SERIOUS INCIDENT

Aircraft Type and Registration:	Fan Jet Falcon 20E, G-FRAI
No & Type of Engines:	2 General Electric Co CF700-2D-2 turbofan engines
Year of Manufacture:	1972 (Serial no: 270)
Date & Time (UTC):	9 August 2012 at 0915 hrs
Location:	Runway 23, Durham Tees Valley Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 2 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Foreign object damage to engines
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	3,066 hours (of which 1,005 were on type) Last 90 days - 78 hours Last 28 days - 27 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft overran the runway when takeoff was abandoned due to a potential birdstrike. The crew stated that V_1 had not been called when the decision to stop the takeoff was made but analysis of available recorded data indicated that the aircraft was approximately nine knots above V_1 when actions were taken to reject the takeoff. No aircraft faults were found to have contributed to the incident although the surface friction characteristics of the runway stopway adversely affected the deceleration rate achieved during the final stages of the rejected takeoff. The lack of a CVR or FDR severely limited the ability of the investigation to determine the exact sequence of events during the incident. Two Safety Recommendations are made.

History of the flight

The crew, comprising a commander and co-pilot, reported for duty at 0745 hrs at their company offices at Durham Tees Valley Airport, together with an electronic warfare officer[1] who was to fly with them that day. On reporting, they were informed that they had been tasked that morning to simulate electronic threats for RAF aircraft training over the North Sea. The crew carried out the necessary pre-flight planning and walked out to the aircraft at about 0845 hrs. They completed the aircraft pre-flight preparation, which went without incident, and taxied for takeoff at 0903 hrs, with the commander acting as handling pilot. The electronic

Footnote

[1] The electronic warfare officer operates equipment carried by the aircraft but, as he is not intrinsic to the operation of the aircraft itself, is not technically considered part of the crew.

warfare operator occupied a seat halfway down the aircraft cabin, situated behind a mission equipment console.

The aircraft was taxied for a full length takeoff from Runway 23, during which the crew received takeoff clearance for a visual departure. They configured the aircraft for a flap zero departure and carried out the pre-takeoff checks, which included a brake and anti-skid check. All checks were normal.

After lining up approximately 40 m from the start of Runway 23 the pilots carried out a power assurance check in accordance with standard procedure, setting an EPR of 1.55 prior to releasing brakes for takeoff. As the aircraft accelerated down the runway the co-pilot carried out the standard acceleration checks[2]. These revealed an indicated longitudinal acceleration reading of 0.27 g against the pre-determined figure of 0.25 g, and a time to 100 kt of 19 seconds, against the calculated time of 21 seconds. Takeoff was continued with the standard calls being made between the two pilots. These included calls on passing 80 kt and 100 kt, with the commander expecting the next call to be on passing the calculated V_1 of 141 kt. Before this call had been made, the commander became aware of a large bird standing close to the runway centreline about 250 m ahead of the aircraft. The bird was seen to take off and fly along the runway, away from the aircraft, before turning round and flying back down the runway towards the aircraft. The bird passed down the left side of the aircraft, sufficiently close that the commander considered a birdstrike inevitable. He was concerned that this might result in damage to the control surfaces or an engine and so he decided to abort the takeoff. The commander stated he called "bird, aborting", retarding the thrust levers whilst applying full brakes and then deploying the airbrakes. The commander said that he called that he was aborting the takeoff at the same time as the co-pilot called V_1.

The crew felt the aircraft decelerate and the co-pilot informed ATC that the takeoff had been aborted. The slope of the runway meant that the end of the runway was not initially visible to the crew. When the end of the runway came into sight a few seconds later the commander considered the aircraft was not slowing at a sufficient rate to stop in the distance remaining. While maintaining maximum force on his own brake pedals he told the co-pilot to apply the brakes as well to ensure full braking pressure was being applied. The co-pilot did so, but with no discernable effect on the aircraft's deceleration.

There were no failure or warning indications apparent to the crew at any point during the aircraft acceleration and deceleration phases and they maintained maximum pressure on the brake pedals as the aircraft continued to slow. Despite this the commander realised the aircraft was not going to stop in the distance remaining and steered to the right of the centreline to avoid the ILS and lighting arrays beyond the end of the runway.

The aircraft departed the end of the runway, crossed the 119 m stopway, the remaining 60 m of the runway strip and continued onto the grass Runway End Safety Area (RESA). The wheels of the undercarriage sank into the soft ground, quickly bringing the aircraft to a halt. The crew shut down the engines and made the aircraft safe before vacating the aircraft through the left cargo door, this being the normal door used for entry and exit. The airfield emergency services were quickly in attendance, followed by emergency vehicles from the local authority. There was no fire, although fire crews reported that when

Footnote

[2] Three seconds after brake release the indicated longitudinal acceleration is checked to ensure it equals or exceeds the pre-determined value. The time for the aircraft to accelerate to 100 kt is then also checked to ensure it is equal to, or less, than the pre-determined value.

they arrived there had been smoke or steam coming from mud which had become caked between each pair of main wheels. The mud was removed from the brake units to assist with brake cooling.

Incident site

The aircraft came to rest within the RESA, on a soft grass surface 54 m beyond the end of the Runway 23 strip (Figure 1). The aircraft's tyre marks were discernible on the concrete-surfaced section of the runway and on the stopway and strip, both of which had an asphalt surface covered by scattered loose gravel. Inspection of these tyre marks showed no evidence of mainwheel skidding or locking.

The aircraft sank above the mainwheel axles into the soft grass surface and slewed to the right, onto a heading of 244º M, due to softer ground beneath the right main landing gear. A small quantity of fuel leaked from the right wing fuel tank vent, due to the resting attitude of the aircraft. Mud and stones were ingested into both engines. The right inboard brake unit had seized and was removed to allow the aircraft to be recovered.

The remains of a single carrion crow, weighing approximately 1 lb, were recovered from the runway at a point approximately 1,400 m (4,600 ft) from the start of the aircraft's takeoff roll. The crow was largely intact and showed no evidence of having been ingested by either of the aircraft's engines. No witness mark from a bird impact was visible on the aircraft, although it may have struck the landing gear with any impact marks having been subsequently obscured by mud.

Figure 1

Incident site

Weather

The weather at the time of the incident was good with dry conditions and a light wind of 2 kt from the SSW. The temperature was 18° C and the QNH was 1026 hPa. The temperature at the time the crew carried out their performance calculations had been 12° C and this figure was used in their calculations.

Pre-flight performance calculations

Takeoff performance for the flight was determined as part of the pre-flight preparations by the crew using the relevant aircraft manuals. Section 5, sub-section 10, page 1a of the aircraft flight manual describes the take-off field length as the greatest of:

> '• *115% of all engines operating distance up to 35 ft*
>
> • *The total distance considering an engine failure recognition at V_1 appropriate to a dry runway*
>
> • *The total distance considering an engine failure recognition at V_1 appropriate to a wet runway'*

Section 5, sub-section 1, page 2 of the aircraft flight manual defines V_1 as the critical engine failure speed (dry or wet) for which, if an engine failure occurs:

> • *'The distance to continue the takeoff to a height of 35 feet for "dry V_1", or not less than 15 feet for "wet V_1" will not exceed the usable takeoff distance, or,*
>
> • *The distance to bring the aeroplane to a full stop will not exceed the accelerate-stop distance available.*
>
> • *The speed V_1 corresponds to the time a failure is detected.'*

It further states that V_1 must not be greater than the rotation speed, V_R.

Takeoff performance

The aircraft had underwing stores fitted to three of its four pylons and a fuel load of 8,400 lb, giving a takeoff mass of 29,171 lb.

The maximum takeoff weight for the aircraft under the prevailing conditions (but with a temperature of 12° C) was 29,800 lb, restricted by an obstacle in the second segment climb. The dry V_1 speed was 141 kt and the field length limit allowed takeoff at the aircraft's maximum certified takeoff mass of 30,000 lb.

Using the actual temperature at takeoff of 18° C, the maximum takeoff mass for the aircraft remained limited by the obstacle in the second segment climb with the dry V_1 speed remaining at 141 kt. The field length limit still allowed takeoff at the aircraft's maximum certified takeoff mass of 30,000 lb. Under these conditions the scheduled takeoff distance required was 2,194 m (7,197 ft) with a maximum brake energy speed (V_{MBE}) of 156 kt.

Airfield information

Durham Tees Valley Airport has a single runway, denoted 05/23. It is 2,291 m long and 45 m wide classifying it as a Code 4 runway under CAP 168[3]. The runway is predominantly asphalt except for a concrete section at either end.

The longitudinal profile of Runway 23 complies with CAP 168 requirements. CAP 168 Chapter 3,

Footnote

[3] CAA document: CAP 168 Licensing of Aerodromes.

Section 3.4.1 states that where slope changes cannot be avoided they should be such that for aircraft with the wingspan of the Falcon 20E:

> *'there will be an unobstructed line of sight from any point 2 m above the runway to all other points 2 m above the runway within a distance of at least half the length of the runway'.*

Records held by the CAA do not identify a variation from this requirement at Durham Tees Valley Airport although it has not been possible to determine whether this has ever been properly confirmed through an appropriate survey.

The following distances for Runway 23 are declared in the UK AIP:

Takeoff Run Available (TORA)	2,291 m (equivalent to 7,516 ft)
Accelerate Stop Distance Available (ASDA)	2,410 m (equivalent to 7,906 ft)
Takeoff Distance Available (TODA)	2,500 m (equivalent to 8,202 ft)

CAP 168 provides the following definitions and additional information:

> '*<u>TORA</u> - The distance from the point on the surface of the aerodrome at which the aeroplane can commence its take-off run to the nearest point in the direction of take-off at which the surface of the aerodrome is incapable of bearing the weight of the aeroplane under normal operating conditions.*
>
> *<u>ASDA</u> - The distance from the point on the surface of the aerodrome at which the aeroplane can commence its take-off run to the nearest point in the direction of take-off at which the aeroplane cannot roll over the surface of the aerodrome and be brought to rest in an emergency without the risk of accident.*
>
> *<u>Stopway</u> - A defined rectangular area beyond the end of the TORA, suitably prepared and designated as an area in which an aircraft can be safely brought to a stop in the event of an abandoned takeoff.'* (The stopway's length is equivalent to the difference between ASDA and TORA and equates to 119 m for Runway 23). *'It should have sufficient load-bearing qualities to support the aeroplanes it is intended to serve without causing them structural damage. The surface of a paved stopway should have friction characteristics not substantially less than those of the associated runway and above the Minimum Friction Level stated in CAP 683[4]. It should be kept free from debris and loose material which could damage aeroplanes. A stopway may be an economical substitute for what would otherwise have to be provided as paved runway to meet the take-off field length requirements of some aeroplanes.*
>
> *<u>Runway Strip</u> - An area of specified dimensions enclosing a runway intended to reduce the risk of damage to an aircraft running off the runway and to protect aircraft flying over it when taking-off or landing. A runway strip is an area enclosing a runway and any associated stopway. Its purpose*

Footnote

[4] CAA Document – CAP 683 The Assessment of Runway Surface Friction Characteristics.

is to reduce the risk of damage to an aeroplane running off the runway by providing a graded area which meets specified longitudinal and transverse slopes, and bearing strength requirements. It protects aeroplanes during take-off by providing an area which is clear of obstacles except permitted aids to air navigation. A runway strip should extend beyond each end of a runway and of any associated stopway for a distance of at least 60 m for a Code 4 runway.' (The runway strip at the end of Runway 23 at Durham Tees Valley is 60 m). *'The total area within the runway strip should be capable of supporting unrestricted access for emergency service vehicles.*

RESA - *An area symmetrical about the extended runway centreline and adjacent to the end of the runway strip primarily intended to reduce the risk of damage to an aeroplane undershooting or overrunning the runway. The surface of the RESA does not need to be prepared to the same standard as other associated runway areas but should enhance the deceleration of aeroplanes in the event of an overrun whilst not causing it damage or hindering the movement of rescue and fire fighting vehicles.'* Runway 23 had a RESA of 106 m which exceeds the minimum required length for a Code 4 runway of 90 m. Wherever practical and reasonable CAP 168 recommends a RESA of at least 240 m.

An annotated diagram showing how the above definitions relate to the end of Runway 23 at Durham Tees Valley Airport is shown in Fig 2 below.

Figure 2

The end of Runway 23 at Durham Tees Valley Airport

Runway friction

A runway surface friction assessment conducted in May 2012 found that its friction characteristics exceeded the requirements as defined in CAP 683. The results indicated that the friction characteristics would have remained above the minimum required levels at the time of the incident. Limitations in existing continuous friction measuring equipment makes the measurement of friction characteristics at runway ends and stopways impractical and figures for these areas of Runway 23 were not available. The CAA, with others, is currently undertaking research into friction measurement capability in order to address this problem.

Bird control measures

During daylight hours bird control patrols were conducted continuously on the airfield with bird activity and control measures employed being recorded in a log. A runway inspection was carried out a least once every thirty minutes. Where bird or animal remains are found on airfield they are removed.

The bird control log listed a number of birds having to be dispersed from the airfield on the morning of the incident. A bird inspection of Runway 23 took place at 0845 hrs with two crows being sighted at 0850 hrs on the northern side of the runway in the area of the Runway 05 threshold. The log indicates the birds were moved from the area of the runway by the patrol.

CAP 772 provides information on birdstrike risk management at airfields. Chapter 6, section 4.4.2 includes the following information on carrion crows:

> *'Carrion crows are involved in very few birdstrikes. Although continuously and almost universally present on aerodromes, they occur in small numbers and, being resident, apparently establish routines that help them avoid aircraft. However, their habit of feeding on carrion on runways and the occurrence of nomadic flocks create a potential birdstrike risk, which cannot be ignored.'*

The aircraft

G-FRAI was built in 1972 and acquired by the operator in 1990 for conversion into a special-missions aircraft, which involved the addition of four under-wing pylons for external stores and an electronic warfare officer's (EWO) workstation in the cabin. In 1995 the aircraft's maximum certified takeoff mass was increased from 28,660 lb to 30,000 lb by a UK CAA-approved Supplementary Type Certificate (STC).

The operator upgraded the aircraft's avionics system to incorporate the Collins ProLine IV system in 2004, and certain parameters from this system were recorded on the EWO's Situational Awareness Display System (SADS). Each pilot had an airspeed indicator which had a vertically-moving digital strip.

The aircraft was not equipped with thrust reversers or a drag chute.

Description of the braking system

The aircraft has twin-wheel main landing gears (Figure 3) and each mainwheel is equipped with a three-rotor disk brake assembly. The brake rotors are keyed such that they rotate with the mainwheels and are coated with a friction lining on both faces. The fixed section of the brake assembly consists of a housing plate accommodating ten brake pistons in addition to

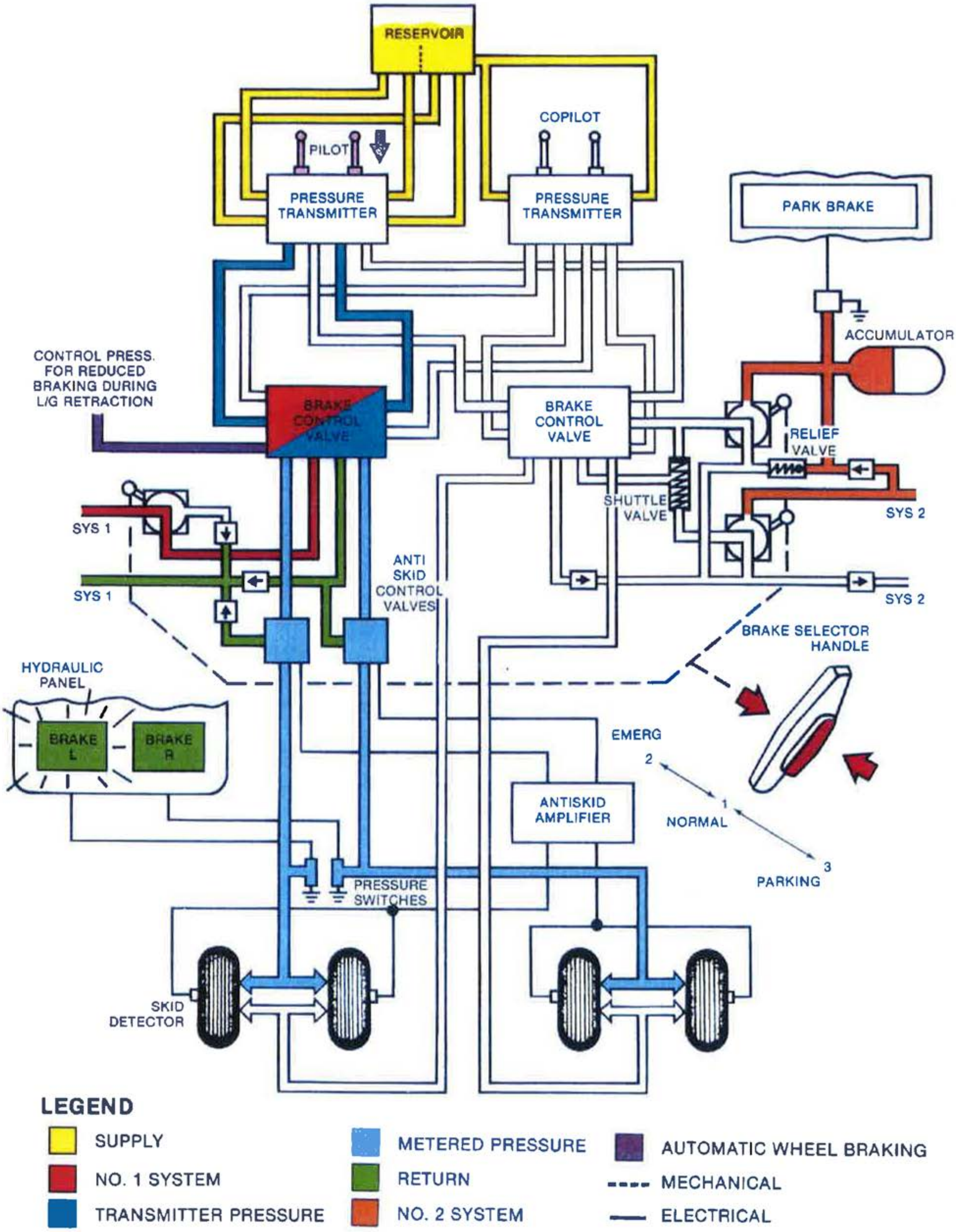

Figure 3

Falcon 20E braking system operation in the normal mode a thrust plate, a pressure plate and two stator disks, all of which are lined with friction pads. When hydraulic pressure is applied to the brakes, the pistons contact the thrust plate and compress the rotor and stator disks against the pressure plate to provide braking action. The housing plate is drilled with two independent hydraulic passageway systems, each supplying five brake pistons, enabling brake pressure to be independently supplied by either the number 1 hydraulic system for normal brake operation, or by the number 2 hydraulic system for emergency braking. Selection of the braking mode is controlled by a three-position mode selector handle mounted in the centre of the instrument panel glareshield.

In the normal braking mode, when the rudder pedals are pushed forwards, transmitters connected to the rudder pedals actuate a brake control valve that increases the pressure in the brake pistons up to a maximum nominal value of 1,175 psi. An anti-skid system modulates the maximum braking pressure to just below the skid threshold point by means of wheel-speed tacho-generators mounted in each mainwheel axle, two anti-skid control valves and a system control box mounted in the rear fuselage.

During certification flight testing of the three-rotor disk brakes, the manufacturer demonstrated rejected takeoffs (RTOs) from a maximum kinetic energy of 43.2 MJ. Analysis conducted by the manufacturer showed that during these RTOs approximately 84% of the aircraft's kinetic energy, 36.2 MJ, was absorbed by the brake units, with the remaining 16% being mainly accounted for by aerodynamic drag and rolling resistance.

Aircraft records

The aircraft technical log recorded that a daily inspection had been carried out at 1715 hrs on the day preceding the incident, following the last flight that day. The engineer who performed this inspection confirmed that the brake wear indicators were checked using the correct special tool and that the brake wear was within AMM limits.

Aircraft examination

The aircraft was recovered to the operator's hangar for detailed examination. Apart from foreign object damage to both engines, the aircraft was otherwise undamaged. None of the mainwheel thermal fuse plugs had melted and all the aircraft's tyres remained inflated. The aircraft was raised on jacks to allow the hydraulic pressure at each brake unit to be measured using pressure gauges which, for the purpose of the test, required the seized right inboard brake assembly to be replaced with a new unit. In the normal braking mode, full deflection of the pilot's brake pedals resulted in brake pressures of between 1,080 and 1,140 psi being recorded, with minor variations between individual brake units. The acceptable range of maximum brake pressure is specified in the aircraft maintenance manual (AMM) and has a lower limit of 1,073 psi and an upper limit of 1,233 psi. Full deflection of the co-pilot's brake pedals resulted in brake pressures between 1,160 and 1,200 psi and it was therefore demonstrated that full deflection of either set of brake pedals resulted in the required level of maximum brake pressure.

All four brake units were removed for disassembly and, despite having absorbed considerable heat during the rejected takeoff, the brake rotors still retained an average thickness of 0.4 mm of friction lining material[5]. The cause of the seized right inboard brake assembly was traced to small areas of brake lining material that had melted, fusing the rotors and stators together as it subsequently cooled; the reason why this brake unit

Footnote

[5] A new brake pack was measured which had a brake rotor friction lining thickness of 1.7 mm.

had become marginally hotter than the other brake units could not be determined.

The anti-skid system was checked for correct operation by performing the test procedure set out in the AMM and additionally by carrying out an approved *'Local Maintenance Instruction'* procedure using a test box to perform more detailed testing of the anti-skid control electronics. Both tests demonstrated that the anti-skid system was serviceable.

Samples of hydraulic fluid from both hydraulic systems were taken and analysed by a specialist laboratory and the results did not reveal any abnormalities that would cause a significant reduction in the aircraft's braking action. A pitot/static system calibration and leak check was carried out in accordance with the AMM and all measurements were within the required tolerances.

Recorded data

The aircraft was being operated under the UK Air Navigation Order 2009 but had a UK CAA exemption from the requirement to be equipped with an FDR and a CVR, and had neither fitted. However, the SADS, a Windows XP based tablet, recorded data gathered from the Collins ProLine avionics via a dedicated interface unit. This recorded UTC, radio altitude, pressure altitude, IAS, temperature, ground speed, track, heading, drift, pitch, latitude, longitude and magnetic variation. However, the SADS was designed to give the operator situational awareness and, as the sampling rate used by the system to gather data is not sufficiently consistent, the system is inadequate for detailed incident analysis.

Data point timing

The SADS gathers data samples from avionics busses at a nominal rate of one per second but, as the tablet uses an operating system that is not designed for real-time applications, this rate can vary. Testing by the interface unit manufacturer, using a computer system representative of, but not identical to, the SADS tablet, indicates that the majority of samples are likely to be requested within approximately 50 ms of the nominal one second sample period but occasionally a larger gap between samples was observed.

Parameters are time-stamped but, with limitations of the time stamp resolution and refresh rate, a parameter value could have sampled anywhere within a 1.2 second period. This results in recorded data with insufficient fidelity for detailed analysis.

It is unlikely that successive samples will have been requested by the tablet at intervals of significantly less than 1 second, but the actual time between requests for samples with a time-stamp of one second apart could theoretically have been up to 2.2 seconds apart.

During the RTO, at the time of peak speed and another point shortly after this, two time-stamps and their associated parameters were not recorded. With a missing time-stamp, samples that are stamped as 2 seconds apart could theoretically be between 0.8 and 3.2 seconds apart.

GPS data

The recorded position, track and groundspeed are GPS based. These GPS based parameters were unreliable at low speeds at the start of the takeoff run and towards the end of the RTO and so were not used for further analysis. However, when the GPS parameters appeared more stable, the recorded values of IAS were consistent with those of groundspeed.

The average GPS position of the stationary aircraft on the runway was taken as the start point of the takeoff roll. This was approximately 40 m (131 ft) from the start of the runway. Integrating the IAS over time from this start point provided a calculated distance travelled that correlated well with the actual distance travelled.

Event data

Figure 4 shows the pertinent recorded parameters and acceleration calculated from the recorded IAS.

Calculations indicate that on passing 141 KIAS the aircraft had travelled approximately 1,171 m (3,842 ft).

The data shows continued consistent acceleration between 140 KIAS and 150 KIAS. The peak recorded airspeed was 151.9 KIAS, three seconds after 140.6 KIAS was recorded. Even taking into account the time-stamp issues discussed above, it is unlikely that the time between these values was less than 2.8 seconds.

From 140 KIAS to 100 KIAS, assuming accurate time-stamps, the average deceleration was -0.42 g. The aircraft left the end of the runway at approximately 75 KIAS. Once on the stopway and then the runway strip, deceleration reduced significantly and the aircraft continued until it ran onto the grass. The aircraft departed the stopway with a speed of approximately 60 KIAS and entered the grass with a speed of approximately 50 KIAS. The data indicates the grassed area provided significant retardation, bringing the aircraft to a stop.

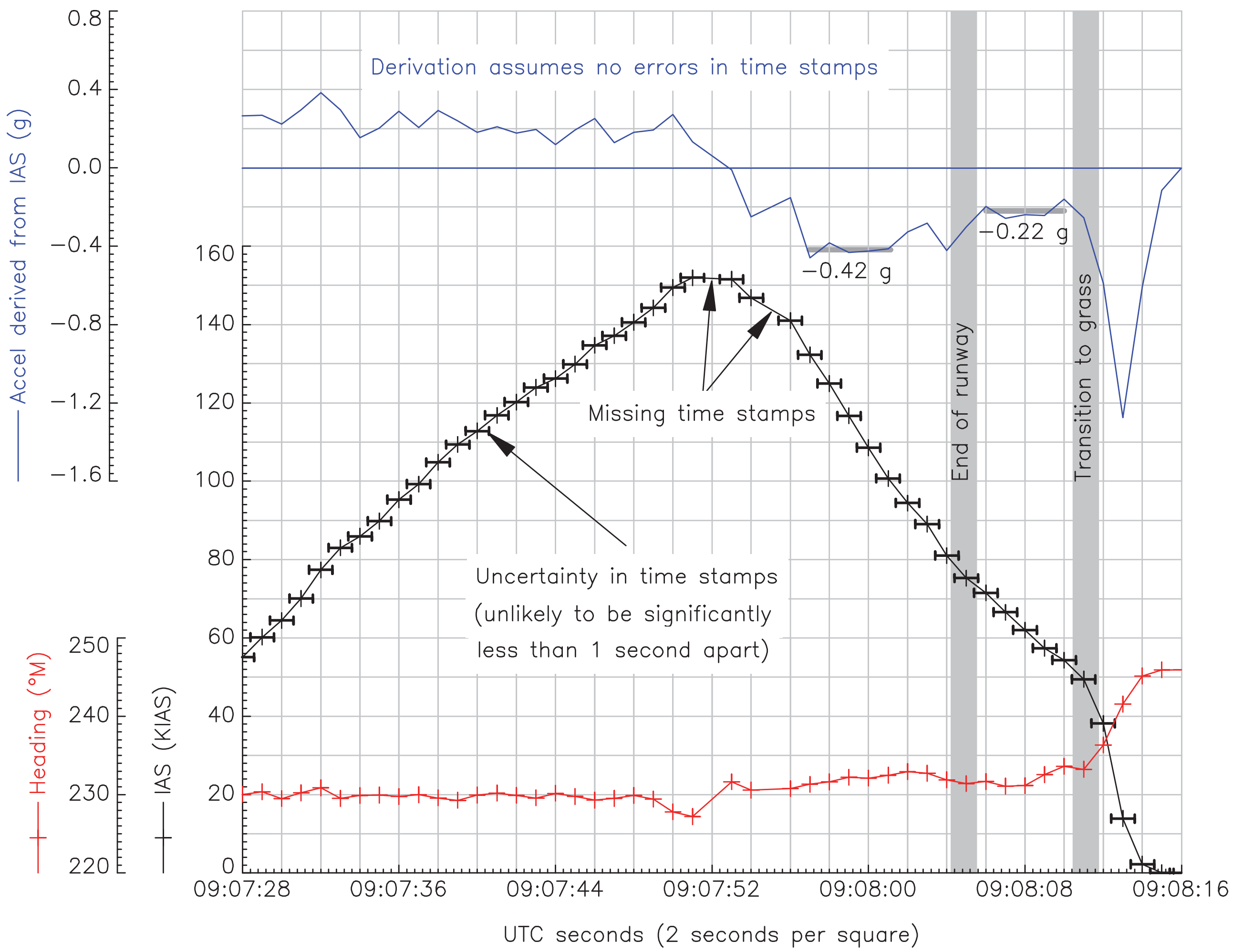

Figure 4

Pertinent recorded data and calculated acceleration

FDR and CVR exemption

Under the requirements of the UK Air Navigation Order 2009, this type of aircraft should be fitted with an FDR and CVR. However, the operator has a UK CAA exemption from this requirement for its Dassault Falcon 20 fleet. The application for the exemption was made due to perceived difficulties and cost in retrofitting the recorder systems required when weighed up against the expected remaining life of this particular fleet. The UK CAA granted this exemption on an annual basis since the fleet was acquired by this operator. The exemption renewal granted in 2009 followed correspondence between the CAA and the AAIB as to the acceptability of its continuation.

A significant part of the cost of retrofitting an FDR system is associated with providing additional wiring and interfacing to the existing aircraft systems to capture the required parameters. This investigation has highlighted that, since the original exemptions were granted, this operator's aircraft have been retrofitted with a modern avionics suite with provisions for interfacing to an FDR. This would significantly reduce the cost of interfacing to the majority of the required parameters should an FDR system be retrofitted.

Discussions with the appropriate maintenance organisation did not identify any significant obstacles to retrofitting a modern CVR.

Crew information

The commander had carried out three RTOs prior to this incident. The first was when flying fast jets in the military and he had carried out a high speed RTO from about 150 kt due to a hydraulic failure. He had also had to stop from about 120 kt when flying a Falcon as a co-pilot for the operator due to birds on the runway (at a different airfield). Finally, two months before this incident, he had rejected a takeoff due to an instrument failure at about 60 kt. All of these RTOs had been conducted without incident.

The commander had received training in RTOs during both his initial training with the operator as a co-pilot, and again when training as a commander. This had been conducted in a simulator and had considered a number of different scenarios.

The co-pilot was an experienced pilot with the operator. He stated that, when acting as the non-handling pilot, he would switch his scan during takeoff between the flight and the engine instruments. As V_1 approached he would switch his scan to the flight instruments and would call 'V_1' when the appropriate speed was indicated on the digital scale, as he stated that he did during the incident takeoff.

Operator's Operations Manual – Rejected takeoffs

Part B, Section 2.2.5.1 of the operations manual considers rejected takeoffs and states:

> *'Either pilot shall call STOP for any problem affecting aeroplane safety up to 100 KIAS. If runway length is limiting, either pilot shall only call stop between 100 KIAS and V_1 if there is a control restriction or two or more indications of engine failure. If runway length is not limiting, the Commander shall brief which emergencies shall trigger a STOP call between 100 KIAS and V_1.'*

Whilst it has not been possible, without the benefit of a CVR, to determine exactly which emergencies the commander briefed he would stop for, he believes his decision to reject the takeoff under the circumstances was correct. He considered an impact with the bird was inevitable and that, due to its size, damage to a control surface might have resulted.

Brake system and anti-skid system malfunction checklist

A review of the checklist revealed a discrepancy in the font and layout used to identify the '*brake failure on landing*' section of the checklist which had the potential to make the appropriate checks hard to identify. It was also apparent that the checklist only considered a brake failure on landing, and not during other phases of ground operation. Finally, the brake failure checklist was not a memory item, as might be expected, and also included references to the drag chute which is no longer carried on the aircraft.

Aircraft manufacturer's performance data

The aircraft was originally certified by the manufacturer with a MTOW of 28,660 lb. In order to issue the STC to increase the MTOW to 30,000 lb, only limited flight testing was required (which did not include formal takeoff performance tests) as the increase in MTOW was not greater than 5%.

In support of this investigation, the manufacturer extrapolated their original data to the takeoff weight of G-FRAI during the incident in order to generate a performance model that could be used to analyse the event.

The following assumptions were made:

- *The UK performance model used for AFM data expansion (reference: DTM 918), extrapolated above the certified MTOW of 28,660 lb,*
- *Transition times used for the UK certification as shown below, where T is the time the failure was detected:*

  T + 0.5 seconds: throttles set to IDLE position-35
  T + 2.5 seconds: pilot commands airbrakes extension and initiates braking
  T + 3 seconds: full braking action achieved
  T + 4 seconds: airbrakes fully extended
- *Full brake application according to the AFM procedure,*
- *TOW = 29,171 lb,*
- *Field Pressure Altitude = 0 ft,*
- *OAT = ISA+3°C,*
- *No wind / No runway slope,*
- *Dry runway,*
- *Take-off configuration: flaps 0°,*
- *Drag index = 47 (i.e. +24 dm^2 additional drag),*
- *EPR = 1.55 (as set by the pilot),*
- *Airspeed correction (DIAS= CAS-IAS) during ground roll computed for aircraft fitted with Rosemount pitot/static probes (DFS 2016 modification): DIAS = -1.2 kt.*
- *Both engines[6] remained running throughout*
- *Runway friction remained constant throughout*

Figure 5 shows the manufacturer's modelled speed profiles for V_1 speeds of 141 KIAS and 151 KIAS.

Figure 5 (b) illustrates that with a V_1 of 151 KIAS an aircraft would only decelerate to a speed of about

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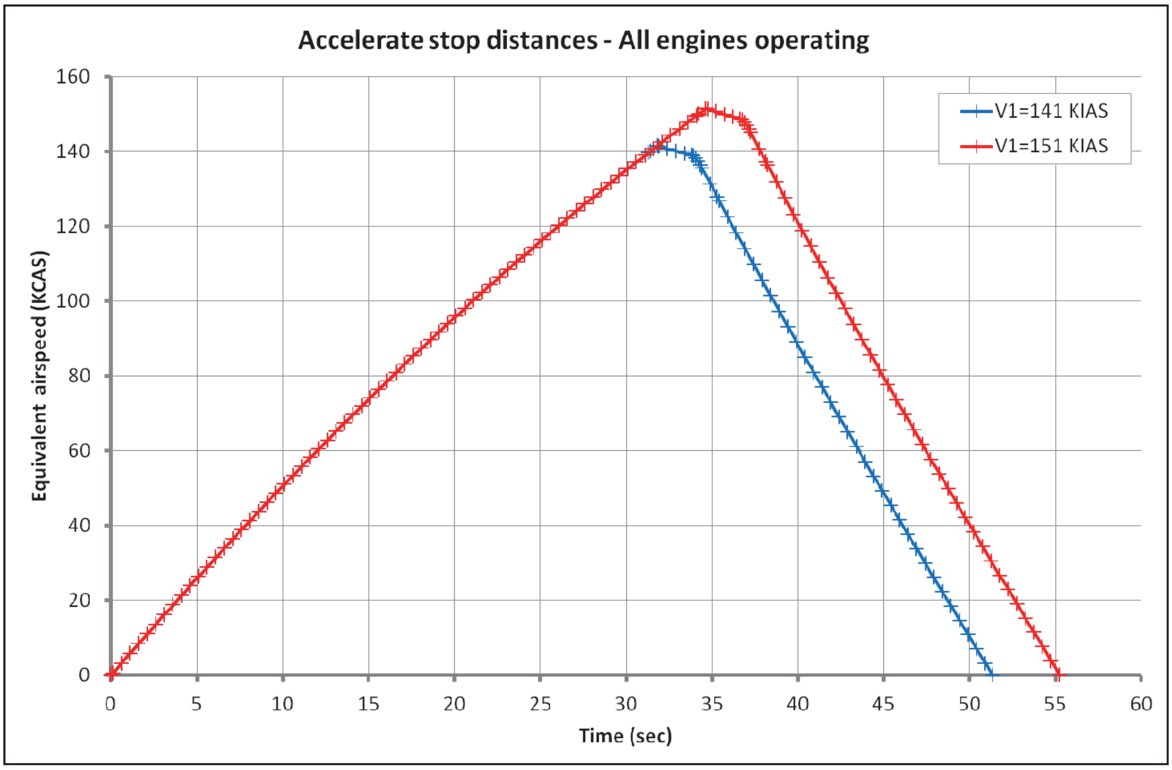
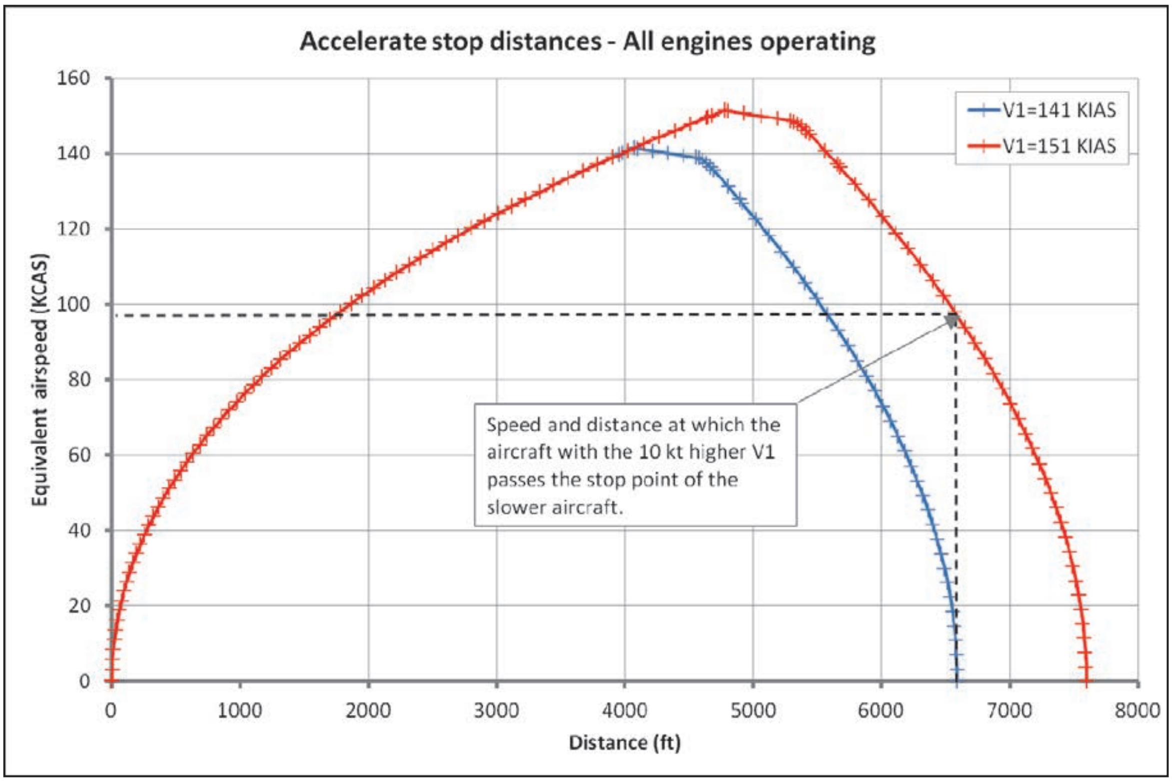
6 The aircraft manufacturer confirmed that, due to low residual thrust, the difference in stopping distance between both engines selected to idle versus one engine selected to idle and the other inoperative, is negligible.



(a)



(b)

Figure 5

Modelled profiles for (a) speed over time and (b) speed over distance travelled for the V_1 = 141 KIAS and V_1 = 151 KIAS scenarios

100 KIAS in the same distance it would take an aircraft with a V_1 of 141 KIAS to stop. The graph also shows the difference between the calculated accelerate stop distances for the two different V_1 speeds of just over 1,000 ft.

The calculated stopping distance from a V_1 of 141 KIAS was 2,635 ft (803 m) and the accelerate stop distance was 6,592 ft (2,009 m). With a V_1 of 151 KIAS the stopping distance increases to 2,944 ft (897 m) and the accelerate stop distance to 7,597 ft (2,316 m).

Assuming a start point of 120 ft from the start of the runway this would result in the aircraft entering the stopway at approximately 42 KIAS.

Modelling for a V_1 of both 141 KIAS and 151 KIAS yielded a peak RTO airspeed reached of less than 2 KIAS above the respective V_1 speeds. Taking the highest recorded speed of 151.9 KIAS as the peak during a modelled RTO, the associated V_1 would have been 150.2 KIAS. Assuming fully functioning systems and fully compliant crew actions, the accelerate-stop distance would have been 7,513 ft (2,290 m) plus the line-up distance. This indicates that over running the runway onto the stopway was inevitable. The calculated deceleration, after full braking is achieved in this scenario, reduces from an initial peak of -0.466 g to -0.398 g at slow speed, averaging -0.437 g. From 140 KIAS to 100 KIAS the average modelled deceleration is -0.45 g. The energy absorbed by the brakes during such deceleration would not have exceeded the maximum demonstrated braking energy.

AAIB calculations based on the manufacturer's performance model

The modelled decelerations were used to assess how changing the stopway and strip surface to perform as well as the runway would have affected the event profile. With the recorded stopway entry speed but runway levels of friction, the aircraft would have left the stopway at approximately 44 KIAS and entered the grass at approximately 6 KIAS.

Joint Industry/FAA Pilot Guide to Takeoff Safety - 2004

Whilst accurate statistics aren't available, the guide estimates that approximately one in 3,000 takeoff attempts ends with a rejected takeoff. This, it argues, will mean a short haul pilot might expect an RTO every three years, whilst a pilot flying long haul might expect one every thirty years.

Available data indicates that 94% of RTOs are initiated at speeds of 100 kt or less, 4% between 100-120 kt and 2% above 120 kt. RTOs in this latter high speed group account for the majority of overrun incidents. In 55% of the 97 accidents and incidents studied in producing the guide, the RTO was initiated above V_1. 7% of the cases involved birdstrikes.

Further analysis determined that 52% of the 97 accidents and incidents would have been avoided had the takeoff been continued. It conceded however that the decision to stop would have been based on a number of factors, not all of which can easily be analysed after the event.

The guide highlights possible ambiguity in the interpretation of the meaning of V_1. The FAA definition quoted differs from that used by the CAA in that it represents the speed at which the first *action* in rejecting the takeoff must be taken, rather than the point at which the *decision* to reject has been taken. It also allows a time between the failure of an engine and the first pilot action as the longer of the flight test demonstrated time or one second, at least double that allowed by the CAA. However, the latest definition of V_1 now used by the FAA and EASA for the certification of Part 25, Transport Category Aircraft, is the same.

Of note is the following statement:

> *'At heavy weights near V_1, the airplane is typically travelling at 200 to 300 feet per second, and accelerating at 3 to 6 knots per second. This means that a delay of only a second or two in initiating the RTO will require several hundred feet of additional runway to successfully complete the stop. If the takeoff was at a Field Limit Weight, and there is no excess runway available, the airplane will reach the end of the runway at a significant speed.'*

This is further demonstrated in Figure 6, based on a graph in the guide, but using the G-FRAI incident conditions and data provided by the aircraft manufacturer:

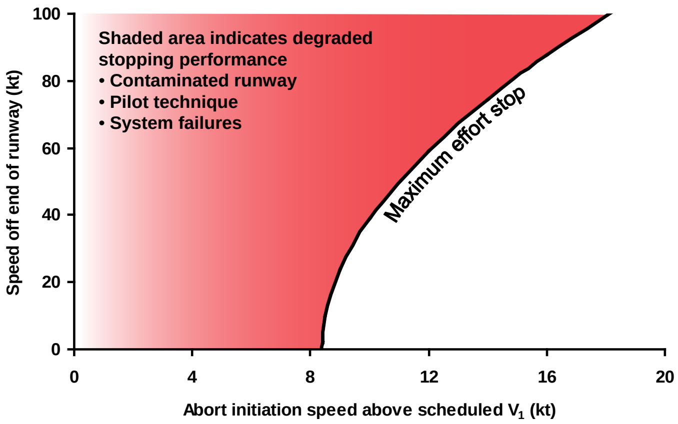


Figure 6

Effect of initiating RTO above V_1

Analysis

Airspeed indications

There were no identifiable problems with the pitot-static system and, as the aircraft had not rotated it is considered that any possible position errors could be discounted. Thus it is considered that the airspeed indications were correct during the takeoff.

Achieved braking

Inspection of the aircraft's braking system did not reveal any defect that could account for a lack of braking action and the recorded data shows that, following the decision to reject the takeoff and once sustained full braking was applied, the aircraft decelerated from 140 KIAS to 100 KIAS over a five-second period, which equates to a longitudinal deceleration of -0.42 g. This figure is very close to the performance data supplied by the aircraft manufacturer that showed that the aircraft should achieve a longitudinal deceleration of -0.45 g on a dry runway at the incident takeoff weight. The small difference between these two decelerations could be as a result of the data timing issues previously discussed. Given the quality of the recorded data and the limitations of modelling, the data indicates that the braking system was fully operational for at least the high speed portion of the deceleration.

The change in the aircraft's kinetic energy during the incident, based on the reduction in speed between the peak of 150.7 KCAS and the speed of approximately 49 KCAS (approximately 50 KIAS) at which it departed the runway strip, was 35.6 MJ. This figure is 82% of the maximum kinetic energy absorption demonstrated during certification flight testing.

Crew actions

The manufacturer's performance figures indicate that with fully operational systems, applying the correct actions in the appropriate transition times yields a peak speed of less than 2 KIAS above the V_1 speed. In the absence of any known system failures and assuming the correct crew actions and timing, the performance modelling indicates that the decision to reject the takeoff was made at a speed such that the equivalent V_1 was 150.2 KIAS.

The modelled accelerate-stop distance using a V_1 of 150.2 KIAS is only 3 ft shorter than the Runway 23 TORA. When the extra line-up distance is added, even when matching the CAA certification transition times for an RTO, the aircraft would have left the runway onto the stopway. Under the same circumstances but with a V_1 of 141 KIAS the aircraft would have stopped 319 ft before the end of the runway.

The pilots were candid in their description of what they could recall but despite this, without the benefit of either a CVR or FDR, it has not been possible to determine the exact sequence of events. The data and performance modelling, however, indicate that the takeoff was rejected above V_1, by up to 9 kt, and that the actions taken after the decision to reject the takeoff to some degree did not exactly mirror certification conditions.

The commander believed the bird represented a significant threat to the aircraft. He was confident in his ability to stop the aircraft on the runway as he did not believe the aircraft had reached V_1 at the time he decided to abort the takeoff. Equally, he stated he would not have attempted to abandon the takeoff had he known the aircraft was above V_1.

The co-pilot believed he had called V_1 at the correct speed. A call of 'V_1' should coincide exactly with the relevant speed being indicated on his airspeed indicator. Due to the high rate of acceleration, any delay to the call will result in a significant increase in aircraft speed above V_1. Similarly, any delay in carrying out the actions required following a decision to reject would result in a similar effect.

Safety action taken

The operator has been proactive in seeking to address issues raised by this incident. In particular it is seeking to clarify the RTO decision process and is reviewing the relevant information contained in its operations manual and the training given to pilots. This includes section 2.2.5.1 where it differentiates between takeoffs where runway length is limiting and those where it is not.

The operator is also reviewing the brake system and anti-skid system malfunction checklist and references in its documentation to the drag chute which is no longer carried.

As a result of this incident and other events, including the publication of draft rules for aerodrome by the European Aviation Safety Agency (EASA), the CAA is reviewing its policy and requirements on stopways.

Stopway friction characteristics

The recorded data indicates significantly less retardation, about -0.22 g, whilst the aircraft was on the stopway and runway strip. This is approximately half that of when the aircraft was on runway and is considered to have been as a consequence of the reduced friction afforded by the change in surface material or contamination by loose debris.

Had the friction levels been the same as that of the runway, it is estimated that the aircraft would have entered the grass area at 6 KIAS rather than the 50 KIAS recorded. The current inability to measure the friction levels accurately of such areas is of concern as it may result in friction levels below those required in CAP 683. The airport has advised that it is reviewing this issue, However, as it is evident from the incident data that the stopway friction is significantly below that of the runway the following recommendation is made:

Safety Recommendation 2013-004

It is recommended that Durham Tees Valley Airport takes action to ensure that, in accordance with the requirements of *CAP 683 – The Assessment of Runway Surface Friction Characteristics*, the surface of the Runway 23 stopway has friction characteristics not substantially less than those of the associated runway.

FDR and CVR exemption

The lack of flight recorders has been a significant handicap to the investigation, even with the availability of the unprotected SADS data.

The investigation has highlighted that the work required to retrofit flight recorders to this fleet has reduced due to other extensive retrofit programmes that have been undertaken since the original exemption was granted. Many of the required parameters are available on a data bus provisioned for that purpose. Others would probably still necessitate the installation of sensors.

Safety Recommendation 2013-005

It is recommended that the Civil Aviation Authority cease to grant Cobham Leasing Limited exemptions from the Air Navigation Order flight recorder requirements for their Falcon 20 fleet.