INCIDENT

Aircraft Type and Registration:	Boeing 737-377, G-CELA
No & Type of Engines:	2 CFM56-3B2 turbofan engines
Year of Manufacture:	1986
Date & Time (UTC):	7 July 2006 at 2350 hrs
Location:	En-route from Newcastle Airport to Stansted Airport
Type of Flight:	Public Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	33 years
Commander's Flying Experience:	3,395 hours (of which 2,575 were on type) Last 90 days -122 hours Last 28 days - 50 hours
Information Source:	AAIB Field Investigation

Synopsis

During a climb to FL270 with autopilot 'B' engaged, the aircraft did not capture the selected altitude. The commander disconnected the autopilot and then experienced difficulty in accurately controlling the aircraft in pitch. He declared an emergency and was given radar vectors and an unrestricted descent to Stansted Airport, where he made a safe landing. The investigation revealed that a tripped circuit breaker for the autopilot stabiliser trim actuator had caused the failure of the aircraft to capture the selected altitude. No malfunction was found to explain the commander's difficulty in accurately controlling the aircraft in pitch.

History of the flight

The crew were on the third of a series of four flights. The previous two flights had been uneventful with no significant unserviceabilities, apart from a reported anomaly with the thrust reversers on landing at Newcastle Airport. The crew had reported that No 1 reverser had unlocked slightly before No 2 and that there had been no discernible 'spooling up' of the engines during the landing roll. Subsequent ground runs by engineers confirmed that the reverser system was operating correctly.

For the incident flight from Newcastle to Stansted, it had been agreed that the first officer would be the Pilot Flying (PF) and would fly the aircraft manually using the flight director. For takeoff, the aircraft weight was calculated as 48,423 kg with the CG at

17.6% Mean Aerodynamic Chord. The takeoff and climb, using autothrottle, was uneventful and the first officer levelled the aircraft at FL210 and then engaged autopilot 'B'. Shortly after, the aircraft was cleared direct to Manchester and to climb to FL270. As the aircraft approached FL270 with 'Lateral Navigation' (LNAV) and 'Vertical Navigation' (VNAV) selected, the first officer saw 'FMC SPD' and 'VNAV PATH' annunciate but was not aware of any change in aircraft attitude as it approached the selected level. She alerted the commander, who had been on the radio checking weather. He checked the level and saw that the aircraft was approximately 300 ft above the selected level and still climbing with the 'ALTITUDE ALERT' light illuminated. He disconnected the autopilot using his control wheel switch, disconnected the autothrottle and manually flew the aircraft back to FL270. Around this time, both crew members recalled seeing the 'STAB OUT OF TRIM' light illuminate for a few seconds but could not be certain whether it came on with the autopilot engaged or disengaged.

The commander was now flying the aircraft manually using the flight director but found that it was difficult to control in pitch and he could not seem to get the correct pitch trim position using either the electric or manual trim. During the rest of the flight, the commander did not attempt to re-engage either autopilot. He informed the first officer of his difficulties and, after a few minutes with no apparent improvement, informed Manchester ATC that he was having difficulty maintaining level flight. Shortly after, the commander declared a 'PAN' and asked for radar vectors towards Stansted Airport; he was very familiar with Stansted and had already set up the aircraft systems for an approach to Runway 23. During the subsequent descent, the commander was aware of feeling a vibration feeding back through the control wheel, mainly when he applied an aft force. Becoming increasingly concerned, he upgraded his emergency to 'MAYDAY' and asked for radar vectors to Runway 23.

Throughout the subsequent unrestricted descent, the commander used 'Level Change' (LVL CHG) and manual thrust to control his descent and noted that the aircraft appeared steady with a descent rate of about 1,000 ft/min. However, he was still aware of the vibration whenever he applied an aft force to the control wheel or increased thrust. He levelled the aircraft at 2,000 feet amsl and was still experiencing difficulties holding the aircraft level. The final ILS approach was flown at an approach speed of 140 kt with 'Flap 30'. During this final approach, the commander considered that the pitch controls appeared lighter than normal and was aware of an apparent uncommanded control wheel input to the left at about 400 feet agl, which he corrected. The landing flare appeared normal as did the final landing; the surface wind on landing was reported as from 260º at 6 kt.

Subsequent to the incident, the pilots confirmed that they had not checked the state of the Circuit Breakers (CBs) following the failure of the aircraft to capture the selected altitude.

The first officer was the holder of a Commercial Pilot's Licence with a total flying experience of 756 hours, of which 180 hours were on type. She subsequently confirmed that she had kept her hands and feet well clear of all aircraft controls following the commander's declaration that he was having difficulty controlling the aircraft.

Meteorological information

The Met Office Headquarters at Exeter provided an aftercast for the area between Newcastle and Stansted.

There was an unstable westerly flow covering the British Isles with little evidence of any cloud above 8,000 feet amsl along the aircraft route. The 0ºC isotherm level was at 9,500 feet amsl. There was no indication of any turbulence.

The Stansted weather for landing was reported as follows: Surface wind was from 260º at 6 kt, cloud was scattered at 4,000 feet amsl, air temperature was 15ºC with a dew point of 11ºC and the QNH was 1017 Mb.

Communications

An ATC recording was available of all the frequencies used by the crew of G-CELA from the declaration of the handling difficulties until the final landing at Stansted. Full and effective assistance was provided by Manchester, London and Stansted ATC services.

The initial 'PAN' was declared at 2217 hrs and was upgraded to 'MAYDAY' at 2220 hrs. The landing at Stansted was at 2249 hrs.

Flight recorders

The aircraft was fitted with a magnetic-tape 25-hour Flight Data Recorder (FDR) which recorded a range of flight parameters from the time of engine start. The aircraft was also fitted with a magnetic-tape 30-minute Cockpit Voice Recorder (CVR) which recorded crew speech and area microphone inputs when electrical power was applied to the aircraft. Both recorders were downloaded at the AAIB where data was recovered for the incident flight. CVR recordings were not available having been overwritten when G-CELA was on the ground after the flight. Additional altitude data was recovered from Radar Mode C and Mode S recordings, provided to the AAIB by National Air Traffic Services (NATS).

Horizontal Stabiliser Trim Data

Although a parameter recording horizontal stabiliser trim position was available, it was found that the recorded data for this parameter was invalid due to sensor or wiring problems. This lack of data together with the lack of a discrete replicating the 'STAB OUT OF TRIM' light severely reduced the usefulness of the recorded data to the investigation.

Altitude Exceedance

A time history of the relevant parameters recorded during the cleared altitude exceedance is given at Figure 1. The data starts with the aircraft climbing through 26,000 ft at 1,650 ft/min, an airspeed of 272 kt and autopilot 'B' engaged in 'VNAV PATH'. The Mode Control Panel (MCP) selected altitude, obtained from the Mode S recording, was 27,000 ft.

At 26,700 ft, the VNAV mode changed from 'PATH' to 'SPD' and the control column moved forward (from a nominal value of +0.6º pull used for the climb to +0.1º), reducing the pitch attitude from 5.6º to 4.2º nose up and slowing the climb rate to 1,100 ft/min. The pitch attitude remained at 4.2º for just under ten seconds while the control column moved back to the +0.6º position.

As the aircraft continued to climb between 27,300 and 27,400 ft, autopilot 'B' disengaged and an 'ALTITUDE ALERT' activated. The control column was then pushed forward momentarily to -1.4º and the thrust levers were pulled back from 48º to 30º thrust lever angle and then to about 20º, with corresponding reductions in engine N1s.

The aircraft achieved a peak altitude of 27,450 ft before descending to 27,000 ft.

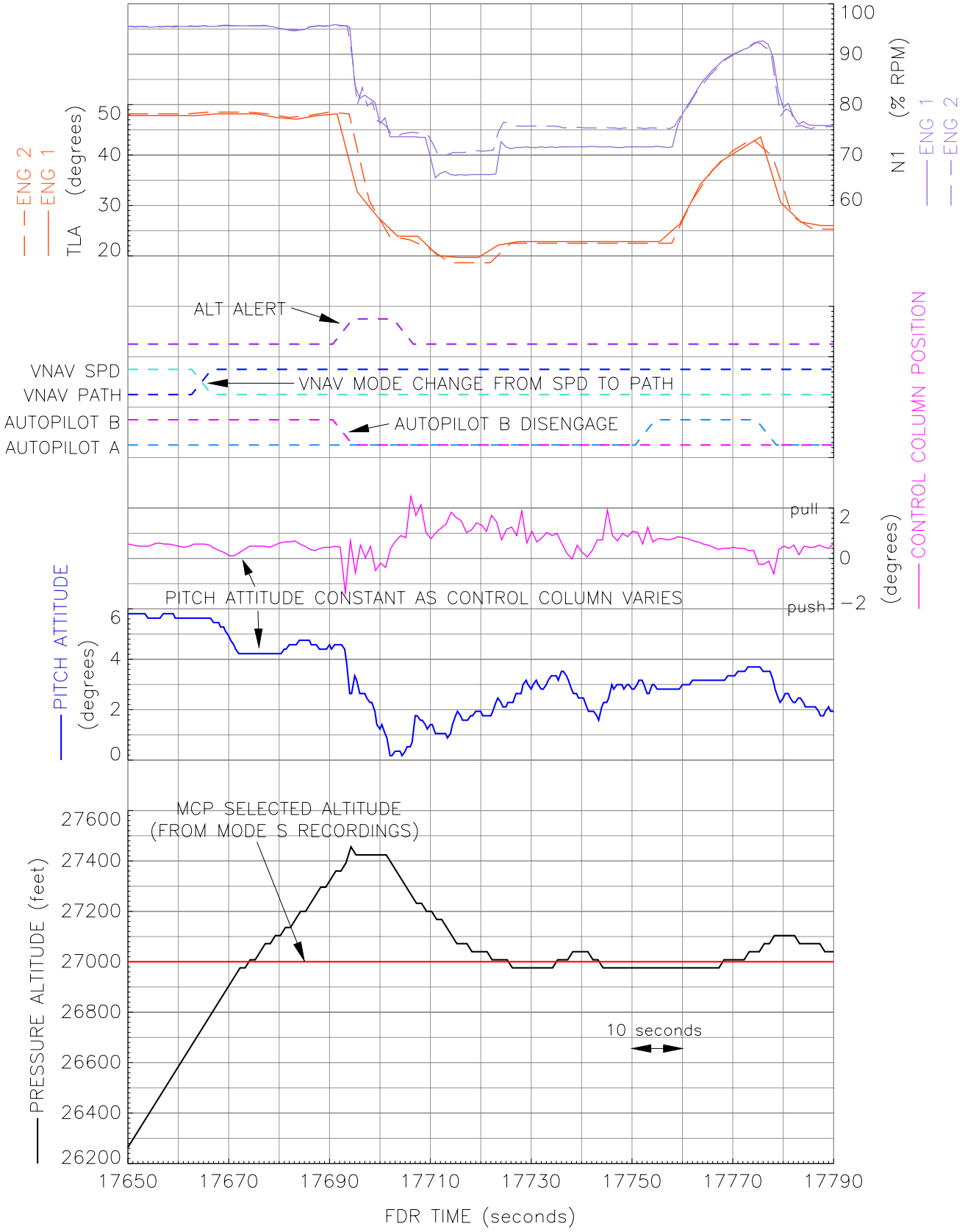

Figure 1

Descent to Stansted

A time history of the relevant parameters during the manually controlled descent to Stansted is given at Figure 2.

During the manually controlled flight, considerably more activity was recorded on control column position compared to when autopilot 'B' was engaged and flying the aircraft. A similar increase in activity was also recorded in pitch attitude and normal load factor. This indicated that basic control column/elevator inputs were driving the activity.

Several large and rapid control wheel inputs were recorded around 400 ft agl but with no corresponding large roll attitudes.

System description

Hydraulics

The Boeing 737-300 has two primary hydraulic systems, A and B, and one standby system.

Elevator

Control cables, connected to the two control wheels, command the elevator movement. The cables are connected via quadrants and pulleys to the torque tubes which provide inputs to the two hydraulic elevator Power Control Units (PCU). The elevator feel and centering unit provides artificial feel and centres the elevator when the control wheel is released.

An elevator feel computer provides artificial feel to the pilot by applying resistance to the control quadrants. This is achieved by varying the hydraulic pressure input to the elevator feel and centering unit based on the pitot pressure from pitot heads mounted on the side of the vertical fin.

In the event of a failure of both hydraulic systems, the elevator can be manually controlled directly from the control columns. Elevator tabs, mounted to the rear of each elevator surface, augment the control forces during manual control.

Autopilot

The aircraft has two autopilot channels, 'A' and 'B', both controlled by separate Flight Control Computers (FCC). When an autopilot is selected to 'Command' (CMD), certain systems are checked for serviceability before the autopilot will engage. One system that is not checked is the autopilot stabiliser trim. Following engagement of an autopilot channel, several control modes can then be selected.

'VNAV' is one of the autopilot modes. In this mode the aircraft's vertical profile is controlled by the autopilot using commands from the Flight Management Control System (FMCS). The vertical profile is calculated based on the constraint of the altitude selected on the MCP. During a climb with 'VNAV' selected, the mode displayed to the flight crew is 'VNAV SPD'. As the aircraft approaches the MCP selected altitude, the mode changes from 'VNAV SPD' to 'VNAV PATH'. This indicates that the autopilot is now in an altitude acquire mode and will attempt to level the aircraft at the selected altitude. This is accomplished through the use of the elevator autopilot PCU in combination with the autopilot stabiliser trim actuator. The autothrottle is not used to control the pitch of the aircraft, but does maintain the aircraft's speed by altering engine power during pitch changes. Once the aircraft has attained the selected altitude, the mode continues in 'VNAV PATH' with the mode similar to that of an altitude hold.

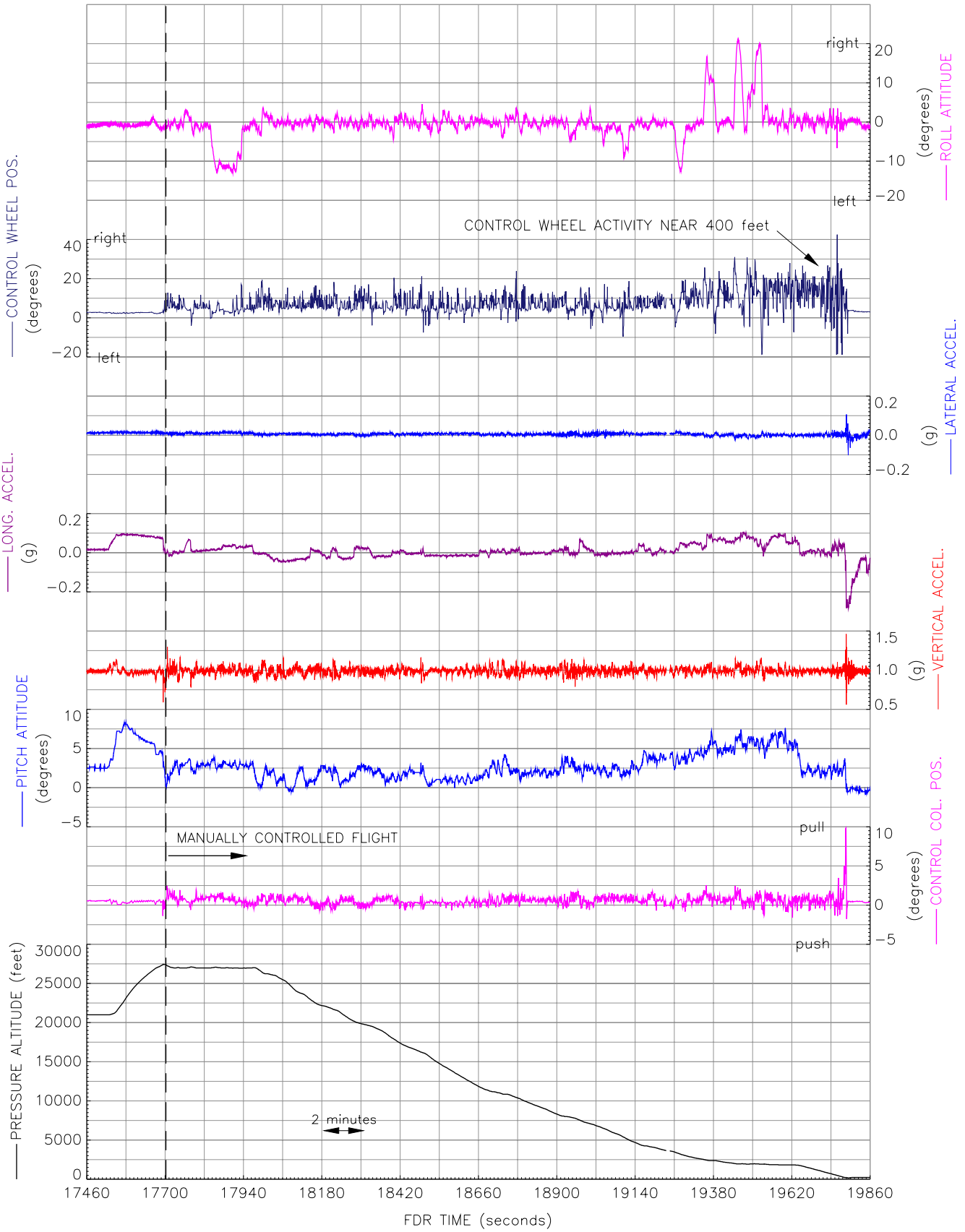

Figure 2

Altitude Alert

Two 'ALTITUDE ALERT' amber lights indicate that the aircraft is approaching the MCP selected altitude. When the aircraft is 900 feet below the selected altitude, the lights illuminate and an aural warning sounds. The lights remain illuminated until the aircraft is within 300 ft of the selected altitude, at which point the lights extinguish. They will also illuminate if the aircraft climbs or descends 300 ft from the selected altitude.

Stabiliser Trim

The horizontal stabiliser trim consists of an electrically commanded manual system, a cable commanded mechanical manual system and an autopilot commanded system. All three are connected to a stabiliser trim screwjack which provides movement of the all-moving horizontal tail plane.

Switches on each of the control wheels command the electrical manual system. The signal from these switches operates the primary stabiliser trim actuator which subsequently drives the stabiliser trim gearbox and the stabiliser screwjack.

Mechanical manual operation of the stabiliser trim is by a trim wheel mounted on the centre pedestal which is connected by control cables to the gearbox cable drum at the bottom of the stabiliser gearbox. Operation of the trim wheel commands mechanical movement of the stabiliser gearbox and the stabiliser screwjack.

Automatic control of the stabiliser trim is by commands from the FCC to an independent autopilot stabiliser trim actuator mounted on the stabiliser trim gearbox. The FCC commands the autopilot trim actuator to move the stabiliser via the stabiliser trim gearbox and the stabiliser screwjack. The commands are related to the elevator movement. If the elevator displacement is continuous for more than three seconds, the FCC commands the stabiliser trim to compensate for the input. The actuator is protected by a 7.5 amp CB located on the P18 panel behind the left cockpit seat.

An amber 'STAB OUT OF TRIM' light illuminates on the centre instrument panel whenever the autopilot is not trimming the stabiliser correctly. There is no associated aural warning or master caution and the autopilot will remain engaged. There are three detectors which can trigger the warning light:

1. A 3° difference between the elevator position and the elevator autopilot PCU position.
2. A stabiliser movement of less than 0.5° in 10 seconds when stabiliser movement is commanded by the autopilot.
3. The elevator PCU position is more than 5° from the elevator neutral position.

The autopilot stabiliser trim actuator also provides a speed trim function when the flaps are extended and the autopilot is disengaged. This function is to ensure positive speed stability during low speed and high thrust situations. A failure of the system results in an amber 'SPEED TRIM FAIL' light on the forward overhead panel, an associated master caution and an aural warning.

Engineering examination

Engineers from the airline operator's contracted maintenance organisation at Stansted carried out an initial examination of the aircraft on arrival. A test of the autopilot revealed a failure of the automatic stabiliser trim and upon investigation the engineer found the autopilot stab trim actuator CB tripped off. After resetting the CB,

the test was successful. Additional functional tests of the elevator, manual electric stabiliser trim and autopilot were also completed without any fault indication.

Under AAIB supervision, engineers then conducted a thorough examination of the aircraft and relevant systems. An initial BITE check of the Digital Flight Control System (DFCS) revealed a recorded failure, on the last (incident) flight, of the speed trim system on both FCC 'A' and FCC 'B' channels.

A full examination of the elevator control run, including cable tension, cable friction and rigging checks, was satisfactory. The only anomaly was in the elevator feel system. During a check with the 'A' system hydraulics off and the 'B' system hydraulics on, the force required to move the elevator was 50 lb with 173 kt applied to the feel computer pitot ports; the limits were between 35 and 43 lb. The feel force of the elevator at all other settings, and in particular with both 'A' and 'B' system hydraulics on, were all well within the prescribed limits.

Two hydraulic leaks were found which related to system 'A', one on the hydraulic pressure module in the left wheel well and one on the No 3 flying control shut-off valve in the tail. Both of these were rectified.

The tests of the autopilot only revealed one failure. This was related to the pitch Control Wheel Steering (CWS) force transducers; the failure was due to a discrepancy between forces being measured at the commander's and first officer's transducers. Each transducer's individual force output was within limits.

Due to the autopilot stabiliser trim CB being found tripped, a full test of the wiring and the actuator was conducted. This did not reveal any defects with the wiring or any of the electrical connectors. The CB was rated at 7.5 amps.

As a precaution, the autopilot stabiliser trim actuator, autopilot stabiliser trim actuator CB and the two FCCs were removed for bench testing. In addition, the elevator feel computer and the stabiliser trim position transducer were also replaced, with the removed units sent for testing.

Component examinations

The component manufacturer, under AAIB supervision, conducted bench tests on the two FCCs. The BITE information for FCC A and FCC B both revealed an in-flight fault for the incident flight related to a speed trim system failure. The only bench test failure was with the roll function in FCC 'A'. This was due to a resistor being slightly out of tolerance. FCC 'B' had no other reported faults during its bench test.

A component overhaul organisation conducted a bench test and strip examination of the autopilot stabilizer trim actuator. During the test, the friction clutch slipped at a load of 160 lb in; this was lower than the required limits of between 240 and 320 lb in. However, the current draw from the actuator during the tests and with the clutch slipping, never exceeded 3 amps and was mostly at about or below 1 amp. With the CB rating of 7.5 amps, this should not have resulted in the CB tripping. The strip examination of the actuator showed normal wear on the friction clutch plates but did not reveal any faults.

The bench test and strip examination of the elevator feel computer was satisfactory and no fault could be found to explain the reported high feel force experienced on the aircraft.

The test of the autopilot stabiliser trim CB was conducted in a workshop. The tests showed the CB to perform within its specification. A force of 6 lbf was required to manually trip the CB.

The stabiliser trim position transducer tests showed that it performed within its specification. However, one connector failed the insulation resistance test due to contamination. There was also signs of grease and dirt contamination of the connector pins.

CB visibility

The autopilot stab trim actuator CB is located on the P18 panel behind the commander. It is the uppermost CB on the panel, which makes it difficult to see from the seating position of the commander and first officer. Furthermore, a map light is mounted to the right of the CB panel with its lead dropping down in a loop beside the panel. This coil of lead to the light is in such a position that it obscures the CB. Refer to Figure 3 below.

Aircraft maintenance

A full review of the operating history of the aircraft did not reveal any previous reported problems with the autopilot, stabiliser trim, elevator or hydraulics.

The last maintenance carried out on the aircraft was a service check on 5 June 2006, about 202 flying hours prior to the incident flight.

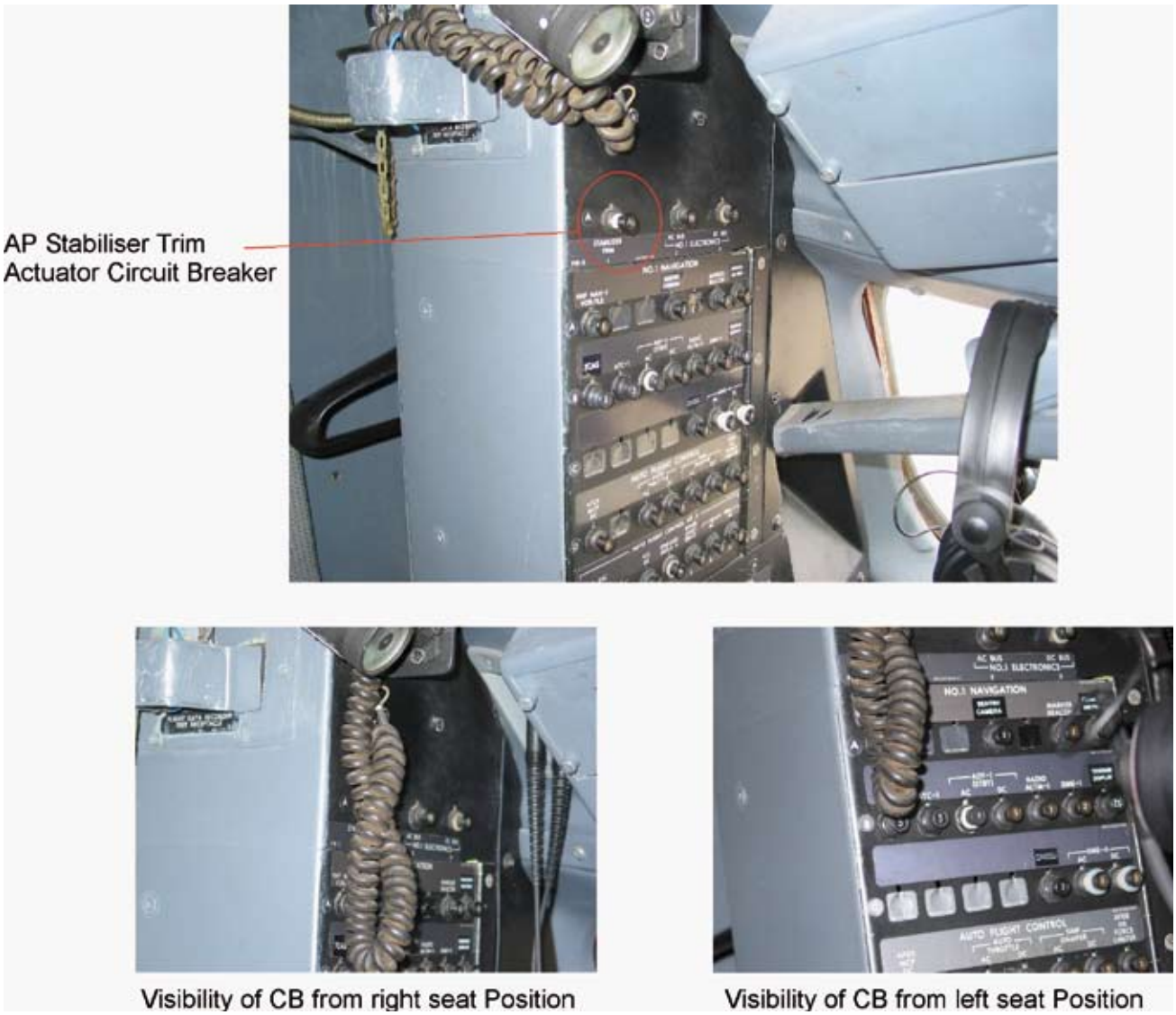

Figure 3

Analysis

The investigation indicated two apparent anomalies during the flight. Firstly, the failure of the aircraft to capture the MCP selected altitude and secondly, the difficulties experienced by the commander in controlling the aircraft in pitch.

Failure to capture selected altitude

The failure of the autopilot to level off at the MCP selected altitude can be directly attributed to the autopilot stabiliser trim actuator being inoperative due to its CB being tripped off. With a fully functional system, as the aircraft approaches a selected altitude, the autopilot would use the autopilot elevator PCU to level the aircraft. As the elevator moves away from its neutral position, the autopilot would command the autopilot stabiliser trim actuator to follow up on the elevator. This would give the elevator greater authority in pitch. However, with the autopilot stabiliser trim actuator inoperative the stabiliser could not follow up on the elevator command. The autopilot would run out of elevator authority and the aircraft pitch attitude could not move any further nose down. This was evident on the FDR trace which showed the pitch attitude flat line as the aircraft climbed through FL270. Concurrently, the autopilot would have detected that the stabiliser movement was less than 0.5° for 10 seconds and would have triggered the 'STAB OUT OF TRIM' warning. The crew acknowledged that this warning occurred around the time that the aircraft was near FL 270. Later in the flight, with the CB still tripped and as the flaps were lowered, the 'SPEED TRIM' warning was activated as recorded on both FCCs.

While the tripping of the CB would explain the failure of the aircraft to capture the selected altitude, there was the question of why the CB tripped. Despite thorough testing of the autopilot stabiliser trim actuator, the CB and the aircraft wiring, no defect could be identified to explain the tripping. Furthermore, after the CB was reset the system operated normally. While accepting that a check of the CB panel by the crew after the initial problem may have highlighted and rectified the reason for the altitude overshoot, the investigation continued to consider when and why the CB had tripped.

There was no reason for the CB to be intentionally tripped for any rectification. Therefore, it could only have been manually tripped by accident or by an unidentified transient electrical event. It was not possible to identify by performance evaluation when the CB tripped. The only certain factor was that it had tripped before the aircraft attempted to level at FL270.

One possibility was that the CB had been tripped inadvertently prior to flight. However, the force required to do so was measured as 6 lbf. This force would require more than a passing knock and therefore is considered unlikely. Furthermore, part of the crew pre-flight checks involved a check of the CB panels and, while such an omission cannot be ruled out, particularly when the location of the CB is considered, it is also unlikely that it would have been missed. An electrical transient fault may also have tripped the CB but despite extensive checks, no evidence of any relevant fault could be identified. Regardless of the reason for the tripping, subsequent tests confirmed that the CB could have been reset and normal autopilot operation would have been possible. The location and associated difficulties with seeing the CB from either pilot seat may have been factors in the crew not identifying the source of the problem. However, a check of CBs is a prudent action for any apparently unexplained aircraft defect.

Pitch control difficulties

Despite a thorough examination of the pitch control system, no technical reason could be found to account for the symptoms of the pitch control problems experienced by the commander following the disconnect of the autopilot. Although hydraulic leaks were found that were associated with the 'A' system, discussions with the aircraft manufacturer indicated that it was unlikely that these were significant enough to cause control problems. No hydraulic low pressure warnings were activated during the incident flight and, even if the 'A' system had failed, the' B' system would still have provided full pitch control authority. The elevator feel system also failed during one of the post-incident checks on the aircraft. The feel was higher than expected, but this was only with 'B' system pressurised and at a simulated airspeed of 173 kt. With both 'A' and 'B' system pressurised, the forces were normal. Similarly at other airspeeds, with just 'B' system pressurised, the feel forces were within limits. The removal and bench testing of the elevator feel computer revealed no faults. Installation of a replacement feel computer did resolve the problem with subsequent checks of the feel forces all being within limits. The mechanical elements of the elevator system were fully serviceable. The aircraft was returned to service and subsequently operated satisfactorily, and the investigations of the components removed did not identify any relevant defects. Nonetheless, the possibility remains that the work carried out on the aircraft had eliminated some undetected deficiency.

FDR information indicated that the control wheel movement was greatest when the aircraft was being flown manually after the level off at FL270. This was associated with an increase in pitch attitude and normal load factor and indicated that the control movements were the result of manual control inputs. While a slight difference in control forces could not be ruled out, it is possible that the failure of the aircraft to level off induced some concern within the commander and may have resulted in him overcontrolling. In that situation, it may have been appropriate for him to hand over control to the first officer for another opinion. Nevertheless, with an apparent control difficulty the crew ensured priority and full assistance from ATC by declaring an emergency.