BULLETIN RE-ISSUED

In its August 2008 Bulletin, the AAIB published a report into a serious incident to an Airbus A319.

The report identified an element of training given to the co-pilot which appeared to conflict with the normal duties expected of a handling pilot in the right seat during a rejected takeoff. A Safety Recommendation (2008-027) was made in the report which recommended that the operator '*review their flight crew simulator training to ensure that it reflects their current Standard Operating Procedures (SOPs).*' After completion of the consultation period (Regulation 12.1) for the final report and just before publication, the operator advised the AAIB that, under '*Flight Crew Incapacitation*', their Operations Manual contained an SOP which required a right seat handling pilot to carry out those duties usually assigned to the commander of an aircraft under some circumstances. As a consequence, the operator stated that there was no conflict between their SOPs and the training provided to their pilots. Given this new information the AAIB has accepted these observations and has withdrawn Safety Recommendation 2008-027.

In addition, following publication, a review of the report was requested under Regulation 15(1) of the Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996.

Consequently, the Chief Inspector decided that, following review, the report should be updated and re-issued in full to incorporate new and revised information.

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INCIDENT

Aircraft Type and Registration:	Airbus A319-131, G-DBCI
No & Type of Engines:	2 International Aero Engines V2522-A5 turbofan engines
Year of Manufacture:	2006
Date & Time (UTC):	18 April 2007 at 0944 hrs
Location:	Amsterdam Schiphol Airport, The Netherlands
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 5 Passengers - 112
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	11,123 hours (of which 3,493 were on type) Last 90 days - 132 hours Last 28 days - 44 hours
Information Source:	AAIB Field Investigation

Synopsis

The Dutch Safety Board delegated the investigation to the UK AAIB.

The aircraft was departing Amsterdam, in good weather and light winds, on a flight to London. During the latter stages of the takeoff roll the aircraft yawed rapidly to the right and took off over the side of the runway on a heading that was 18° to the right of the runway centreline. It lifted off at a speed 5 kt below V_R before reaching the edge of the runway. It was then manoeuvred back onto the runway centreline and continued on its assigned Standard Instrument Departure (SID) as it slowly accelerated.

Recorded data showed that the rapid yaw during the ground roll had been caused by a deflection of the rudder. The evidence indicated that there had been no malfunction of the aircraft, nor significant wake vortex effects from the preceding heavy aircraft, and that the rudder deflection had been in response to rudder pedal movements.

The reasons for the right rudder pedal inputs could not be positively determined. The speed at which the aircraft began its uncontrolled heading deviation to the right was such that it would have been possible to abort the takeoff, albeit at a speed approaching V_1. It was conceivable that under-arousal, in the benign operating conditions that prevailed, may have affected the performance of both flight crew.

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As a result of miscommunication, the aircraft remained in service for a period after the incident without comprehensive checks being carried out to determine if an aircraft malfunction might have been responsible for the rapid yaw.

One Safety Recommendation is made.

History of the flight

The crew had reported at 0450 hrs at the company's Manchester Airport offices for a four sector duty. The commander was Pilot Flying (PF) on the first sector to London Heathrow and the co-pilot was PF on the second sector to Amsterdam. Both flights were completed without incident and the co-pilot continued as PF, as planned, for the third sector back to London Heathrow.

The conditions at Amsterdam were good; visibility was greater than 10 km, there were a few cumulus clouds between 3,200 ft amsl and 8,000 ft amsl and the temperature was 12°C. The aircraft pushed back off stand at Amsterdam at 0924 hrs and taxied a distance of 7.4km for a departure from Runway 36L. The co-pilot was PF for the taxi, which lasted approximately 14 minutes. G-DBCI was cleared to line up on the runway after a departing Airbus A330. ATC cautioned the flight crew against wake turbulence from the A330, and advised them that the surface wind was from 350° at 7 kt. G-DBCI commenced a rolling takeoff at 0944:20 hrs at a weight of 58,124 kg. At that weight, V_1 and V_R were both calculated to be 143 kt and V_2 was 147 kt.

The commander reported that the takeoff was normal up to 100 kt, when he, as the pilot not flying (PNF), made the standard '*one hundred knots*' call. He stated that, at approximately 130 kt, the aircraft yawed about 30° to the right, and he called "engine failure" as the aircraft rotated. The co-pilot's recollection was that, at the same speed, he felt the right rudder pedal move forward and the aircraft 'slew' to the right, without any corresponding input from him. He applied corrective left rudder pedal and heard the PNF call "V_1 engine failure". With the aircraft heading towards the right edge of the runway, the co-pilot rotated the aircraft and it became airborne at 0944:57 hrs, before reaching the grass area to the side of the asphalt runway surface at an airspeed 5 kt below V_1. He manoeuvred the aircraft back towards the runway centreline and it continued on the assigned SID. This involved maintaining the extended centreline to a point 4.4 nm from the AMS VOR, which is located abeam the Runway 36L threshold, before turning left. The departure was unencumbered by obstacles and the surrounding terrain was flat.

Both pilots realised that the engine indications were normal and that an engine failure had not occurred. They considered that wake turbulence from the preceding aircraft may have been another possibility and mentioned this to the ATC tower controller. He had observed the takeoff and had seen a small amount of smoke/dust appear as the aircraft took off over the right shoulder of the runway. However, he advised the crew of G-DBCI that the A330 was 8 nm ahead of them.

The commander commented that, during the takeoff roll, he had placed his feet lightly on the rudder pedals, more lightly during the latter part of the takeoff roll, and his left hand near his sidestick. He remarked that the takeoff had been normal up to the point the aircraft started to yaw, with small movements of the rudder pedals.

G-DBCI continued on its flight-planned route to London Heathrow and the commander and co-pilot discussed whether the co-pilot could have made an inadvertent rudder input. This was discounted and they concluded that the cause lay in the 'atmospheric

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conditions'. Towards the end of the flight, the crew understood from ATC that tyre debris had been found on the runway at Amsterdam and there was a concern that the aircraft's right main landing gear was 'locked'. The flight crew had no indications to confirm this and the cabin crew had not been aware of anything during the takeoff, other than that the aircraft had 'swung' to the right. However, concerned at the possibility of damage to one or both of the tyres on the right main landing gear, which could have explained the yaw to the right, the commander and co-pilot agreed to carry out an emergency landing and informed the cabin crew of their intentions.

The commander advised the passengers that the crew would carry out a 'precautionary' landing and that the aircraft may veer slightly to the right during the landing. He then took control and the cabin crew prepared the passengers and cabin. The flight crew declared a 'MAYDAY', completed the relevant abnormal and emergency checklists and decided to land with the autobrake selected off, using idle reverse and gentle braking on the left main landing gear. As it transpired, the landing was uneventful with only a slight rumbling noise audible during the latter part of the landing roll. The Airport Fire Fighting and Rescue Service attended the landing and observed nothing unusual when the aircraft stopped on the taxiway. The aircraft continued to taxi slowly on to a stand and the passengers were disembarked normally.

Later, the commander had a telephone conversation with Amsterdam ATC. They advised him that the crew of the aircraft which was departing behind G-DBCI had observed the takeoff and had reported skid marks on the runway. A runway inspection was carried out and the skid marks were confirmed. It was reported to the crew of G-DBCI that the aircraft's right main landing gear may have become 'blocked'. This information, which had been passed to the crew during the flight, had been interpreted by the commander as the landing gear being 'locked', preventing the wheels from rotating.

Surface wind recordings

Anemometers are located at each end of Runway 18R/36L, which is 3,800 metres long and orientated 184°/004°M. One anemometer is positioned 414 metres south of the Runway 18R threshold, 105 metres west of the runway centreline and the other is positioned 315 metres north of the Runway 36L threshold, also 105 metres to the west of the runway centreline.

Snapshots of the instantaneous wind speed and direction readings, which were recorded every 12 seconds from these two anemometers, showed the variation in wind velocity between 0943:12 hrs and 0946:12 hrs. The anemometer near the threshold for Runway 36L indicated a variation in wind direction between 325° and 005°, with the speed varying between 4 kt and 8 kt. For the same period, the anemometer near the threshold for Runway 18R indicated the wind direction varying between 285° and 330°, with wind speeds between 7.5 kt and 9.5 kt. At 0945:00 hrs, the instantaneous readings from the Runway 36L anemometer and the Runway 18R anemometer were 325°/5 kt and 320°/8.5 kt respectively.

Aircraft description

The A319 is a member of the A320 family of aircraft (A318, A319, A320 and A321). The aircraft is of conventional layout, with two underwing engines and tricycle landing gear. Each landing gear has twin wheels. A Tyre Pressure Indicating System (TPIS), providing flight deck indication of tyre pressures, is an option on the A319 but was not fitted to G-DBCI (Manufacturer's Serial Number 2720).

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On the ground, aircraft yawing moments can be produced by nose landing gear steering, differential wheel braking, asymmetric engine thrust, crosswind effects and rudder deflection.

The rudder is controlled by three hydraulic Powered Flight Control Units (PFCUs) in the fin, each fed from a different hydraulic system and signalled mechanically (Figure 1). A transducer mechanically linked to the rudder surface provides rudder position signals. Commands from the pilots' rudder pedals are transmitted by a cable-pulley system to a mechanical differential unit in the fin and thence to the PFCUs via a rod and bellcrank system. The input to each PFCU is in the form of a spring-centred rod that allows continued rudder operation in the event of one of the PFCUs ceasing to function. The two pairs of rudder pedals are mechanically linked and do not have a separation facility. Each pair of pedals drives a transducer which supplies pedal position information to the respective Elevator and Aileron Computer (ELAC) and thence to the respective Flight Augmentation Computer (FAC).

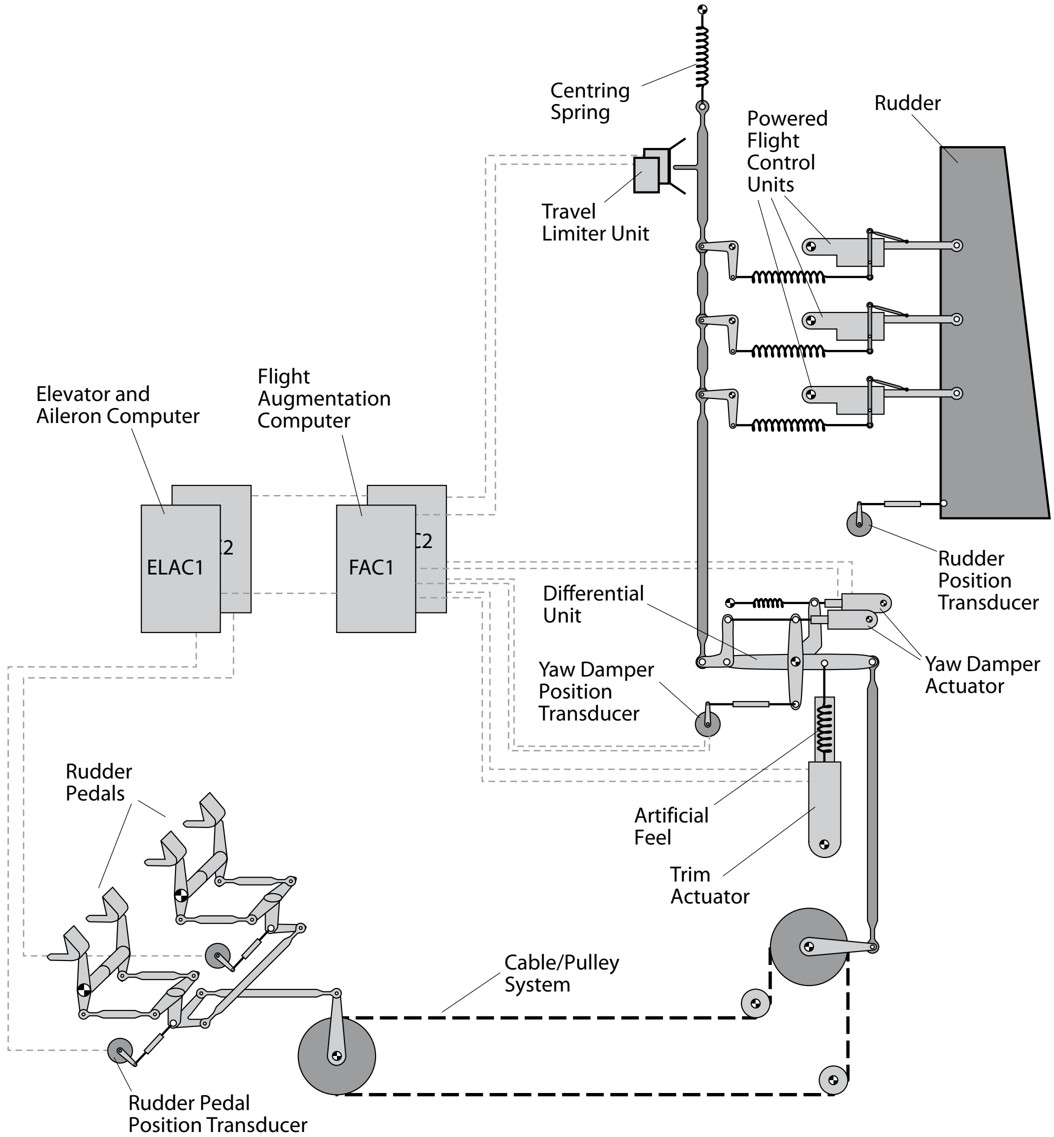

Figure 1

A319 Rudder Control System Schematic

The maximum rudder deflection is controlled by a Travel Limiter Unit (TLU), signalled by the FACs, that restricts the range of movement of the PFCU input linkage as a function of aircraft calibrated airspeed (CAS). Maximum rudder deflection is ±30° at low speeds and progressively reduces with CAS above 160 kt.

Artificial feel for the pedals is generated by a feel spring acting on the mechanical input system in the fin. A centring spring also acts on the input mechanism for the upper two PFCUs to prevent rudder runaway in the event of disconnection of the input system. The arrangement provides a constant pedal force/displacement characteristic irrespective of the flight conditions. Pedal force/deflection characteristics for the A319 are shown in Figure 2.

Figure 2

A319 Normal Rudder Pedal Force vs Rudder Deflection

Rudder trim is effected by an electrically motorised actuator controlled by a flight deck selector via the FACs. The actuator alters the datum position of the artificial feel spring and deflection of the rudder by the trim system thus causes corresponding displacement of the pedals. Trim authority below the TLU threshold speed is limited to ±20° rudder deflection; trim rate is 1.2°/second.

An automatic aircraft yaw damping system also acts on the PFCU input linkage to oppose changes in aircraft yaw rate. The system has two yaw damper actuators, one active and the other on standby, each controlled by a FAC. A transducer driven by the linkage supplies the FACs with information on yaw damper displacement. Pedal and yaw damper commands are additive, such that the yaw damping system tends to oppose the pedal commands. Yaw damper signals are input to the differential unit, which acts such that yaw damper activity does not displace rudder pedals. Yaw damper authority is limited to ±5° rudder deflection, at a maximum rate of 40°/second.

The system transducers provide information to the Flight Data Recorder (FDR) on pedal displacement, rudder angle and the extensions of the rudder trim actuator and yaw damper actuators. An Electronic Centralised Aircraft Monitor (ECAM) displays aircraft condition, caution and warning messages to the flight crew. A Centralised Fault Display System (CFDS) registers component and system faults and exceedences detected, which can be printed as a post-flight report (PFR) for maintenance purposes, and enables Built-In Test Equipment (BITE) testing of the aircraft's systems on the ground. Rudder trim and yaw damper faults should generate messages for display on the ECAM and recording on the PFR. No flight deck or PFR failure messages are provided for either the mechanical system linking the rudder pedals with the PFCUs or with the PFCUs themselves.

In an attempt to rule out the possibility that a rudder system malfunction had resulted in rudder pedal deflection, the AAIB requested that the aircraft manufacturer conduct a detailed assessment of the system, including consideration of spring rates and geometry. Information from the aircraft manufacturer confirmed that, in the absence of a failure in the

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rudder control mechanical system, hydraulic pressure in the PFCUs would prevent the rudder from being back-driven by external forces. The manufacturer also conducted testing, using a ground rig that it confirmed was fully representative of G-DBCI's rudder system. The tests indicated that, with all three hydraulic systems depressurised, a full deflection of the rudder (measured at approximately 32°) resulted in a maximum pedal displacement of 15°, because of the combined action of the centring spring and the PFCU input spring-rods.

Aircraft examination

Following its arrival and inspection at Heathrow after the incident, G-DBCI flew two further sectors on 18 April, with no reports of yaw control anomalies, before it was taken out of service for further examination. The AAIB was notified of the incident at approximately 1640 hrs on 19 April and began an examination of the aircraft that evening at Heathrow. No abnormalities with the landing gears, including the tyres, were apparent, and no relevant aircraft faults or exceedences were recorded on the PFR. Inspection of the rudder control linkage in the fin revealed no anomalies and the rudder operated normally in response to both pedal and trim inputs. Rudder operation was checked both with all three hydraulic systems pressurised and with each system alone pressurised in turn. With all three hydraulic systems pressurised, the rudder deflected from neutral to full travel in approximately 1 second following rapid full pedal deflection. The rudder response to trim selections was normal.

The operator reported that the records for G-DBCI did not suggest that any yaw control problems had been experienced with the aircraft prior to the incident. The aircraft returned to service on 20 April 2007; after several months in service no further yaw control anomalies had been reported.

Runway examination

Inspection of Runway 36L at Amsterdam by the Dutch authorities shortly after the incident identified two pairs of tyre track marks that appeared likely to be associated with G-DBCI's takeoff ground roll deviation. The Dutch Safety Board supplied photographs of the marks and their approximate dimensions and AAIB subsequently examined the runway. The marks were found to consist of pronounced black rubber deposits on the light-coloured asphalt surface of the runway. Their lateral spacing corresponded to the A319 main landing gear wheeltrack and their position (Figure 3) corresponded closely to the aircraft track estimated from FDR data. It was therefore concluded that G-DBCI's mainwheel tyres had made the marks during the takeoff ground run.

The track marks from the left main wheel tyres commenced approximately 1,035 m from the start of Runway 36L, adjacent to a turnoff (V2 turnoff) from the reciprocal Runway 18R, with the aircraft near to the centreline. The marks indicated a brief slight turn to the left, followed by a sustained right turn, during which track marks from the right mainwheel tyres became evident. After turning approximately 20° right of the runway heading, both the left and right track marks ceased, at points respectively 9 m and 6 m from the runway edge. No signs were found to indicate that any of the tyres had run on the runway shoulder or the grass surround.

Recorded data

The aircraft was fitted with a Cockpit Voice Recorder (CVR) and a Flight Data Recorder (FDR). By the time that the AAIB was notified, the CVR recordings had been overwritten, and therefore the CVR was not removed from the aircraft. The operator downloaded the FDR on the aircraft and supplied the downloaded

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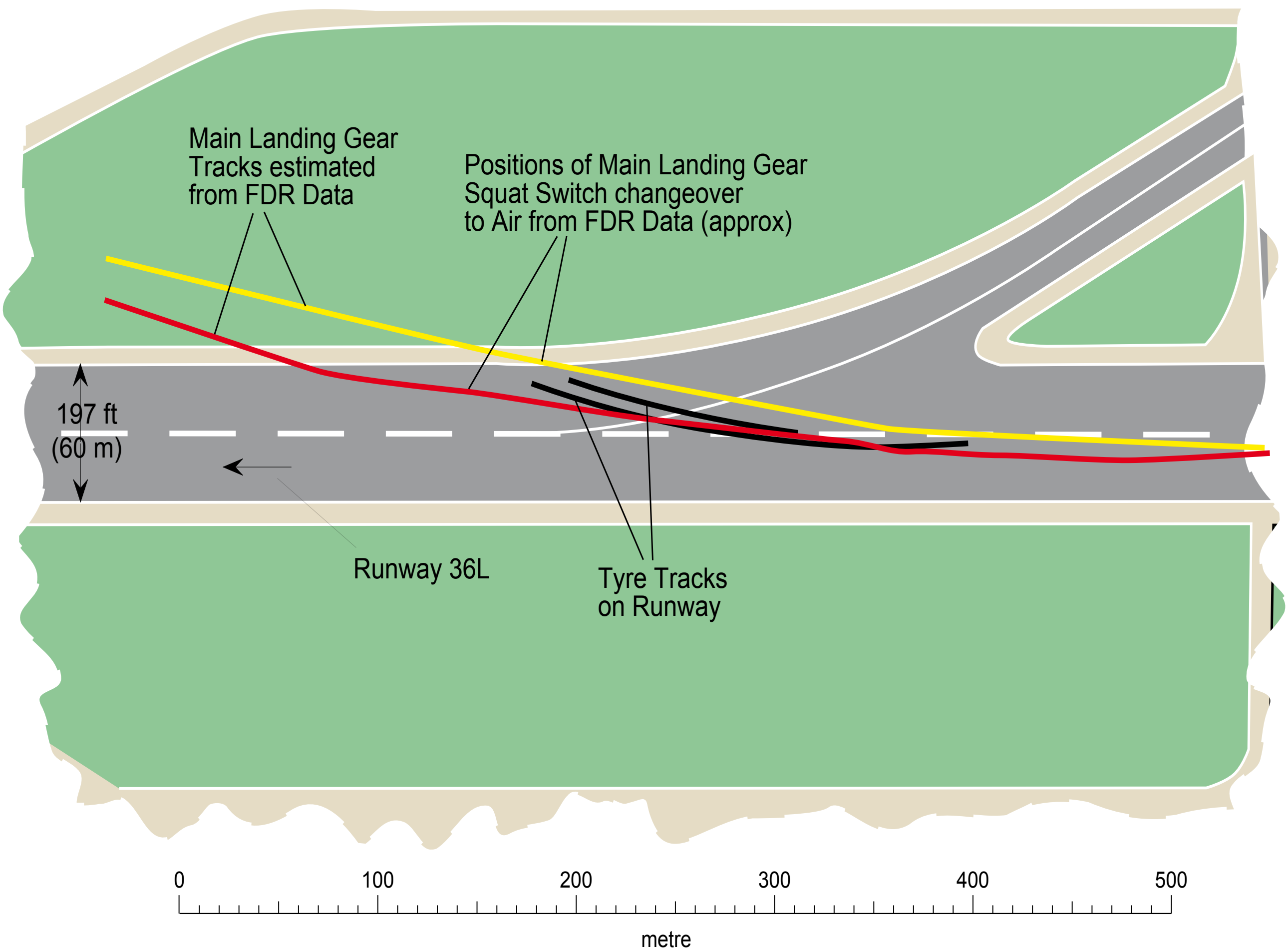

Figure 3

Plan View of Runway Tyre Marks and Main Landing Gear Tracks estimated from FDR Data

data to the aircraft manufacturer and to the AAIB for further analysis.

The following description of events is based on the recorded data extracted from the FDR. All times are given in UTC.

The aircraft started taxiing from its stand at 0928 hrs and taxied a distance of 7.4 km to the runway. During the taxi, full and free flight control checks were carried out, first by the commander and then by the co-pilot. The recorded values of brake pedal positions and metered brake pressures were entirely consistent with normal aircraft taxiing. The runway was reached at 0942 hrs.

The aircraft was positioned on Runway 36L with a heading of 004ºM and configured with 10º of flap (equates to a flap lever position of 1+F). The autopilots were not engaged and both flight directors were on.

At 0944:13 hrs the thrust levers were advanced; the aircraft started to accelerate. With the exception of an initial left pedal/rudder input, the pedal/rudder inputs were minor and to the right; heading remained within 1.5º of runway heading (004ºM). Figure 4 shows salient recorded parameters from the point when the aircraft accelerated through an indicated airspeed of about 90 kt.

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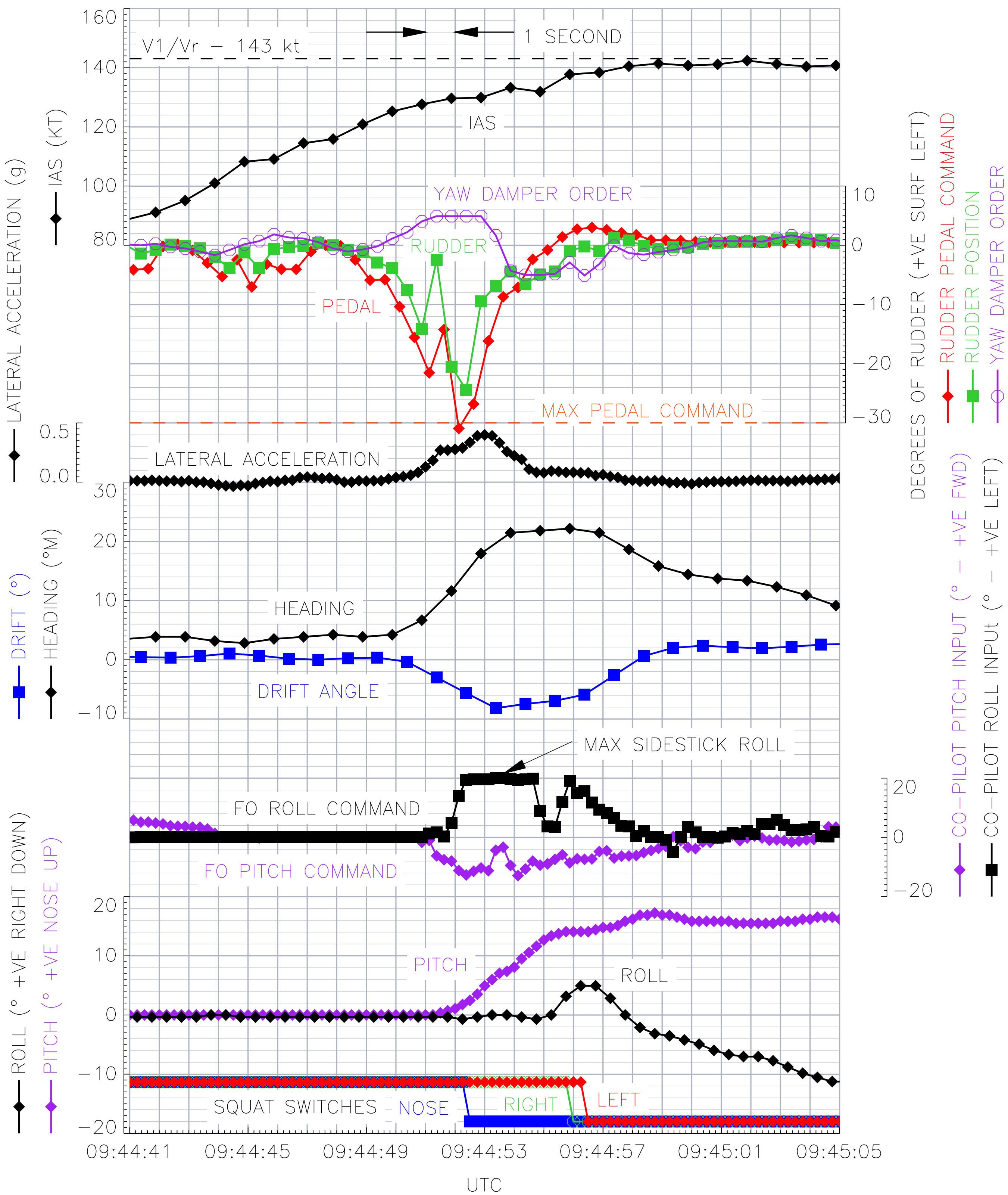

Figure 4

FDR Parameters showing control inputs and aircraft motion.
(Incident to G-DBCI on 18 April 2007)

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At 0944:48 hrs, with an IAS of 116 kt, another right pedal input was initiated. Two seconds later, whereas previous inputs had started to return towards neutral, the right pedal input continued increasing and the heading increased through 005ºM. A further second later the data shows a brief peak in pedal input at approximately 72% of full deflection. At this point the IAS was 128 kt and increasing, aircraft heading was passing through 007ºM and recorded drift angle was increasing through 3º.

The co-pilot's sidestick showed the start of a pitch up command. Half a second later, the commander's sidestick registered a brief roll left input and the co-pilot's sidestick started to move towards a full left roll input. There was a one sample reduction in pedal input and rudder deflection. This was followed, half a second later, by a 31º yaw right command from the pedals (effectively a maximum 30º right rudder surface command) and an opposing 5º left rudder command from the yaw damper. This combination resulted in a recorded rudder surface deflection of 24º to the right.

At an IAS of 130 kt, with heading increasing through 015ºM and with full roll left command applied, the aircraft had started to rotate, increasing through a pitch attitude of 2º nose up. This airspeed equates to V_R - 13 kt.

The pedal and rudder deflection reduced over the next 3.5 seconds and the heading stabilised at approximately 022ºM. Drift angle peaked at 8º to the left of heading and started slowly reducing. During the rotation period, significant left roll was being commanded but this was opposed by the secondary roll effect of the yaw to the right and, with both main landing gear on the ground, main gear oleo compression. Hence no significant roll attitude was observed until the left roll command was brought to near neutral, resulting in a slight right roll. The co-pilot reapplied the left roll input using his sidestick but the aircraft continued rolling right. With a stable pitch attitude of 14º, an airspeed of 138 kt and a right roll of just over 3º, the aircraft left the ground.

Throughout the takeoff, the recorded lateral acceleration values were always to the right.

Figure 5 shows the aircraft speed and altitude compared to the noise abatement procedure requirements applicable to the departure from Schiphol Airport. The aircraft did not reach the V_1/V_R speed of 143 kt until passing 460 ft amsl (about 470 ft aal) and did not reach V_2 until passing 740 ft amsl (about 750 ft aal). The target initial climb speed was achieved at a height of 1,100 ft aal.

The remainder of the flight appeared to be uneventful and the aircraft touched down at London Heathrow Airport at 1053 hrs.

Other parameters were examined over the period of the takeoff roll. The thrust lever angles and engine N_1 and N_2 values were symmetrical throughout. From initial brake release at the start of the takeoff roll until after the aircraft became airborne, no other brake pedal inputs or indications of brake pressure being applied were recorded. Additionally, no faults were recorded from the normal braking, antiskid or autobrake systems. The rudder trim position remained neutral.

The parameters that record system faults did not show any faults for the flight and normal pitch/roll laws were in effect throughout.

The rudder position parameter appears to be consistent with the rudder pedal position and yaw damper parameters. It was not possible to understand completely how these three parameters interacted because of the way that they were recorded, all being sampled at the same

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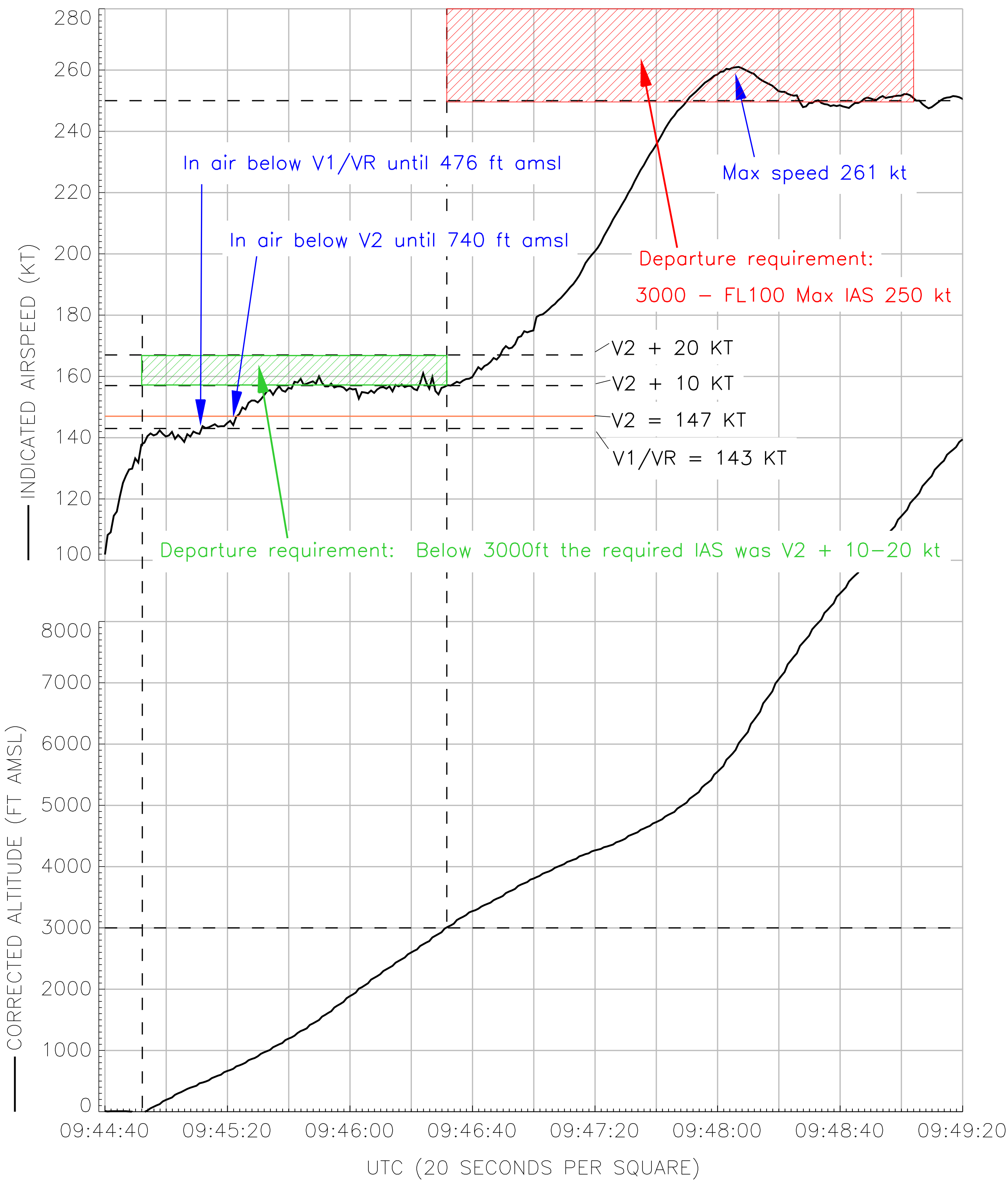

Figure 5

FDR parameters showing recorded airspeed relative to required airspeed after takeoff
(Incident to G-DBCI on 18 April 2007)

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rate, four times a second, but not at the same time. An additional complication was the fact that the sample rates were not high enough to capture the full dynamics of the parameters. As a result it was not possible to establish from the recorded data whether the rudder was driving the pedal movement or whether pedal movements were driving the rudder. No pedal force parameters were recorded.

Following a recommendation made by the USA National Transportation Safety Board, proposals have been tabled to require higher recording rates for primary control surface positions, such as the rudder, on future build aircraft. However, it is considered impractical to increase these sample rates for in-service aircraft and therefore no corresponding safety recommendation is made in this report.

Aircraft modelling and simulator testing

The aircraft manufacturer used a computer model of the A319 to determine its expected behaviour in response to the control inputs indicated by G-DBCI's FDR data. The modelling was carried out using the wind velocity and other conditions as recorded during the incident. The results produced a close match with the FDR data for flight control surface deflections and aircraft manoeuvre parameters, such as heading, pitch angle and lateral load factor, indicating that G-DBCI had responded correctly to the recorded control surface deflections. Modelling scenarios including a wind gust, engine or brake problem did not yield a close correlation between the recorded data and predicted aircraft performance.

A number of takeoffs were performed in an A320 simulator to explore the differences between an engine failure before V_1, and a deflection of full right rudder pedal on the takeoff roll, as occurred during the incident takeoff. At the same speed of 120 kt, the rate of yaw experienced after a failure of the right engine was similar to that produced by full deflection of the right rudder pedal, as recorded during the incident takeoff. It was also noted that introducing full left sidestick input (roll) on the ground, again as recorded during the incident, produced indiscernible aircraft roll while the aircraft remained on the ground.

Wake turbulence

Information on Wake Turbulence Spacing Minima for Departures is included in the CAA's Aeronautical Information Circular (AIC) 17/1999, entitled *Wake Turbulence*. This conforms to the International Civil Aviation Organisation (ICAO) requirements, with certain modifications which were not applicable in this case. It states that the minimum spacing at the time aircraft are airborne, departing from the same position, when a Medium aircraft (maximum takeoff weight between 40,000 kg and 136,000 kg) follows a Heavy aircraft (136,000 kg or greater) is two minutes.

It was calculated that G-DBCI became airborne exactly two minutes after the preceding A330.

Takeoff performance

The aircraft manufacturer advised that there was no performance penalty as a result of the aircraft becoming airborne 5 kt below the V_R speed of 143 kt. The Joint Aviation Requirements (JAR) Certification Specifications (CS), applicable to large aeroplanes, state under CS25.107(e)(4):

> *'Reasonably expected variations in service from the established take-off procedures for the operation of the aeroplane (such as overrotation*

> *of the aeroplane and out-of-trim conditions) may not result in unsafe flight characteristics or in marked increases in the scheduled take-off distances…'*

This is amplified in the relevant Acceptable Means of Compliance (AMC), AMC No. 2 to CS 25.107(e)(4), which states:

> *'For the early rotation abuse condition with all engines operating and at a weight as near as practicable to the maximum sea-level take-off weight, it should be shown by test that when the aeroplane is rotated rapidly at a speed which is 7% or 19 km/h (10 kt), whichever is lesser, below the scheduled V_R speed, no 'marked increase' in the scheduled field length would result.'*

Previous incidents of yaw disturbances during the takeoff roll

Previous reports by crews of A320 series aircraft of unusual yaw disturbances during the takeoff roll had prompted an investigation by the aircraft manufacturer. These events were characterised in recorded data by a lateral acceleration and heading change, followed by a large counter rudder deflection and then the reversal of these parameters.

Following the investigation, the manufacturer published Flight Crew Operating Manual (FCOM) Bulletin No. 829/1, entitled '*Yaw Disturbances during the Takeoff Roll*', in September 2004. It advised operators that:

> *'tests confirmed that the lateral perturbations were not caused by an aircraft system malfunction, but were always due to external lateral gusts.'*

The Bulletin stated that A320 series aircraft had experienced approximately 30 cases '*of "unusual" yaw movement during the take-off roll'*, sometimes referred to as a '*lateral jerk*'. It noted that the most significant of the events had included '*an initial sharp lateral disturbance, associated with short, but substantial, lateral acceleration and heading variation*' during the takeoff ground roll. Typical FDR traces of relevant parameters, including lateral load factor, rudder deflection and heading, were provided in this Bulletin, but without any indication of the magnitude of the excursions in these parameters.

The aircraft manufacturer had made a presentation on these yaw disturbances at an Operator's Flight Safety Conference in 2004. At that conference they presented quantitative data for one event which showed excursions of ±0.2g in lateral load factor and a heading change of 3°. This contrasts with the G-DBCI event where the commander reported a heading change of approximately 30° (later confirmed by the FDR to have been 18°).

The FCOM Bulletin also advised flight crews:

> *'that they may encounter such lateral disturbances, particularly in areas and in weather conditions where strong thermals have a tendency to develop. Pilots should, therefore, be prepared to react to such isolated disturbances by using the rudder normally, and avoiding excessive rudder input.'*

Evidence was found of other types of serviceable aircraft experiencing lateral deviations during the takeoff roll. In most of these cases a strong crosswind was the trigger for the event. This included an accident in 1997 involving an A320 aircraft in which the crosswind

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exceeded the handling pilot's limit as specified by that operator. One conclusion of the official investigation was that the cause of that accident was that:

> *'incorrect and excessive rudder was applied at high speed on take-off for indeterminable reasons, whilst the aircraft was under the control of the co-pilot.'*

Reports of lateral deviations during takeoff in serviceable aircraft where there has been either a light crosswind or none at all are rare. Investigation revealed three instances, which all involved A320 aircraft. Two of these takeoffs, in 1998 and 2001, were continued and another, in 2006, was aborted.

Post incident aircraft operation

This investigation included an assessment of the reasons why G-DBCI continued in service after the incident, flying two further sectors before being removed from service by the operator for additional investigation. The relevant factors were as follows.

The crew of the aircraft waiting to takeoff behind G-DBCI had reported to Amsterdam Tower having seen the sudden turn and the runway tyre track marks left on the runway. However, it appeared that G-DBCI's flight crew had probably already changed radio frequency after takeoff and did not hear the message. The report was passed to London ATC and thence to G-DBCI, but at some point the marks became referred to as 'tyre debris' on Runway 36L. At this point G-DBCI's crew suspected that the sudden turn had been caused by damage to the right main landing gear tyre(s), but did not have a tyre pressure indicating system to help verify or deny this. The Aircraft Technical Log for the incident flight contained a defect entry '*Suspect RH MLG tyre burst on T/Off. Emergency landing at LHR*'. The operator's maintenance personnel, having found no anomalies with the tyres after inspecting the landing gear when the aircraft arrived at Heathrow, cleared the reported defect.

The operator's Duty Pilot Manager commenced an investigation immediately following the incident, using the operator's published '*Incident Procedure - Duty Pilot Manager Guidance*'. This listed a substantial number of responsibilities, actions and points to consider, the last of which was consideration of whether the aircraft recorders should be downloaded. He debriefed the flight crew and in light of their description of the event, which mentioned a substantial heading variation, referred to the manufacturer's FCOM Bulletin No 829/1. As previously noted, this did not give any indication of the typical order of magnitude of the yaw deviations due to gusts.

From the available information at that time, and in the absence of a flight recorder printout, the operator concluded that wake turbulence had caused G-DBCI to suffer a 'lateral jerk' and that further investigation of the aircraft was not required.

Later on the day of the incident the commander of G-DBCI learned that his aircraft had left tyre marks on the runway at Amsterdam. When he reported this information back to his base, G-DBCI was grounded for further examination and assessment of the FDR information.

Procedures

The procedure for takeoff is laid down in the company's Operations Manual. The guidance for a briefing for a Right Hand Seat (RHS) takeoff includes the advice that:

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> *'If during the takeoff roll before V1 the call is STOP, the stop actions will be taken by the LHS (Left Hand Seat) pilot. The RHS pilot will revert to PNF duties.*
>
> *... above 100 knots but before V1 the LHS pilot will only stop for an ECAM* (Electronic Aircraft Centralised Monitoring) *Warning, Engine Failure or a malfunction which renders the aircraft unflyable. In the event of a Warning or Caution during take-off, he will respond STOP or GO as applicable.'*

On the subject of the technique to use for the takeoff, the guidance given is:

> *'To counter the nose-up effect of setting engine takeoff thrust, apply half forward stick until the airspeed reaches 80 knots. Release the stick gradually to reach neutral at 100 knots.*
>
> *For crosswind takeoffs, routine use of the into wind aileron is not recommended…*
>
> *'Once the thrust is set the captain keeps his hand on the thrust levers until V1 is reached.*
>
> *PNF will announce "ONE HUNDRED KNOTS"*
>
> *The PF crosschecks speed indicated on PFD and responds "CHECKED"*
>
> *Below 100 kt the decision to abort the take off may be taken, at the discretion of the captain, according to the circumstances.*
>
> *Above 100 kt, rejecting the take off is a more serious matter….'*

> *'After lift-off, follow the SRS* (Speed Reference System) *pitch command bar.'*

The SRS mode controls pitch to direct the aircraft along a path in the vertical plane at a speed defined by the SRS guidance law. In SRS mode, the aircraft maintains a speed target equal to V_2 + 10 knots in normal engine configuration. When the Flight Management Guidance System detects an engine failure, the speed target becomes the highest of V_2 or current speed, limited by V_2 + 15 knots. The SRS pitch command bar is activated as part of the Takeoff mode, which combines the SRS vertical mode with the RWY (runway) lateral mode. Takeoff mode is available during the takeoff run and initial climb for flight director (FD) bars guidance.

The RWY lateral mode is represented by the green Ground Roll Guidance Command Bar on the PFD. This symbol is displayed when the aircraft is on the ground or below 30 feet radio altitude, provided a localizer signal is available. It shows the flight director yaw orders, to maintain the runway centreline. In this instance there was no localiser available on Runway 36L, so the RWY lateral mode was not activated and the green Ground Roll Guidance Command Bar was not displayed, leaving only the SRS pitch command bar displayed on the PFD.

The Operations Manual also gives advice on how PNF should guard the flying controls during the takeoff. It states:

> *'During take-off roll and initial rotation ….. PNF should "GUARD" the side stick and take-over push button, and be ready for an immediate take-over should this become necessary. When guarding the side stick, PNF must ensure that no inadvertent inputs are made.'*

> *'PNF should also "GUARD" the rudder pedals with heels on floor ready to take over if necessary. PNF should be careful not to exert any pressure or make any inadvertent input to the rudder.'*

The Operations Manual provides advice and guidance on the procedure to follow in the event of *Flight Crew Incapacitation.* Under *Chain of Command,* it states:

> *'The fit pilot must assume control and return the aeroplane to a safe flight path.'*

The operator stated that, should incapacitation of the commander be detected by PF in the right seat during takeoff, PF should assume command and make the decision to continue or abort the takeoff, as appropriate. As part of their recurrent training programme, the operator provides all their flight crew, whether LHS or RHS, with the facility to exercise this decision making process in the simulator every three years.

Personnel

The co-pilot had accumulated 4,378 hrs in the A320 series of aircraft, of which the A319 is a common type, and had operated out of Amsterdam many times before. He commented that when he was PF during a takeoff it was his practice to glance at the sidestick order indication on the Primary Flight Display (PFD), colloquially referred to as the 'maltese cross', to check the position of the sidestick control and that it was in the neutral position at 100 kt, as specified in the Standard Operating Procedures (SOPs).

During the co-pilot's last three assessments, a Licence Proficiency Check (LPC), an Operator's Proficiency Check (OPC) and a Line Check in the previous August, January and February, respectively, his 'manual flight' had been graded as 'standard' by the operator's flight operations training department. No concerns had been raised in the comments that had accompanied these assessments.

He had been PF in an A320 during a previous, aborted takeoff in March 2006. During that event the aircraft was taking off on a westerly runway in wind conditions which were described as being blustery from the south-west. It was reported that, at approximately 115 kt during the ground roll, the aircraft experienced a very strong gust of wind from the left and the co-pilot correctly applied control inputs to counter the yaw to the left. However, after a number of rudder pedal inputs, the aircraft started drifting to the right and the commander, who initially suspected but saw no sign on the instruments of an engine failure, took control and aborted the takeoff.

The data recorded during that event indicated that varying amounts of right pedal were used to maintain a relatively stable aircraft heading. Towards the end of the takeoff ground roll, a slight deviation to the left was recorded and corrected with right rudder. However, the aircraft heading then deviated right of the centreline and instead of correcting this with less right rudder or with left rudder, slightly less than half full right rudder was applied, increasing the deviation. When the ensuing yaw rate exceeded 2 degrees per second, the takeoff was rejected.

It was concluded by the operator that the yaw to the right was a result of the wind variations and the co-pilot's rudder pedal inputs.

Following the event, the co-pilot was given refresher training in the simulator. This comprised two parts: a *Takeoff Safety Programme,* which was designed to assist pilots in reaching and maintaining proficiency in making '*GO/NO GO*' decisions and employing the correct techniques to stop the aircraft, and, secondly,

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improved use of rudder during takeoff in gusty crosswind conditions.

The Takeoff Safety Programme involved engine failures, mainly at V_1-5 kt with one carried out at V_1-20 kt, and a blown tyre and a cockpit alert, both at V_1-10 kt. The co-pilot completed the training to a satisfactory standard and displayed well-controlled handling in maximum crosswind conditions. Following this he was given further line flying training and his use of the rudder controls during takeoff was described as smooth and appropriate.

Following the incident in Amsterdam, the commander received refresher training in the simulator, which included the guarding of the flying controls as PNF and the taking over of control in the event of mishandling by PF during takeoffs and landings. This was supplemented with supervised line flying operations before the commander was returned to full line flying duties. The commander's performance during this period was assessed as being '*all to a good standard*.'

Aviation psychology

The events and circumstances of this incident were examined by an aviation psychologist who commented that:

> *'it is unusual, but not unknown, for pilots to make large, inappropriate, apparently unconscious rudder inputs and sustain them for long periods.'*

The advice given was that:

> *'for trained and experienced operators, closed loop control is generally a process that functions without much conscious thought about the details of command inputs.'*

It was also pointed out that:

> *'memory of unexpected, confusing and alarming events is notoriously unreliable.' These factors often make the causes of erroneous control inputs difficult to determine.'*

The aviation psychologist further commented that:

> *'the differences between the rudder control system and the manual elements of the primary flying controls are relevant to the directional error. In the elevator and aileron systems, the direction of control inputs is consistent with the resulting direction of rotation of the airframe. This is not the case with the rudder system, where the angular displacement of the rudder bar is opposite in sense to the resultant yaw command. Ab initio student pilots quickly adapt to this control law and generally are able to make appropriate rudder inputs without conscious difficulty. A possibility remains that, in exceptional circumstances, for example when alarmed or startled, a pilot might operate the rudder in the wrong sense.'*

Consideration was given to why an inappropriate response might remain undetected and uncorrected for several seconds. In his report, the psychologist stated that:

> *'A key factor is the liberation of closed loop control from conscious attention that results from training and practice. In a tight control loop, where attention is closely focussed on feedback from the system, errors in control input will be corrected relatively rapidly. The commands required to achieve this close control do not demand much, if any, conscious thought in routine*

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circumstances. When attention is intermittent or feedback is delayed, detection of an error could take seconds or even longer. For example, an inappropriate, discrete switch selection could easily pass unnoticed; the physical action is not closely monitored once the decision is made and evidence that the selection is wrong may take some time to arrive or command attention.

In addition, in aviation, primary control is generally effected manually. Where foot inputs are required, they tend to be discrete commands executed less frequently and potentially with less continuous monitoring of the feedback than manual commands. Where a task requires both manual and pedal inputs and there is acute competition for attention, it is likely that manual control will dominate and pedal control will receive less attention.'

Comparison was drawn to a similar phenomenon to inappropriate rudder activation which is better documented in road safety.

'Unintended acceleration occurs when a driver depresses the accelerator instead of the brake. Cases have been recorded of continuing and increasing acceleration. Obvious differences here are that only one limb is involved and the characteristic error is to select the wrong pedal rather than the wrong direction of application. In other respects, there are important similarities. The error remains undetected. The operator persists and even increases the force applied. Effective corrective action is not taken for some time. The operator may remain unaware of the error even after the situation has been resolved. The underlying mechanisms are probably similar to those involved in inappropriate rudder commands. In particular it is noteworthy that the effect of the initial feedback, i.e. the unexpected acceleration, is to increase arousal level and with it the strength of the erroneous movement. Conscious attention is captured by the visual scene and the demands of manual control; lower limb activity is effectively unmonitored.

Factors which might, in principle, contribute to an extended period of unmonitored control movement include distraction, high workload, over-arousal and under-arousal. Collateral evidence for any of these is lacking. In the absence of specific causes for any of the others, under-arousal is the most likely.'

The rest periods that the crew had received prior to the incident were examined and it was not considered likely that their performance was compromised by fatigue. However, it was thought conceivable that, in this instance, taxiing for a long period in benign conditions, before commencing the takeoff, could have led to a degree of relaxation and under-arousal.

Discussion

The takeoff roll continued normally until the aircraft reached a speed of 124 KIAS. A rudder pedal movement to the right then occurred, coincident with a proportionate movement of the rudder in the same direction, alleviated by a yaw damper input to the left, and the aircraft's heading increased to the right. The FDR data and the runway tyre track marks showed that G-DBCI started turning right off the centre of the runway approximately 1,035 m after the start of Runway 36L, at an airspeed of around 128 kt. The rudder pedal and rudder movement continued for 1.5 seconds before the FDR indicated that the rudder pedals and rudder were moved to the

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left for 0.5 seconds. The rudder pedals and rudder then continued moving to the right for another 0.5 seconds, reaching their maximum positions as the aircraft speed was passing 130 KIAS, although, again, the yaw damper reduced the magnitude of the rudder deflection.

During the last second of this sequence, the co-pilot's sidestick, which had been in the neutral position from the time the aircraft had reached 100 KIAS, was moved to give left roll and pitch up control orders. Thereafter, the rudder pedals were returned to the neutral position over a period of 3 seconds, during which a full left roll control order was maintained on the co-pilot's sidestick for 2.5 seconds and the commander's sidestick also registered a left roll order for one second. The aircraft had not rolled, so it is considered that the sidestick commands for a roll to the left were made in response to the yaw to the right, either because of the effect of the lateral acceleration on the flight crew or as instinctive inputs to stop the turn, or both.

A number of FDR parameters showed that asymmetric thrust or wheelbrake activity had not occurred during the takeoff ground run and were not responsible for the rapid yaw. The computer modelling showed that the control surface deflections recorded on the FDR had been fully consistent with the recorded movement of the flight deck controls, that G-DBCI had responded correctly, and confirmed that the right yaw had resulted from the rudder deflection.

The investigation consequently examined in detail the possible reasons for the rudder deflection. FDR data indicated normal behaviour of the rudder trim system and the yaw damper. Additionally, the trim system could deflect the rudder only at a rate that was much lower than that recorded and the yaw damper authority was much lower than the maximum recorded deflection angle; thus neither system was capable of producing the rudder deflection recorded.

It was therefore evident that either the rudder deflection had been commanded by displacement of the rudder pedals or a malfunction had caused an uncommanded rudder deflection that had back-driven the pedals. Determination as to whether the rudder or the pedals were leading the deflection was not possible from the FDR data alone because the parameter sampling rates were insufficient, pedal force was not recorded and the data transport delays could not be determined with adequate precision. However, information from the aircraft manufacturer indicated that, in the absence of a failure in the rudder control mechanical system, hydraulic pressure in the PFCUs would prevent the rudder from being back-driven by external forces. Additionally, in the event of depressurisation of all three hydraulic systems, even full-scale rudder deflection would cause only part-scale movement of the rudder pedals. No defect with the rudder system was found, and no anomalies with the system were found during service following the incident. Thus it was concluded that the rudder deflection had been caused by displacement of the pedals.

The initial right rudder pedal input and aircraft turn to the right was countered by a brief rapid reversal of the rudder pedals. However, continuation of the rudder pedals to full right travel may have been as a result of a startled response to another factor. Exactly when the commander called 'engine failure' is not known, but it might have been that announcement which caused sufficient alarm for the application of full right rudder. From that point on, the rudder pedals were returned to the neutral position. G-DBCI lifted off before reaching the edge of the runway surface and the co-pilot manoeuvred the aircraft back towards the runway centreline, before

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it continued to follow the SID, accelerating slowly to the SRS target speed of V_2+10kt by 1,100 feet amsl. The time taken for the aircraft to accelerate to V_2, the takeoff safety speed, was undesirable, bearing in mind that it is the speed that should be achieved by the screen height (35 feet agl) if an engine failure occurs at V_1.

The responsibility for aborting or continuing a takeoff lay with the commander. Although he called 'engine failure', it is not clear at what speed he made that call. The tests in a simulator suggested that the aircraft's rate of turn to the right, as a result of the right rudder pedal application, was similar to that which would be experienced during a failure of the right engine at the same speed. The speed of the aircraft at which the turn started was about 20 kt below V_1 and, if the engine had failed, the operator's SOPs indicate that it would have been appropriate to abort the takeoff. In the event, there was no engine failure and the call was incorrect. However, deviation of the aircraft's heading should have raised concerns regarding the control of the aircraft. Recognised at an early enough stage in the sequence, before the uncontrolled heading deviation was allowed to develop, it would have been possible to abort the takeoff, albeit at a speed approaching V_1.

The commander did not call *'STOP'* or *'GO'*, so the co-pilot continued as PF and continued the takeoff, in accordance with the SOPs. The aircraft lifted off on a heading which was 18° to the right of the runway centreline, at an airspeed 5 kt below V_R. The recorded data shows that the aircraft had stopped turning before the main landing gear had extended, as indicated by the squat switches. Had the takeoff been aborted when the turn to the right was well established, the aircraft would probably have departed the runway surface, with potentially severe consequences. Once airborne, there was no indication of any turbulence and the aircraft continued to respond correctly to the inputs made on the co-pilot's flying controls. It is possible that vestiges of the wake turbulence behind the A330 remained, but there were no signs that it was significant enough to disturb G-DBCI during the takeoff.

The circumstances of this incident differed from the previous event involving the co-pilot, in March 2006, in that that aircraft was disturbed by a strong gust of wind. Initially, the rudder moved in the correct sense to counter the yaw to the left. However the aircraft drifted right as more right rudder was applied and the commander took control, aborting the takeoff. The refresher training following that event gave the co-pilot practice in maintaining directional control of the aircraft during takeoffs in strong crosswinds. His aircraft handling was assessed as smooth and appropriate. The element of that training which required the co-pilot to abort the takeoff was not relevant because the SOPs require the LHS pilot to take control of the aircraft and perform that function when he has made the decision to STOP. The co-pilot's three most recent assessments raised no concerns about his 'manual flight', which was rated as 'standard'.

It was a matter of some concern that the aircraft had continued in service for two flights following the incident, before a comprehensive investigation to ascertain whether there might have been an aircraft malfunction. The evidence indicated that communication difficulties had been responsible.

The initial report of 'tyre debris', describing what were more specifically tyre rubber marks, led the crew to suspect a tyre burst. A TPIS could have provided an indication that this was not the case but was not fitted. The diagnosis of a tyre burst was then entered as a defect in the aircraft's Technical Log, rather than a description of what had happened. After having found no tyre

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anomalies, the operator's engineers cleared the defect and no outstanding report that might have suggested a possible aircraft malfunction then remained in the Technical Log to prompt further maintenance action.

Once it had been established that the tyres were undamaged, the operator's operational investigation considered that the yaw deviation described by the crew had probably resulted from wake turbulence from the aircraft that had taken off shortly before G-DBCI. This appeared to be generally consistent with the events described in the FCOM Bulletin No 829/1, which described 'lateral jerks' resulting in '*substantial*' heading variation. It is unlikely that this conclusion would have been reached had the bulletin provided an indication of the typical order of magnitude of yaw deviations observed due to gusts. On this basis the aircraft continued in service until the operator became aware of the presence of tyre marks on the runway.

On examination, the FDR data showed that the characteristics of this event differed from those described in the Bulletin, in which typical FDR traces showed that rudder activity occurred after the yaw deviation. However, the FDR data was not available when the operator initially assessed the incident, based solely on the contents of the crew report. Following the event, the operator has stated the intention to revise its Incident Procedure guidance, including specifying early involvement of its Flight Safety Department and earlier readout of the FDR.

Conclusions

The aircraft deviated to the right during the takeoff roll as the result of a full right rudder pedal input, which was initiated at 124 KIAS. The speed of the aircraft was between 100 kt and V_1 and the rate of turn was such that the commander considered that there had been an engine failure. The appropriate SOP in such circumstances, if recognised early enough, was to abort the takeoff, which required the commander to announce '*STOP*' and take control, albeit in the late stages of the takeoff roll. No '*STOP*' call was made and the co-pilot continued with the takeoff, which, in the absence of the commander becoming incapacitated, he was trained to do.

At some point the commander called 'engine failure', but when he did so is not clear. The aircraft stopped turning after deviating 18° from the centreline heading and rotated, becoming airborne before the main wheels had reached the edge of the runway surface. Its speed was 5 kt below V_R but there was no performance penalty resulting from this underspeed rotation and the aircraft was manoeuvred back over the runway centreline.

There was no indication of any wake turbulence from an Airbus A330, which had rotated 2 minutes before G-DBCI, having had an effect on the A319, although vestiges of that wake turbulence may have remained. G-DBCI slowly accelerated to the SRS target speed of V_2+10kt and continued on its assigned SID. The emergency landing at the aircraft's planned destination, which the flight crew elected to carry out in case of damage to the right main tyres, was uneventful and a subsequent engineering check revealed no fault with the tyres.

G-DBCI continued to operate two further sectors before being grounded, pending further investigation. As a result, the recording of the crew discussions on the flight deck during the takeoff from Amsterdam was overwritten. This deprived the investigation of valuable information relevant to this serious incident, bearing in mind that memory of unexpected, confusing and alarming events is unreliable.

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The reason for the initial rudder pedal input and deviation of the aircraft from the centreline during the takeoff roll could not be determined. However, it was considered that under-arousal of the flight crew in benign conditions was a possible factor. The application of full right rudder pedal may have been an alarmed response during the sequence of events, before the aircraft lifted off.

The operator had initially believed that the yaw deviation had been consistent with the type of event described in FCOM Bulletin No 829/1. It was unlikely that this conclusion would have been reached had the Bulletin provided an indication of the typical order of magnitude of the yaw deviations due to gusts, thereby making it apparent that the excursion in G-DBCI's case had been very much greater. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2008-028

It is recommended that Airbus revise Flight Crew Operating Manual Bulletin No 829/1 to include a quantitative indication of the typical range of aircraft heading and lateral acceleration deviations which may be observed due to gusts occurring during the takeoff ground roll.

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