufficient fluid introduced to allow this to happen.

A further imperfect seal was discovered around the area where the hand basin drain pipe passed through the toilet compartment floor. Any fluid escaping from the toilet/hand basin systems behind the vanity unit would run onto the floor. Since this area is not subject to passenger weight, floor panels are not used and a thin metal diaphragm is used instead. This has to be sealed to prevent leakage below the floor, including the holes where utility piping passes through it. As noted an improper seal had been achieved with the handbasin drain pipe such that, when the diaphragm was deliberately flooded, the fluid dripped down the flexible tube below the floor. However, this location was well forward of the E&E Bay and it was not considered that it could have migrated back towards the Yaw Damper Coupler.

A potential path for fluid dripping forward of the E&E Bay to migrate rearwards was discovered during examination of another Boeing 737-200. The aircraft had extensive toilet fluid contamination of the E1-3 rack disconnect shelf on the left side of the E&E Bay (note: not the racks themselves). Testing showed numerous leak paths allowing fluid to drip below the floor forward of the E&E Bay where the drips impinged on the two Captain's instruments pitot-static drain tubes. These run aft and downwards towards the bay, where they are routed above the E1-3 rack disconnect shelf. The somewhat encrusted and corroded appearance of the pipes suggested that this had been happening for some time. Fluid from a leaking toilet dump valve was thought to have been the source of the contamination. Boeing has recognised this path as an undesirable feature and proposed a simple modification to put 'drip-triggers' on the line to prevent fluid running aft along the pipes. (The E&E Bay Assessment Team report on this subject is discussed in §1.16.8.)

1.12.5 Post-test flight intrusive wiring and connector checks

A programme was drawn up so that, immediately following the test flight, electrical integrity testing of all the wiring and connectors which might affect operation of the Yaw Damper system could be conducted. This involved the wiring of all systems which had any connection, direct or via other equipment, to the connector D295 of the Yaw Damper Coupler.

Before doing some of these tests, which included high voltage insulation checks, it was necessary to remove the electronic modules involved, both to avoid damaging them and to gain access to the connectors. It was also necessary to isolate the affected wiring by disengaging the 28V dc and 115V ac circuit breakers. Apart from the Yaw Damper Coupler, which had to be removed to gain access to the pins and sockets of connector D295, other units disconnected were:

<u>Component Location Connector</u>

i. Air Data Computer No 1 E&E Bay D309A

ii. Autopilot Accessory Unit E&E Bay D293(A& B)

iii. Flight Control Module Flight Deck Overhead D630

iv Rudder Power Control Unit Fin base D291

v Yaw Damper Position Indicator Centre Instrument Panel D309A

The first test applied to connector D295 was a check of the physical engagement of the two halves; both of the tightness of individual pin to socket connections and the depth of engagement of the pins as a group into the sockets.

The first part of this test was done by inserting a single pin, with a light wire 'pull' attached, into each socket of the aircraft rack connector and established that it required perceptible force to draw the pin out of the socket. A similar test was done using a single socket pushed over each individual pin of the connector on the Yaw Damper Coupler itself. Both the elements of connector D295 were demonstrated to have satisfactory grip on all electrical contacts.

The second part of the test, to determine the depth of engagement, was done by impaling a sheet of .004 inch thick paper, cut to remain inside the connector periphery, on all the pins of the Yaw Damper Coupler connector. The connection was then made and secured and then released and separated. The depth to which the paper had been driven down the pins showed that the depth of engagement was satisfactory.

Before disturbing the rudder PCU connectors, other than D295, measurement of the resistance of components within the rudder PCU, together with the intervening wiring and connectors, was made. This showed that all the electrical components in the rudder PCU which could affect the Yaw Damper system were within specification and their connections through to D295 were good. After this, the measurements were repeated whilst the connector at the PCU (D291) was shaken, by hand, to simulate the effectsof vibration. This showed that the connection was sound.

Following these tests, the electrical bonding of all the components listed above was verified. They were then removed and the wiring, with all intermediate connectors, was subjected to continuity and insulation tests. These demonstrated that there were no detectable breakdowns in the isolation of any wire resulting in unwanted wire/wire or wire/earth faults; nor were there any breaks in the continuity of any tested conductive path.

The final action in this series of tests was to perform pin grip and connector depth of engagement tests on the rack connector of the Autopilot Accessory Unit (D293A) and the connector of the rudder PCU (D291). All proved satisfactory.

1.12.6 Tests on Yaw Damper engagement circuits (Appendix 1, Figures 1 & 2)

After examination of the Yaw Damper Coupler unit had raised concerns about the possibility of electrolytic activity between the pins of connector D295 inside it, consideration was given to the possibility that unwanted electrical paths could be generated between pins. The theoretical effects of these paths could be broadly divided into those which affected the behaviour of the electronic control circuits, which are reported on at paragraph 1.16.3, and those affecting the power switching which activates the Yaw Damper.

An initial test was made to establish the resistance, to aircraft ground, of the path from pin 14 on the rack side of connector D295 (with the Yaw Damper Coupler removed), through the earthed OFF pole of the Yaw Damper engage switch on the Flight Control panel. Comparison of this resistance on the incident switch with another showed the incident switch to have a persistently higher resistance of about 2 Ohms.

As a result of these tests, the switch itself was later subjected to destructive examination; see paragraph 1.12.7

A series of tests was then performed, on the subject aircraft, which demonstrated that the Yaw Damper engagement interlocks and indications could, under dormant fault conditions, be defeated by the addition of particular unwanted paths bridging between the pins of connector D295. These were performed using a specially constructed extension lead which permitted electrical access to pins 4, 12 & 14 of connector D295 by means of breakout flyleads. These tests were extended by setting up electrolytically formed conductive paths between the breakout leads and are described at §1.16.6.

1.12.7 Yaw Damper system engage switch examination

As a result of finding that the engage switch had a persistently high resistance on the ground contact, approximately 2 Ohms, it was decided that it should be fully examined in the presence of the aircraft and switch manufacturers. The switch was presented for this examination still installed in the flight controls module from the flight deck. Since the incident flight and before the time of first checking the switch OFF pole earth resistance, the switch had been functioned an indeterminate number of times.

When subjected to laboratory testing, both whilst installed in and later after removal from the flight controls module, the switch did not demonstrate any high resistance earth path. The switch unit was tested and found to be in compliance with its manufacture specification, both in terms of contact resistances and electromagnetic hold-on characteristics. Testing of the wiring within the flight controls module did not reveal any evidence of potential intermittently high resistance paths.

The switch unit was disassembled and the basic micro switches from within operated whilst being observed by real-time X-ray techniques. This showed that the movement of the contacts during switching was correct and effecting the designed self wiping action.

The basic micro switches were then dismantled and the contacts examined. This revealed the presence of a carbon-rich contamination of the earth switch contacts but no evidence of loose particle contamination. It was considered that the carbon-rich contamination of the contacts might have accounted for the earlier measurements of high contact resistance but did not appear to be sufficient to have been responsible for a contact resistance greater than the measured 2 Ohms observed whilst fitted in the aircraft.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival information

Not applicable.

1.16 Tests and research

1.16.1 Function tests of the flying control and Yaw Damper systems

Although the detailed series of checks described in § 1.12.1 had involved several function tests of the flying control and Yaw Damper systems, it was decided that further testing should be carried out with the aircraft pressurised and undergoing a depressurisation cycle, as occurred during the incident flight. To this end the aircraft was towed out of the hangar and placed in a 'flight' condition by disabling the air/ground sensors and using a pitot-static test set to simulate an airspeed of roughly 290 kt. Using a ground pneumatic rig and the APU, the aircraft was pressurised to a differential appropriate to flight at 20,000 feet and hydraulic and electrical power was applied.

The Autopilot and Yaw Damper were engaged with no malfunctions evident. The entire aircraft was 'nudged' several times using the nosewheel steering tiller to evoke a response from the Yaw Damper, and also by using the Yaw Damper test switch. This was repeated during the depressurisation cycle, again with no abnormal responses from either the Autopilot or the Yaw Damper.

1.16.2 High speed taxi and test flight

A Portable Airborne Digital Data System (PADDS) was installed in G-BGJI by the aircraft manufacturer to record parameters additional to those available on the FDR/QAR. These included rudder control system aft quadrant and surface position,Yaw Damper engaged signal and other Yaw Damper system control parameters, plus lateral accelerations at the fin and rudder.

Ground tests were performed by the manufacturer to determine whether the rudder and Yaw Damper system were operating correctly prior to the flight test. These included a frequency response check of the rudder and Yaw Damper LVDT, the results showing the correct phase and gain data for both. Yaw Damper engagement and disengagement via the flight deck overhead switch and the circuit breaker were also checked, and found to operate correctly.

Initially a high speed taxi run was carried out to identify whether any unusual rudder/Yaw Damper system characteristics could be generated during normal taxiing and by applying aggressive nosewheel steering inputs to produce yaw rate inputs to the Yaw Damper Coupler. Cyclic nosewheel steering inputs with a period of 3 seconds (approximately the Dutch Roll frequency) were used during normal taxi, and a high speed run up to 80 kt was carried out; no unusual system characteristics were observed.

A flight test was then planned in an attempt to reproduce the oscillations seen in the incident. The aircraft was loaded to a similar gross weight and CG position and prepared for flight under 'B' conditions. It was crewed by the same commander as the incident flight together with a Boeing 737 test pilot provided by the manufacturer. The manufacturer's regular complement of a flight test director and observers were also on board. The flight test plan was to incrementally approach the flight conditions of the incident (290 kt and FL200), initially with the Yaw Damper OFF to ensure that there was no basic airframe/flight control anomaly. The aircraft was equipped with an alternative method of electrically isolating the Yaw Damper system.

The aircraft took off from Runway 08R at Gatwick and was flown to the same test area, between the Southampton VOR and Boscombe Down Airfield. The weather conditions on the day of the test flight (10 November 1995) were significantly worse than those existing at the time of the incident. There was light to moderate turbulence present generally, and the crew had to ensure that the aircraft did not sustain any ice accretion by avoiding cloud layers as much as possible during the climb to test altitude.

At each test point, the test pilot performed rudder doublets in order to excite the Dutch Roll mode and the aircraft response was monitored. Final tests were conducted with the aircraft depressurised, again to simulate the actual incident flight conditions. Some testing was also carried out with the Autopilot engaged, as on the incident flight.

The testing was unable to reproduce the forced lateral oscillations experienced during the incident flight. All of the tests indicated that the rudder/Yaw Damper systems on the aircraft were operating correctly.

1.16.3 Simulator studies

The aircraft manufacturer provided access to and support in using a mathematical computer model and a versatile three axis engineering simulator in attempts to simulate the incident flight characteristics.

1.16.3.1 Initial Engineering Simulator Evaluation (M-Cab)

The aircraft Manufacturer's Engineering Simulator was used to perform an evaluation of the pilot's influence overdriven Dutch Roll oscillations. In this case the oscillations were driven from the rudder deflection calculated as a function of yaw rate. The relationship between rudder and yaw rate was chosen to generate behaviour consistent with the aircraft during the incident in terms of lateral g oscillations and magnitude of maximum and minimum bank angle, and thus demonstrated the effect of driving the Dutch Roll mode. Figure 1 and 2 at Appendix 5 show this effect.

The simulation was performed at flight conditions representative of the incident, level at 20,000 feet and 295 kt. During the manufacturers tests with a company test pilot in the left-hand seat, "the pilot's first reaction was to reduce airspeed which resulted in the oscillations becoming damped....further cases involved maintaining the flight condition which provided a continuous oscillation with controls free. The pilot was not able to reduce the oscillation nor did he drive the oscillation to greater amplitude while using normal control inputs."

1.16.3.2 EASY 5 computer simulation

A manufacturer's control system simulation/analysis tool, EASY 5, was used to investigate the effect of fluid contamination of the Yaw Damper Coupler connector causing shunt resistance between pins. The EASY 5 consists of a control system model of the Yaw Damper Coupler with mathematical approximations for the behaviour of the hydraulic system and aerodynamics at various flight conditions. The simulation is excited using a crosswind pulse gust, and the response of the model is then computed and output as a time history of various parameters.

Theoretical analysis of the Yaw Damper Coupler circuitry was carried out by the manufacturer to identify shunt resistances between pins which could have been possible candidates to cause the aircraft response seen in the incident flight. The coupler connector has 57 pins, and for this analysis the unused pins and those used as part of the BITE were not considered. The analysis also assumed that the fluid saturated the region of the connector surrounding pins 3, 4, 12 and 14 (Appendix 6, Figure 1) and below these pins it was assumed that pins were coupled to each other by a fluid film which ran along the adjacent wires. Only the effects of shunt resistances between adjacent pins were considered. The effects of both 400 Hz and dc power shunts were discounted. The bandwidth of the hydraulic servos are two orders of magnitude less than 400 Hz, so any signals injected with a frequency of 400 Hz would have no effect. Similarly any dc power shunts would have introduced a bias into the system, an effect which would have been shown in the incident flight, and was not evident. A summary of the pin to pin shunt analysis is at Appendix 7.

Of the possible candidates identified, the effects of three shunt resistances were modelled in the EASY 5, both singly and in combination. These were the most likely to have caused the effects seen during the incident. The first was between pins 46 to 47, the case where the rudder feedback signal from the LVDT is attenuated, and corresponded to the open feedback condition. It produced an oscillation with a frequency in the 0.8 to 1.0 Hz range, and only small bank angle changes. This response had been predicted in the Failure Modes and Effects Analysis (FMEA), and was not the response seen in the incident case.

The second case was a shunt between pins 37 to 38, which established a path from the output of the rate gyro demodulator directly, rather than applying the normal 180 ° phase shift necessary for the rudder motion to be applied in a direction which would counter the yaw rate. The shunt bypassed the phase shift, so the gyro signal was in phase with the yaw rate. The effect of this shunt therefore was to produce an instability which resembled that seen during the incident. A gain of -10 was used in the simulation which approximated to a shunt resistance across the pins of 89 Kilohms. This produced a rudder demand from the Yaw Damper Coupler which saturated to maximum within 7 seconds at 350 kt; the frequency of the oscillation produced was about 0.4 Hz, with ± 25° roll oscillations within 17 seconds of the disturbance; the oscillation was undamped but stable. At an airspeed of 250 t the same gain produced a damped oscillation. Figures 2 and 3 at Appendix 6 show the results from the EASY 5 for these cases.

A shunt resistance between pins 40 to 51 would change the gain characteristics of the rate gyro path; it does not produce a phase change. The effect of this shunt is to attenuate the signal going into the washout filter and thus reduces the ability of the Yaw Damper Coupler to provide control. It was reasonable to model the effect of a shunt between pins 40 to 51 as pins 40 to 50 are adjacent and pins 50 to 51 are electrically equivalent. Simulation of this shunt had no effect on the response on its own, but with a combination of this and a shunt between 37 to 38 the effect was to modify the frequency from 0.43 Hz to 0.35 Hz.

1.16.3.3 Final M-Cab simulation

The EASY 5 simulation had shown that there were possible shunt resistances which could cause the aircraft response seen in the incident. In order to model the complete system it was necessary to have a better aerodynamic model and include a production Yaw Damper Coupler unit. The manufacturer's M-Cab simulator was used for these tests. The M-Cab is a full motion engineering simulator capable of being flown either from the simulator cab flight deck, or from data inputs. In this case the yaw rate signals from the simulator were input to a Yaw Damper Coupler unit, and the subsequent rudder demand signal was output to the M-Cab simulation of the rudder hydraulic system. The M-Cab was set up at the airspeed, altitude and configuration required for the test and then either allowed to respond without intervention, or flown from the simulator cab to maintain the required conditions. The Yaw Damper Coupler system gain changes with airspeed in the Autopilot Accessory Unit were accomplished manually. The shunt resistances were simulated using a set of decade resistance boxes which could be put between any two individual or combination of pairs of pins. A beta (yaw) release and/or a gust (turbulence) model was used to excite the simulation.

The first tests were to reproduce the shunt resistance from the EASY 5 simulation. An open circuit between pins 46 to 47 produced a 1 Hz oscillation, confirming again the FMEA. A shunt resistance of 110 and 89 K Ohms between pins 37 to 38 produced no oscillations. Reducing the resistance to 30 K Ohms, lower than the value of the shunt resistance in the EASY 5 simulation, produced an oscillation similar to the incident, with roll angles of ±15°, and lateral acceleration of ±0.5 g. This case is shown in Figure 1 at Appendix 8. The rudder demand saturated in 20 seconds, and the frequency of the oscillation was 0.4 Hz at 350 kt IAS, and 20,000 feet.

The effect of a shunt resistance between pins 40 to 51 was then investigated, varying between 60 and 500 Kilohms a t20,000 feet, 290 kt and using light and medium turbulence as well as a beta release to excite the simulation. A shunt resistance up to 300 Kilohms produced small oscillations after the beta release, which in medium turbulence had a frequency of 0.33 Hz and ±0.02 g oscillations in lateral acceleration. Figure 2 at Appendix 8 shows the oscillation produced with a shunt resistance of 230 Kilohms. In light turbulence the lateral acceleration was ±0.01 g. This compared with the oscillations seen in the Yaw Damper disengaged case which in medium turbulence has the same frequency and magnitude of lateral accelerations. Figures 3 and 4 show the normal aircraft response with Yaw Damper engaged and disengaged respectively. At 500 Kilohms the oscillations had a smaller magnitude, similar to the Yaw Damper engaged case, showing that at this value of resistance the Yaw Damper was able to reassert control. These tests were repeated at 7,000 feet, 250 kt, shunt resistance varying between 120 and 300 Kilohms with light and medium turbulence. Similar small oscillations were evident.

A combination of the shunt resistance varying from 200 to 400 Kilohms between pins 37 to 38 and 40 to 51, was then tested. At 20,000 feet and 290 kt, the results showed that the combination of resistances on both pins produced an oscillation which resulted in roll angles of up to ±15°, and lateral accelerations of up to ±0.46 g,with a frequency of 0.3 Hz. The time of the Yaw Damper rudder demand to saturate to maximum increased with the resistance; above 250 K Ohms the oscillation was slow to develop and above 350 K Ohms the oscillation was damped. The same shunt resistance test conditions were used at 7,000 feet, 250 kt. This generated an oscillation which, at shunt resistances at and above 230 Kilohms damped out. The time for the oscillations to damp decreased with increasing resistance. Figures 5 and 6 at Appendix 8 show these oscillations.

A number of flight profiles were then flown in the M-Cab, following the descent and speed reduction seen on the incident flight. Figure 7 at Appendix 8 shows one of these profiles using a shunt resistance of 230 K Ohms between both 37 to 39 and 40 to 51.

1.16.4 Normal aircraft behaviour with and without Yaw Damper

The QAR data was examined from another Boeing 737-200 aircraft, where the Yaw Damper had been engaged and disengaged for periods during the flight. This data showed that when the Yaw Damper was disengaged, small oscillations similar to those seen on G-BGJI prior to the incident, were present. This demonstrated also the basic Dutch Roll mode of the aircraft. The oscillations had a frequency of around 0.32 Hz and produced small lateral accelerations of less than ±0.05 g. With the Yaw Damper engaged there were no significant lateral oscillations.

1.16.5 Humidity testing and detailed examination of Yaw Damper Coupler connector

The presence of corrosion/electrolytic deposits around the wire-wrap posts of the Yaw Damper Coupler connector first discovered during the manufacturer's testing and examination of the unit (§ 1.12.3.1) had not apparently had any effect on the coupler's operation during testing at ambient and high-temperature conditions.

It was therefore decided to test the electrical properties of the Yaw Damper Coupler in humid conditions having first taken samples of the deposits on the connector shell and the cover plate in an attempt to discover the nature of the apparent fluid contaminant. A description of this examination appears in §1.16.6.

Unfortunately, there were no facilities which could subject the unit to functional testing equivalent to that achieved by the ATE whilst it was in an humidity chamber. An attempt was made to measure the resistance between adjacent pins of the connector at ambient conditions (18°C/46% RH) and under conditions of about 94% RH at 35 to 40°C. Measurements of the ambient impedance values between adjacent pins were taken and the unit placed in a humidity chamber with a 'breakout' lead routed outside the chamber to measure the impedances under humid conditions.

As expected, there was a wide variation in impedance values, without exception the humid values were less than the ambient. The significance of these findings is, however, open to question when it is realised that the impedances measured are not simply those between adjacent pins of the connector. Since it was considered unwise at that stage to isolate the connector from the internal circuitry, the impedance values measured had to include those of the individual components and printed circuits of the Yaw Damper Coupler itself as well as the resistance between the connector pins. Typically, impedances measured as greater than 30 Megohms in ambient conditions fell to fractions of a Megohm when placed in the chamber.

Since it was impossible to determine how much, if any, of the lost impedance was due to shorting between the connector pins, it was then decided to compare the performance of a known serviceable Yaw Damper Coupler under the same conditions to see whether the impedances were markedly different under humid conditions. Only certain selected pins on the latter were sampled under humid conditions. At ambient conditions, similar impedance readings were obtained between adjacent pins and, as expected,these values fell off markedly under humid conditions. In general, the results were similar to those measured on the incident Yaw Damper Coupler, with only a few, apparently random, occasions where the humid impedance of the spare unit was better by an order of magnitude.

1.16.6 Connector pin contamination testing

Connector D295, and the Yaw Damper Coupler lower closing panel, with the evidence of a dried fluid run on its inside face, were submitted to a specialist company of electrical research engineers for laboratory analysis. The focus of this effort was to determine the nature of the fluid contaminant and to confirm that electrical current had flowed between the pins. It was considered that the latter would be proven if it could be established that the blue/green and white deposits seen around the wire-wrapping of the pins were the products of electrolysis as opposed to simple corrosion.

The chemical tests could only be conducted using an X-ray dispersive technique which can only detect the individual elements of a substance and cannot identify the compound which is constructed from these elements. Such a method will detect all elements present in the sample, such as those used in the construction of the connector, not just those from the contamination. Thus metals such as copper, gold, cadmium, nickel and zinc were present in nearly all the sampled areas along with a range of other elements, including chlorine, phosphorous, calcium and sulphur. Unfortunately, it was not possible to positively identify the nature of the contaminant fluid, despite comparing it with samples of toilet sanitising fluid used by the aircraft operator. This was largely because, although the specimens and the fluid samples both contained similar elements, it appears that samples of other common fluids found on aircraft, such as waste water and galley waste would yield similar results. An independent analysis conducted by the Boeing Company came to a similar conclusion with the additional observation that there were no signs of urea, which could be reasonably expected were the contaminant to contain toilet waste. During dismantling of the connector, however, it was found that the contaminant had also penetrated between the two halves of the insulator block (Appendix 6, Figure 1b) as evidenced by dried stains. Also noted was the fact that none of the pins themselves seemed to have suffered from corrosive attack - the gold plating was intact and not pitted. However, when the pins were later sectioned, repolished and examined under high magnification small pits were identified beneath the gold plating.

Whilst contamination was observed on most of the pins to a greater or lesser degree, the blue/green and white deposits were mainly in evidence around the pins and wires in the top-left quadrant of the connector (viewed from the back). Some of these pins were found to be those which would carry 28V dc for the Yaw Damper engage circuitry and were therefore most likely to cause electrolysis of the contaminant to occur if partial short-circuiting did take place. Variations were found in the composition of the deposits on various pins, most notably on pin 4, which exhibited a strong chlorine peak as expected for negative ions in an electrolyte, and pin 14 which had strong sodium peaks. Pin 14 is at 0V when the Yaw Damper is turned OFF and pin 4 is at 28V. It was therefore concluded that electrolysis of some form of liquid contaminant containing sodium chloride (salt) had occurred and that current had flowed between the pins.

1.16.7 Generation of errant electrical paths in connector D295 (Appendix 1, Figs 1 & 2)

As considerable amounts of the products of electrolysis had been found at pins 4, 12 & 14 of connector D295 inside the Yaw Damper Coupler, consideration was given to how this might have caused bridging between pins leading to errant electrical paths, capable of sustaining Yaw Damper system engagement for 7 minutes after it was selected from ON to OFF. To establish the viability of such bridges required the formulation of a series of tests and trials based on conditions which other testing indicated to have existed.

The operation of the Yaw Damper system electrical engagement interlocks has been described in § 1.6.4, but the rationale for sustaining the engaged state even though the Yaw Damper engage switch was selected to OFF, the basis for formulation of the test series, can be summarised as follows:

1 For the Yaw Damper Actuator to be active, the solenoid valve on the rudder PCU must be held open to allow hydraulic pressure to the actuator. This required that sufficient voltage was present at the solenoid 'live' terminal to maintain it in the open position.

Tests on the Yaw Damper solenoid valve , when isolated from the Yaw Damper system, indicated that the minimum current for holding this valve in the 'active' position was 56 ma. and about 3.2V was required to sustain this.

2 As the basic aircraft wiring tests showed no evidence of insulation weaknesses in any of the Yaw Damper system wiring, the electrical supply to activate the solenoid valve had to be provided from the 'b' contacts of the relay k12 in the Autopilot Accessory Unit.

3 For the 'b' contact supplying the PCU solenoid to be 'live', relay k12 had to remain activated.

Again, as there was no evidence of insulation weaknesses in any of the Yaw Damper system wiring, the electrical supply to activate the relay had to be supplied from pin 12 of the connector D295 at the Yaw Damper Coupler.

Initial tests at the AAIB, showed that the voltage at pin 12 had to rise above 18.7V to activate the relay k12 and remain above 18.4V to maintain relay engagement. Similar tests were made on a later occasion, with the whole Yaw Damper engagement system connected together complete with actuator valve solenoid. These showed that to activate relay k12 the voltage at pin 12 had to rise above 18.2V with a current of 17 ma. and remain above 17.8V with 10 to 11 ma to maintain engagement. The maximum current that the relay would draw was about 40 ma when full aircraft dc voltage was applied. Pin 12 could be supplied from pin 14 through circuits within the Yaw Damper Coupler. In that event, the minimum voltage which would be required at pin 14 would imply a current of at least 380 ma flowing from pin 14.

4 With the 'b' contact supplying the PCU solenoid 'live', the voltage required to hold the solenoid in the open position had to be present at pin 14.

5 If the Yaw Damper system was selected to OFF, pin 14 of connector D295 should be connected to 'aircraft earth' through contacts in the Yaw Damper engage switch.

If any voltage was to be sustained at pin 14, the earth of the Yaw Damper switch would have to have had significant resistance.

6 Unintended dc supply to either pin 12 or pin 14, within connector D295, was judged to be viable only from pin 4; the other permanently 'live' dc pins, 8 and 57, being considered too remote. (Appendix 6, Figure 1)

Dc supply to pin 4 was via a 5 amp circuit breaker; implying a minimum resistance of about 0.7 Ohms in the engage switch earth path if pin 14 were to sustain only about 3V but more if the voltage on pin 14 were allowed to rise.

In order to test the viability of such a mechanism, under conditions most conducive to success, the series of tests on the subject aircraft using the breakout fly lead (§1.12.6) was extended into an electrolytic bridge growth trial. The techniques used and the scope of this 'ad hoc' trial were reviewed and amended as it progressed.

In this trial, the pins were represented by the two single strand copper conductors of a length of domestic power cable (2.5 mm^2),with their insulation cut back for about 1 cm. The bare conductors were placed parallel separated by about 1 mm for the preliminary tests, and for the later test at the same separation as the pins within D295 (0.1 inch). During this later test, to simulate the effect of the insulated wirewrap looming of the connector, a single short length of this wire was used as a non-conducting physical bridge between the two conductors. One of the copper strands was connected to pin 4 and the other to pin 12 of the breakout leads with meters connected to measure both voltage at pin 12 and current from pin 4 to pin 12. Normal operation of the engage system was checked at this point.

Two preliminary tests were done, with the electrodes only separated by about 1 mm, one using tap water and the second using a saline solution. To start electrolysis, the Yaw Damper engage switch was set to ON, the electrolyte placed between the conductors and the switch then set to OFF. In both cases, electrolysis started immediately the system was switched OFF. In the water test however, although the current rose to the measured 'sustain' value, when the system was switched ON and OFF again, the electrolytic cell would not sustain engagement for more than a few seconds. With the saline solution, however, the current rose to the point where the relay k12 pulled into engagement and held, even though the system was not selected ON.

The electrodes were then reconfigured to the more realistic geometry, separated by 0.1 inch, with the insulated wire bridge. Having started the electrolysis with weak saline solution, as in the preliminary tests, the current rose to the 'sustain' level. The system was then switched ON and OFF again and the bridge maintained relay k12 closed. The current through the electrolytic cell continued to increase and finally peaked at about 40 ma, the potential drop across the cell being only 1.5V. No additional electrolyte was added from this point but the current remained stable at 40 ma for about 20 minutes.

In the preliminary tests the electrolyte was introduced as a drop of liquid which was suspended between the two conductors by wetting and surface tension. When the realistic separation of the pins was modelled the gap was too wide for this mechanism to be feasible but, with the insulated wire bridging between the two electrodes, the electrolyte clung to this bridge and the conductors and thus formed an electrolytic bridge between the two. It was noted during the second test that the current increased as the electrolyte clinging to the bridging wire dried out. It remained stable for a long time when there was little apparent moisture bridging the gap between the electrodes.

Following this test, an attempt was made to support the complete Yaw Damper system through the electrolytic cell. Before doing this the engage switch earth was taken out of the circuitry by removing the flight control panel. The electrolytic bridge was re-established and then pins 4 & 12 were connected together with a conductor. Pins 12 & 14 were then connected and the connection between 4 & 12 removed. This left the electrolytic bridge supporting the currents to maintain the engagement of relay k12 and the solenoid shut-off valve. It was able to do this with little moisture apparent, supplying a current of approximately 300 ma for about 10 minutes; the current flow stopped abruptly, however, when the bridge dried out completely. Confirmation that the system had been active was demonstrated by operating the system test switch and observing appropriate rudder response.

Whilst these tests were being conducted, there was clear evidence of electrolysis occurring and deposits formed on the two electrodes which were similar to those found on pins 4 and 14 within connector D295. It was also noted that little obvious surface damage was inflicted on the electrodes although closer inspection revealed that surface damage had occurred. The appearance of the bridge formed between the electrodes was blackish and appeared to bean oxidised copper film deposition.

Having demonstrated that electrolytic bridges, in particular those with limited moisture apparent, were able to maintain engagement of the system, with no earth path available through the engage switch OFF contacts, it was decided to attempt to generate electrolytically formed bridges between representative connector pins; first between correctly spaced pins and subsequently within a replica of connector D295. It was also decided to simulate a high resistance earth rather than no earth at the engage switch.

A comprehensive series of tests and experiments was formulated by the AAIB, the manufacturer and the operator jointly, and performed at the manufacturer's physical laboratories. The intent of the tests was to resolve whether it was possible to generate and maintain suitable pin to pin bridges without damaging the pins significantly more than those of connector D295 were observed to be. The sustained currents which it was considered essential to demonstrate in these tests were the minima established for the individual components of the Yaw Damper system and assuming an open circuit on the engage switch earth.

The preliminary tests of this series involved a large number of simple pin to pin bridges with specific electrolyte mixes which were done in two batches; the first using wet bath electrolyte bridges and the second using electrolyte drops on physical bridges of wirewrap wire. These tests were intended to establish the amount of damage which the pins sustained under the test conditions and, therefrom, the electrolyte most likely to have been involved. The electrolytes were those determined from the results of the earlier analysis on the connector performed by the specialist laboratory. These had shown the presence, amongst other elements, of chlorine, phosphorus and some sulphur, implying the presence of chloride, phosphate and sulphate ions.

These tests showed that if chlorine was a significant element in the electrolyte, its activity was so aggressive that the pins suffered far more severe damage than had been seen on the pins from the incident connector. However, both phosphate and sulphate ions were able to act as charge carriers without inflicting significant damage on the pins. It was also observed that, in the 'near-dry' bridges formed in the second batch of preliminary tests, copper, in some form, was deposited on physical bridge paths as they became dryer. It was noted, however, that where new insulated wiring was used to form physical bridges, it did not 'wet' readily and, consequently, it was difficult to achieve the electrolyte bridge necessary to start the process of generating a stable pin to pin path.

As a result of the findings of these preliminary tests it was decided to proceed with tests on wire wrap connectors configured as nearly as possible identical to connector D295 from the incident aircraft; particular attention being given to the geometry of the wire wrapping around the pins of greatest interest. Having reviewed the possible scenarios for generation of conductive bridges and features noted in the initial tests, it was decided to attempt to form 'near-dry' conductive paths by two different methods one which was predominantly a steady slow generation process and the other a pulsed generation process. The 'slow' process was intended to imitate what might happen if power were left on the aircraft for about ten days, the approximate period that this condition was estimated to have existed during the P6 inspection, following a single run of contaminated fluid onto the connector followed by an afterdrip. The 'pulsed' method representing persistent slow dripping of contaminated fluid onto the connector throughout the same period.

The wirewrap wired connectors were artificially aged before testing to improve the tendency of the new insulated wires to be wetted. Each connector was, in turn, then used as part of the circuitry of a near complete Yaw Damper electrical system (the BITE and indicator circuits were not connected) so that it fed and received power from the appropriate components, including the Yaw Damper Actuator solenoid. To do this the connector was installed in the middle of a fly lead connection to the Yaw Damper Coupler and placed in an agreed controlled environment which attempted to emulate estimated conditions in the E&E Bay during the P6 check. The currents in and out of the relevant connector pins and their voltages relative to ground were continuously monitored and recorded throughout the attempts to grow the bridges as well as during the subsequent test phases. The resistance of the earth path on the OFF side of the Yaw Damper engage switch was initially very high but it was intended to reduce this if sustained 'hung' engagement was achieved. The method of initiating sustained hung engagement was agreed to be:- to engage the system normally, add a small amount of extra wetting to the connector and then switch OFF the system. The rationale behind this procedure was that it was only necessary to generate electrical paths capable of carrying enough current to sustain engagement but not to initiate it.

For the slow path growth, the conditioned connector was moistened, in the area of pins 4, 12 & 14, with a spray of composite contaminant consisting of 0.5% Sodium Chloride solution combined with 6% saturated solutions of Potassium Phosphate and Sodium Sulphate. Six hours later, the same area was rewetted using a micro-pipette. At the time of rewetting, the voltages on pins 12 & 14 rose sharply, relay k12 activated and the solenoid pulled in. This caused the pin voltages to fall sharply, k12 then deactivated, the solenoid dropped out and the pin voltages then rose sharply again. This cycle persisted for about 23 minutes but stable solenoid engagement was not achieved. Following this episode the circuit was then left for about 10 days for the unwanted paths to develop without any further wettings. At the end of this period, the voltage on pin 12 resulting from leakage along the 'near-dry' bridge which had developed was not of the right order to hold the relay k12 in the activated state and an attempt to demonstrate hung engagement of the system failed. The area around pins 4, 12 & 14 was rewetted using a pipette but even after this, 'hung' engagement would not occur. A final attempt to produce conditions in which 'hung' engagement could be demonstrated was made by spraying the area of the pins. This lead to a wet path short circuit between the 115V ac resident on pin 2 and the earth pin 3 which rendered this connector useless for further testing.

Post-test examination of this connector showed that much of the electrolytic activity had been taking place between pin 4 and its two adjacent earths at pins 3 and 5 rather than the intended activity between pin 4 and pins 12 & 14. It was also observed that, ignoring the damage caused by the final wet short circuit, the damage inflicted on pin 4 by the electrolytic activity was considerably greater than had been seen on the incident connector.

For the pulsed path growth, a good sized drop of fairly clean water (provided from Gatwick) was dropped onto the pin 4, 12 &14 area of the connector for three days and then a 50/50 mix of this water with the solution used in the slow growth experiment was applied twice daily for the remainder of the 10 days. Attempts were then made to induce 'hung' engagement, with a series of rewettings being performed, and the assembly left with power applied to achieve a subsequent 'slow' bridge growth several times. Although short periods of 'hung' engagement were observed, the longest being 28 seconds, several periods of rapid cycling of relay k12 occurred. Examination of the connector after testing again revealed much greater pin damage than in the incident connector and evidence of copper deposition between the pins.

1.16.8 E&E Bay Assessment Team

Arising from concern that fluid contamination might be more widespread than they were aware, Boeing launched an 'E&E Bay Assessment Team' initiative in January 1996. In addition to a large number of Boeing personnel, airlines and vendors were co-opted and canvassed for their experience with this problem.

The terms of reference of the team were; 'To develop recommendations that when implemented will preclude liquid leakage and contamination within the E&E Bay from having an adverse effect on the equipment/systems'. The team's strategy was essentially to define the scope of the problem, and to attempt to see whether individual operator experience and aircraft build/modification standard might give clues as to which modifications or operator practices were effective in minimising E&E Bay contamination.

The team's findings and recommendations were extensive, reflecting the very large number of man-hours spent in producing the report. Much of the report deals with detail improvements both to hardware and maintenance practices. As an example of the latter, the team found that many airlines treated water/waste system components as 'on-condition' items and recommended that periodic inspection and overhaul should be performed.

In general, however, the team found a wide variation in operator experience but the findings may have been influenced by a lack of appreciation by some operators that they had an E&E Bay fluid contamination problem. For example, one aircraft showed a history of a particular item of avionics equipment being returned from the repair shop repeatedly with reports of fluid contamination over a period of four months. Clearly the operator had failed to make the connection between the high removal rate of this component and a persistent leak somewhere in the aircraft. Equally so, there was variation in operator expectation regarding the condition of the underfloor area, with some, including the operator of GBGJI, apparently accepting that evidence of blue staining is inevitable after a few years in-service whilst others managed to achieve high standards of cleanliness.

This underlines the report's conclusion that most problems with E&E Bay contamination '....*related to aircraft maintenance and servicing, rather than how components are originally designed and installed"*. The report also*"....did not uncover any evidence that a specific fluid leakage event will produce a near term, unexpected, aircraft flight path deviation.*'

1.17 Organisational and management information

None relevant.

1.18 Additional information

1.18.1 Aircraft manufacturer's Operational Bulletin

On 4 August 1995, the aircraft manufacturer issued an Operational Bulletin detailing the 'Uncommanded Yaw or Roll Procedure'. The procedure is reproduced below and the full contents of the Bulletin is at Appendix 9.

UNCOMMANDED YAW OR ROLL

Accomplish this procedure if uncommanded yaw or roll occurs in flight.

AUTOPILOT (if engaged) ....

DISENGAGE

The pilot should be prepared to make control wheel corrections to return to wings level upon disengagement. The autopilot may be putting in an appropriate correction for an uncommanded yaw or roll. Allowing the control wheel to go to neutral after disengagement may allow the aircraft to roll even more.

If yaw and/or roll forces continue:

YAW DAMPER SWITCH ....

OFF

The YAW DAMPER Light illuminates when the yaw damper is disengaged.

If it is confirmed that the autopilot is not the cause of the uncommanded yaw or roll, the autopilot may be re-engaged at the pilot's discretion.

1.19 Useful or effective investigative techniques

None new.

2 Analysis

2.1 General

The uncommanded roll activity experienced during this incident was unusual. The flight crew carried out the correct initial actions, as defined by the manufacturer earlier in 1995. These actions were intended as part of a memory recall drill in the event of an uncommanded yaw or roll occurring in flight. The initial action was to disengage the Autopilot, while being prepared to make control wheel corrections to return the aircraft to wings level upon disengagement, as the Autopilot may have been putting in an appropriate correction for an uncommanded roll or yaw induced roll. In this case, after Autopilot disengagement,the roll oscillations continued despite the best efforts of the crew to control the aircraft using opposite roll inputs. The next item in the sequence (if the roll/yaw continues) was to select the Yaw Damper switch, which is located on the overhead panel just above the Captain's head, to OFF. During the post-incident debrief, the crew stated that the Yaw Damper had been switched OFF at the time in accordance with the procedure, but again this had no noticeable effect on the roll/yaw motion being experienced. With two pilots making individual attempts at reducing the oscillation in sequence, and with a handover occurring between the two, it is most unlikely that the continuation of the oscillation was a result of 'pilot coupling' with the aircraft, inducing the motion, without some form of additional input from an aircraft control system.

With the Autopilot removed from the control loop and the Yaw Damper manually switched off, then all of the flight controls should have been in the hydraulically actuated/mechanically signalled state, with pilot inputs causing essentially linear control responses at the elevators, ailerons and rudder. In this basic configuration, there should have been no mechanism for an oscillation to continue. The fact that it did so meant that the flight crew were initially somewhat alarmed and unsure as to the precise nature of their situation. The possibility of the Yaw Damper system remaining active after its control switch on the overhead panel had been switched OFF had never been considered as a possible scenario by the aircraft manufacturer.

During this investigation, some consideration was given to the possibility that the crew may have misidentified the Yaw Damper ON/OFF switch and operated some other switch. The switches adjacent on the same overhead panel are shown diagramatically in Appendix 1. The majority of these switches have lift-flap type, guard covers. Of the remainder, there is no other switch on this panel which, when switched off, would produce a FLIGHT CONTROLS amber warning caption on the Master Caution system. The flightcrew recalled that this amber Master Caution caption was illuminated during the pre-landing checklist completion at the Master Caution recall check and that the commander switched the Yaw Damper back on at that time. He sensed a further roll/yaw disturbance and so switched it OFF again prior to landing. It was not possible to confirm, from the DFDR, when these switch selections had been made.

2.2 M-Cab simulator analysis

From the M-Cab simulator testing it was possible to conclude that shunt resistances between combinations of pins in the Yaw Damper Coupler connector could cause an aircraft response similar to that experienced by G-BGJI during the incident. Initially a shunt resistance of at least 300 K Ohms between pins 40 to 51 would have caused the small oscillations that were seen prior to and post the large oscillations. Similar oscillations were detectable on the QAR data from flights prior to the maintenance activity which could be caused by a shunt, or due indeed to the Yaw Damper being disengaged. The effect of this shunt was to reduce the ability of the Yaw Damper Coupler to provide control, and so the response of the aircraft was similar to the Yaw Damper disengaged case.

However, when a resistance of at least 230 Kilohms was applied between pins 37 to 38 and 40 to 51, the aircraft immediately would have started to experience the large oscillations. It can be concluded that the pin 40 to 51 shunt resistance may have been an incipient problem, the only symptoms of which were to produce aircraft behaviour consistent with the Yaw Damper being disengaged. However when a shunt resistance appeared between pins 37 and 38, in conjunction with the pre-existing condition, the Yaw Damper system would immediately start to drive the Dutch Roll mode, and the aircraft would respond accordingly with the rolling/yawing motion seen during the incident.

2.3 Continued engagement of Yaw Damper system

Analysis of the aircraft's flight path, from the recorded Flight Data, showed that its aberrant motion was consistent, in form and frequency, with a fairly constant amplitude 'Dutch Roll' motion. Because the aircraft type has a naturally damped 'Dutch Roll' mode, this indicated that the motion was being forced. This conclusion directed attention to the Yaw Damper system early in the investigation.

The occurrence of unstable Yaw Damper characteristics should not have been a continuing problem if the system had been switched OFF. Since the crew recollection was that they had selected it OFF early in the sequence of events following the onset of the aberrant behaviour (ref; §2.1), it was necessary to investigate if and how it might be possible for the system to remain active when selected OFF.

Critical analysis of the Yaw Damper system (Appendix 1) had shown that, in addition to the two faults required to destabilise it (see §2.2), two further stray connections had to be made to keep it engaged when switched off; one supplying dc power to relay k12 in the Autopilot Accessory Unit and the other supplying dc power to the engage solenoid valve. Furthermore, it required the earth path attached to the OFF terminal of the Yaw Damper engage switch to have considerable resistance if the 28V dc supply circuit breaker were not to trip.

The physical evidence of liquid ingress into the connector D295 in the Yaw Damper Coupler module and the fact that this connector appeared to be the only single place where all the necessary stray connections and reduced resistances could be made, further focused the investigation onto this connector. The evidence of fluid ingress did not indicate that the whole connector had been affected but only a few pins. However, the contaminated pins included those indicated by the M-Cab analysis to be critical. The analysis made of the contaminants observed within the connector showed that some electrolytic activity had taken place there; an undesirable state of affairs even if it were not to give rise to instability or loss of control of the Yaw Damper system.

The tests on the aircraft using breakout flyleads (1.12.7) confirmed the analysis that in order for the Yaw Damper System to remain engaged due to stray connections at connector D295, after it had been switched OFF, the interlock relay k12 in the Autopilot Accessory Unit had to remain made. Furthermore, sufficient current had to continue to flow through the contacts 'b', of this relay, and the solenoid of the Yaw Damper Actuator solenoid valve, in order to hold this valve in the 'active' position. These tests also confirmed that the OFF terminal earth path of the Yaw Damper engage switch had to have significantly raised resistance, if the necessary stray connections to engage the system were not to cause the 28V dc circuit breaker to trip.

To get these conditions to occur due to stray connections at connector D295 required that current paths became available from pin 4, which carries dc power directly from the system circuit breaker, to pin 12, to keep the engage relay k12 activated, and to pin 14, to supply the actuator solenoid valve. It can be seen, in the diagram of connector D295 at Appendix 6, Figure 1, that the pins 4, 12 & 14, are grouped together. Furthermore, these pins showed evidence of contamination and local electrolytic activity.

A scenario was postulated that, if contaminated water got into the wire wrapping at the back of the plug unit of the Yaw Damper Coupler (D295), an electrolytically driven process might generate electrically conductive paths from pin 4 to both pins 12 &14.

For electrolysis to have taken place, the presence of 28V dc on pin 4 was required, which would be true whenever the dc bus was live. It would also have required paths to earth to exist from pins 12 & 14; from pin 12 via the k12 relay coil and from pin 14 via the engage switch earth path or, if this were open circuit, through the solenoid valve coil after k12 relay had been activated. If dc power were available on the bus and the Yaw Damper selected ON, pins 12 & 14 would also be at 28V dc and so the conditions for the electrolysis to take place would not exist. It is, therefore, only when the dc bus is live and the Yaw Damper selected OFF that the right conditions can exist.

The electrical system status for it to be possible to lay down the requisite conductive paths by this kind of mechanism had been available as the aircraft had just been on a major check during which it spent many days with dc power live but the Yaw Damper switched OFF. However, the physical conditions and the effect of the connector's history, over the 17 years it had been in service, were recognised as potentially important in influencing the likelihood of a path forming. Another unquantifiable influence was the unique lie of the wirewrap wires between the pins of the connector which could be seen to affect the likelihood of damp paths between the relevant pins being a possibility.

When the Yaw Damper is switched off, the electrical paths to earth which exist, by design, from pins 12 & 14 are fundamentally different. That from pin 12 is through the (k12) engage relay coil and the time delay circuits in the Autopilot Accessory Unit, which limit the maximum current to about 40 ma even when full aircraft dc voltage is applied. By contrast, the earth path from pin 14 is through the engage switch OFF contact which should be a dead short to aircraft earth and effectively maintain pin 14 at aircraft earth potential whenever the switch is selected to OFF.

This difference was reflected in the relative ease of generating effective stray paths during test. The natural current limiting characteristics of the relay k12 coil circuits meant that the stray path between pins 4 & 12 was only required to carry a maximum of 40 ma and to have sufficiently low resistance to maintain at least 18.2V at pin 12.

The path to pin 14, however, had to be able to satisfy a more demanding role, one affected by both its own resistance and the resistance of the engage switch earth path. As an absolute minimum,on the assumption that the engage switch earth path was close to being an open circuit, the 4 to 14 path had to be capable of carrying 60 ma whilst dropping the voltage to 3.2V dc at pin 14, to keep the solenoid valve energised. The lower the resistance of the pin 4 to 14 stray path, the higher the voltage at pin 14 and consequently an increased current flow through the solenoid so the more robust the stray path would need to be.

The minimum permissible resistance of the engage switch earth path would have be about 0.7 Ohms if pin 14 were to sustain only about 3V as the dc supply to pin 4 was via a 5 amp circuit breaker. However, if the voltage on pin 14 were to be higher, the resistance at the engage switch earth path would also have to be higher in order to limit the total current to 5 amps, the capacity of the circuit breaker which did not trip on the incident flight. In order to reduce the current flow through the stray connection, 5 amps demanding a very robust path, the resistance at the engage switch earth path would need to have been higher still.

Therefore, a very particular set of circumstances had to pertain for a stray path to develop between pins 4 and 14 capable of supplying the 'hold on' voltage and current requirements of the Yaw Damper Actuator solenoid valve without the 5 amp circuit breaker tripping. For the 4 to 14 path to develop at the same time as the 4 to 12 path, the engage switch earth path had to be sufficiently resistive to restrict the total current and be sufficiently conductive enough to allow the electrolytic formation of the path. If the engage switch earth path were open circuit, formation of the 4 to 14 path could not occur until a sufficiently robust path had been generated between pins 4 & 12 for the k12 relay to have pulled in without being selected.

The basic aircraft wiring integrity testing had not revealed any relevant discrepancies of continuity or isolation except the persistent existence of a relatively high resistance (about 2 Ohms) at the earth contacts of the engage switch. During the course of testing, this resistance was established to be associated only with the Flight Controls module which was fitted during the incident flight. This indicated that it was possible that a raised switch earth resistance had existed at the time of the incident. Detailed examination of the module wiring and the switch itself indicated neither evidence of undue contact or joint resistance nor a possible explanation for it, beyond the presence of some deposits around the microswitch contacts but these were not confirmation of an open circuit. However, the switch had been functioned an indeterminate number of times since the incident with an unquantifiable effect.

The Yaw Damper system had to be positively engaged by the crew, as part of the preflight checks. It can be inferred that if the stray paths to pins 12 & 14 existed at that time, they were not sufficiently conductive to cause the system to engage itself and thus extinguish the warning light. The crew would have been expecting to energise the system and its being live without being selected should have been noticed and, if so, would have been a matter of concern. If, however, the stray paths had developed to the point where once the Yaw Damper was engaged, they were sufficiently robust to sustain the requisite voltage and current combinations at pins 12 & 14 (see 1.16.7) to maintain engagement, they could have been exploited when the crew selected the system OFF.

The experimentation and tests, using both plain copper conductors and gold plated pins as used in D295, showed that it was relatively easy to form an electrolytic current path capable of sustaining the currents needed to keep the Yaw Damper system engaged. It was observed, however, that the degree of damage sustained, particularly by the pins, was considerably more severe than that suffered by the pins of the incident Yaw Damper connector. This indicated that pure electrolytic conduction of the stray currents needed to keep the system engaged had not been a potential mechanism for causing this incident.

The experimentation was, therefore, focused on developing, what were called 'near-dry', current bridges which were, in effect, attempts to see if it was possible to lay down a basic metallic current path using phosphate and sulphate ions as charge carriers; rather than chlorides which were chemically too aggressive to leave the pins of the connector as little damaged as was found in the incident connector.

The current carrying capacity of those paths and the voltages which had to be sustained at the pins were specific to the units of the system which were installed at the time of the incident. The tests done on the aircraft system to prove which stray connections were needed had shown that actuator solenoids, in particular, could vary considerably in their voltage and current demands for the 'held on' condition. The tests to see if it was possible to reproduce any 'hold on' condition were, therefore, conducted using the components fitted to the aircraft at the time of the incident.

When looking at the attempts to introduce the necessary stray connections into a representatively wired up connector, it was seen that none could be classified as successful, in the sense that the Yaw Damper system did not remain solidly engaged after being selected OFF, although some type of stray connection had clearly formed.

In summary, the experiments demonstrated that it might be possible to generate stray current paths capable of sustaining engagement of the Yaw Damper system when selected to OFF, but only in the presence of a high resistance in the engage switch earth path. Although the evidence was tenuous, the possibility that such a resistance was present during the incident flight cannot be discounted.

2.4 Possible sources of connector contamination

The nature of the deposits observed on the Yaw Damper Coupler connector pins appeared to be relatively long term, almost certainly pre-dating the P6 check activity. As such, it was highly unlikely that the investigation and testing would reveal a contamination source from that period and indeed none was found. The only evidence indicating a fluid path into the connector was the whitish dried deposit on the connector shell, suggesting a very particular localised drip (as opposed to a more general soaking of the unit). The tray in which the Yaw Damper Coupler was located bore no signs of any contamination although its mating connector did have some of the dried residue similar to that found on the Yaw Damper Coupler connector, indicating that the two were joined at the time of the contamination. The Technical Log entry in March 1995 indicating a leak in the toilet hand basin drain may be relevant, but for the same reasons discussed below, moisture should still have been prevented from contaminating the E1 rack.

Attempts to analytically determine the origin of the deposits were unsuccessful. The conclusion in §1.16.6 that electrolysis of a solution containing sodium chloride had definitely occurred, whilst demonstrating the passage of current, did not assist in identifying the contaminant since this is obviously such a common substance and could have come from almost any source.

The scenario connecting the incident to the connector contamination requires a further source of moisture nearer to the time of the incident to activate the electrical 'bridge' between the pins.

Chemical analysis of the dried deposits did not point towards any particular source of fluid and, although some defects were found in the wet systems of the aircraft, these systems were essentially non-functional and drained during the incident flight. The weather was dry whilst the aircraft was outside the hangar preparing for the flight.

It would appear that for any fluid leak to drip onto the subject connector, it is necessary to penetrate the rubberised fabric shroud which is fitted above it. Once through this, it may drip onto the cooling plenum, whose forward lip coincides with the array of connectors at the back of each unit on the E1 rack, particularly the Yaw Damper Coupler which is at the top. The evidence of a dried fluid run on the upper and lower surfaces of the plenum was of interest because it did indeed correspond to the centreline of the Yaw Damper Coupler but there was no indication of a leak in the shroud at the location from where the run appeared to originate. Notwithstanding this, G-BGJI's operator has developed a modification which puts an aluminium tray between the plenum and the shroud which completely covers the forward face of the E1 rack thus preventing any fluid which penetrates the shroud from dripping onto the connectors. A Boeing modification to achieve a similar standard of protection already existed but was not applicable to aircraft fitted with airstairs.

The E&E Bay Assessment Team were not specifically tasked with finding the cause of contamination which caused this incident but it formed part of their statistics and the operator of G-BGJI was one of the airlines whose procedures and aircraft were examined, after the operator had conducted their own internal checks. As mentioned in §1.16.8, the team generally found that occasional E&E Bay contamination was an accepted fact-of-life by many airlines This appeared to be the case at the operator's Gatwick facility, where the condition of aircraft after a few years service following a P6 check, both by physical examination and discussion with the technicians, was expected to show signs of the characteristic blue staining of toilet sanitising fluid under the floor area. G-BGJI's operator did not necessarily regard water/waste system components as 'on-condition' as they were generally overhauled or renewed at each P6 check, but this represents 5 years service of systems which are often troublesome and prone to abuse. This incident led the operator to review all aspects of E&E Bay protection and maintenance practices and it might be speculated that other airlines would be well advised to do the same rather than wait until they, too, have an in-flight incident. By its nature, a contamination event is unpredictable as is demonstrated by this incident. It is unlikely that anyone could have foreseen the dramatic effect that contamination of the connector had on the behaviour of the aircraft.

The following recommendations were made in January 1996:

It is recommended that the FAA :

1) Require as soon as practical a visual inspection of all Boeing 737 aircraft Electrical and Equipment (E&E) Bays to check for fluid ingress into avionics components, their connectors and associated wiring. Such inspection should involve the minimum disturbance of equipment and connectors commensurate with a thorough examination for contamination. Where such contamination is found, the component should be removed and despatched to workshops for examination.

2) Require as soon as practical an inspection of the area in and around the E&E Bay for evidence on the structure and fittings of recent fluid leakage such as wet corrosion, staining and crystallised deposits. Such evidence should be investigated to ensure that, where the source of the leak is not apparent or readily rectifiable, no potential exists for it to impinge upon the avionics components, their connectors or wiring.

(Recommendation 96-3)

It is also recommended that the FAA and Boeing:

3) Conduct an urgent review of the measures incorporated into the Boeing 737 to prevent fluid ingress into the E&E Bay, its equipment, connectors and wiring and as necessary require modifications to ensure that the equipment, connectors and wiring are provided with protection consistent with reliable operation.

4) Conduct a review of the Aircraft Maintenance Manual to ensure that clear and specific instructions are contained therein to enable evidence of fluid ingress, even if not apparently directly impinging on electrical equipment, to be identified during routine maintenance. It should also be ascertained that any routine testing for leaks in the toilet, galley and airstairs systems should be done with the systems functioning fully throughout their normal operational cycle to ensure that any leaks which only occur during, for example, draining or replenishment cycles are detected.

(Recommendation 96-4)

It is accepted that the findings of the E&E Bay review team identified differing maintenance practices as being highly significant in determining the in-service condition of the E&E Bay and its associated avionics components, their connectors and wiring. However, the location of the bay, below the cabin floor in areas susceptible to fluid leaks from toilets, galleys and aircraft doors does make the bay unnecessarily vulnerable. Although the chances of fluid contamination directly affecting aircraft handling, as in this case, would appear to be a most unlikely outcome, the wetting of sensitive avionics equipment will undoubtedly lead to unserviceabilities. This will become of more significance as aircraft continue to develop an increased dependence on electronic equipment. The location of the E&E Bay was undoubtedly arrived at following a variety of design considerations but in modern aircraft is possibly based on historic precedent as much as current design constraints.

It is therefore further recommended that:

The Boeing Airplane Company promulgate the findings of the E&E Bay Assessment Team to all operators and that the recommendations be actioned through Service Bulletins to maximise the protection from fluid ingress of bay housed electronic components in current aircraft.

(Recommendation 97-60)

The CAA with the FAA review FARs and JARs with a view to requiring that the location of electronic equipment be arranged during the aircraft design so as to minimise the potential for contamination by fluid ingress, with the intention of ensuring that the equipment, connectors and wiring are provided with protection consistent with reliable operation less heavily dependant on maintenance practices.

(Recommendation 97-61)

3 Conclusions

(a) Findings

1 The crew members were properly licensed, medically fit, adequately rested and technically qualified to conduct the test flight.

2 The aircraft was on a test flight before being returned to line service following a scheduled major (P6) service and was operating within the normal limits of weight and centre of gravity.

3 The aircraft was being operated within the normal flight envelope at the time of the incident, using the Autopilot and Autothrottle systems and with the Yaw Damper system engaged.

4 The aircraft entered a cyclic oscillation in roll and yaw which was consistent with a critically damped Dutch Roll motion and persisted for seven minutes. The aircraft type has natural positive damping of the Dutch Roll mode.

5 The crew's initial actions, as they recalled them, of disconnecting the Autopilot and Autothrottle, and switching OFF the Yaw Damper were in accordance with the manufacturer's recommended procedure.

6 The commander's decision to issue a MAYDAY call in response to the incident was appropriate.

7 The ATC response to the MAYDAY call was timely, helpful and appropriate.

8 The crew's decision to conduct a low speed handling check to determine a suitable configuration in which to carry out a landing demonstrated good airmanship.

9 The decision to maintain the Flap 15°, landing gear down configuration for the return to London Gatwick was judicious.

10 The decision to re-engage the Yaw Damper system during the final approach sequence was unwise, but the system was switched OFF once again prior to landing.

11 The main rudder PCU had been replaced but in all other respects the rudder/Yaw Damper system components were the same as those fitted prior to the check.

12 After the incident, all components (mechanical, electrical and electronic) capable of affecting rudder movement were tested and none was found to be significantly out of specification.

13 From the M-Cab simulator testing it was possible to conclude that shunt resistances, simulating the effect of fluid ingress, between combinations of pins in the Yaw Damper Coupler connector could cause an aircraft response similar to that experienced during the incident.

14 The Yaw Damper Coupler had not been overhauled during its life and had run 17 years and about 34,000 hours without any recorded defects.

15 Examination of the aircraft's Technical Log did not reveal entries related to Yaw Damper defects during the last two years.

16 No component defects were found in the Yaw Damper Coupler apart from those on the connector D295.

17 The portion of the connector D295 on the outside of the Yaw Damper Coupler enclosure had evidence of liquid spillage onto it.

18 Despite various attempts it was not possible to analyse the contaminant and hence identify its origin.

19 There was a considerable build up of products of corrosion and electrolysis between pins of the connector D295, within the Yaw Damper Coupler enclosure.

20 The nature of the deposits observed on the Yaw Damper Coupler connector pins appeared similar to those produced when attempting to create stray electrical paths.

21 The pins most affected by these deposits were related to the 28V dc power supply and the circuits involved in activation of the Yaw Damper system.

22 The scenario connecting the incident to the connector contamination, requires a further source of moisture nearer to the time of the incident to activate the electrical 'bridge' between the pins but no such source of moisture was identified.

23 The airframe wiring affecting the Yaw Damper circuits was found not to have any deficiencies.

24 Tests using a 'breakout fly-lead' confirmed theoretical analysis that it was possible to maintain engagement of the Yaw Damper system after it had been switched OFF by introducing stray connections between pins within the Yaw Damper Coupler connector (D295) but only if the engage switch OFF earth was high resistance or open circuit.

25 Experimentation demonstrated that possibilities existed to build the necessary stray connections to achieve continued Yaw Damper engagement after it had been selected OFF.

26 The experimentation demonstrated that it was very difficult to generate robust stray connections between pins of connector D295 without causing more severe damage to the pins than had been observed on the unit involved in the incident.

27 None of the experimentally produced stray connections with appropriately damaged pins was sufficiently robust to sustain continuing Yaw Damper engagement after it had been selected OFF.

28 There was little chance of finding evidence that a source of moisture existed in the past, as the electronic units in the E&E Bay (including the Yaw Damper Coupler) were removed and the E&E Bay and structure immediately above it were cleaned or replaced during the P6 check.

29 Visual inspection of the structure was carried out and evidence from the technical records along with the recollections of the individuals involved

indicated that the degree of corrosion found and rectified was typical of any aircraft on such a check and there were no indications of any abnormalities which may have indicated heavy fluid contamination.

30 The E&E Bay was vulnerable to fluid leaks because it housed the forward airstairs, was located immediately below the main entry vestibule and forward galley and just aft of the forward toilet.

31 Examination of the aircraft technical documents only revealed one entry relating to a fluid leak capable of affecting the E&E Bay, dated 5 March 1995, when a leak was traced to the forward toilet sink drain.

32 The E&E Bay Assessment Team's findings and recommendations were extensive and identified detailed improvements both to hardware and maintenance practices to maintain a desirable environment in the bay.

(b) Causal factors

The investigation identified the following causal factors:

1 Contamination of the connector on the Yaw Damper Coupler, in the E&E Bay, by an unidentified fluid had occurred at some time prior to the incident flight and compromised the function of its pin to pin insulation.

2 Sufficiently conductive contaminant paths between certain adjacent pins had affected the phase and magnitude of the signals transmitted to the Yaw Damper Actuator, thereby stimulating a forced Dutch Roll mode of the aircraft.

3 The location of the E&E Bay, beneath the cabin floor in the area of the aircraft doors, galleys and toilets made it vulnerable to fluid ingress from a variety of sources.

4 The crew actions immediately following the onset of the Dutch Roll oscillations did not result in the disengagement of the malfunctioning Yaw Damper system.

4 Safety recommendations

4.1 It is recommended that the FAA :

1) Require as soon as practical a visual inspection of all Boeing 737 aircraft Electrical and Equipment (E&E) Bays to check for fluid ingress into avionics components, their connectors and associated wiring. Such inspection should involve the minimum disturbance of equipment and connectors commensurate with a thorough examination for contamination. Where such contamination is found, the component should be removed and despatched to workshops for examination.

2) Require as soon as practical an inspection of the area in and around the E&E Bay for evidence on the structure and fittings of recent fluid leakage such as wet corrosion, staining and crystallised deposits. Such evidence should be investigated to ensure that, where the source of the

leak is not apparent or readily rectifiable, no potential exists for it to impinge upon the avionics components, their connectors or wiring.

(Recommendation 96-3)

4.2 It is recommended that the FAA and Boeing :

3) Conduct an urgent review of the measures incorporated into the Boeing 737 to prevent fluid ingress into the E&E Bay, its equipment, connectors and wiring and as necessary require modifications to ensure that the equipment, connectors and wiring are provided with protection consistent with reliable operation.

4) Conduct a review of the Aircraft Maintenance Manual to ensure that clear and specific instructions are contained therein to enable evidence of fluid ingress, even if not apparently directly impinging on electrical equipment, to be identified during routine maintenance. It should also be ascertained that any routine testing for leaks in the toilet, galley and airstairs systems should be done with the systems functioning fully throughout their normal operational cycle to ensure that any leaks which only occur during, for example, draining or replenishment cycles are detected.

(Recommendation 96-4)

It is further recommended that:

4.3 The Boeing Airplane Company promulgate the findings of the E&E Bay Assessment Team to all operators and that the recommendations be actioned through Service Bulletins to maximise the protection from fluid ingress of bay housed electronic components in current aircraft.

(Recommendation 97-60)

4.4 The CAA with the FAA review FARs and JARs with a view to requiring that the location of electronic equipment be arranged during the aircraft design so as to minimise the potential for contamination by fluid ingress, with the intention of ensuring that the equipment, connectors and wiring are provided with protection consistent with reliable operation less heavily dependant on maintenance practices.

(Recommendation 97-61)

D F King

Inspector of Air Accidents

Air Accidents Investigation Branch

Department of the Environment, Transport and the Regions

November 1997

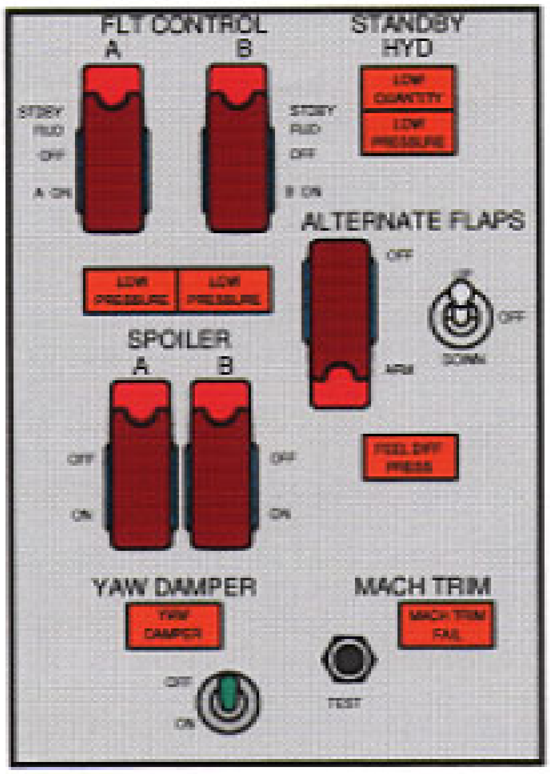


Figure 1 Flight Control Module. System selector panel in flight deck overhead

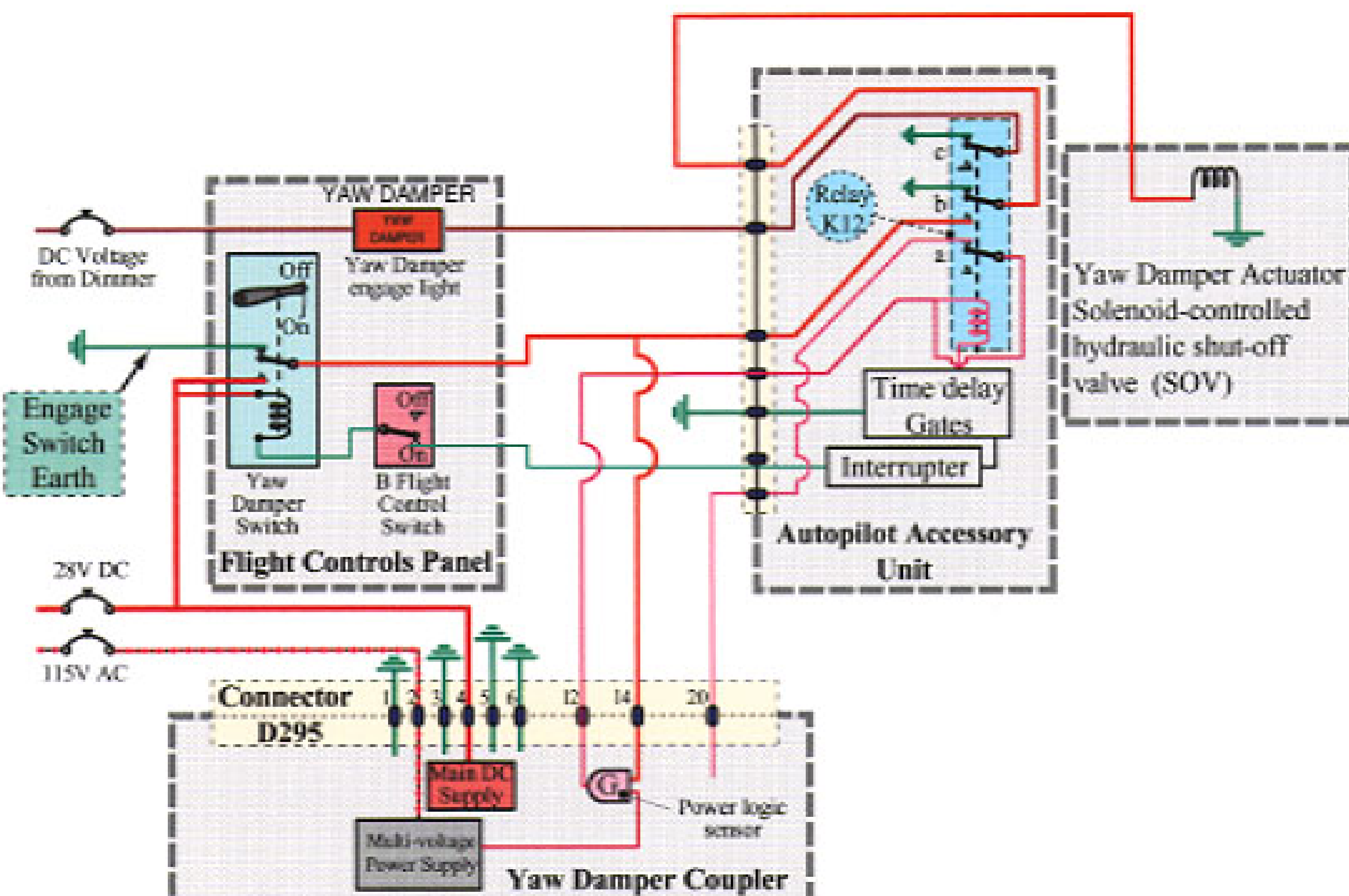
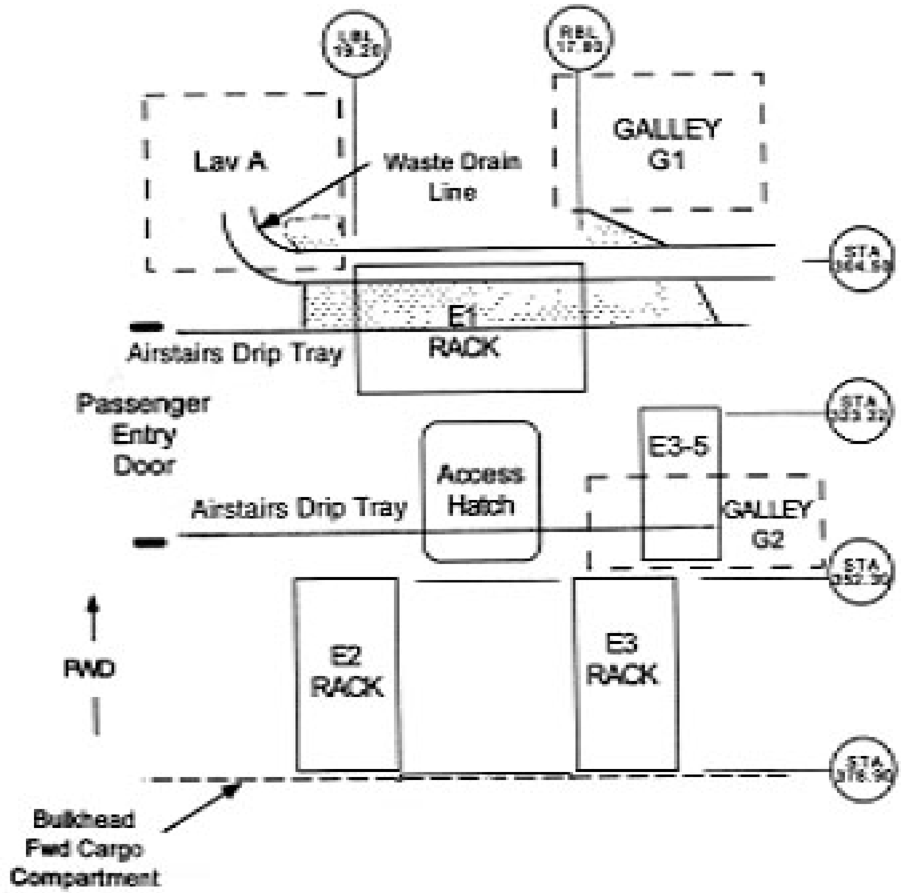
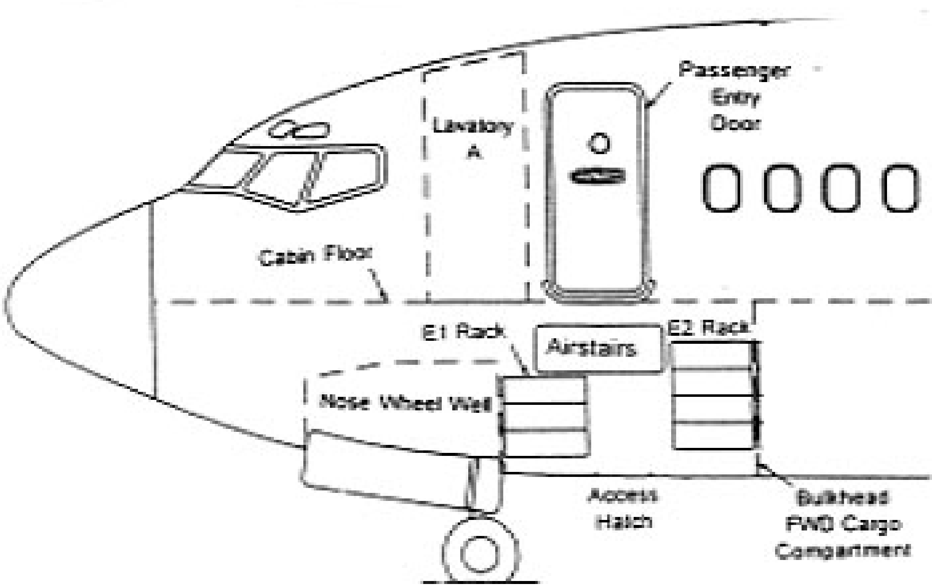


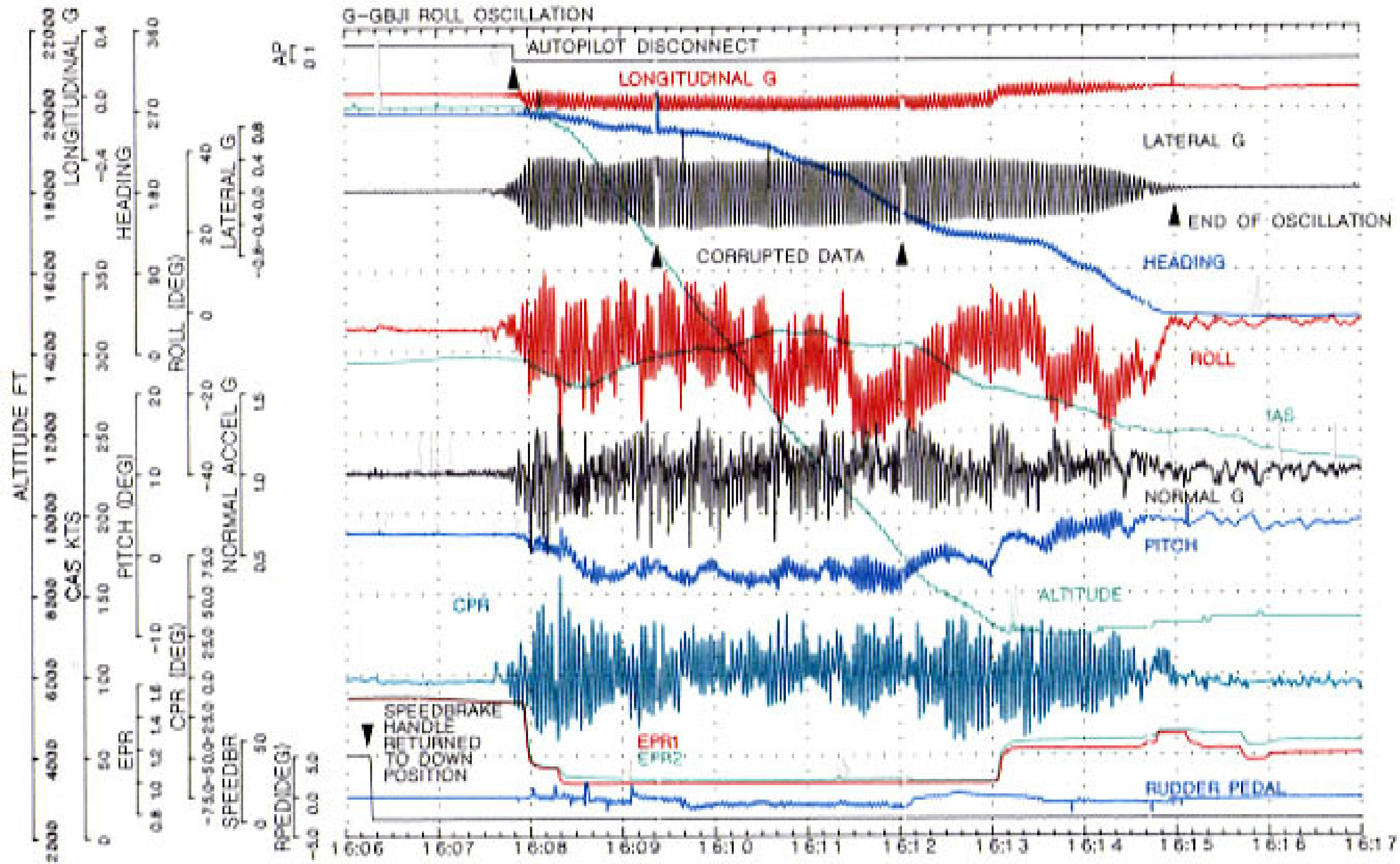
Figure 2 Schematic diagram of Yaw Damper system electrical power engagement interlocks



Plan - view of E&E Bay showing location of avionic racks and rubberised fabric shroud protecting E-1 rack (shaded)

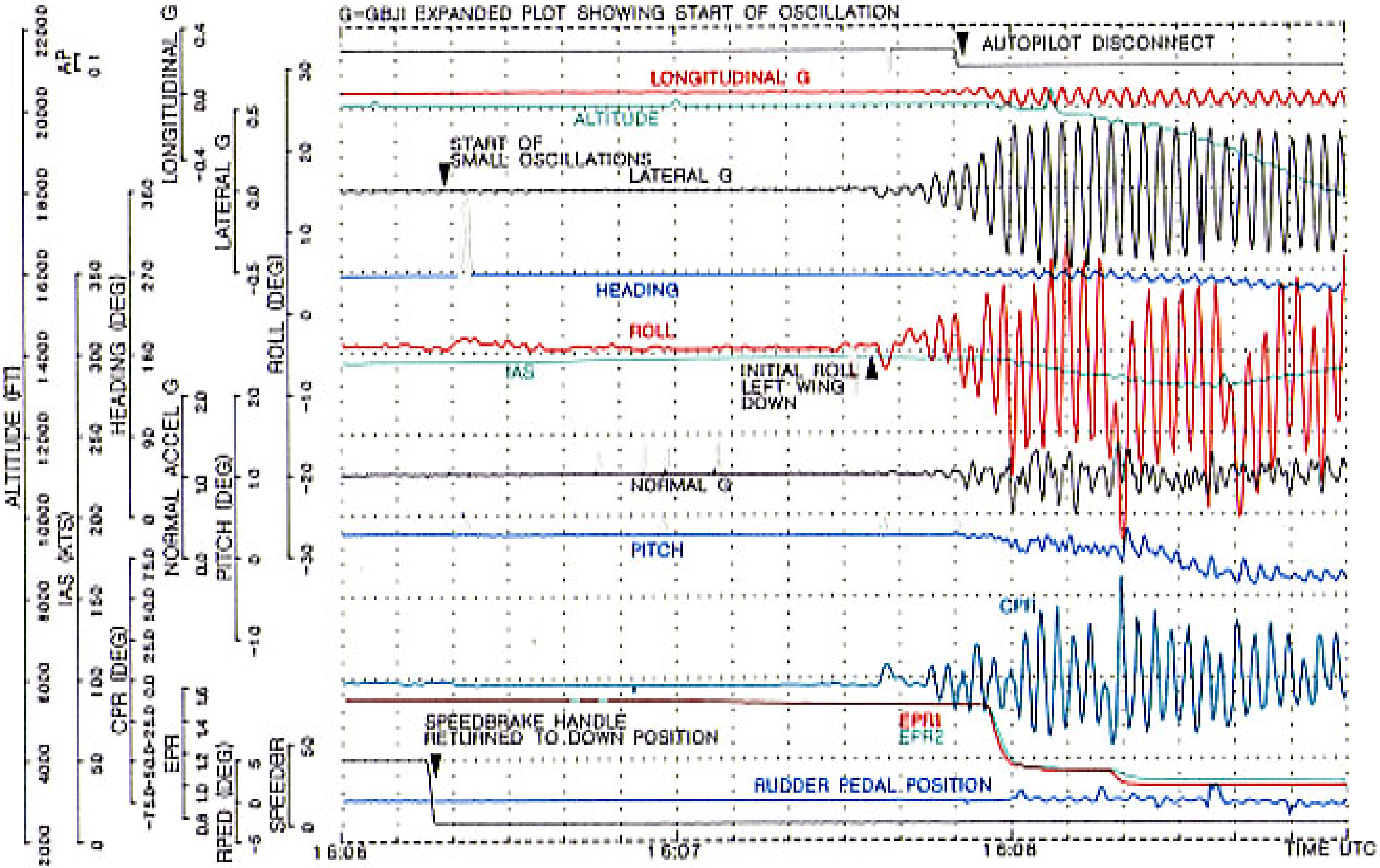


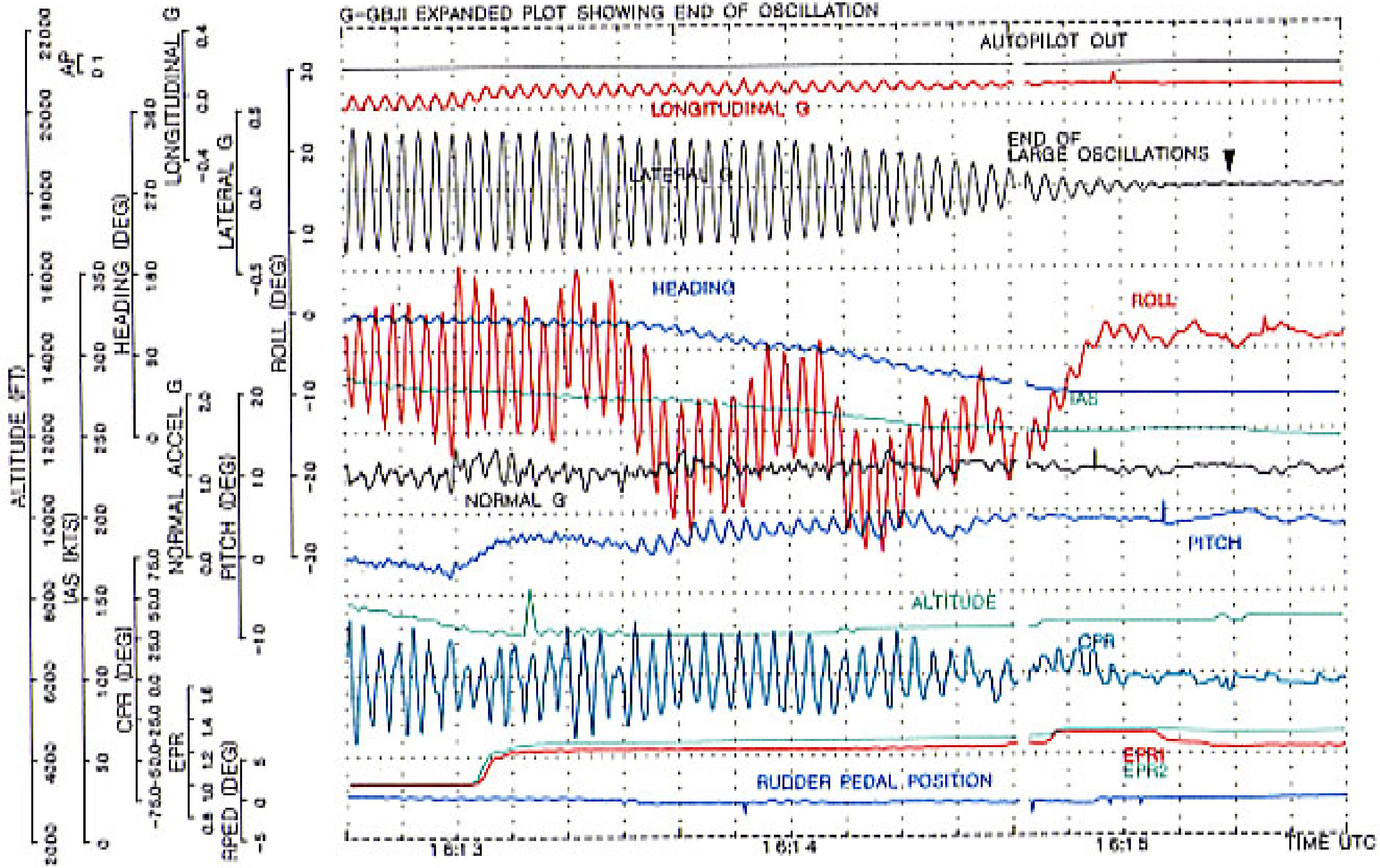
Side elevation of forward fuselage showing location of E&E Bay (shroud and waste drain line omitted for clarity)



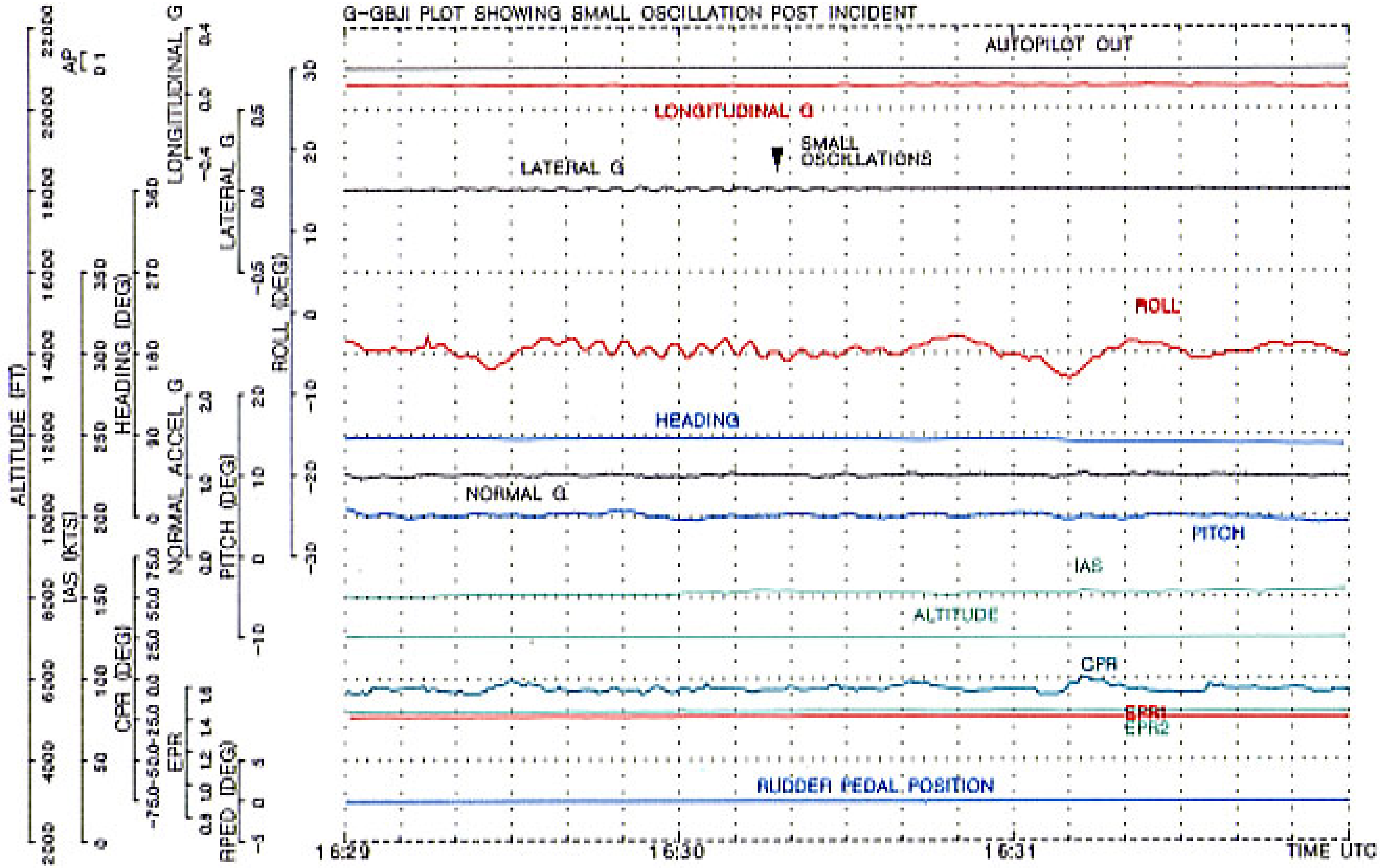
APPENDIX 3
FIGURE 1

Appendix 3
Figure 2



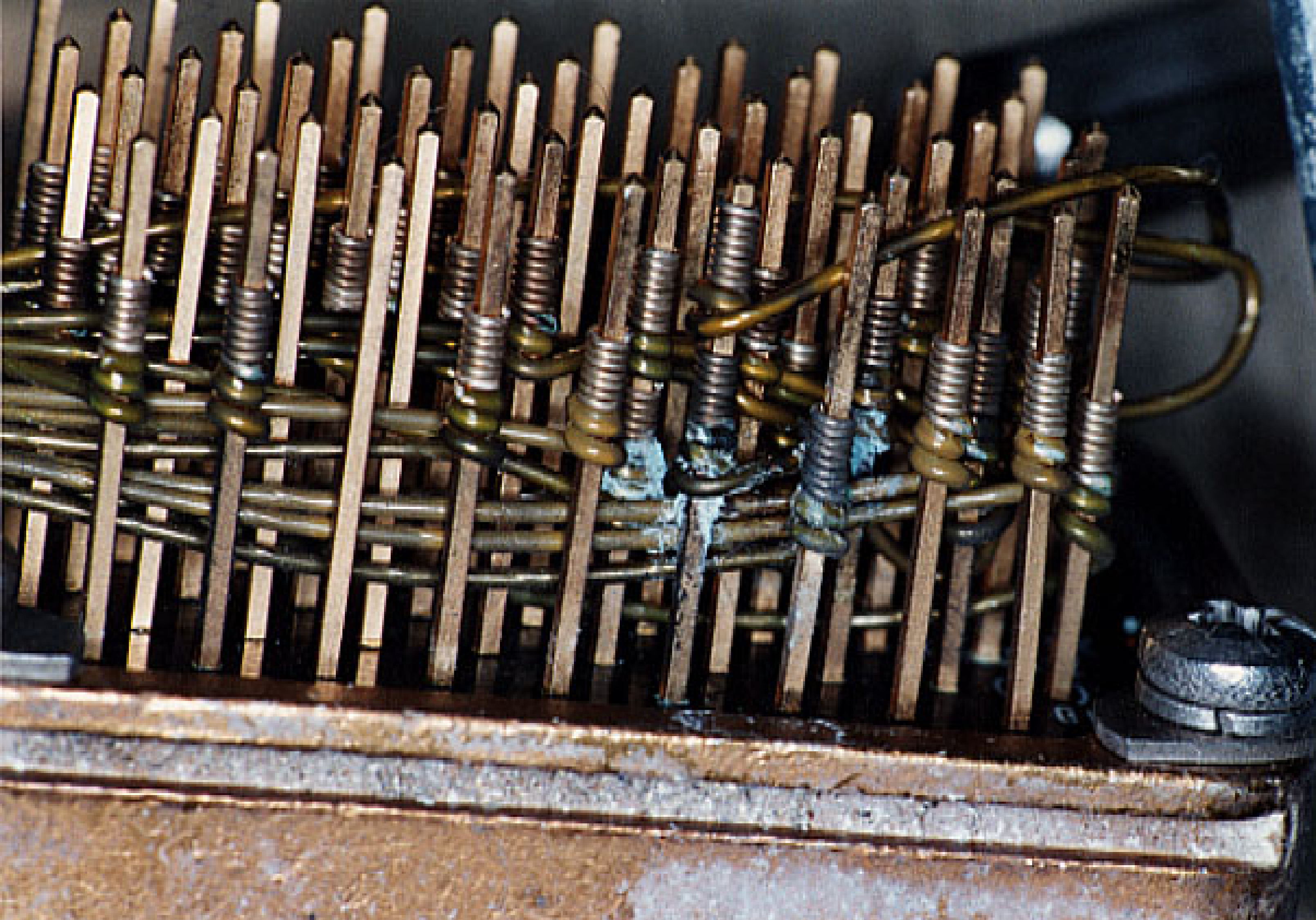


APPENDIX 3
FIGURE 3



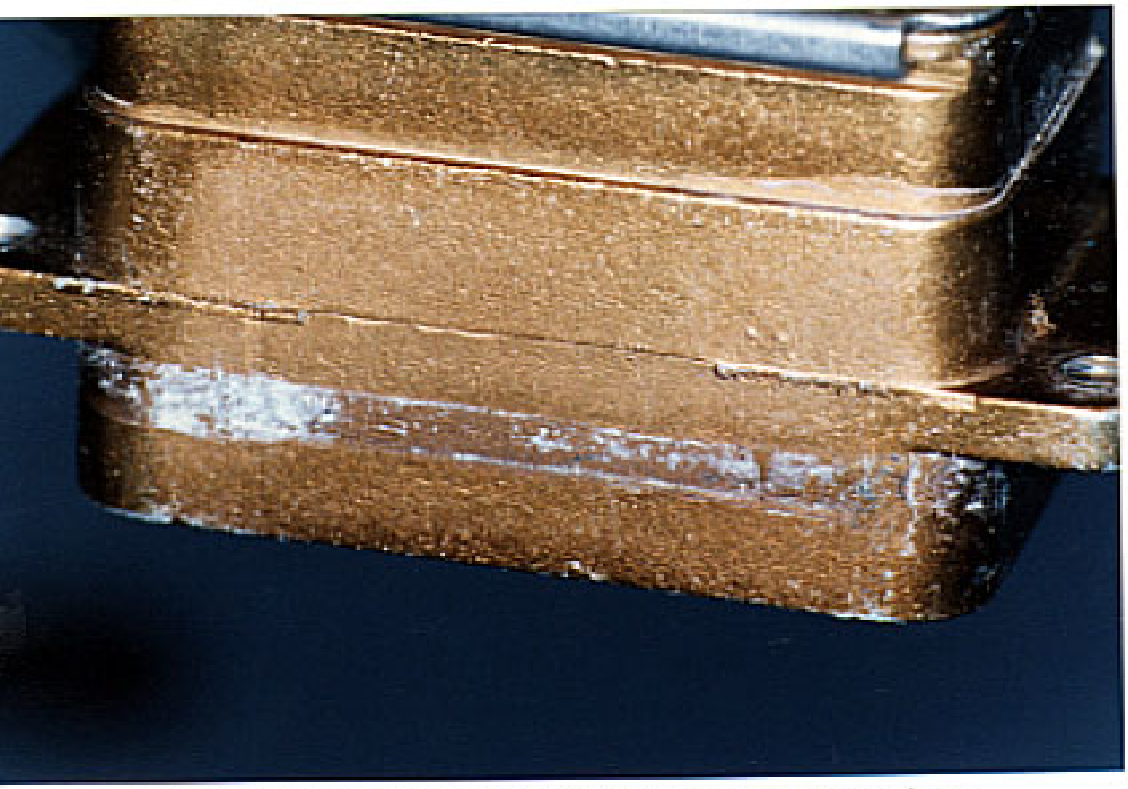
APPENDIX 3
FIGURE 4

APPENDIX 4
FIGURE 1



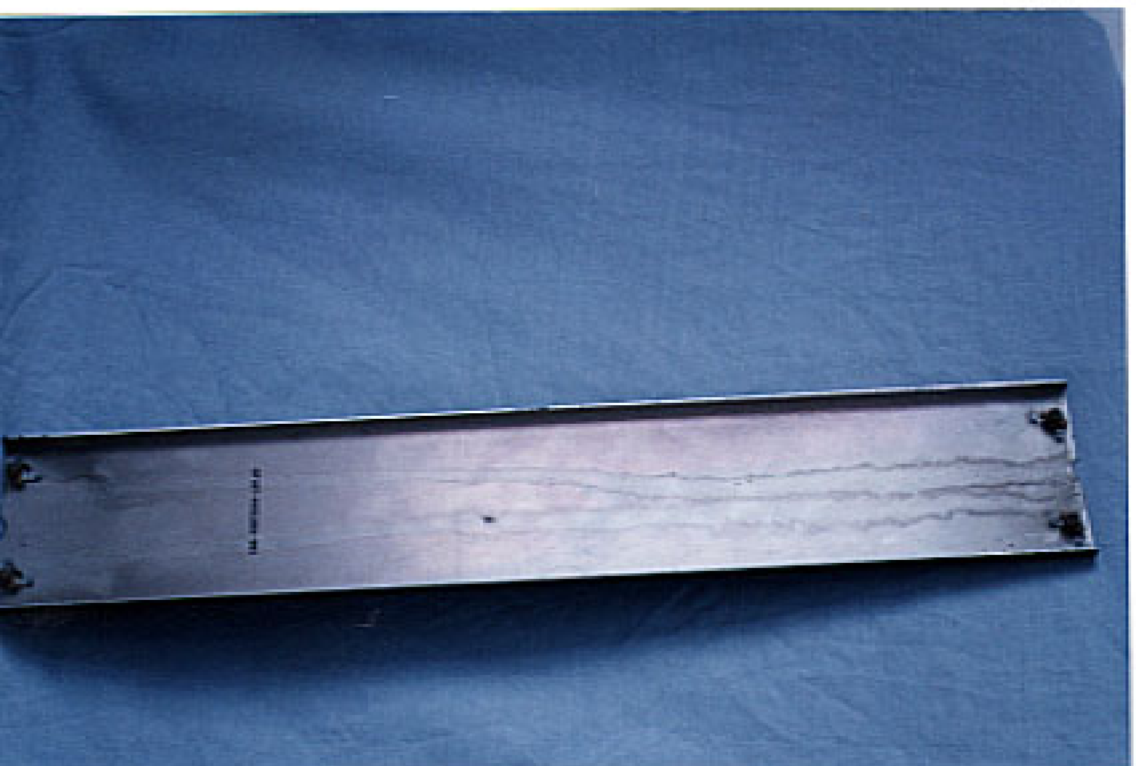
Close-up view of terminal posts at the back of Yaw Damper Coupler connector
showing accumulation of electrolytic/corrosion deposits around wire-wrapped joints

APPENDIX 4
FIGURE 2

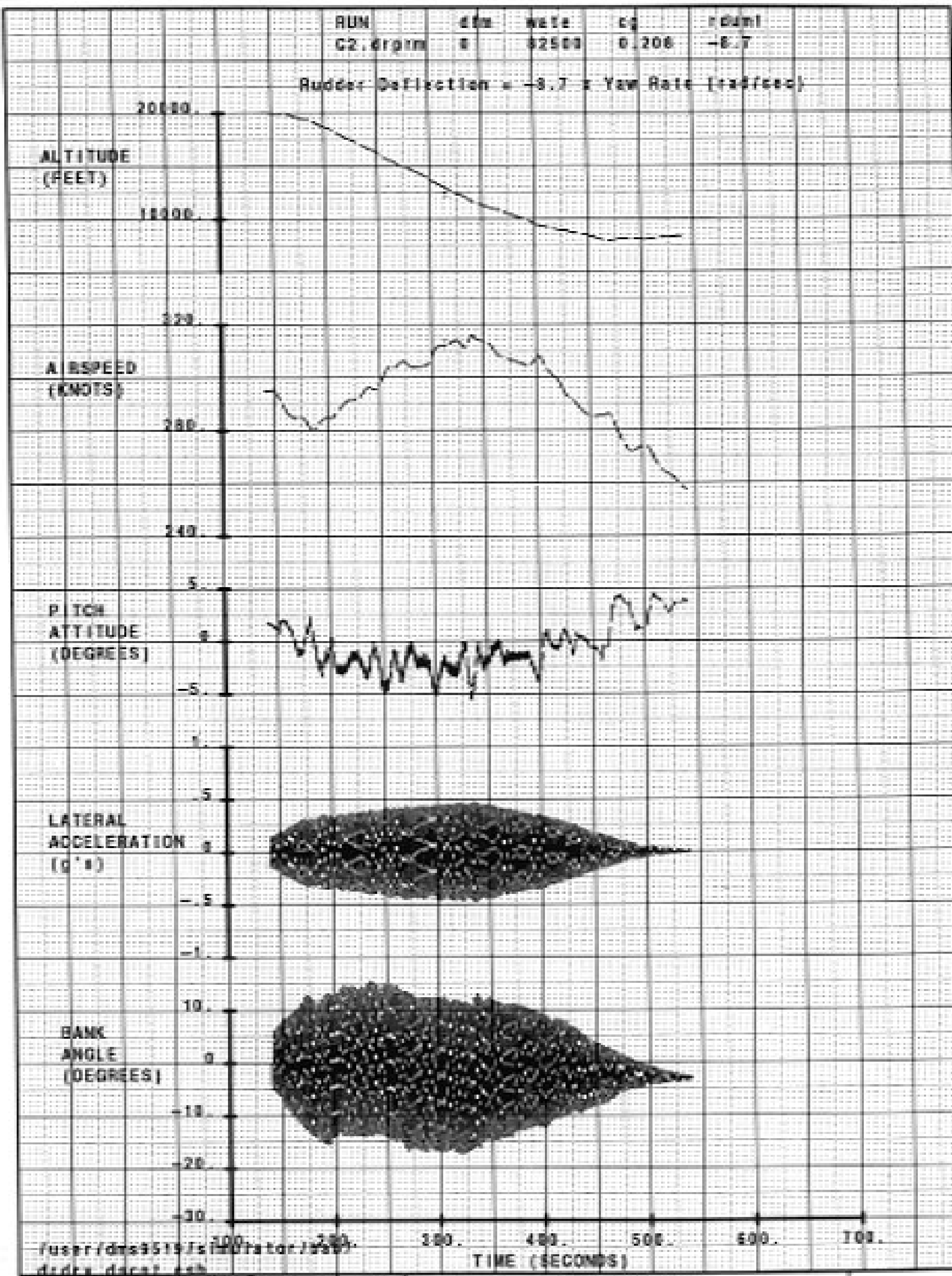


View of YDC connector shell showing evidence of dry corrosion products on exterior surface

APPENDIX 4
FIGURE 3



View of YDC lower cover plate showing evidence of dried fluid runs on the inner face



CALC		28OCT95	REVISED	DATE	SIMULATOR DATA BRITISH AIR DUTCH ROLL OSCILLATORY RUDDER INPUT GAIN = -6.7	737-236
CHECK						P8775
APR					THE BOEING COMPANY	PAGE
APR						

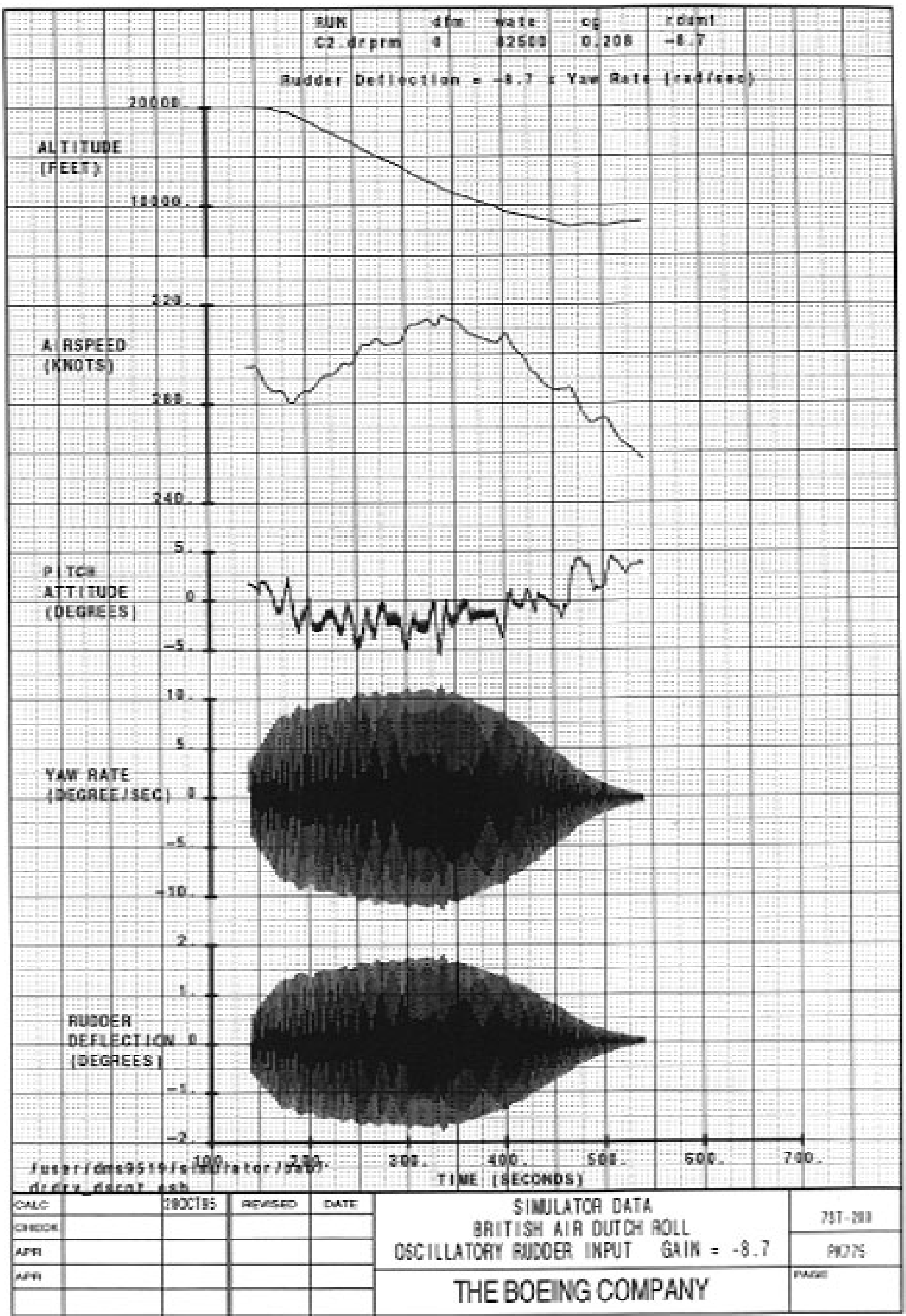
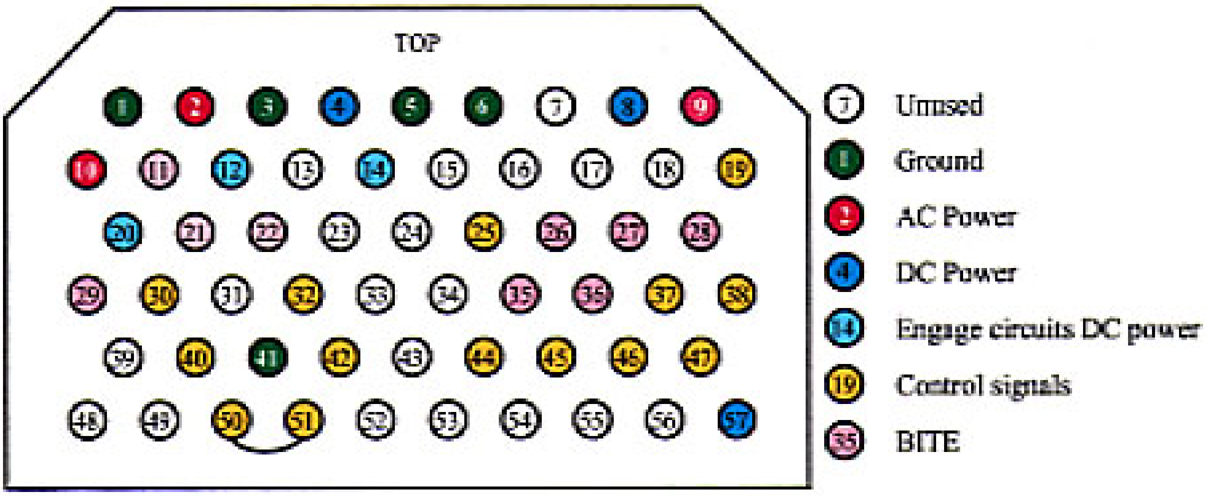

ALTITUDE (FEET)
AIRSPEED (KNOTS)
PITCH ATTITUDE (DEGREES)
YAW RATE (DEGREE/SEC)
RUDDER DEFLECTION (DEGREES)
TIME (SECONDS)
SIMULATOR DATA
BRITISH AIR DUTCH ROLL
OSCILLATORY RUDDER INPUT GAIN = -8.7
THE BOEING COMPANY

Figure 1a Geometric layout of pins in connector D295



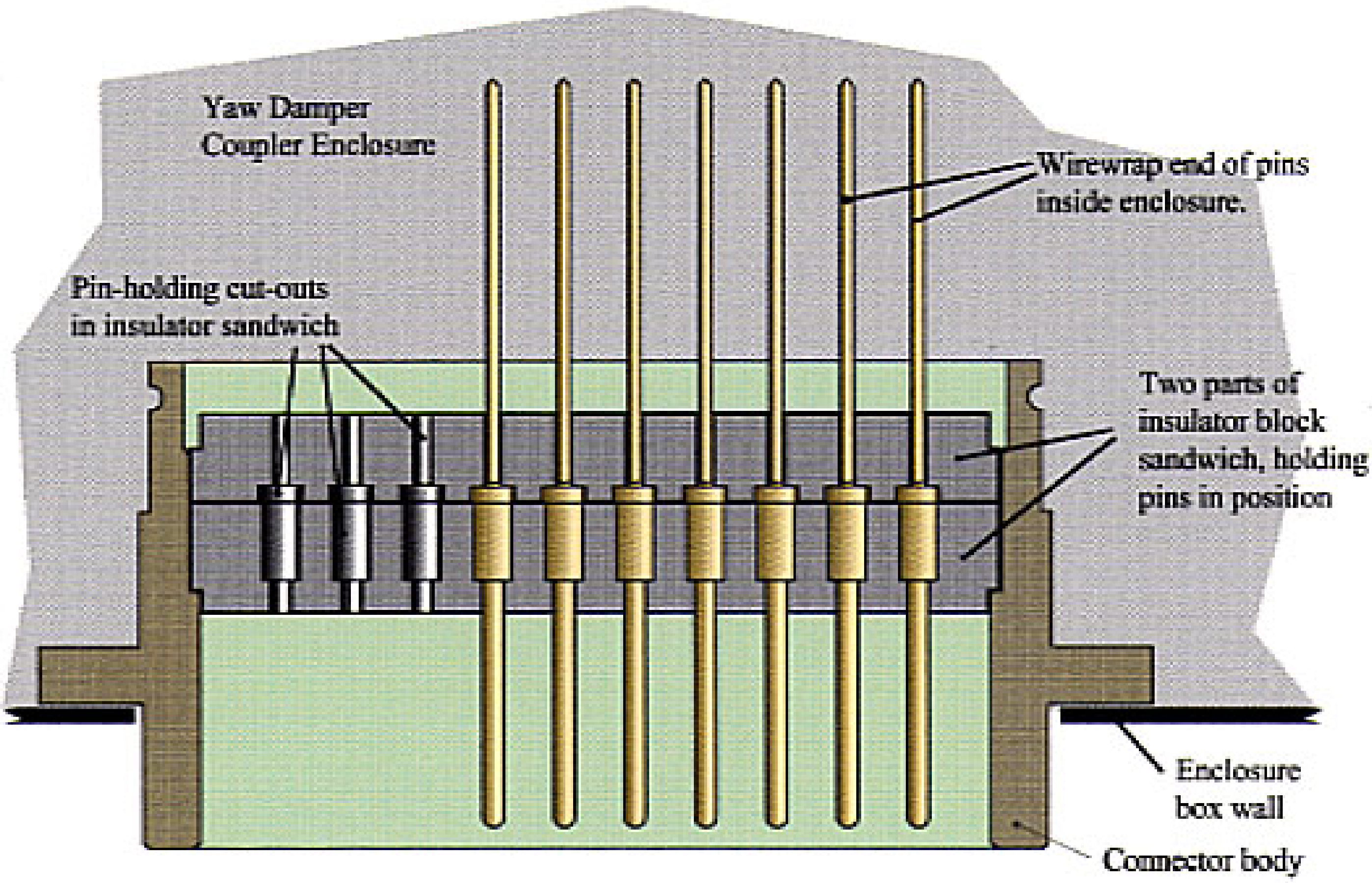
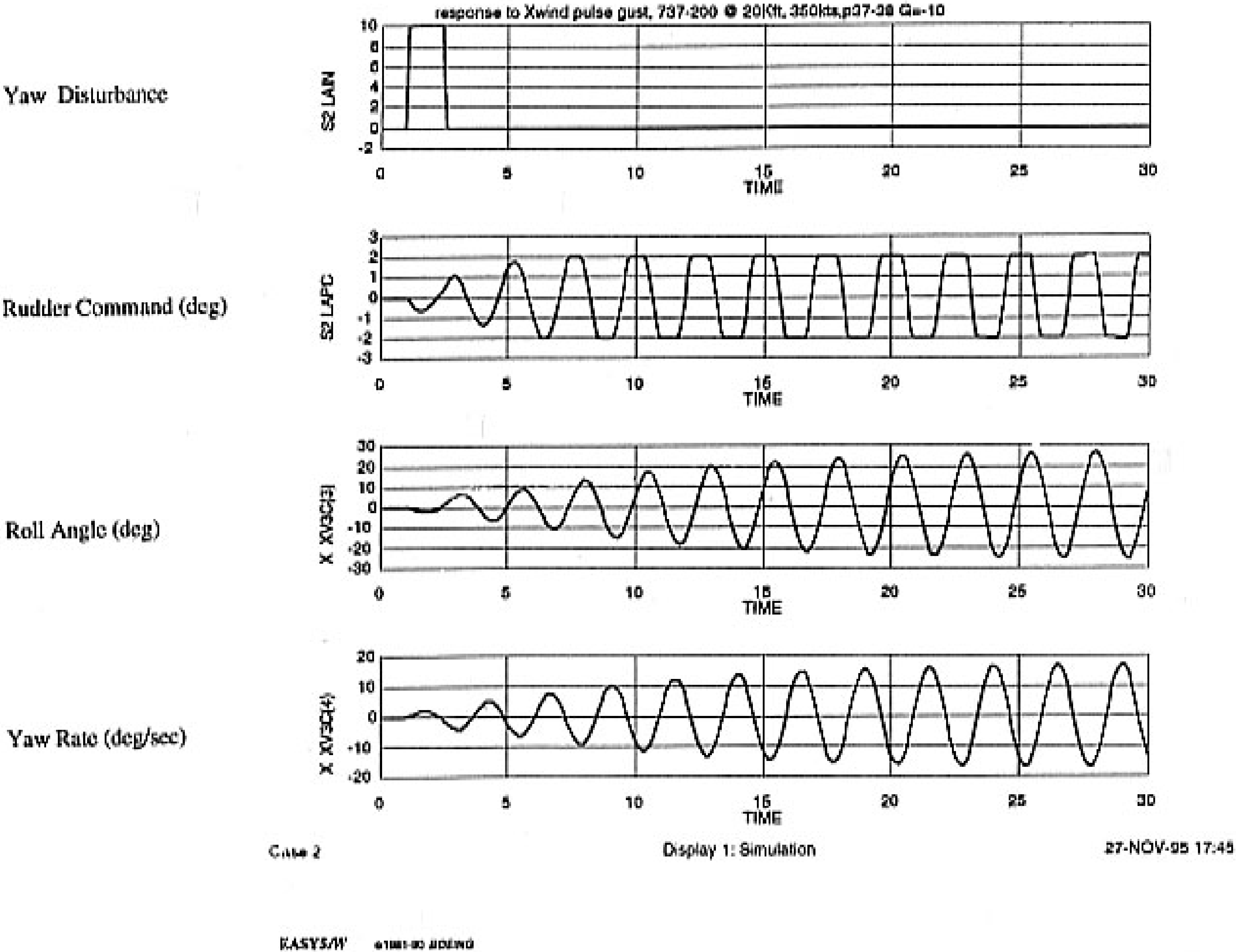
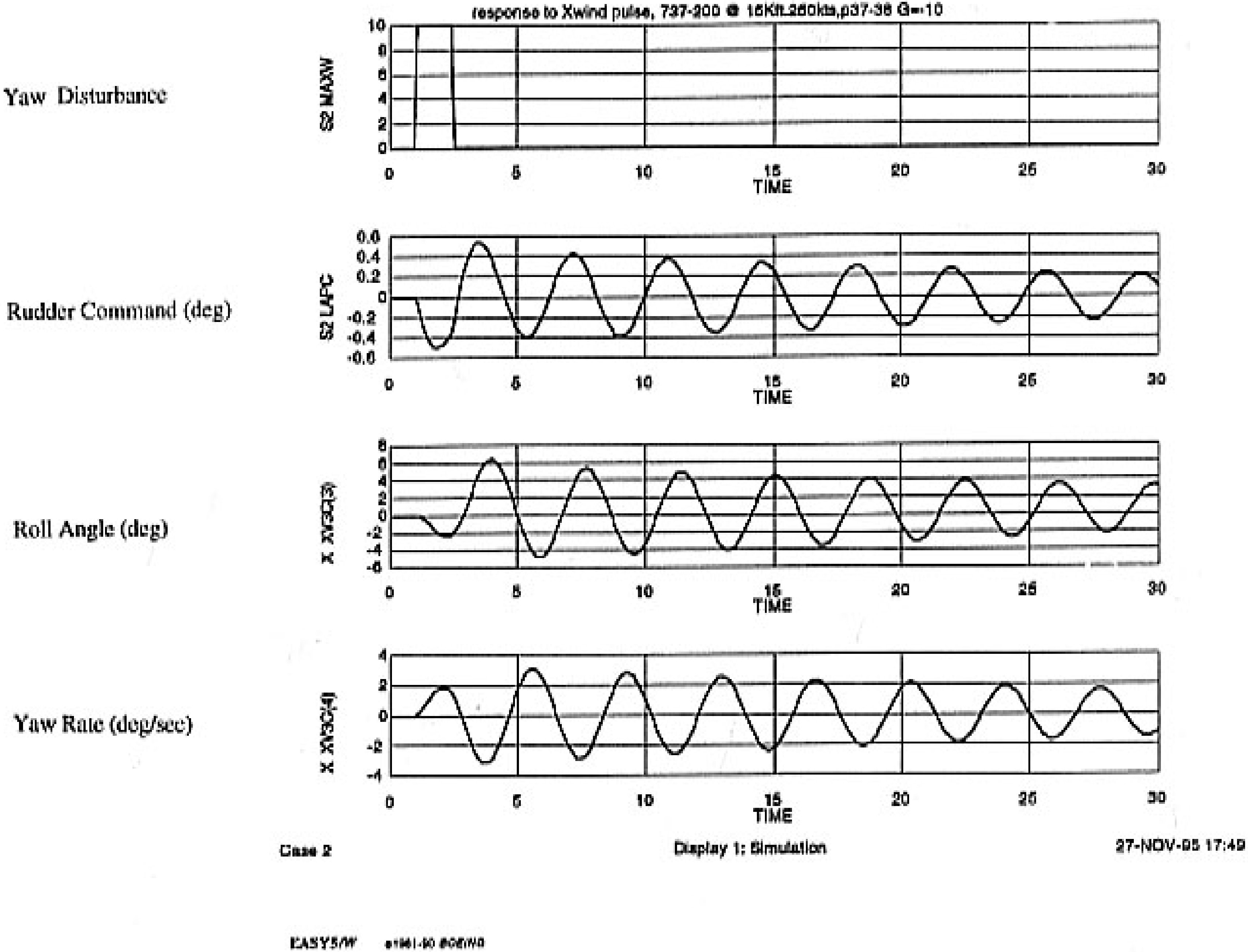


Figure 1b Cross section through a line of pin holes of connector D295 showing assembly.



APPENDIX 6
FIGURE 2



APPENDIX 6
FIGURE 3

Boeing 737-236 Advanced, G-BGJI: Appendix 7

Aircraft Incident Report No: 1/98 (EW/C95/10/4)

Report on the incident to Boeing 737-236 Advanced, G-BGJI 15 nm north-west of Bournemouth International Airport on 22 October 1995

APPENDIX 7

PIN TO PIN SHUNT ANALYSIS

Extract from: Yaw Damper Coupler Connector - Fluid Contamination Analysis (Boeing Reference Enclosure 1 to B-B600-15718-ASI) Figure 4 Pin-to-Pin Shunt Analysis

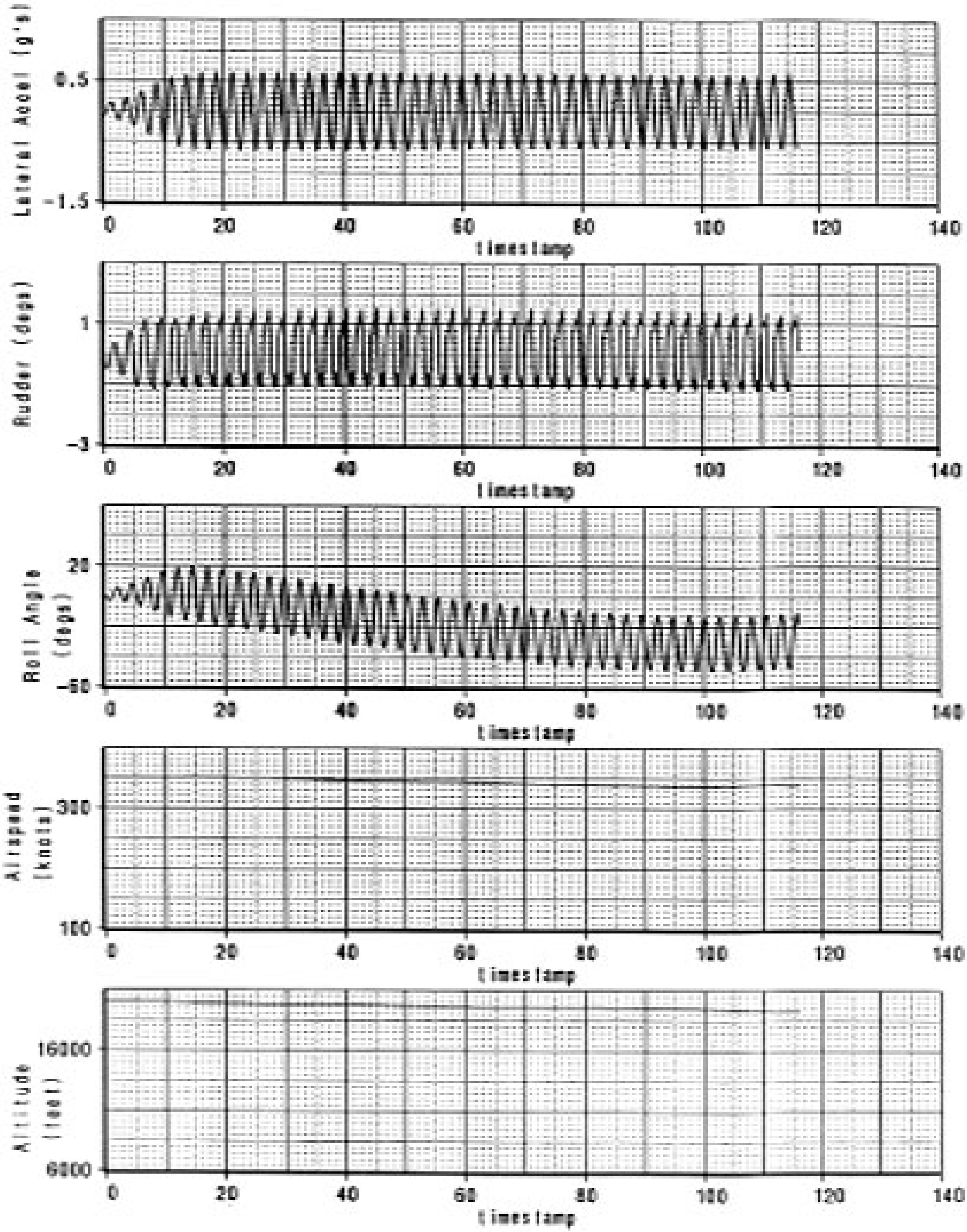
NB Bold Typeface denotes combinations which were simulated in both the computer EASY 5 model, and the M-Cab testing.

Pin-to-pin Shunt	Additional Facts/Assumptions	System Effects
1-2, 1-10, 2-3	Photos show that the fluid had little if any contact with these pins. If the fluid had contacted these pins, it is believed that a circuit breaker would have tripped or the fluid would have evaporated almost instantaneously.	No effect
2-12	AC signal will not affect the DC engage function	No effect
3-12	Photos show that a fluid path may not have been established	Will pull down voltage on 12. If pull down is large, system will disengage
3-4	Pin 4 has two wires connected to it. The bottom wire which was closest to the fluid provides a direct path to pin 12. The top wire provides a direct path to pin 3. It is assumed that all fluid was conducted along the bottom wire to pin 12 and away from the top wire and pin 3. If the fluid had made a path between 3 and 4 it is likely that a circuit breaker would have tripped or the fluid would have evaporated almost instantaneously.	No effect
4-5	The photos show that it is unlikely	No effect

	that a fluid path was established between these pins.	
4-14	A shunt here would have allowed 28V DC to be connected directly to the output of the yaw damper disengage switch.	No effect if the system was engaged. Circuit Breaker C286 would trip or the fluid path would evaporate almost instantaneously if the system was disengaged.
4-12	These pins are not adjacent, however the wire wrapped to pin 4 take a path that directly contacts with pin 12. Because it is believed that this area was saturated with fluid. It is also believed that a low impedance path existed between these pins.	This could keep the output of the coupler engage signal in an engaged state (assuming the engage signal is allowed to 'float', not forced to ground when pin 14 is grounded). This would cause the relay in the Autopilot Accessory Unit to remain in the engaged state
Pin-to-pin Shunt	Additional Facts/Assumptions	System Effects
5-6, 8-9	The photos show that it is unlikely that a fluid path was established between these pins.	No effect
9-19	Pin 9 carries the 400 Hz 26v ac excitation for the LVDT. Rate gyro signal is also 400 Hz	Full yaw damper command
10-20	Pin 10 is the 400 Hz, pin 20 the DC engage signal	No effect
20-30	Pin 30 is the servo valve ground pin. The photos show it is unlikely that a fluid path was established between these pins.	A low impedance shunt would disengage the system.
30-40, **40-41,** **41-42**		**A shunt here would produce an attenuation of the Q-pot gyro signal thereby reducing further the ability of the coupler to provide control. It would not be sufficient in itself to cause this incident.**
40-50, 42-51		Changes the gain characteristics of the rate gyro path but does not produce a gyro signal sign change which is believed to be necessary to reproduce the incident.
50-51	These pins are electrically equivalent.	No effect
41-50, 41-51		A shunt here would attenuate the signal to the washout filter thereby reducing the ability of the coupler to provide control. It would not be sufficient in itself to cause this incident.

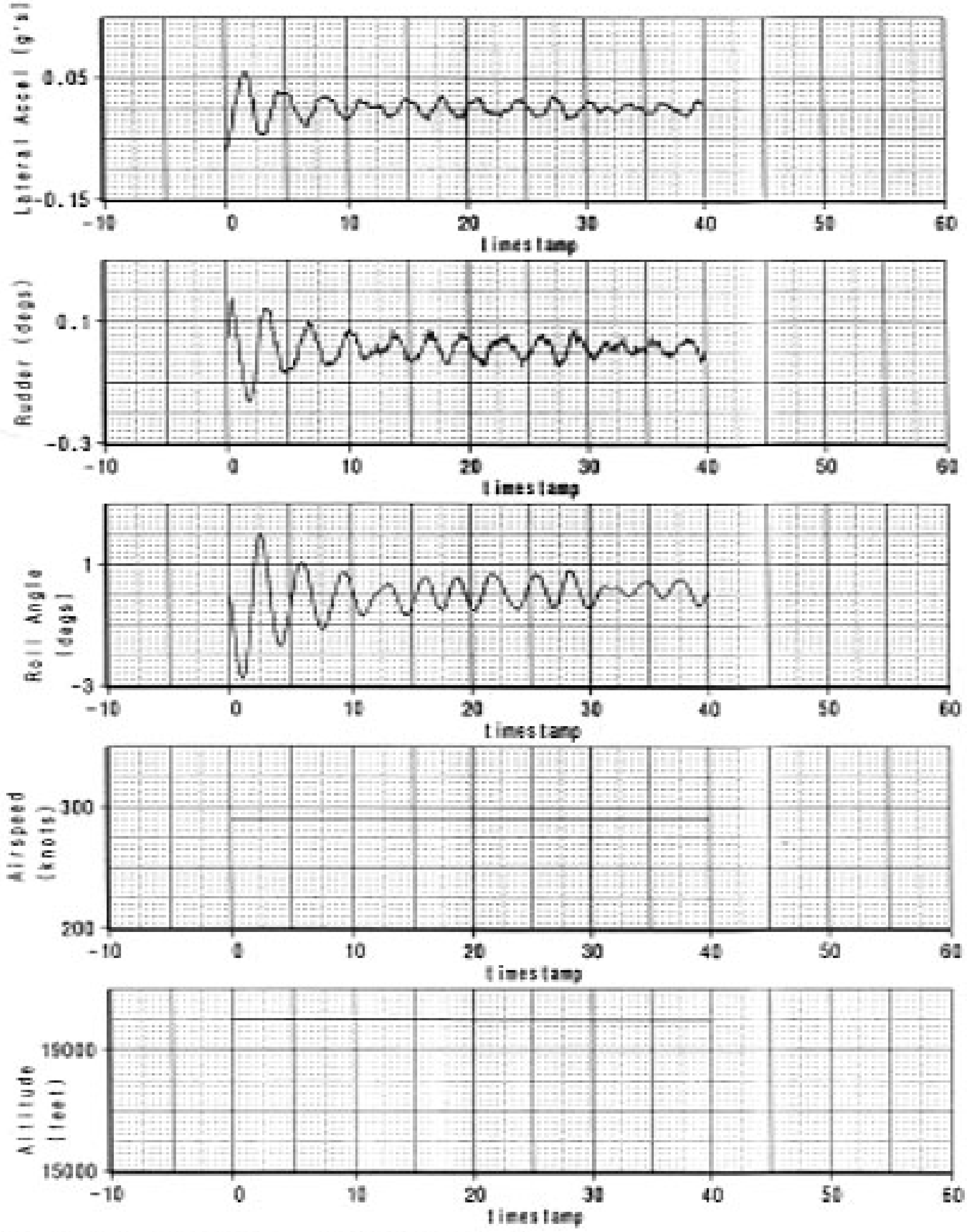
32-41		A shunt here would attenuate the signal to the PCU T-valve thereby reducing further the ability of the coupler to provide control. It would not be sufficient in itself to cause this incident.
32-42		A shunt here changes the gain of the gyro signal to the coupler valve amplifier but does not produce a gyro signal sign change which is believed to be necessary to reproduce the incident.
44-45		No effect
45-46		A shunt here appears to add a low gain positive feedback path to the LVDT feedback signal. It is possible that it could raise the overall gain of the feedback signal which should not be a problem. Detailed circuit analysis would be required to make a more definitive evaluation or a lab test simulating the shunt.
37-46, 37-47	Pins 46 and 47 are 400 Hz signals being summed into the servo loop	No effect
37-38	**This establishes a path from the output of the rate gyro demodulator directly into the servo loop summing junction. The normal rate gyro signal path applies a sign change (180° phase shift) to the gyro signal prior to the summing junction so that the rudder motion is applied in a direction which would counter the yaw rate. This shunt however bypasses the sign change, feeding a gyro signal into the summing junction which is in phase with the yaw rate.**	**A high impedance shunt would most likely produce an instability given the magnitude of the feedback resistance at the summing junction. Further evaluation should be possible using an EASY 5 computer simulation.**
38-47	Pin 47 is a 400 Hz signal	No effect should be seen if the Pin 47 signal is injected at pin 38 as it is introduced downstream of the rate gyro modulator. Conversely, however of the pin 38 signal is injected into the LVDT demodulator, then it may serve to oppose or even cancel (depending on the magnitude of the shunt) the LVDT signal producing an effect similar to the open feedback. This could be confirmed with a lab test.
46-47		**A shunt here serves to attenuate the feedback signal. This would ultimately leads to the open feedback condition where the system oscillates**

		at a frequency of 0.8 Hz.
46-57	Pin 46 is a 400 Hz signal and pin 57 is a DC engage signal.	No effect



[A]: /acct/smw0585/pk775_m_cab/ydbab_121295.esb C17.swe?

CALC.	S.White	15Dec95	REVISED	DATE	PK775 – M Cab studies Test Case 17 from Tues 12/12/95 30kohm across Pins 37/38	
CHECK						
APPD.						
APPD.					BOEING	PAGE



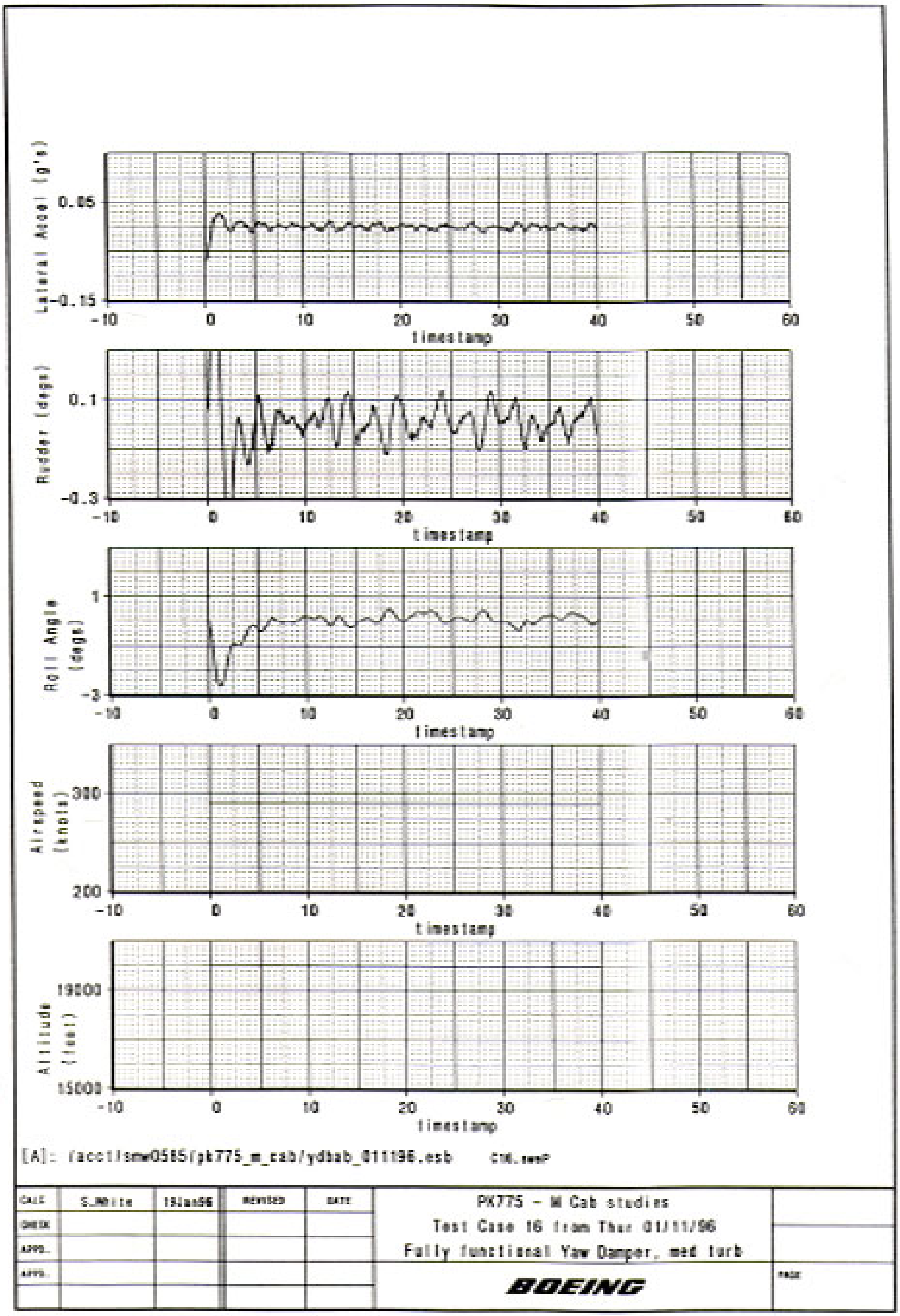
[#]: /acct/smw0585/pk775_m_cab/ydbsb_011196.esb C10.swmP

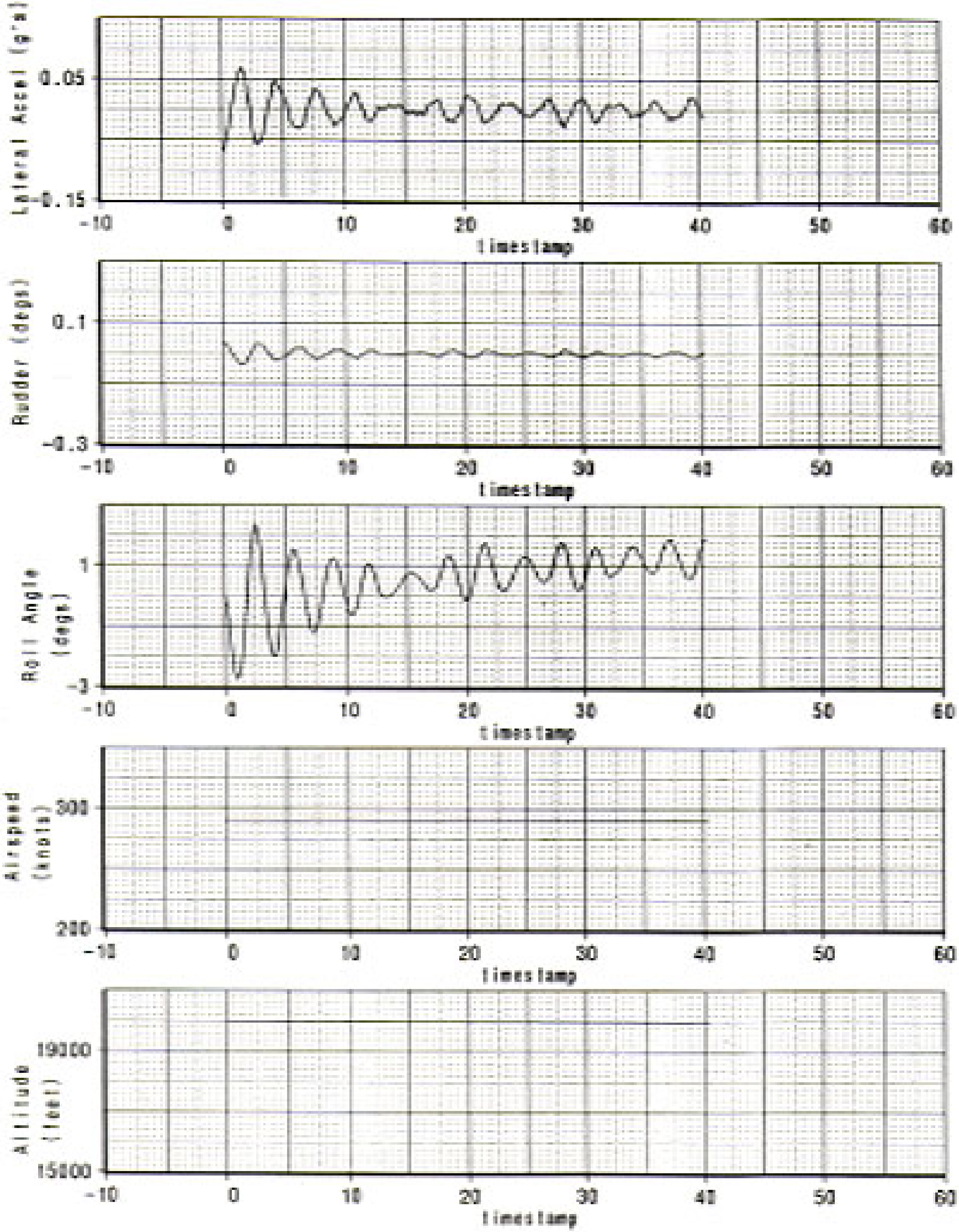
CALC	S.White	19Jan96	REVISED	DATE
CHECK				
APPR.				
APPR.				

PK775 - M Cab studies
Test Case 10 from Thur 01/11/96
230kohm across 40/51, med turb

BOEING

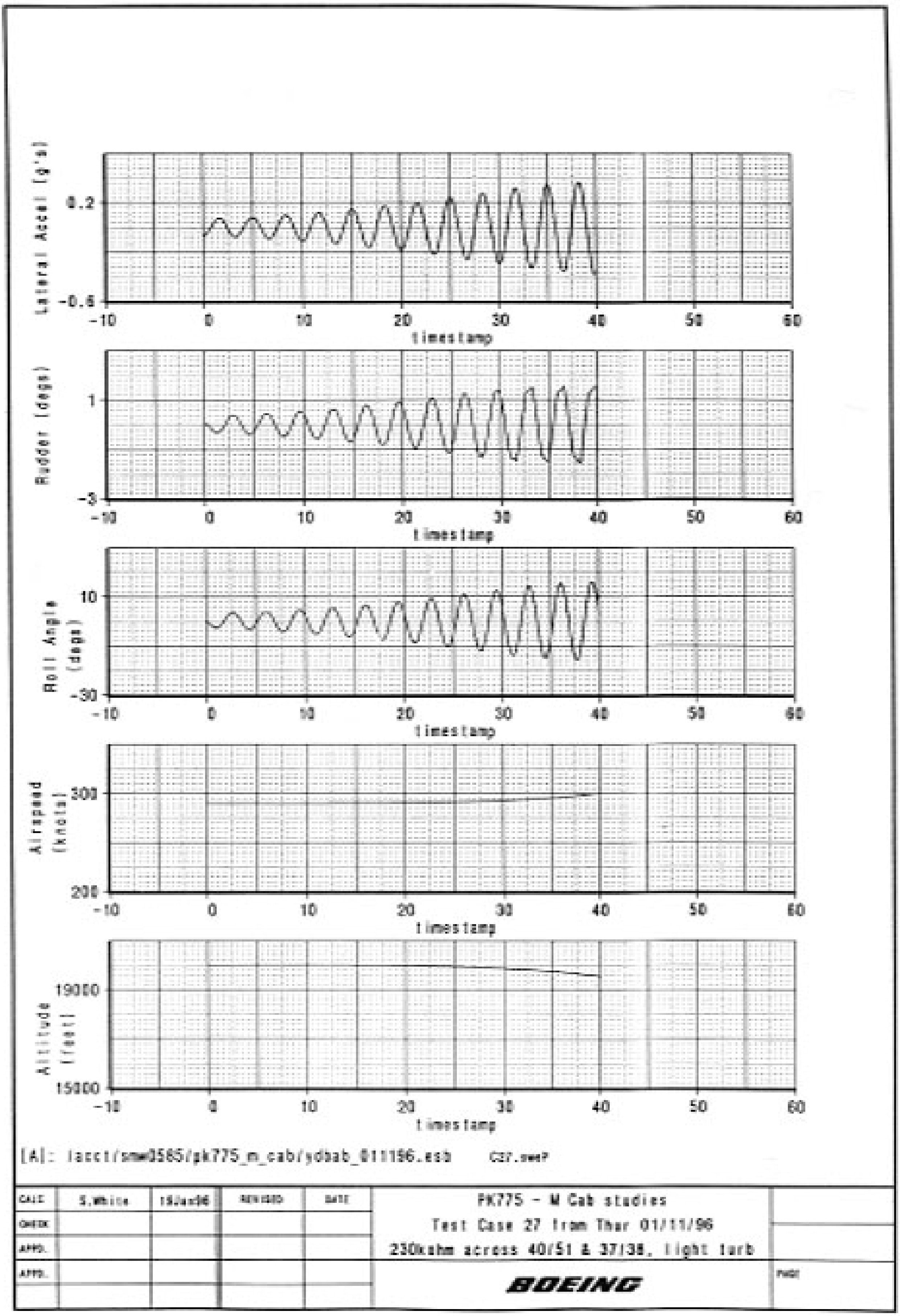
PAGE

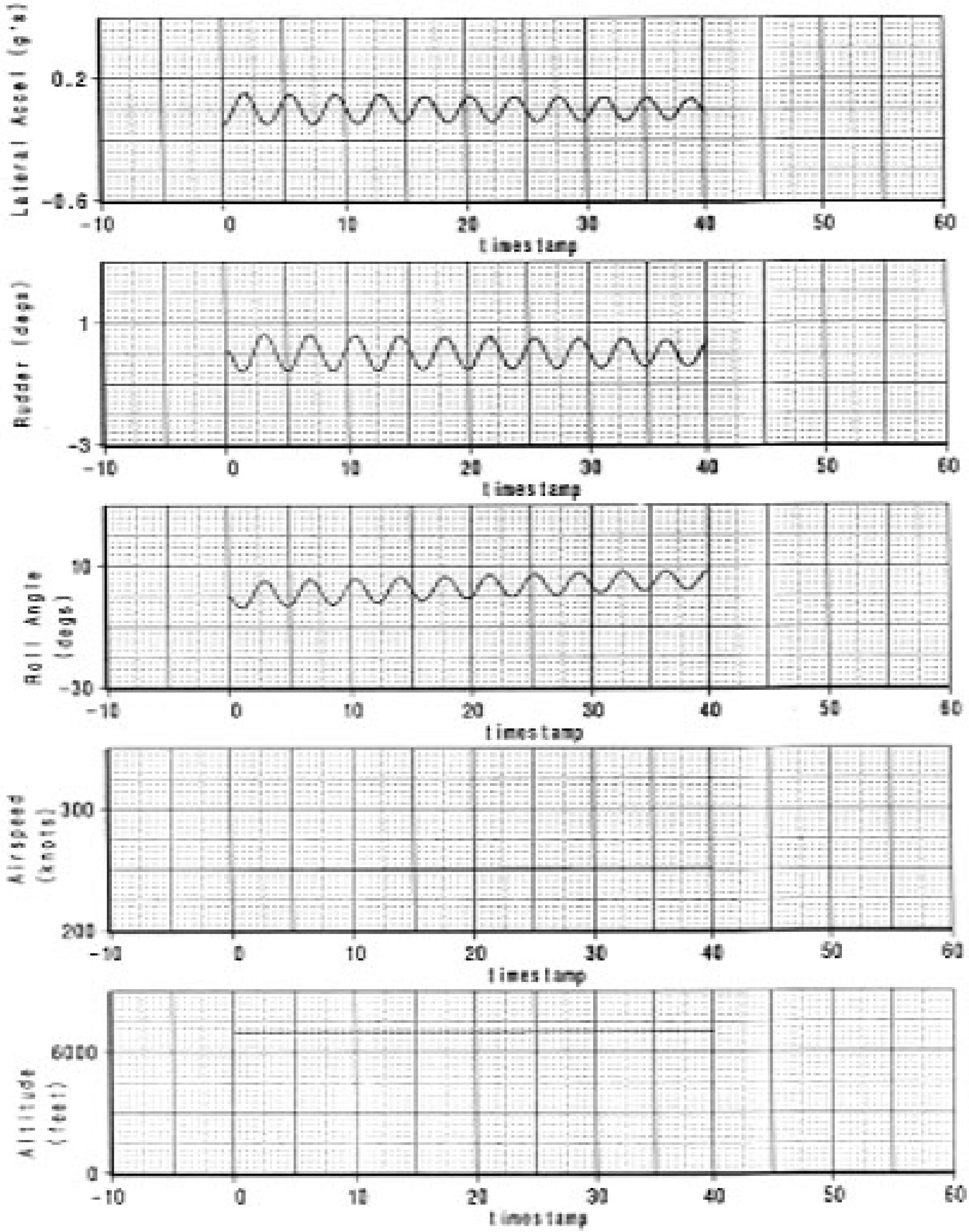

Lateral Accel (g's)
0.05
-0.15
Rudder (degs)
0.1
-0.3
Roll Angle (degs)
1
-3
Airspeed (knots)
300
200
Altitude (feet)
19000
15000
-10 0 10 20 30 40 50 60
timestamp
[A]: /acct/smw0585/pk775_m_cab/ydbab_011196.esb
CALC S_White 19Jan96 REVISED DATE
CHECK
APPD.
APPD.
PK775 - M Cab studies
Test Case 16 from Thur 01/11/96
Fully functional Yaw Damper, med turb
BOEING
PAGE



[A]: /acct/smw0585/pk775_m_cab/ydbab_011196.esb C2.swePs

CALC	S.White	19Jan96	REVISED	DATE	PK775 - M Cab studies Test Case 2 from Thur 01/11/96 Yaw Damper OFF, med turb BOEING
CHECK					
APPD.					
APPD.					PAGE


Lateral Accel (g's)
0.2
-0.6
timestamp
Rudder (degs)
1
-3
Roll Angle (degs)
10
-30
Airspeed (knots)
300
200
Altitude (feet)
19000
15000
-10 0 10 20 30 40 50 60
[A]: /acct/smw0565/pk775_m_cab/ydbab_011196.esb
CALC. S.White 19Jan96
REVISED
DATE
CHECK
APPD.
APPD.
PK775 - M Cab studies
Test Case 27 from Thur 01/11/96
230kohm across 40/51 & 37/38, light turb
BOEING
PAGE



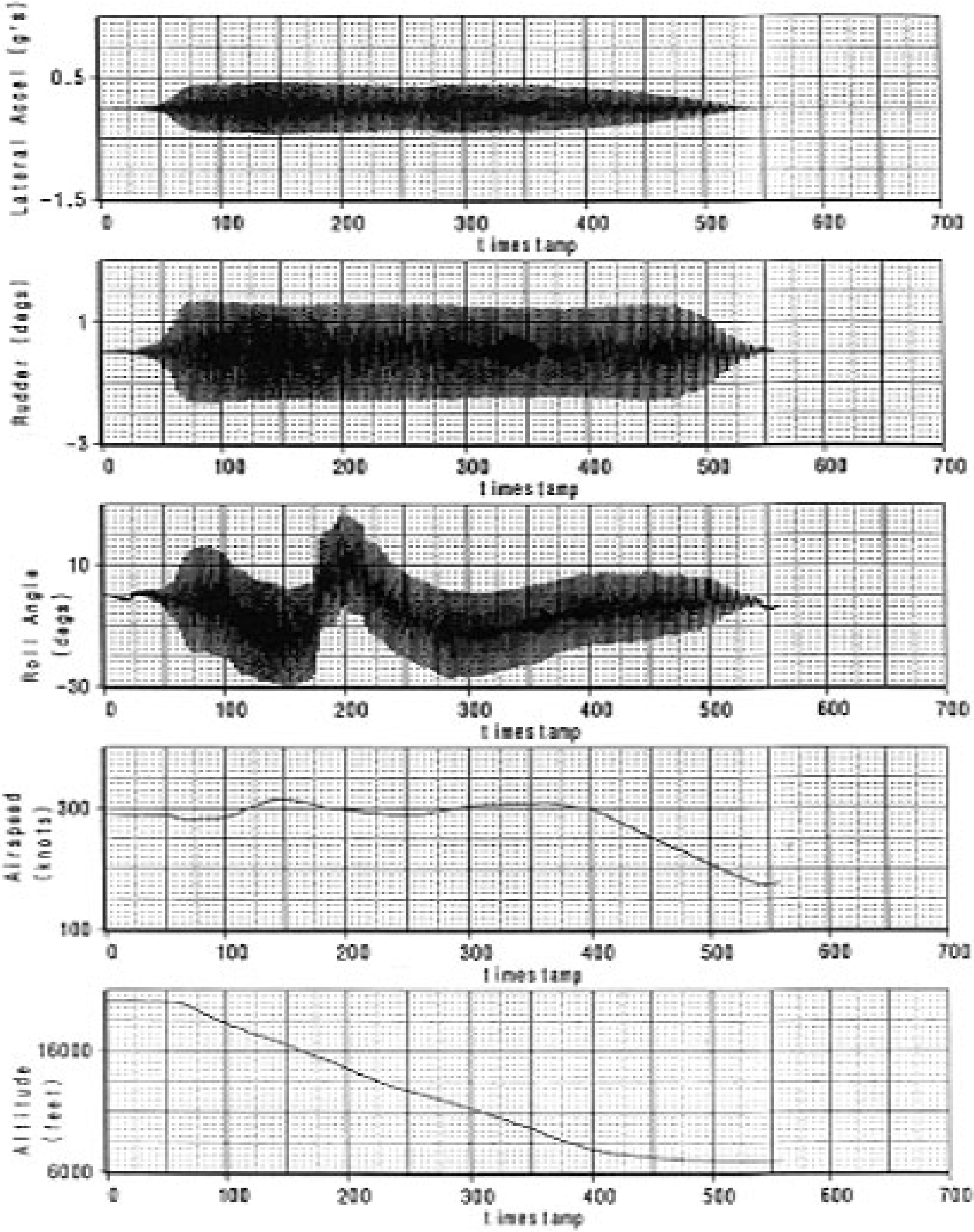
[A]: facct/smw0585/pk775_m_cab/ydbab_011196.esb C33_swmP

CALC	S_White	15Jan96	REVISED	DATE
CHECK				
APPD.				
APPD.				

PK775 - M Cab studies
Test Case 33 from Thur 01/11/96
230kdhm across 40/51 & 37/38, light turb

BOEING

PAGE



[A]: /acct/smw0585/pk775_m_cab/ydbab_121395_2.esb C78.swef

CALC	S.White	18Dec95	REVISED	DATE	PK775 - M Cab studies Test Case 78 from Wed 12/13/95 Pins 40/51 & 37/38, 200k & 200k, low turb
CHECK					
APPD.					
APPD.					BOEING
					PAGE

THE BOEING COMPANY, SEATTLE, WASHINGTON 98124

NUMBER: GUI(C/K/L)-15

DATE : August 4, 1995

SUBJECT: UNCOMMANDED YAW OR ROLL PROCEDURE

REASON : To inform flight crews of the revised UNCOMMANDED YAW Procedure, to change the title and to provide additional guidance when accomplishing the procedure.

Information in this bulletin is recommended by The Boeing Company, but may not be FAA approved at the time of writing. In the event of conflict with the FAA approved Airplane Flight Manual (AFM), the AFM shall supersede. The Boeing Company regards the information or procedures described herein as having a direct or indirect bearing on the safe operation of this model aircraft.

THE FOLLOWING PROCEDURE AND/OR INFORMATION IS EFFECTIVE UPON RECEIPT

BACKGROUND INFORMATION

As a result of numerous customer inquiries regarding the appropriate pilot response to uncommanded yaw or roll, the following procedure enhancement and background information are provided.

Apparent uncommanded yaw or roll can be caused by a variety of events, normal and non-normal. Normal events may include autopilot attempts to maintain course guidance and aircraft attitude during FMC position updates and autopilot approach course intercept. Non-normal events might include wake turbulence, adverse weather, flight control malfunctions, split throttles, engine power loss, yaw damper and autopilot malfunctions.

All aircraft, especially swept wing aircraft, exhibit an aerodynamic characteristic called Dutch Roll. Dutch Roll is a combination of yaw and roll. Active yaw damper systems prevent minor yaw disturbances from developing into Dutch Roll.

The 737 will dampen out any Dutch Roll motion naturally without an active yaw damper. The Yaw Damper on the 737 is designed to improve ride quality and is not required for dispatch. The Yaw Damper is limited to 3 degrees rudder deflection for the 737-300/-400/-500 and 2, 3 or 4 degrees (as installed) for the 737-100/-200. These are the physical limits of the yaw damper actuator. Yaw Damper commands are not fed back to the rudder pedals.

The 737 yaw damper system has three failure modes. First, the system can fail and not provide commands to deflect the rudder. Because there is no resulting movement in any aircraft axis, there are no special techniques for this condition. If the YAW DAMPER Light on the overhead panel is illuminated, accomplish the YAW DAMPER procedure.

In a second failure mode the yaw damper system gives commands that appear as an oscillation or erratic motion in the yaw axis. The Yaw Damper should be turned OFF in accordance with the UNCOMMANDED YAW OR ROLL procedure.

BACKGROUND INFORMATION (Continued)

The third failure mode occurs when the system commands a full yaw damper input. The aircraft responds with an initial yawing motion that may not be noticed by the crew, followed by a readily apparent rolling motion in the same direction as rudder deflection. The roll rate and roll acceleration are quicker than a normal autopilot input. Flight data shows that bank angles rarely exceed 10 degrees in the direction of rudder deflection. If engaged, the autopilot will respond with opposite aileron to counter the roll. At 0.74 Mach and at normal cruise altitudes, the autopilot may not be able to roll the aircraft back to wings level but will reduce the roll rate to 1-2 degrees per second, allowing the pilot ample time to recover. In the event of yaw damper system failure, turning the yaw damper system off will remove yaw damper commands to the rudder. Cross checking the YAW DAMPER Indicator will help identify a yaw damper malfunction. Accomplish the UNCOMMANDED YAW OR ROLL procedure.

Uncommanded roll can also be caused by a malfunction of the lateral axis of the autopilot. This malfunction is characterised by a control wheel deflection in the direction of the uncommanded roll with the autopilot engaged. In this case, the pilot should simultaneously disengage the autopilot and counter the roll input, bringing the aircraft to wings level and complete the UNCOMMANDED YAW OR ROLL procedure.

For uncommanded rolls not associated with an autopilot malfunction, the control wheel position will be opposite the direction of the uncommanded roll. In this case, the autopilot is attempting to oppose the uncommanded roll force. Allowing the control wheel to go to neutral after disengagement may allow the aircraft to roll even more in the uncommanded direction. The pilot should establish control of the aircraft by grasping and holding the control wheel firmly prior to disengaging the autopilot, make appropriate control wheel corrections to return to wings level and complete the UNCOMMANDED YAW OR ROLL procedure.

UNCOMMANDED YAW OR ROLL

Accomplish this procedure if uncommanded yaw or roll occurs in flight.

AUTOPILOT (if engaged) .... DISENGAGE

The pilot should be prepared to make control wheel corrections to return to wings level upon disengagement. The autopilot may be putting in an appropriate correction for an uncommanded yaw or roll. Allowing the control wheel to go to neutral after disengagement may allow the aircraft to roll even more.

If yaw and/or roll forces continue:

YAW DAMPER SWITCH .... OFF

The YAW DAMPER Light illuminates when the yaw damper is disengaged.

If it is confirmed that the autopilot is not the cause of the uncommanded yaw or roll, the autopilot may be re-engaged at the pilot's discretion.