SERIOUS INCIDENT

Aircraft Type and Registration:	Gulfstream G150, D-CKDM
No & Type of Engines:	2 Honeywell TFE731-40AR turbofan engines
Year of Manufacture:	2007
Date & Time (UTC):	6 February 2011 at 1317 hrs
Location:	Royal Air Force Northolt Airport, London
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 2 Passengers - 3
Injuries:	Crew - None Passengers - 1 (Minor)
Nature of Damage:	Fire damage to left brakes and tyres, left and right brakes seized
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	32 years
Commander's Flying Experience:	1,750 hours (of which 490 were on type) Last 90 days - 54 hours Last 28 days - 15 hours
Information Source:	AAIB Field Investigation

Synopsis

A takeoff was attempted from Runway 25 at Northolt Airport, London. When the commander pulled the control column back to rotate at rotation speed, V_R, and subsequently fully back, the aircraft only pitched up to 1º. The takeoff was rejected just before V_2, full braking was applied and the aircraft came to a stop at the end of the paved surface. A fire broke out around the left mainwheels which was suppressed quickly by the Rescue and Fire Fighting Service (RFFS).

The flight data showed that the aircraft's acceleration during the takeoff roll was below normal but the investigation did not reveal any technical fault with the aircraft. The most likely explanation for the lack of acceleration and rotation was that the brakes were being applied during the takeoff, probably as a result of inadvertent braking application by the commander, which caused a reduction in acceleration and a nose-down pitching moment sufficient to prevent the aircraft from rotating. However, it could not be ruled out that another factor had caused partial brake operation.

One Safety Recommendation is made, concerning the provision of flight data recorder conversion information.

History of the flight

The aircraft had been parked at Northolt for three days following a flight from Moscow Vnukovo Airport on 3 February 2011. There were no problems reported by the inbound crew and there were no items outstanding in the technical log.

On 6 February 2011 the flight crew of two pilots arrived to prepare the aircraft for a flight to Moscow. The pre-flight checks were carried out by the commander, who was also to be the pilot flying (PF) for the sector. All the checks were completed satisfactorily.

There were two passengers for the flight and a cabin attendant, who was not trained as a crew member, was also on board. When the passengers arrived they boarded the aircraft and the engines were started. Taxi clearance was obtained and the aircraft taxied off the apron, via Taxiway B, and backtracked to line up on the threshold of Runway 25 (Figure 1). The crew carried out the taxi checks, pre-takeoff checks and a briefing before departure.

The commander, in his briefing, noted that he would be using a static takeoff procedure, because of the relatively short runway length. The technique was to hold the aircraft on the toe brakes until full takeoff power had been achieved, and then to release the brakes.

The aircraft was held at the threshold for about two minutes, waiting for departure clearance to be issued, after which the takeoff commenced. The takeoff roll appeared normal to the crew and the standard calls and actions were made. On the call of rotate the commander started to pull back but there was no response from the aircraft. He pulled further back until the column was

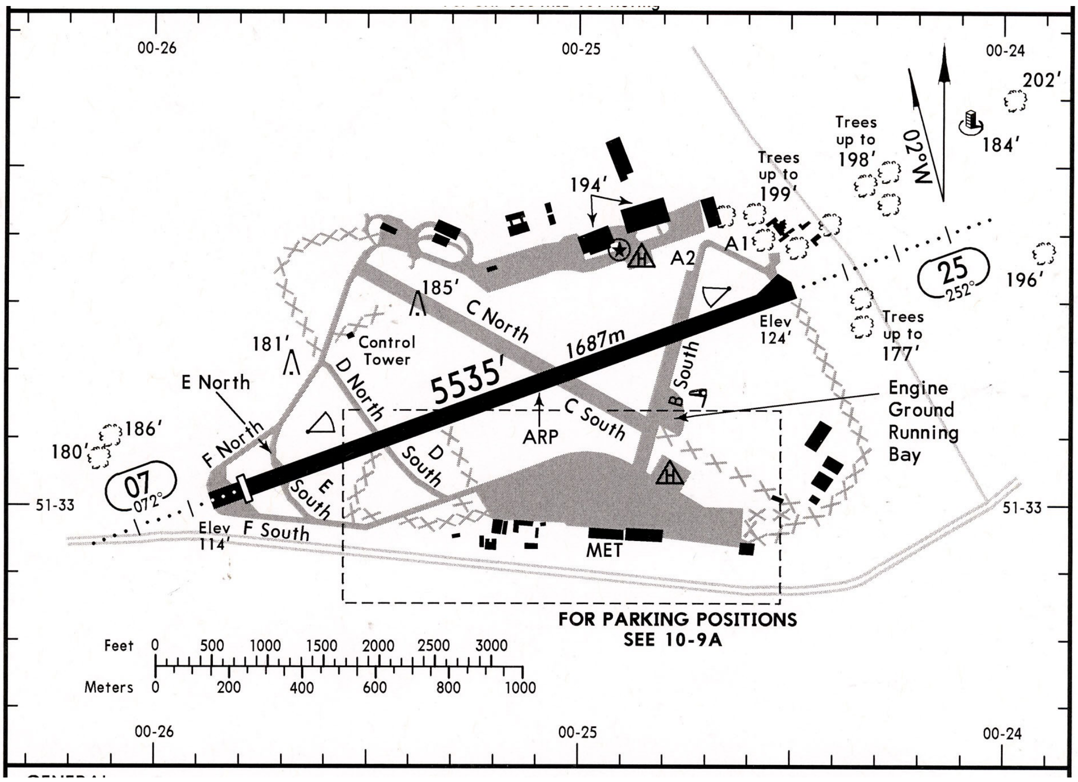

Figure 1

Northolt Airport

in the full aft position and still there was no rotation apparent. The aircraft was approaching the V_2 speed of 129 kt and the commander made an exclamation about the lack of rotation. The pilot not flying (PNF), seeing that the control column was fully back and realising that the aircraft would not rotate, retarded the thrust levers. Both pilots applied the brakes. The commander realised that there was not much runway remaining and used the tiller to steer to the right hand side of the runway before turning sharply left. The aircraft came to a stop at the end of and to the left side of the runway, on a heading of approximately 150°M.

After coming to a stop the commander made one attempt to taxi clear of the runway but the aircraft would not move. He then saw through his side window that there was smoke coming from the left mainwheels. The cabin attendant tried to open the entry door to evacuate the passengers but was not able to do so and the commander went back to assist. He opened the door, evacuated with the passengers and ensured that they moved clear of the aircraft. The PNF remained on board and completed the shutdown of the aircraft before leaving. As he exited, the fire service vehicles arrived and the fire was suppressed quickly. One passenger suffered a twisted ankle while disembarking from the aircraft.

The fire service vehicles had received the emergency call from ATC and deployed along the runway behind the aircraft. The driver of one vehicle observed that it was after the aircraft had come to a stop that a fire started around the left mainwheels.

Initial on-site examination of the aircraft

The aircraft had come to rest about 5 m from the end of the paved surface of Runway 25, orientated approximately 90º to the left of the runway centreline (Figure 2). The left main gear tyres and brakes had suffered fire damage (Figure 3). The left outboard tyre had two flat spots and had deflated as a result of a blown fuse plug, while the right main gear tyres were in good condition. The brake assemblies on both the left and

Figure 2

Final position of D-CKDM, about 5 m from the end of the paved surface of Runway 25 right main gear had seized so it was not possible to taxi or tow the aircraft. In order to tow the aircraft to a hangar the left main gear was jacked and lowered onto a trolley, while the seized brake disks and rotors from the right main gear were removed.

Personnel information

The commander had positioned to the United Kingdom on the day before the incident and the co-pilot had arrived at London Heathrow earlier in the morning. Neither pilot had operated from RAF Northolt previously. The pilots had flown together as a crew on many previous occasions but with their roles reversed.

The commander had recently completed his qualification to fly as Pilot in Command on type and this was his first flight as commander. His conversion training had all been conducted in D-CKDM and during the training and flight test he had completed 12 flight sectors occupying the left-hand seat. This flight was his first since the completion of his training.

The co-pilot, who was also a qualified captain on the type, had a total of 2,950 hours of flight time, 400 of which were on G150 aircraft.

The cabin attendant was on board to assist with the passengers and was not trained as a crew member.

Ground manoeuvring technique

The aircraft can be steered on the ground using the rudder pedals or the tiller. When using the rudder pedals the commander's technique was to place his feet on the pedals with his heels clear of the floor, so that the rudder was operated with the heels and the brakes by flexing forward the toe end of the foot. When taxiing he used the hand tiller for steering, keeping his feet in position on the rudder pedals. During the takeoff roll he maintained directional control using the rudder pedals, and guarded the tiller with his left hand up to a speed of 80 kt.

The commander reported that on some previous occasions he had inadvertently applied some brake while

Figure 3

Fire damage to the left main gear tyres and brakes (view looking forward); flat spot on left tyre taxiing but that it was immediately obvious to him as the deceleration was noticeable. He also commented that the contact with the pedal under his foot could be felt.

The co-pilot reported that his customary technique as PNF in the right-hand seat was to rest his feet flat on the floor and clear of the pedals and he stated that he was doing this during the incident takeoff. When operating as PF in the left-hand seat he would use the tiller for steering while taxiing and also for the initial part of the takeoff roll. His feet would be positioned so that the ball of the foot rested on the lower part of the pedal (the rudder bar) with the heels on the floor, unless braking was required in which case he would lift his feet up so that he could apply the brakes.

Aircraft information

Description of the aircraft

The Gulfstream G150 is a small business jet with a maximum takeoff weight of 26,100 lb. It first entered service in 2006 as a variant based on the G100 which was formerly known as the Astra SPX. D-CKDM was configured with seating for 2 pilots and 7 passengers. The aircraft has conventional mechanical elevator and rudder controls (with no hydraulic assistance), hydraulically-assisted ailerons and a horizontal stabiliser that is electrically actuated for trim.

The nosewheel steering can be controlled using the rudder pedals or the hand-wheel tiller. The rudder pedals can steer the nosewheel up to 3° left or right of centre, while the tiller can command up to 60° left or right of centre. The takeoff technique from the left-hand seat requires the co-pilot to hold the control column up to a speed of 80 kt, allowing the PF to use the tiller if required, and then for the PF to take over.

The braking system consists of four brake assemblies, one per mainwheel, which are operated by applying force to the top of the rudder pedals. The pedals mechanically actuate a power brake valve (PBV) which transmits hydraulic pressure to the brake assemblies via antiskid valves. A parking/emergency brake lever in the cockpit actuates the PBV independently of the pedals and is used to set the parking brake or to apply emergency braking in the event of a loss of the main hydraulic system. When the parking brake is applied, a pressure switch in the return hydraulic line illuminates a PARKING BRAKE ON EICAS message and triggers a discrete parameter recorded by the FDR.

Each brake assembly consists of a pressure plate, back plate, three rotating disks, two stationary disks and six pistons. The brake housing contains two separate hydraulic systems, each system actuating three of the six pistons. Under normal braking all six pistons are actuated, while under emergency braking or when applying the parking brake only three pistons are actuated. When hydraulic pressure is applied to the brakes, the pistons contact the pressure plate and compress the disk stack against the back plate. When the brake pressure is released, four return springs pull the pressure plate from the stack, forcing the pistons back into the piston cavities.

Maintenance history

At the time of the incident the aircraft had accumulated 780 flying hours and 371 cycles. The aircraft's last maintenance was carried out between 18 and 25 January 2011 at 764 hours. This maintenance check did not involve any work on the flight control or brake systems. All four brake assemblies were last replaced on 8 September 2010 and had accumulated 74 cycles at the time of the incident.

According to the aircraft manufacturer their fleet data indicated that the average life of a brake assembly was 305 cycles, with a high of 880 cycles and a low of 15 cycles. They stated that the life of a brake assembly was very variable and was affected by pilot technique, the length of the runway and the weight of the aircraft. However, they did not have data to explain why a brake assembly on one aircraft only lasted 15 cycles.

Performance

The MTOW of this aircraft is 26,100 lb (11,838 kg). The weight and CG calculations were completed by the operator's dispatch office and forwarded to the flight crew. The operator's calculations showed a takeoff weight of 24,228 lb and a CG of 32.96% mean aerodynamic chord (MAC). These figures were used to determine the required stabiliser trim position, which was -5.5°. Final weights, based on the number of passengers and bags loaded, were entered by the crew into the aircraft's flight management system (FMS) prior to flight. The FMS is fully integrated in the operation of the aircraft and provides V speeds and performance computations. The speeds calculated for the takeoff were V_1 118 kt, V_R 122 kt and V_2 129 kt.

The takeoff weight and CG were recalculated during the investigation as 24,417 lb and CG of 36.48% MAC. The revised figures took into account the actual passenger seating positions and the pilot's estimate of the amount of baggage in the baggage bay. These figures gave a stabiliser trim position of -4.3°; there was no change to the speeds. The balanced field length for this weight under the prevailing conditions was 4,555 ft and these revised figures were used for the calculations of braking effects during the investigation.

Meteorological information

The weather conditions at the time of the incident were dry with a strong and gusting south-westerly surface wind. At the start of the takeoff the controller advised the crew that the surface wind was from 240° at 18 kt with gusts up to 30 kt. The pilots stated that during the takeoff roll, although the general conditions were gusty, the airspeed indications were reasonably steady.

The METAR observed at 1329 hrs, 12 minutes after the incident was: Surface wind from 240° at 17 kt, visibility 40 km, cloud broken at 2,400 ft, overcast at 3,000 ft, temperature 12°C, dewpoint 5°C and pressure 1019 hPa.

Airfield information

RAF Northolt is a military airfield which accommodates some civilian aircraft operations. Runway 25 at Northolt is 1,684 m (5,535 ft) in length and 46 m (151 ft) in width. There is an initial downslope from the start of the takeoff position and an overall average downslope of 0.18%. There are arrestor beds in the overrun of each runway. The RFFS are situated abeam the centre of the runway and are linked to ATC by an alarm system and telephone.

Flight recorders

The aircraft was equipped with a Flight Data Recorder (FDR) and a 120-minute Cockpit Voice Recorder (CVR). A complete record of the incident was available from the FDR and CVR. The FDR also contained a record of the previous eight flights.

Salient parameters from the FDR included airspeed, engine N1, engine thrust reverser positions, longitudinal acceleration, lateral acceleration, parking brake, pitch attitude, flap, slat, horizontal stabiliser and spoiler positions. Longitudinal acceleration was sensed by an accelerometer mounted near to the centre line of the aircraft and recorded at a rate of four times per second on the FDR. The parking brake parameter was recorded at a rate of once per second. When the parking brake handle is set to the PARK position and a hydraulic pressure of 200 psi or greater is applied to the brakes, the FDR indicates that the parking brake has been applied. With the parking brake handle set to the OFF position and a hydraulic pressure of 80 psi or less is applied, the parking brake parameter will be recorded as being off. The FDR system did not record the positions of the control column, control wheel, elevator, brake pressure or brake pedals.

The incident takeoff is shown in Figure 4. The engine start was normal and, having configured the aircraft for a flap 20° takeoff with stabilizer trim set to -5.45°, the parking brake was released and the aircraft taxied from the south side apron towards Runway 25. Shortly after releasing the parking brake and the aircraft having started to move, both the commander and co-pilot confirmed that they had checked the correct operation of the brakes. The aircraft entered Taxiway B South before being cleared to enter the runway and backtrack before being positioned for takeoff, near to the threshold of Runway 25. The flight crew did not refer to any problems whilst taxiing. Checklists were carried out, which included a full and free check of the flight controls.

Whilst waiting for departure clearance, the parking brake indicated that it was set to the ON position for a period of 7 seconds. This occurred about 80 seconds after the aircraft had come to a stop at the threshold and approximately 35 seconds prior to the commencement of the takeoff roll. The aircraft was subsequently cleared for takeoff. The commander having previously briefed that he would be carrying out a static takeoff, increased both engines to the maximum takeoff power of 91% N1 (Figure 4). Having confirmed that the engine power was set and the co-pilot was holding the control column, the commander advised "BRAKE RELEASE" and the aircraft started to accelerate. During the initial acceleration phase, the longitudinal acceleration remained predominantly stable at about 0.2 g, and as the airspeed reached 80 kt, the commander took over the control column. At about the same time, the longitudinal acceleration started to reduce, and at 119 kt (V_1), it had stabilised at just greater than 0.1 g. The aircraft was about 860 m from the end of the runway at this time. Approximately one second later, at an airspeed of 122 kt, the co-pilot called "ROTATE". Three seconds later, the commander confirmed that the aircraft was not responding to his control column input and two seconds later the thrust levers were closed, which was shortly followed by deployment of the airbrakes and the rapid deceleration of the aircraft. The flight crew stated that they had applied heavy manual braking at this time. During the five seconds between the rotate command and the rejection of the takeoff, the pitch attitude of the aircraft had increased by less than 2°, from about 1° nose-down to just less than 1° nose-up, and the airspeed had reached a maximum of 128 kt. About two seconds prior to closing of the thrust levers, the longitudinal acceleration had further reduced to nearly 0 g. The aircraft was about 570 m (± 40 m) from the end of the runway at this time.

As the aircraft decelerated, reverse thrust was applied and, approaching the end of the runway the aircraft made a left turn onto a heading of 150° before coming to a stop. The commander then attempted to taxi the aircraft from the runway, but the aircraft would not move. About two minutes later, just as the RFFS were arriving, the aircraft was evacuated when a fire was noticed around the area of the left wheel brake assembly. Both engines were also shut down at this time.

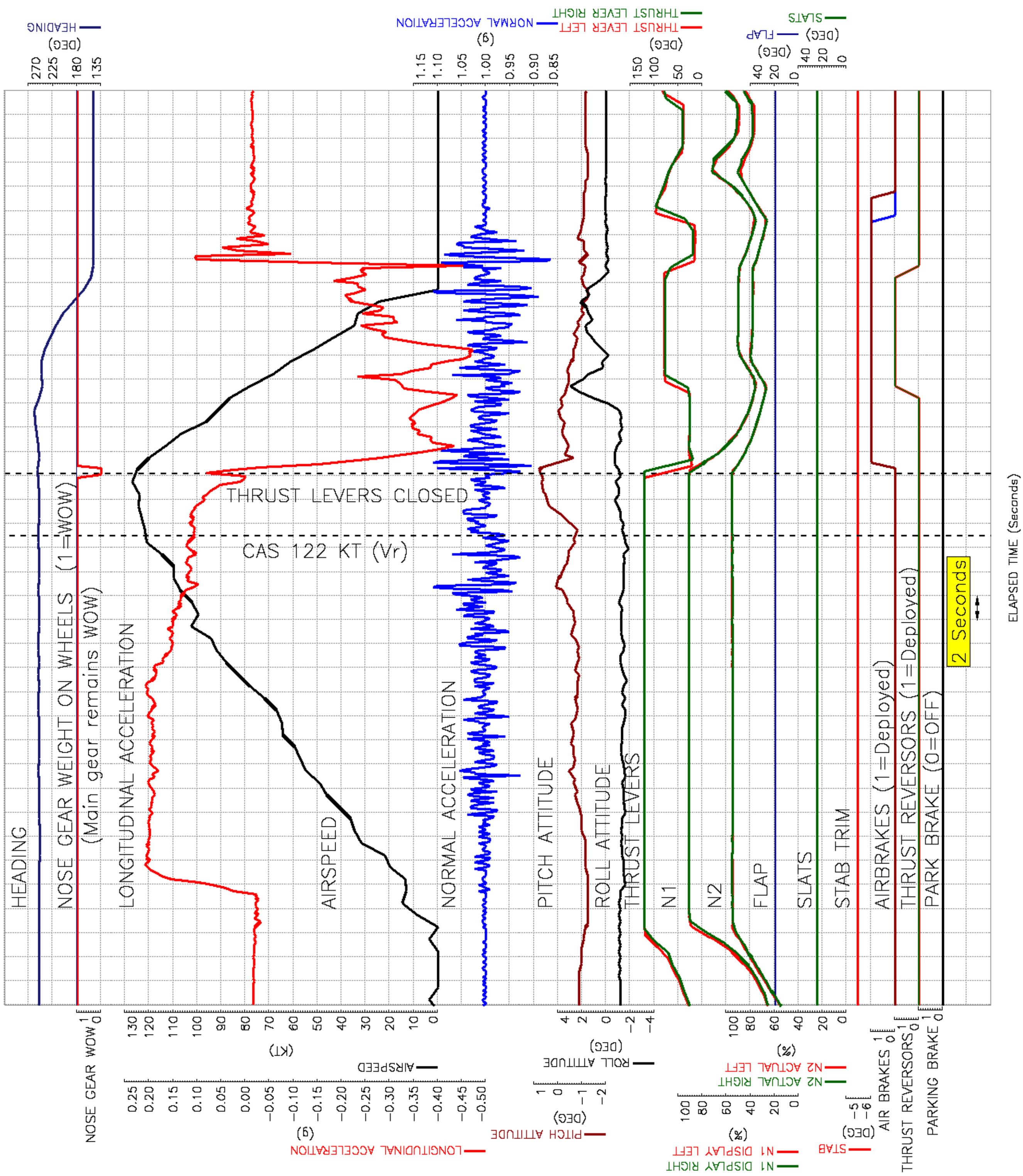

Figure 4

D-CKDM - Rejected takeoff at Northolt

Takeoff performance comparison

The aircraft's longitudinal acceleration profile during the incident takeoff run was compared with the eight previous takeoffs and the subsequent flight from Northolt (Figure 5). The takeoffs were confirmed as having used almost identical power settings as during the incident, of about 91% N1. Takeoff weights were obtained for all of the flights, with weights ranging from 26,023 lb to 17,502 lb. The takeoff weight of the incident flight was 24,417 lb. From the ten takeoffs, the incident takeoff run was found to have the lowest peak acceleration of about 0.2 g. The next lowest was 0.28 g, which was during the heaviest takeoff with the aircraft weighing 1,606 lb more than at the time of the incident. The highest longitudinal acceleration was 0.42 g which was recorded when the aircraft weight was at its lightest, weighing 6,915 lb less than at the time of the incident. Two of the takeoffs (one being from Northolt Runway 25) were within 958 lb of the incident takeoff weight (Figure 5). Both of these takeoffs had very similar acceleration profiles to each other, with similar peak longitudinal accelerations of about 0.3 g. Being of a similar weight and having used the same takeoff technique, aircraft configuration, runway and almost identical power settings to that of the incident takeoff, it may have been expected that the magnitude and acceleration profile of the subsequent takeoff from Northolt Runway 25 would have been very similar to that during the incident takeoff run. However, the aircraft accelerated about 0.1 g less during the incident takeoff run.

The manufacturer was provided with a copy of the FDR data. Their analysis concluded that the reduction in acceleration had been a result of the brakes being applied during the takeoff run.

FDR documentation requirements

Aircraft manufacturer

FDRs record binary data containing encoded parametric information. The binary data can then be converted to engineering units (knots, feet etc.) by referencing detailed documentation specific to the aircraft installation. The organisation most likely to possess the information and expertise required to generate such documentation is the aircraft manufacturer or the design organisation responsible for the FDR installation. To assist aircraft manufacturers or design organisations in producing such documentation, both the CAA and FAA have published guidance information within CAP 731 and AC20-141B respectively.

For aircraft issued with an EASA type-certificate, which includes the Gulfstream G150, Commission Regulation (EC) No 1702/2003 of 24 September 2003 Part 21 requirement 21A.61 '*Instruction for continued airworthiness*' states:

> *'(a) The holder of the type-certificate…shall furnish at least one set of complete instructions for continued airworthiness…to each known owner of one or more aircraft…upon issue of the first certificate of airworthiness for the affected aircraft…and thereafter make those instructions available on request to any other person required to comply with any of the terms of those instructions. …'*

Analysis and Safety Recommendation - FDR documentation requirements

The regulation quoted above does not explicitly reference FDR documentation and this is not reflected in any guidance material. However, correspondence with the CAA and EASA established that Part 21

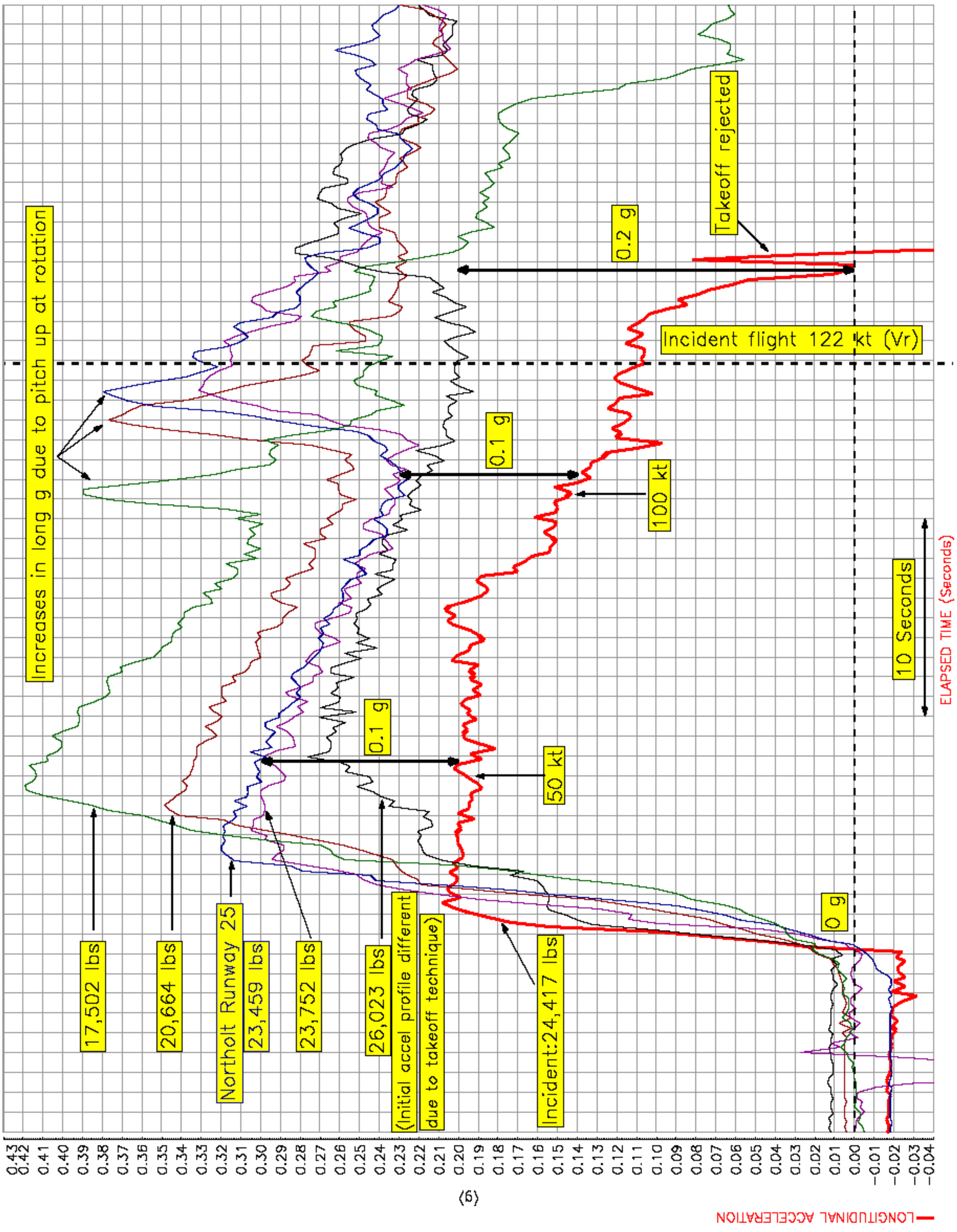

Figure 5

Comparison of incident takeoff with four previous takeoffs and subsequent takeoff from Northolt Runway 25 requirement 21A.61 implicitly includes the provision of FDR documentation that will enable the conversion of the binary record to engineering units. The same is true for requirements 21A.107 and 21A.120, which are applicable to holders of minor and major design change approvals respectively.

During the course of the investigation, the aircraft manufacturer provided five documents relating to the FDR system in D-CKDM. Following an initial delay, it was confirmed that a combination of three of the documents were required to enable the identification and conversion of parameters to engineering units. Further, the documentation was also found to contain anomalies such as conflicting information relating to the source of the normal acceleration parameter and the listing of parameters that were not recorded.

The accuracy of FDR documentation is fundamental to air safety investigation. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-085

It is recommended that the Gulfstream Aerospace Corporation issue flight data recorder engineering unit conversion information for G150 aircraft in a single document that follows the guidance given in Federal Aviation Administration AC 20-141B and UK Civil Aviation Authority CAP 731.

Aircraft operator

Commission Regulation (EC) 859/2008, referred to as EU-OPS, provides common technical requirements and administrative procedures applicable to commercial transportation by aeroplane. EU-OPS 1.160, '*Preservation, production and use of flight data recorder recordings*', (a) (4) states:

'(4) When a flight data recorder is required to be carried aboard an aeroplane, the operator of that aeroplane shall:

…(ii) Keep a document which presents the information necessary to retrieve and convert the stored data into engineering units.'

ICAO Annex 6 (ninth edition) Appendix 8 '*FLIGHT RECORDERS*' 2.3.3 also states:

'2.3.3 Documentation concerning parameter allocation, conversion equations, periodic calibration and other serviceability/maintenance information shall be maintained by the operator. The documentation needs to be sufficient to ensure that accident investigation authorities have the necessary information to read out the data in engineering units.'

The operator of the aircraft was unable to provide the AAIB with the documentation necessary to enable the conversion of the FDR binary data to engineering units. The AAIB drafted a Safety Recommendation to the operator, therefore, to ensure retention of documentation to enable conversion of stored flight data recorder information into engineering units (as required by EU-OPS 1.160). However, it is understood that Triple Alpha Luftfahrt, the operator, filed for bankruptcy in July 2011 and ceased operations, so the Recommendation is not made.

Detailed examination of the aircraft

Flight control system examination

The elevator control system was tested and operated fully and freely. The maximum nose-up elevator deflection was measured at 22° which was within specification. Elevator and elevator tab free play checks were also carried out and found to be satisfactory.

The horizontal stabiliser was found set to -5° based on the index marks at the tail (full travel is -11° to +1°) and this corresponded to an indication of -5.5° on the digital stabiliser position display in the flight deck. This was within the normal green band for the takeoff flap setting of 20°. A complete operational check of the horizontal stabilizer was carried out in accordance with the maintenance manual and no faults were found.

Pitot-static system test

A pitot-static system calibration and leak check was carried out in accordance with the maintenance manual and all measurements were within the required tolerances.

Brake system examination

The rotors and stators of the brake assemblies had seized and were beyond repair so the assemblies were removed and replaced with new ones so that brake system functional checks could be carried out on the aircraft. A number of hydraulic fluid samples were taken and analysed, and although some contained very small particles, the aircraft manufacturer did not consider the levels unusual. The hydraulic filters were also examined and contained only very small particles. Following brake replacement the air needed to be bled from the system. Since this required allowing hydraulic fluid to drain from the brakes, there was a risk that any evidence of contamination inside the PBV could be lost during the flushing process. It was therefore decided to remove the PBV for a stand-alone bench test and strip examination, and to install a new PBV for the on-aircraft functional checks. With the new PBV and new brake assemblies installed all the brake system functional checks in the aircraft maintenance manual were carried out with no faults or anomalies found; these included testing the parking brake and emergency braking system.

The PBV passed all the functional checks when bench tested, and a strip examination did not reveal any evidence of internal contamination.

Brake assemblies examination

The brake assemblies were examined by the brake manufacturer. They determined that the steel disks had welded themselves together on all four brake assemblies, and they stated that it was not uncommon for steel brakes to weld themselves together following a high-speed rejected takeoff. The brake pistons were all extended as can be seen in Figure 6 where the left inboard brake assembly is compared to a new one. The left brake assemblies had suffered more heat damage than the right brake assemblies and this was attributed to the fire. The brake assemblies were leak tested which resulted in one piston on the left outboard brake assembly leaking with a constant flow at 1,500 psi. One piston on the left inboard brake assembly also started leaking with a constant flow at 1,250 psi. None of the right brake assembly pistons exhibited any leakage at 3,000 psi. The leaks were attributed to deformed O-ring seals. The manufacturer could not determine if the brakes were leaking before the stop, but based on the condition of the brake disks, which were deformed due to normal operating pressure and excessive heat, there had been sufficient heat generated to deform the seals and cause the leak during the stop or immediately after. The fire probably started when leaking hydraulic fluid made contact with the hot brake disks.

The manufacturer concluded that the damage, discolouration and deformation of the brake assemblies were typical and acceptable following a high-speed rejected takeoff.

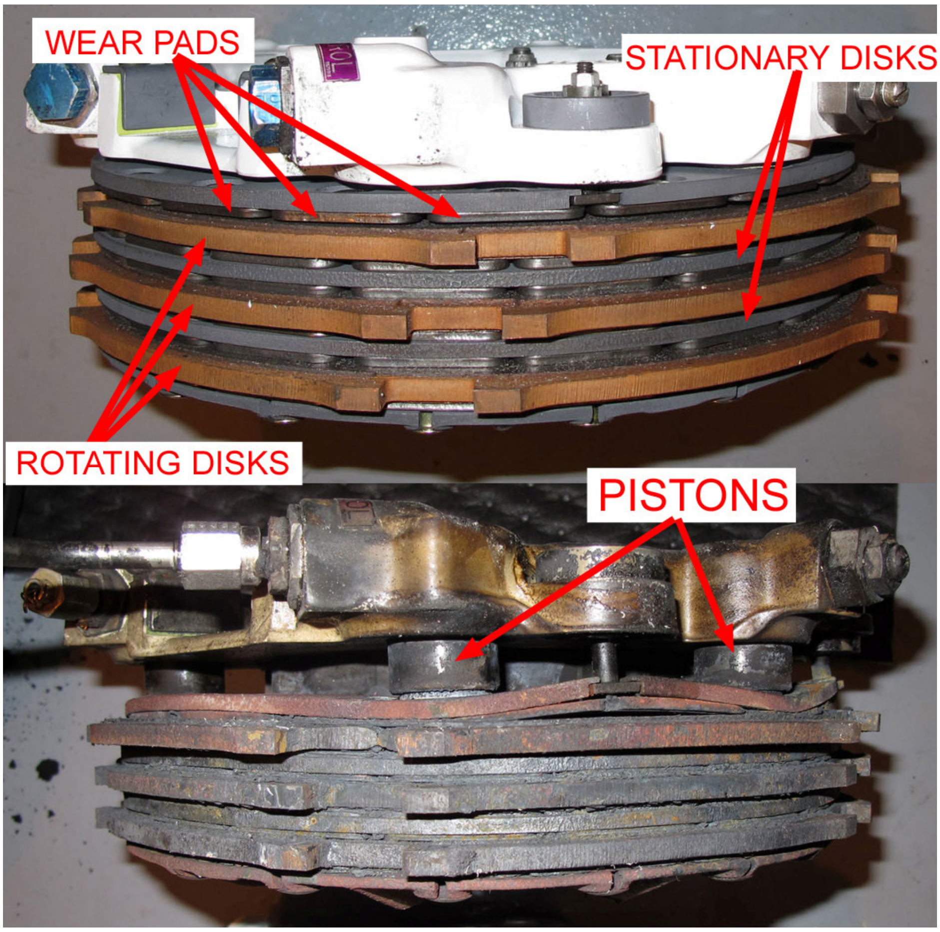

Figure 6

Comparison of new brake assembly (upper image) to the left inboard brake assembly from D-CKDM (lower image)

Brake pedal angle versus brake pressure

The relationship between brake pedal angle and brake pressure was measured using an inclinometer attached to a brake pedal and a pressure gauge attached to one of the brake assemblies. The aircraft was raised on jacks so that the initial brake resistance could be felt by trying to rotate the wheel by hand. The tests showed that at about 0.7° of pedal deflection the first resistance to rotation could be felt, with a brake pressure of about 100 psi. At about 0.9° of pedal deflection the wheels could no longer be rotated by hand and this equated to a brake pressure of 130 psi. At 0.9° of pedal deflection the top of the pedal was deflected by 2.8 mm. A pedal angle of 2° (6.3 mm pedal deflection) produced 380 psi. The maximum braking pressure of about 1,700 psi was achieved at 5.9° pedal angle (18.4 mm pedal deflection).

Post-incident taxi testing and test flight

Following the examinations, functional checks, and rectification work on the aircraft, a taxi test was carried out at Northolt by two of the manufacturer's test pilots. Multiple brake applications were made from speeds of up to 18 kt. The test pilots reported that the brakes operated normally with no tendency to stick. They noted, during the taxi tests, that a small amount of pedal deflection (feet lightly resting on the brake pedals) would produce a measurable reduction in taxi speed, but the braking effect was not necessarily perceptible to the pilot.

The aircraft then departed for a flight to Luton. The aircraft's weight was 23,459 lb, 958 lb below the incident takeoff weight and the aircraft accelerated and rotated normally (Figure 5).

Operator information

The aircraft was being operated in accordance with the operating company's AOC and Operations Manual. The company operated a number of other aircraft but commonly, as in this case, pilots were assigned to a specific aircraft. Both pilots had been flying D-CKDM for the previous few months. The owner of the aircraft was on board on the incident flight.

Other information

Brake pressure required to cause the reduction in takeoff acceleration

The aircraft's acceleration during the incident takeoff roll was significantly below normal for the aircraft's weight and the air temperature and pressure at the time. Compared to the aircraft's subsequent takeoff from Northolt under similar weight and weather conditions, the incident takeoff acceleration was about 0.1 g less at 50 kt and 100 kt (Figure 5) and about 0.2 g less at 128 kt just prior to the takeoff rejection. The engine data from the FDR revealed that the engines were performing normally, so the aircraft manufacturer calculated what brake pressure would have been required to explain the reduction in acceleration. It was determined that a reduction in acceleration of 0.1 g would have been caused by a brake pressure application of about 300 psi, between a groundspeed of about 5 kt and 100 kt. A reduction in acceleration of 0.2 g would have required a brake pressure of about 425 psi at 128 kt.

Brake pressure required to prevent rotation

Brake application causes a rearward force to be applied to the aircraft at the location where the tyre contacts the ground. Since this location is below the aircraft's centre of mass, brake application causes an aircraft nose-down moment. The aircraft manufacturer was asked to calculate what brake pressure would have been required to produce a nose-down moment high enough to counteract the nose-up moment caused by full nose-up elevator deflection, and thereby prevent rotation. They determined that a brake pressure of about 310 psi would be sufficient to prevent the aircraft from rotating at an airspeed of 128 kt, the maximum airspeed D-CKDM achieved.

Analysis

Recorded data

The examination of the recorded flight data showed that during the takeoff roll the aircraft's acceleration was about 0.1 g less than it should have been and, although the correct rotate speed was achieved, the aircraft did not rotate. The examination of the aircraft did not reveal any reason why the aircraft should not have been able to rotate and take off. The aircraft was configured correctly, its weight and balance were within limits, and there was nothing to restrict full nose-up elevator deflection. The stabiliser trim, although not accurately set for the actual weight and CG, would not have made a significant difference.

The only remaining factor that could have prevented the aircraft from rotating with full nose-up elevator at 128 kt was the application of some hydraulic brake pressure. Brake application causes a nose-down pitching moment and the manufacturer determined that 310 psi of brake pressure would have been sufficient to prevent the aircraft from rotating. Brake application would also explain the aircraft's lack of acceleration. About 300 psi of brake pressure would have resulted in a 0.1 g reduction in acceleration. Just prior to the takeoff being aborted, the aircraft's acceleration dropped to 0 g, about 0.2 g less than normal. This level of acceleration would have been caused by a brake pressure of about 425 psi, which is more than the brake pressure required to prevent rotation. These pressures assume symmetric braking on all four brake assemblies. The pilot did not experience any directional control difficulties so it is probable that symmetric braking was applied.

Examination of brake systems

Tests of the parking brake and emergency braking systems did not reveal any anomalies or tendency to stick. If the parking brake had been set during the takeoff roll a flight deck warning would have been triggered, based on the parking brake pressure sensor, and the FDR brake parameter discrete would have shown this. The brake assemblies were severely damaged in the incident so it was not possible to rule out a problem with the brake packs themselves, but it is unlikely that a failure of the brake packs would have occurred simultaneously on both sides to cause the symmetric brake application observed.

Tests showed that a pedal angle of only 2° was required to produce a brake pressure of 380 psi, which results in a 6.3 mm deflection of the upper part of the pedal. Thus, the pedals need only a relatively small deflection to produce the amount of brake pressure required to cause the reduced acceleration and prevent rotation. The manufacturer's test pilots noted that, during taxi, by resting the feet on the pedals some brake pressure could be applied, which was almost imperceptible but could be recognised by the reduction in expected taxi speed.

Reduced acceleration

The most likely remaining explanation for the lack of acceleration and rotation is that pressure was inadvertently applied to the brake pedals by one of the pilots. The co-pilot's technique was to keep his feet flat on the floor as PNF so it is unlikely that he touched the pedals during the takeoff. The commander's technique of holding the toes clear of the upper part of the pedals while placing the heels on the rudder bar allows the possibility that some pressure could have been applied to the brake pedal without his being conscious of it. When using this technique the foot position required to achieve steering without braking can be awkward, requiring the foot to be actively held up at an angle, and any change in the foot position could allow it to contact the pedal.

The static takeoff technique used was to apply full engine power before brake release. As the brakes were released there would have been a tendency for the aircraft to swing, so some steering inputs would have to be made. The commander reported that the tiller was not used during the initial part of the takeoff so it may be that while he maintained directional control with the rudder pedals some brake pressure was inadvertently applied and subsequently maintained. When the aircraft did not rotate as expected he pulled back fully on the control column. In doing so he may have used the pedals to gain extra leverage, thereby applying stronger brake pressure. At this time, between V_R and V_2, the data shows a significant reduction in acceleration.

Additional factors

There were some factors which could have acted to cause operational pressure on the crew. Although the commander had flown a number of sectors in the left-hand seat during training, this was his first flight in command of the aircraft and this represents an unusual circumstance. Other operational considerations were that the runway was relatively short and neither pilot was familiar with the airfield.

It is interesting to note that neither pilot noticed the lack of normal acceleration of the aircraft, even though the acceleration had reduced to nearly zero at one point. A particular aircraft's performance will be different for every takeoff and this demonstrates that pilots are not always able to judge how the takeoff is progressing.

The decision to reject the takeoff was made by the co-pilot. As the pilot monitoring he was probably in a better position to observe and assimilate the information that the aircraft was not performing as expected. The commander at the time would have been engaged in handling the aircraft and was probably confused by the lack of response to his control inputs.

The runway at Northolt is relatively short for this size of aircraft although the balanced field length for the conditions existing at the time of the incident was 1,000 ft less than the available runway. With the reduced acceleration of the aircraft, extra runway was used during takeoff and the remaining runway was too short a distance in which to stop. The action of turning the aircraft to the right, and then to the left, probably prevented the aircraft from running off the end of the paved surface.

The cabin attendant was not able to open the cabin door after the aircraft came to a stop. The door operated normally when opened by the commander, so it is probable that the cabin attendant, who was not trained as a crew member, was unable to open the door because of the unusual circumstances.

Future safety developments

Takeoff performance monitoring systems

In the D-CKDM incident the pilots had not detected that the aircraft's acceleration was significantly below normal. If a system could be developed, and certificated, to measure takeoff acceleration and compares it to expected values based on weight, pressure altitude and temperature, then it could provide an early warning to pilots that the takeoff is not progressing normally and may need to be aborted. In the D-CKDM incident the aircraft's below-normal acceleration was already apparent in the FDR data at a speed of 20 kt, so a warning in this event could have resulted in the flight crew performing a safer low-speed rejected takeoff. Such a system falls under the category of what is entitled a 'Takeoff Performance Monitoring System'. A more advanced system would also measure the aircraft's position and airspeed along the runway and predict if V_1 or V_R were likely to be achieved within a safe distance either to continue the takeoff or abort it.

On 14 October 2004 a cargo Boeing 747-200 (registration 9G-MKJ) departing from Halifax airport in Canada failed to become safely airborne and struck its tail against a concrete berm at the end of the runway, resulting in an accident that fatally injured all seven people onboard. The flight crew had used a reduced thrust setting that was too low for the takeoff weight, and although the aircraft's acceleration was below normal, the flight crew did not abort the takeoff or take action to increase thrust until it was too late. A report on this accident is available on the Transportation Safety Board of Canada's website (www.tsb.gc.ca, report number A04H0004). One of the safety recommendations made in the report is that:

'The Department of Transport, in conjunction with the International Civil Aviation Organization, the Federal Aviation Administration, the European Aviation Safety Agency, and other regulatory organizations, establish a requirement for transport category aircraft to be equipped with a take-off performance monitoring system that would provide flight crews with an accurate and timely indication of inadequate take-off performance.' (Recommendation A06-07)

The AAIB made two Safety Recommendations concerning takeoff performance monitoring systems in 2009. These followed from a serious incident involving an Airbus A330 (registration G-OJMC) departing from Montego Bay in Jamaica on 28 October 2008. In this incident the flight crew used a reduced takeoff thrust setting and 'V' speeds based on a takeoff weight of 120,800 kg when the actual takeoff weight was 236,900 kg. The flight crew perceived that the aircraft was accelerating normally, but when the commander pulled back on the stick to rotate the aircraft it 'did not feel right' to him, so he selected maximum thrust and the aircraft was able to climb away. Based on this incident and a number of other similar incidents highlighted in the AAIB report (Bulletin 11/2009), the AAIB made the following two Safety Recommendations:

It is recommended that the European Aviation Safety Agency develop a specification for an aircraft takeoff performance monitoring system which provides a timely alert to flight crews when achieved takeoff performance is inadequate for given aircraft configurations and airfield conditions. (Safety Recommendation 2009-080)

It is recommended that the European Aviation Safety Agency establish a requirement for transport category aircraft to be equipped with a takeoff performance monitoring system which provides a timely alert to flight crews when achieved takeoff performance is inadequate for given aircraft configurations and airfield conditions. (Safety Recommendation 2009-081)

The European Aviation Safety Agency has not yet accepted these Safety Recommendations but is considering them and has commented that an acceptable reliability of such a system has yet to be demonstrated. One aircraft manufacturer and one avionics manufacturer have also stated that they are investigating the feasibility of developing a Takeoff Performance Monitoring System.