AAIB

Air Accidents Investigation Branch

AAIB Bulletin 6/2019

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(ALL TIMES IN THIS BULLETIN ARE UTC)

AAIB Field Investigation Reports

A Field Investigation is an independent investigation in which AAIB investigators collect, record and analyse evidence.

The process may include, attending the scene of the accident or serious incident; interviewing witnesses; reviewing documents, procedures and practices; examining aircraft wreckage or components; and analysing recorded data.

The investigation, which can take a number of months to complete, will conclude with a published report.

SERIOUS INCIDENT

Aircraft Type and Registration:	1) Boeing 737-800, EI-FJW 2) Airbus A320-214, OE-IVC
No & Type of Engines:	1) 2 CFM56-7B26E turbofan engines 2) 2 CFM56-5B4/3 turbofan engines
Year of Manufacture:	1) 2016 2) 2016
Date & Time (UTC):	13 August 2018 at 0948 hrs
Location:	Runway 06 at Edinburgh Airport
Type of Flight:	1) Commercial Air Transport (Passenger) 2) Commercial Air Transport (Passenger)
Persons on Board:	1) Crew - 7 Passengers - 159 2) Crew - 6 Passengers - 180
Injuries:	1) Crew - None Passengers - None 2) Crew - None Passengers - None
Nature of Damage:	1) None 2) None
Commander's Licence:	1) Airline Transport Pilots Licence 2) Airline Transport Pilots Licence
Commander's Age:	1) 42 years 2) 37 years
Commander's Flying Experience:	1) 6,800 hours (of which 6,650 were on type) Last 90 days - 160 hours Last 28 days - 30 hours 2) 10,000 hours (of which 9,000 were on type) Last 90 days - 200 hours Last 28 days - 70 hours
Information Source:	AAIB Field Investigation

Synopsis

A landing Boeing 737 closed to within 875 m of a departing Airbus A320 when landing at Edinburgh Airport. The airport air traffic control service provider defined this as a runway incursion as the 737 was over the runway surface when the A320 was still on its takeoff roll.

A combination of factors, including brief delays to the departure of the A320 and the speed of the Boeing 737 being higher than normal, led to the reduction in separation before the controllers became aware of the closeness of the aircraft. The trainee controller lacked the experience to resolve the situation in a timely manner and the supervising On-The-Job Training Instructor judged it safer to let the 737 land than to initiate a go-around in proximity to the departing aircraft.

The Air Navigation Service Provider has conducted a review of High Intensity Runway Operations at Edinburgh and taken a number of safety actions to improve procedures and on-the-job training for trainees.

History of the flight

The crew of EI-FJW were scheduled to operate a flight from New York Stewart Airport, USA (SWF) to Edinburgh Airport (EDI). The crew consisted of a captain under training in the left seat who was new to the company, a training captain in the right seat who was also the aircraft commander, and a training captain on the cockpit jump seat who was acting as the check captain for the left seat pilot[1]. They reported for duty at 0025 hrs, having arrived in New York 26 hours previously. The aircraft was pushed back from the parking position at SWF at 0244 hrs for a flight which was expected to take just under seven hours.

The crew of OE-IVC was on the third sector of a four-sector day. The flight was from EDI to London Luton Airport (LTN). The crew consisted of a training captain who was the aircraft commander in the left seat, with a trainee co-pilot in the right seat.

Edinburgh Tower frequency was being manned by a trainee air traffic control officer (trainee controller) supervised by an On-The-Job Training Instructor (OJTI). The OJTI started his shift at 0500 hrs and the trainee started at 0530 hrs. The OJTI completed a period on ground control between 0500 hrs and 0630 hrs before having a 45-minute break. At 0715 hrs, they plugged into the ground control position together to start a training session. They completed this session at 0830 hrs. After having a routine 45-minute break they then plugged into the tower position together at 0915 hrs. The trainee controller was in the second of three phases of training to qualify as an aerodrome controller at EDI.

At 0936 hrs, EI-FJW's pilot monitoring (PM) contacted Edinburgh Radar and was instructed to expect an ILS approach to Runway 06. The radar controller gave the crew a series of vectors to position them for their approach before clearing them to complete the ILS procedure. He instructed them to maintain at least 160 KIAS until they reached 4 nm from touchdown. At 0944 hrs, the crew were instructed to contact Edinburgh Tower. At this point the aircraft was 8.8 nm from touchdown.

At 0936 hrs, OE-IVC began its pushback from the parking stand and started engines. The commander, who was to be PM for the flight to LTN, called for taxi and was given clearance to taxi down taxiway A to hold at A1 for Runway 06 (Figure 1).

At 0945:55 hrs, with EI-FJW at 6 nm from touchdown, the trainee controller cleared OE-IVC to line up on Runway 06. The trainee controller initially did not extinguish the Stop Bar[2].

Footnote

[1] The captain under training in the left seat was undergoing his final line checks having finished the required training.

[2] Stop Bar – located at those aerodromes authorised for low visibility operations. A Stop Bar consists of a row of lights spaced equally across the taxiway normally at right angles to the centreline and showing red towards an approaching aircraft when lit. They act in the same sense as traffic lights and therefore pilots must not taxi an aircraft across a Stop Bar that is lit. (CAP 637 Visual Aids Handbook).

At 0946:00 hrs, another aircraft called ready for departure and the trainee controller was occupied with talking to them for nine seconds. Immediately after this, the commander of OE-IVC transmitted "STOP BAR" on the frequency to remind the trainee controller that it was still illuminated. The trainee controller extinguished the Stop Bar and, with this delay, OE-IVC did not move from the holding point until 0946:29 hrs.

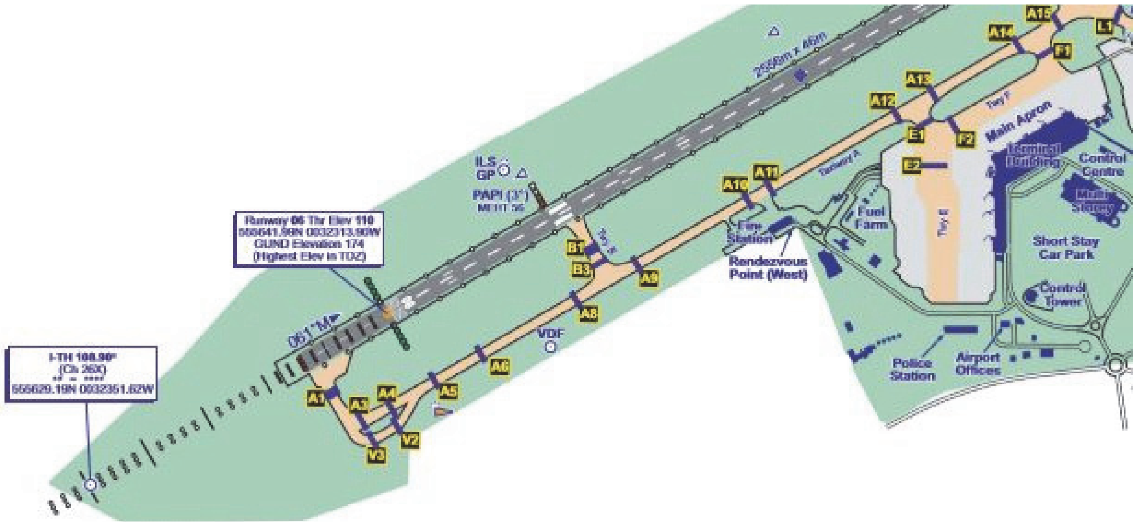

Figure 1

Taxiway layout for Runway 06

At 0947:01 hrs, with EI-FJW at 3 nm from touchdown, the trainee controller cleared OE-IVC for takeoff although the aircraft was not yet aligned with the runway ready to depart. The trainee controller also instructed the crew of EI-FJW that they could expect a late landing clearance.

At 0947:41 hrs, OE-IVC began to accelerate on its takeoff roll with EI-FJW just over 0.5 nm from touchdown. When EI-FJW reached 0.5 nm from touchdown, the PM called the tower to remind them that they were not yet cleared to land. Shortly after EI-FJW called at 0.5 nm, the OJTI took over the tower frequency from the trainee controller.

At 0948:13 hrs, OE-IVC left the ground, at which point EI-FJW was in the landing flare and was given a landing clearance. EI-FJW touched down at 0948:15 hrs.

As EI-FJW was over the runway at the same time as OE-IVC was completing its takeoff roll, the event was classed as a runway incursion by the air navigation service provider (ANSP). At the closest point of approach, the two aircraft were separated by approximately 875 m, with OE-IVC being at 60 ft aal when EI-FJW touched down. Figure 2 shows a CCTV view looking down the runway which, although partially obscured by rain on the camera, shows both EI-FJW and OE-IVC visible in the frame.

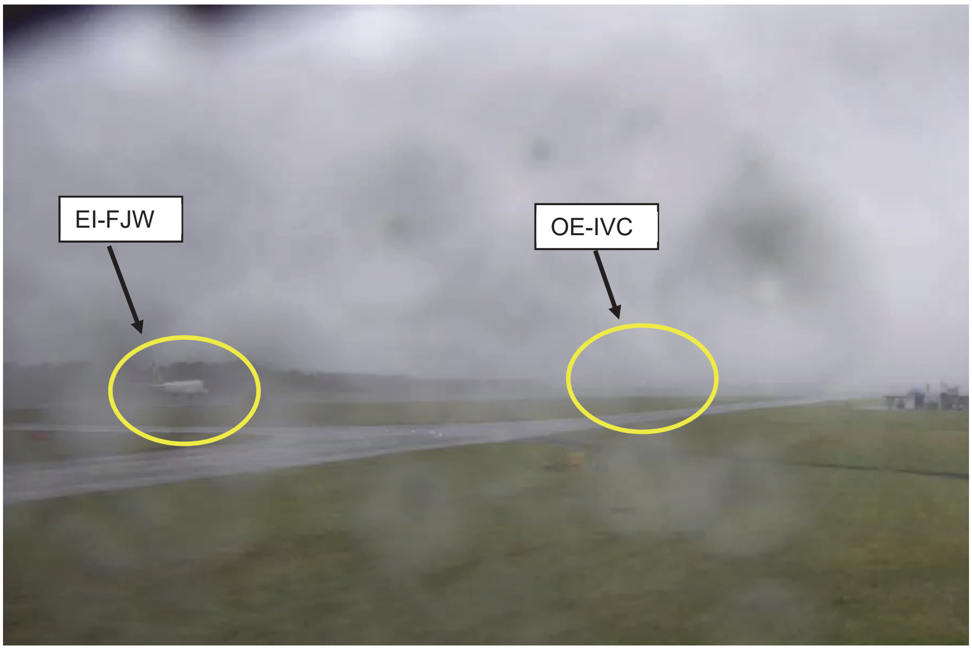

Figure 2
CCTV showing both aircraft over the runway

Recorded information

Data was available from several sources including radar and ATC recordings, as well as closed-circuit television (CCTV) equipment installed at EDI, and the Quick Access Recorder (QAR) installed on each aircraft. However, due to the delay in reporting the event to the AAIB, both cockpit voice recorders were overwritten and were not downloaded.

Radar

EDI is equipped with a radar-based approach surveillance capability. This shows the tower controller the arriving traffic, and other traffic near the airport, with a textual information block for relevant aircraft showing their callsign, altitude above airfield elevation (in hundreds of feet) and groundspeed (GS) in kt (prefixed with the letter G). In addition, the display shows local airspace boundaries, areas of airspace with restrictions (circled in dark red) and a distance scale aligned with the runway axis marked at 2 nm intervals. Part of this display is shown in Figure 3 depicting EI-FJW, as IBK1601 and circled in yellow, on approach at 8 nm.

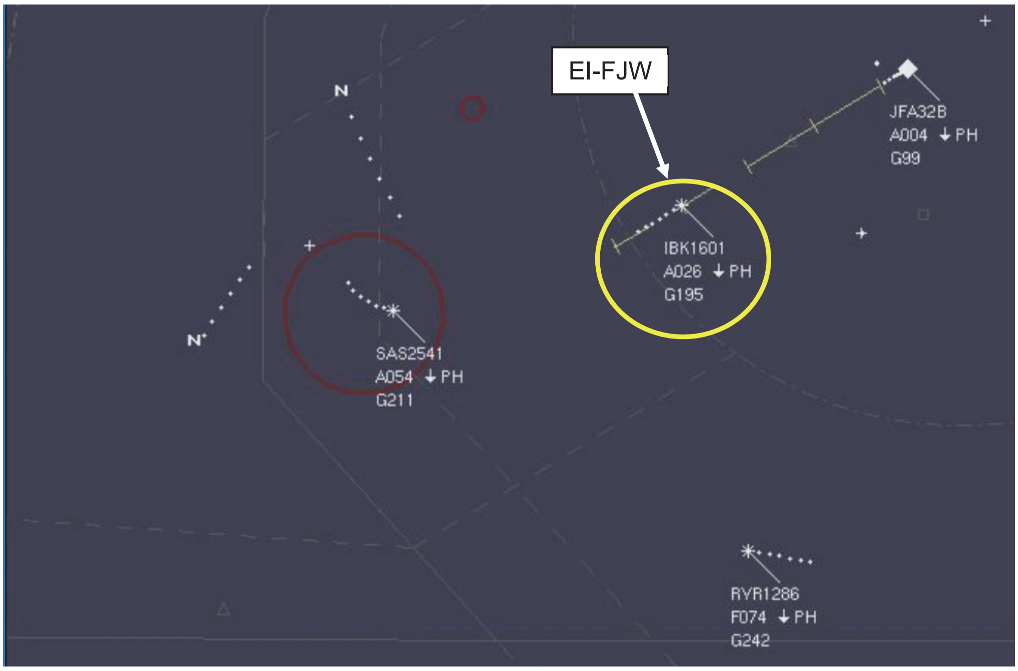

Figure 3

Approach surveillance at EDI, showing EI-FJW on approach at 8 nm

EDI also has a Surface Movement Radar (SMR) which shows radar imagery, updated once per second, overlaid on plans of the airport's taxiways and runway. Figure 4 shows an example of a typical SMR display at EDI. All radar data and ATC communications at EDI are recorded.

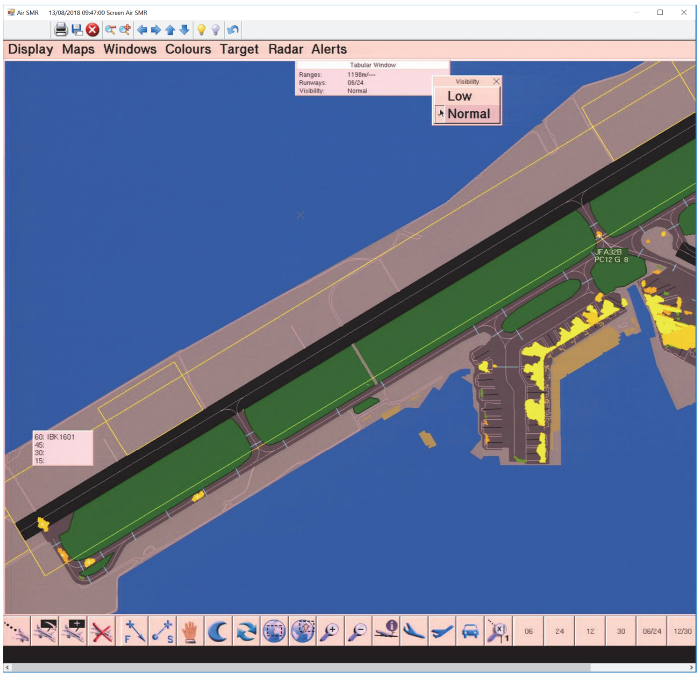

Figure 4

A typical SMR display at EDI

Runway Incursion Monitoring and Collision Avoidance System

The SMR installation at EDI incorporates a Runway Incursion Monitoring and Collision Avoidance System (RIMCAS) which monitors, within a pre-determined area, the separation between aircraft approaching and occupying the runway, and between ground vehicles operating on the airport. The system provides time-to-touchdown information to the controller, as shown in Figure 4, where EI-FJW is represented as IBK1601 at 60 seconds to touchdown. Other times to touchdown which can be shown are 45, 30 and 15 seconds. In addition, RIMCAS can generate alerts to the controller; the first level of alert is termed a Stage 1 alert, which is generated 30 seconds prior to a predicted collision, and is purely a visual alert of a conflict between radar returns. This results in the textual information block for each aircraft being highlighted in amber and, if appropriate, the time-to-touchdown display. An example of an active Stage 1 alert is shown in Figure 5.

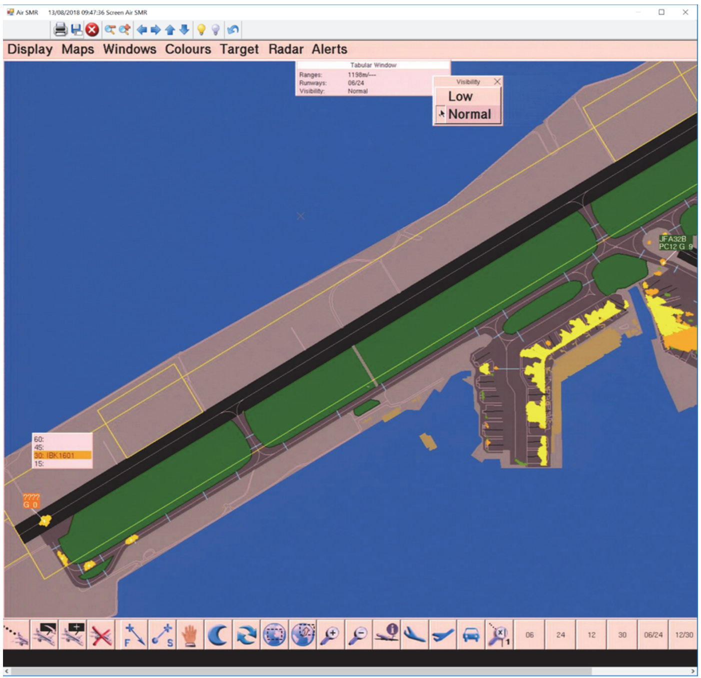

Figure 5

An active Stage 1 RIMCAS alert at EDI

Stage 2 alerts can also be generated by RIMCAS at 15 seconds prior to a predicted collision. These alerts result in the textual information block for each aircraft being highlighted in red and, if appropriate, the time-to-touchdown display. In addition, an aural warning is given over a loudspeaker. This consists of a computer-generated voice announcing “RIMCAS Alert, RIMCAS Alert.” The warning continues to sound until acknowledged or the conflict which caused the alert no longer exists.

CCTV

Two CCTV cameras captured the event and the recordings were used to provide an overview of the event, and to verify the timings derived from other data sources. A screenshot from one of these cameras is shown in Figure 6.

Figure 6

CCTV screenshot of the event showing both aircraft

Quick Access Recorders

The operators of EI-FJW and OE-IVC provided flight data recordings from the QAR installed on each aircraft. These were analysed to establish that the separation distance between the aircraft decreased to a minimum of approximately 875 m horizontally, when EI-FJW was six seconds from touchdown and 40 ft above the runway, and OE-IVC was accelerating through 148 kt during its takeoff roll, 4 seconds prior to becoming airborne.

Incident timeline

Using the data from radar and the radio transmissions recordings, a timeline (Table 1) was generated of the incident. This information was then used to compare the incident against other similar operations at the airport.

Time	ATC	OE-IVC	EI-FJW	Other
0945.55	Clears OE-IVC to line up	Acknowledged	6nm from t/d GS 181 kt	
0946:00 to 0946:09				RT between another aircraft and ATC
0946.11		"STOP BAR"		
0946.29		Begins to move on SMR		
0946.34		Crosses Stop Bar	4nm from t/d GS 171 kt	

Time	ATC	OE-IVC	EI-FJW	Other
0946.56				Landing aircraft vacates
0947.00	**RIMCAS 60s**			
0947.01	OE-IVC cleared for takeoff	Acknowledges clearance. 90 degrees to runway.	3 nm from t/d GS 155 kt	
0947.12	EI-FJW told to expect late landing clearance		<2.5 nm from t/d GS 150 kt	
0947.20		Lined up		
0947.20	RIMCAS 45s			
0947.36	**RIMCAS 30s**			
0947.41		Moving on SMR		
0947.51	EI-FJW told to continue approach		"HALF A MILE"	
0947.52	**RIMCAS 15s**			
0948.10		Nosewheel off		
0948.13		Main gear off		
0948.14	EI-FJW cleared to land		Acknowledged	
0948.15			Touchdown	

Note: All RT clearance times refer to the end of the ATC transmission.

Table 1

Incident timeline

Incident timeline comparison

Figure 7 shows the incident timeline compared to two uneventful examples. In both examples there was a 6 nm gap between the landing aircraft and another aircraft which departed in the gap without incident. The comparison examples were taken from a training session with the trainee controller conducted with Runway 24 in operation, in the evening in dark conditions, without low visibility procedures (LVPs) or safeguarding[3] in operation. The Stop Bars were in use because it was dark. Although the examples are for Runway 24, the layout of the holding points in relation to the runway at Edinburgh is symmetrical.

Footnote

[3] Safeguarding is when the airfield protects the Localiser Sensitive Area (LSA) which is a rectangular area contained within parallel lines 127 m either side of the runway centreline between the beginning of the runway and the localiser aerial (EDI MATS Part 2).

Each example starts at the point where the first approaching aircraft crosses the runway threshold with the second approaching aircraft at 6 nm behind and an aircraft is given clearance to take off in the gap. The examples are shown on a synchronised timescale for ease of comparison. The timing and duration of all RT is shown as black shaded areas on the timeline and all times for clearances correspond to when the ATCO finishes the relevant transmission.

AAC1 is first approaching aircraft, AAC2 is second approaching aircraft, DAC is departing aircraft. Black shaded areas represent radio transmissions.

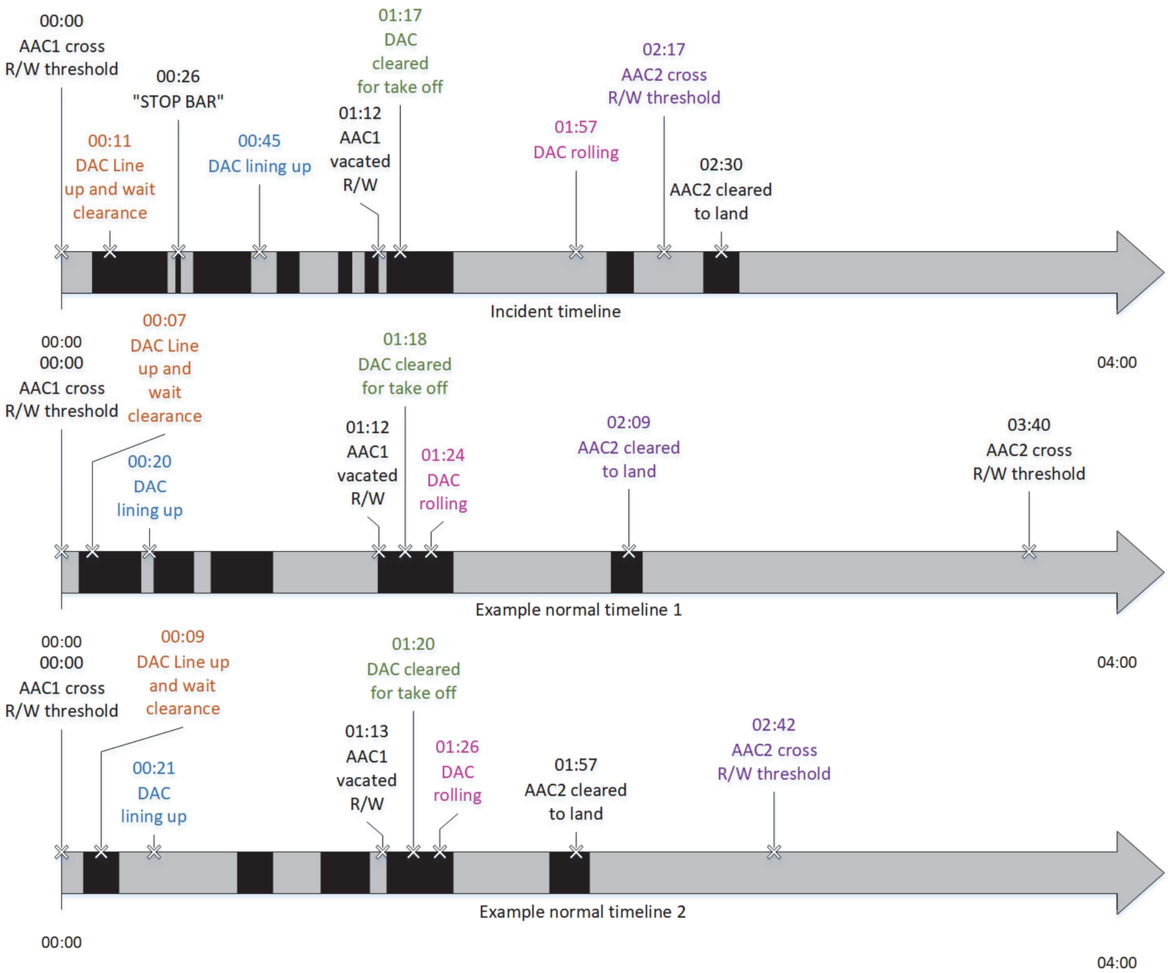

Figure 7

Incident timeline compared to normal examples

The comparison shows three significant timeline differences between the incident and the two normal examples:

- In the incident example, the approach speed of EI-FJW resulted in the aircraft arriving at the runway threshold quicker than in the examples.
- In the normal examples, the time between line up clearance being issued and starting to line up was 12 to 14 seconds as opposed to 34 seconds in the incident.

- In the normal examples, the time between receiving takeoff clearance and starting the takeoff roll was six seconds compared to 40 seconds in the incident.

In the time between the first approaching aircraft crossing the threshold and the second approaching aircraft being issued a landing clearance, the controllers were occupied with making or receiving transmissions for 52% of the time in the incident example and for 50% and 46% of the time in the normal examples respectively.

TCAS

Both EI-FJW and OE-IVC were fitted with TCAS which was operational at the time of the incident. Neither crew received a TCAS resolution advisory (RA) as both aircraft were at radio heights below which the system is inhibited. For EI-FJW, all RAs are inhibited below 1,000 ft radio altitude, with all aural alerts inhibited below 500 ft radio altitude. For OE-IVC, all RAs are inhibited below 1,100 ft radio altitude, with all aural alerts inhibited below 600 ft radio altitude.

Meteorology

The EDI forecast for 13 August 2018 was for an easterly wind with the airport affected by low cloud and drizzle for much of the day. The forecast also included the possibility of fog, particularly overnight from 12 August and into the morning of 13 August.

The METAR reports for EDI showed the cloudbase to be at 200 ft aal at 0820 hrs and 0850 hrs, 400 ft aal at 0920 hrs, before becoming 300 ft aal from 0950 hrs.

The airport has equipment to measure the cloudbase automatically and this system showed that the measured cloudbase varied between 600 ft aal and 300 ft aal during the 10 minutes before and after the incident.

The crew of EI-FJW saw, from the initial ATIS that they obtained, that the airport was in LVPs due to the cloud base and so prepared for an automatic landing on Runway 06 from the ILS. Company procedures required that, for an automatic landing, the left seat pilot would become PF for the approach and landing. As they approached the airfield, the weather improved, and LVPs were no longer in force. This meant the crew could revert to a manually-flown landing, with the right seat pilot continuing as PF.

Airfield information

EDI operates using a single runway orientated 06/24. The runway has a CAT3 ILS at both ends.

In 2005, the airport began a project to build a new air traffic control tower. Progressive development at the airport meant that the sightlines from the old control tower were being eroded and the building was no longer suitable. A new 57 m tall tower was built with the visual control room (VCR) on the top floor. The VCR has sightlines across the whole airport site. The airport has its own radar control room which provides approach control services to arriving aircraft as well as radar services for aircraft looking to cross through controlled airspace around the airport. Following a public tender in 2016, the ANSP at EDI changed, with the changeover occurring at the end of March 2018. The company that took over the contract also runs the air navigation services at London Gatwick Airport (LGW).

The airport had an average of 353 aircraft movements a day in 2017, making it the sixth busiest airport in the UK.

ATC workstations

The VCR at Edinburgh has three workstations: ground control, tower control and an assistant's station.

The tower control workstation is the middle of the three workstations. It has an unobstructed view of the runway and the approaches at both ends. This workstation is shown at Figure 8. In front of the controller, mounted on the desk, is an interactive screen which displays information about the flights, both on the ground and on approach to the airport. Each flight has a 'strip' which contains details of the flight and the controller amends the strip as the flight progresses through a departure or an arrival. Mounted vertically in front of the controller is a screen showing the radar picture of the arriving and departing traffic. This allows the controller to see the sequence and spacing of the aircraft on the approach (see Figure 3 earlier in this report).

On the right of the controller are two screens which are the ground lighting panel and the support information screen; the latter shows ancillary information such as the latest weather at the airport. To the left of the radar screen is a wind direction and speed display. Further to the left is the SMR/RIMCAS display screen (see Figure 4 earlier in this report).

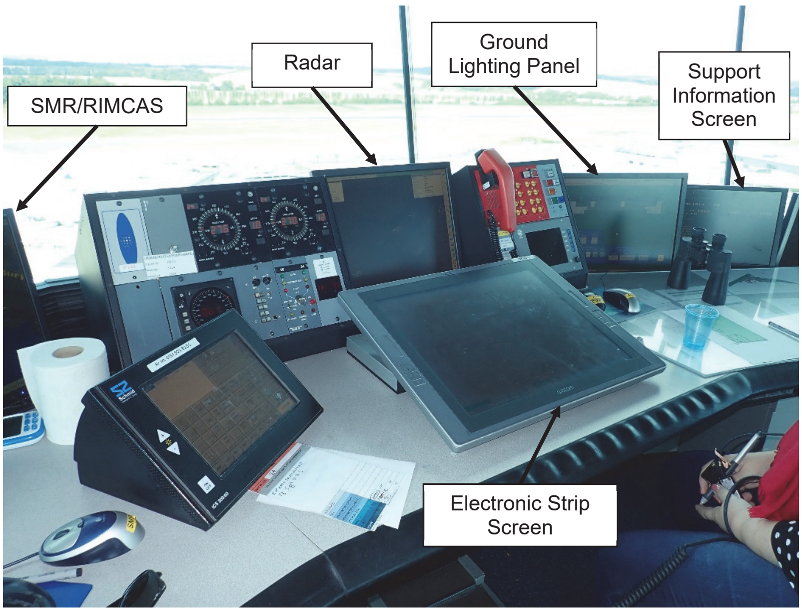

Figure 8

Tower controller's workstation at Edinburgh as viewed from the OJTI's approximate position

Figure 9 shows the electronic strip screen. When an approaching aircraft is issued a speed instruction by the radar controller, the instructed speed is shown on the strip as shown on Figure 10.

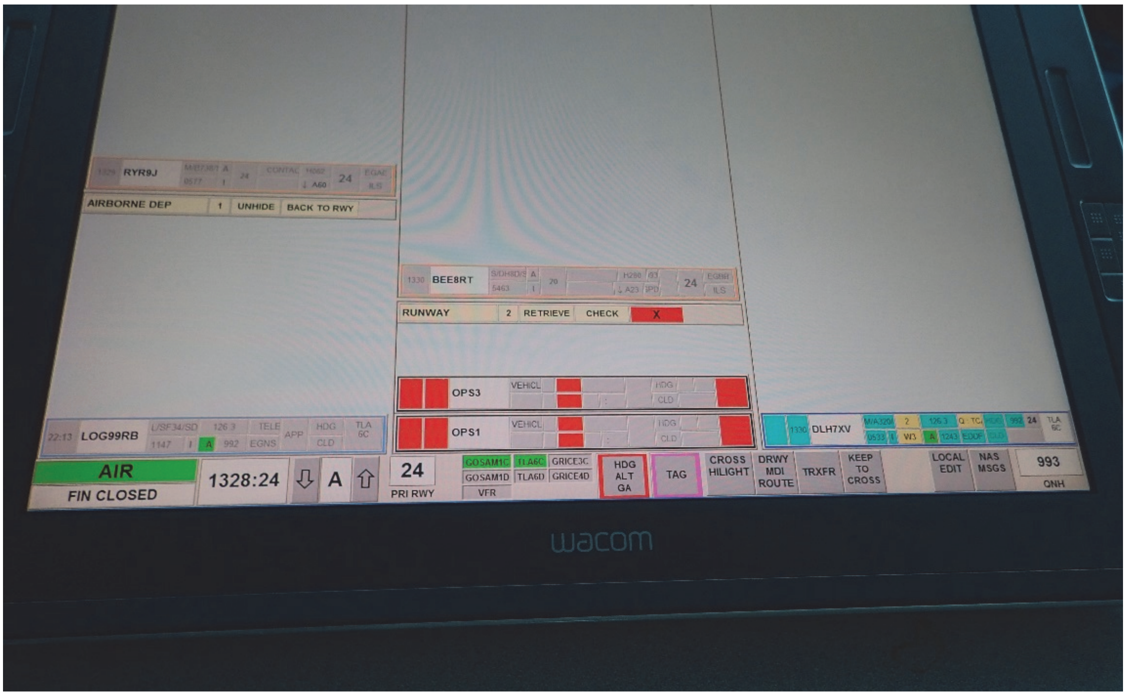

Figure 9

Electronic strip screen

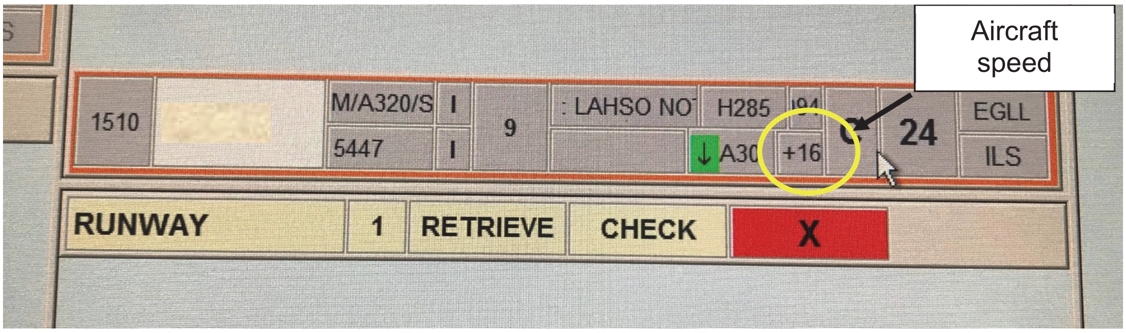

Figure 10

Electronic strip showing an instructed speed of 160 kt or greater

The lighting control panel is interactive. The controller selects different boxes on the screen using a mouse to turn on and off lights and change the intensity of some. Turning off the Stop Bar for the holding point A1 for Runway 06 requires the controller to click accurately inside the A1 box followed by a click in the box at the start of the runway.

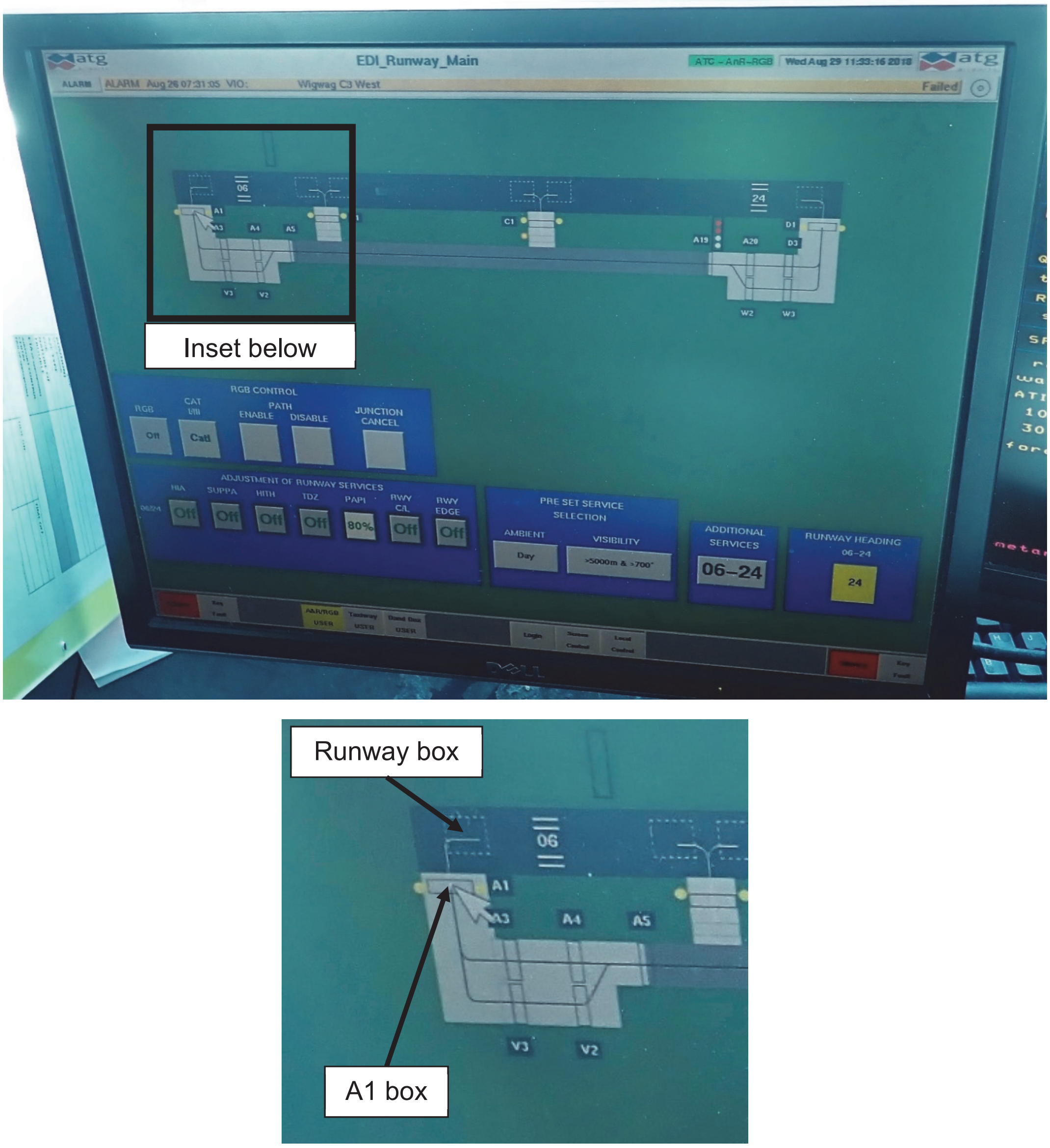

Figure 11
Lighting control panel

During training, the trainee controller sits in the main seat central to the workstation. The OJTI plugs in a headset and sits behind and to the left of the trainee. The OJTI usually uses a higher chair than the controller to get a better view of the various screens.

On a day with poor visibility and/or low cloud, less information is available out of the window and both the OJTI and the controller need to rely more on information presented on the screens. The design of the screens is such that there is not a good view of them from any position other than the controller’s position. Therefore, the OJTI may need to be more active in changing positions to see the information they need to effectively monitor the trainee controller. Figure 8 illustrates the difficulty of seeing the information on the screens if not seated in the controller’s position.

Airfield procedures

Manual of Air Traffic Services (MATS) Part 1

MATS contains procedures, instructions and information which form the basis of Air Traffic Services (ATS) within the UK. The manual is divided into two parts. Part 1 contains instructions that apply to all Air Traffic Service Units (ATSU) within the UK, whilst Part 2 contains instructions for a specific ATSU. Part 1 is produced and published by the UK CAA as CAP 493, with Part 2 being produced by the ATSU and approved by the CAA.

MATS Part 1 defines a runway incursion in Section 2, Chapter 1[4] as:

> *'A runway incursion is any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for aircraft take-off and landing. The protected area of a surface for aircraft take-off and landing is determined by the existence and location of the runway strip, clear and grades area, obstacle free zone and ILS sensitive areas. The precise configuration of these areas is dependent on the aerodrome layout and the operations taking place.'*

This definition reflects that stated in International Civil Aviation Organisation (ICAO) Document 4444, Air Traffic Management[5]. Whilst, in this event, the two aircraft were not on the runway surface at the same time and did not therefore meet the definition of a runway incursion, the separation had been significantly eroded.

MATS Part 1 also specifies that[6]:

> *'Unless specific procedures have been approved by the CAA, a landing aircraft shall not be permitted to cross the beginning of the runway on its final approach until a preceding aircraft, departing from the same runway, is airborne.'*

No specific procedures have been approved for EDI.

MATS Part 1 also has instructions for the controller on cancelling a takeoff clearance[7] which state:

> *'The cancellation of a takeoff clearance after an aircraft has commenced its takeoff roll should only occur when the aircraft will be in serious and imminent danger should it continue. Controllers should be aware of the potential for an aircraft to overrun the end of the runway if the takeoff is abandoned at a late stage.'*

Footnote

4 MATS Part 1, Section 2, Chapter 1, 10C.2.
5 ICAO Doc 4444 '*Procedures for Air Navigation Services Air Traffic Management*', Sixteenth Edition, 2016, Chapter 1.
6 MATS Part 1, Section 2, Chapter 1, 19.2.
7 MATS Part 1, Section 2, Chapter 1, 16.3.

Furthermore, it states:

> *'As the aircraft accelerates, the risks associated with abandoning the takeoff increase significantly. For modern jet aircraft, at speeds above 80 kt flight deck procedures balance the seriousness of a failure with the increased risk associated with rejecting the takeoff…. The typical distance at which a jet aircraft reaches 80 kt is approximately 300 m from the point at which the takeoff roll is commenced. The unit MATS Part 2 shall contain further guidance on the likely position on the runway at which those aircraft types commonly using the aerodrome typically reach 80 kt.'*

MATS Part 2

EDI specifies standard final approach spacing for each runway and radar configuration in MATS Part 2[8]. The spacing used is dependent upon whether the airport is operating under LVPs, and upon what radar and secondary surveillance systems are active. At the time of the incident, the airport was not using LVPs and all surveillance equipment was functioning. This meant that the minimum proscribed spacing between landing aircraft with no departure in between (pack mode) was 4 nm, with the distance increasing to 6 nm if a departure was required between the two landing aircraft (gap mode).

Section 3[9] describes what the controller should consider if the spacing is not sufficient between two landing aircraft (pack mode) before stating:

> *'However, in both modes, only if radar separation cannot be maintained, an aircraft is dangerously positioned on the approach or the runway is obstructed should the aircraft be sent around.'*

Section 3 also contains further guidance on cancelling a takeoff clearance as described in MATS Part 1 above. On Runway 06, 300 m from the start of the takeoff roll is approximately abeam the glide path aerials. This is the point to be used when assessing whether to cancel a takeoff clearance.

MATS Part 2 also describes the use of the airfield RIMCAS system. In the event of a Stage 2 (red) alert[10]:

> *'A 'go-around' shall be issued to the arriving aircraft unless it is positively known (for example, from visual observation) that there is no actual runway infringement.'*

Footnote

8 EDI MATS Part 2, Section 4, Chapter 2.10.3.
9 EDI MATS Part 2, Section 3, 2.8.
10 EDI MATS Part 2, Section 6, 3.6.3.3.1.

RTF Procedures

United Kingdom Radiotelephony Manual (CAP 413) sets out standardised phraseology to be used within UK airspace. Specific phraseology can be used when the controller needs an aircraft to depart immediately[11]:

> *'For traffic reasons a controller may consider it necessary for an aircraft to take off without any delay. Therefore, when given the instruction 'cleared for immediate take-off', the pilot is expected to act as follows:*
>
> 1. *At the holding point: taxi immediately on to the runway and commence take-off without stopping the aircraft.*
> 2. *If already lined up on the runway: take-off without delay. Should an immediate take-off not be possible, the pilot is to advise the controller.'*

The CAP 413 does not specify the use of 'expect late landing clearance' but EDI MATS Part 2[12] specifies:

> *'If landing clearance has not been issued at 2nm from touchdown, the pilot shall be instructed to "continue approach" and advised to expect a late landing clearance together with the reason, e.g. "aircraft to vacate".'*

Use of Stop Bars

Stop Bars are only used at EDI when safeguarding is in operation. In MATS Part 2 this sets out that this will occur whenever the '*meteorological conditions are likely to fall to 1,000 metres or below*'[13]. At other airfields the Stop Bars may be used at all times.

Flight Crew – EI-FJW

The crew of EI-FJW were experienced on the Boeing 737. They had all operated into and out of EDI on previous occasions and were familiar with the airport and procedures. Some of the crew also had significant experience of LGW. The captain under training had experience as a commander at his previous operator so was not new to the role. Both training captains had more than a year's worth of training experience on the Boeing 737.

The flight from SWF to EDI was slightly longer than normal as the aircraft had a technical defect which prevented it from taking the usual more direct routing across the Atlantic.

The dynamics of a training flight with three captains in the flight deck can be challenging. In the right seat is the aircraft commander as the left seat captain is not yet fully qualified. However, for the purposes of the check flight, the left seat pilot acts as if he were the commander to demonstrate he has the required levels of skills to complete his training

Footnote

[11] CAA CAP 413, Chapter 4, 4.31.
[12] EDI MATS Part 2, Section 3, Chapter 2.7.
[13] EDI MATS Part 2, Section 3, Chapter 4.1.1.

and act as an unsupervised commander. The captain on the jumpseat must observe without comment unless he believes the aircraft to be at risk.

All three pilots of EI-FJW were familiar with operations at LGW. LGW also operates using a single runway[14]. The average movements per day in 2017 were 772, making it the second busiest airport in the UK, and the busiest single runway airport by movements in the world. Being familiar with operations at LGW meant all three of the crew were used to very high movement rates and were familiar with receiving landing clearance late or very late on the approach.

EI-FJW flight crew interviews

The flight crew of EI-FJW were interviewed both separately and together. They all stated that they were visual with OE-IVC from approximately 800 ft. At this point, they remembered it being at 90 degrees to the runway. From the point that they could see OE-IVC, all three reported that they were monitoring the situation and considering whether to go around.

All three commented that they have a high level of trust in UK ATC. The trainee captain was PM at the time of the incident. He reported that he made a call at 0.5nm to remind ATC of their position and prompt them for a go-around instruction if required. When they received an instruction to continue their approach, they interpreted this to mean that ATC were fully in control and they followed the instruction accordingly while continuing to monitor the situation.

The aircraft commander, who was PF, reported that he felt tired at the time of the incident having flown through the night from SWF. His roster pattern was compliant with the operator's approved flight time limitation scheme. Nevertheless, his sleep and work history for the seven days leading up to the incident was reviewed and assessed using the SAFTE-FAST biomathematical fatigue model. This model considers duration of duties, timing of duties, circadian rhythms, sleep duration and sleep inertia. The model produces a predicted 'effectiveness score' expressed as a percentage. Effectiveness scores of 90 - 100% are what would be expected for someone sleeping eight hours per night and working during the day. The commander's predicted effectiveness score at the time of the incident was 77.6%[15].

At the time of the incident, he was working on the final day of a seven-day roster block that included two return trips to SWF from the UK. The amount of sleep obtained overall in a combination of main sleep periods and planned naps was in line with what the commander reported as his normal sleep need. The pattern of shifts and the time zone changes resulted in several large changes to the start time of his main sleep periods over the course of the seven-day block. At the time of the incident he had been awake for approximately 13 hours following a planned nap.

Footnote

[14] Although the airport has a standby runway which can be used when the main runway is not available.

[15] The default threshold for this model, below which people are considered fatigued is 77%. In laboratory conditions, people at a predicted effectiveness score of 77% display impaired task performance such as increased reaction time. The model also indicates equivalence with the Samn-Perelli crew status check scale. The equivalent predicted level was 5.43. 5 = '*moderately tired, let down'*, 6 = '*extremely tired, very difficult to concentrate'*.

Flight crew - OE-IVC

The commander of OE-IVC was an experienced line trainer for the operator. The co-pilot in the right seat was undergoing line training having joined the operator from flight school and had completed around 70 hours flying in the A320 family with the operator. The commander of OE-IVC commented that an inexperienced pilot may take 10 – 15 seconds longer to line up on the runway.

The crew of OE-IVC were not given any instruction to expedite their line up or takeoff by ATC and were unaware of how close EI-FJW was at touchdown.

Air traffic controllers - trainee

The trainee controller attended the initial ATCO training course between July 2017 and April 2018 and had a Student Air Traffic Controller Licence that was issued in May 2018. The trainee controller started training at Edinburgh in May 2018 and was in the second of three levels of training.

Trainee training record

During the second level training prior to the incident, the trainee controller had completed 20 training sessions on a mixture of ground and air over a period of seven weeks. At the start of the session when the incident occurred the trainee controller had completed a total of 167 hours which included the core level training and the level two training undertaken so far.

The training record only includes details of the weather and the procedures practiced if an OJTI records it in the comments section. During the core and second levels of training, the use of LVPs was only referred to once and the use of safeguarding only once. On the two training days immediately before the day of the incident, the trainee controller worked at night. The comments noted that the trainee controller needed to be reminded to use the Stop Bars.

'*Control go arounds safely*' was only assessed on one occasion out of 20 during the second level training.

During the second level of training, the trainee controller and OJTI had worked together on five days. On the two days they last worked together prior to the incident, the trainee received highly positive written comments from the OJTI.

Trainee's interview comments

The trainee controller was interviewed together with the OJTI and then individually early in the investigation. Another individual interview was conducted several months later. The trainee controller had little experience working in the weather conditions that were present on the day of the incident and said that it was the "worst cloudbase" experienced while controlling. The trainee controller reported that there was no brief from the OJTI prior to the session and that this was common practice. Furthermore, it was normal for trainee controllers to perform a 'self-brief' covering NOTAMs etc. and then plug straight in for the session.

The trainee controller was aware of the need to catch up after the delay caused by not turning off the Stop Bars, but the developing situation was not fully apparent until EI-FJW appeared to break through the cloud.

The trainee controller heard EI-FJW make a transmission at 0.5 nm but did not hear what they said and so turned to the OJTI for advice; he advised to respond "negative". The trainee controller transmitted "NEGATIVE" and "CONTINUE APPROACH" to the crew of EI-FJW.

The trainee controller had not been aware of EI-FJW's groundspeed on approach or the speed instruction that had been issued to EI-FJW by the Edinburgh radar controller. During the second individual interview, the trainee controller reflected that the speed instruction was on the strip and the groundspeed was on the radar display but, being unfamiliar with the conditions, the trainee's strategy still focussed most attention out of the window instead of using information on the screens.

Air traffic controllers - OJTI

The OJTI had a valid Air Traffic Controller Licence and he was initially validated at Edinburgh in 2012. His licence included an OJTI endorsement valid until March 2021. The OJTI had completed a CAA approved practical instructional techniques[16] course during March 2018 and so, at the time of the incident, he had been working as an instructor for five months.

OJTI interview comments

The OJTI was interviewed initially with the trainee controller and then twice individually during the investigation.

He stated that, at the time of the incident, two training sessions were taking place, one on the tower position and one on the ground position. The trainer instructing on ground was using the only higher chair available so the OJTI used a standard lower chair. The OJTI stated that it is not possible to read the radar label readouts, including aircraft ground speeds, when seated in either chair due to glare and reflections on the screen. From the higher chair, it is possible to read the information on the strips but the radar screen label readouts are still not legible.

The OJTI commented that when planning to depart an aircraft in the gap between two landing aircraft he is looking for a 6 nm gap between landing aircraft and for the takeoff clearance to be issued to the departing aircraft by the time the second approaching aircraft is at 3 nm. He stated that he actively checked this was met and would have stood up and leaned over as necessary to see. The OJTI had worked with the trainee controller on many occasions before. He judged the trainee controller to be quite far through the training and at the point where less OJTI input was needed. Therefore, he recalled that, once he had checked the gap and takeoff clearance were sufficient, he had returned to his normal seated position.

Footnote

[16] Regulation (EU) 2015/340 of 20 February 2015 laying down technical requirements and administrative procedures relating to air traffic controllers' licences and certificates refers.

He said that he became aware of the situation a few seconds before the time that EI-FJW called 0.5 nm. From his perspective, this was when the aircraft appeared to suddenly come out of the cloud. He recalled that OE-IVC was at the threshold and had just started its takeoff roll.

The OJTI admitted that he was surprised to see EI-FJW so close and did not immediately react. By the time he was able to do so, he felt that it was too late to stop OE-IVC from taking off as it was beyond the glide path aerials and he was reluctant to send EI-FJW around. He feared that this would result in having two aircraft, over which he had limited control, close together in cloud.

The OJTI explained that with OE-IVC at speed and beyond the glide path aerials during the takeoff and EI-FJW at a very late stage of their approach he decided the best solution was to allow EI-FJW to land. He took control from the trainee controller and issued the landing clearance. He did recall the RIMCAS alert sounding.

After the incident, the OJTI retained control for a short time before handing back to the trainee and continuing the training session until the next break.

Organisational information

ANSP changeover

The changeover of ANSP at EDI resulted in the need for a period of sustained training due to a turnover of controllers. In the 15 months leading up to the ANSP transition, a total of eight controllers with previous experience elsewhere were recruited and trained at EDI. This training was completed by the previous ANSP under a commercial arrangement. A further five ab-initio controllers were recruited by the ANSP and began their training after the changeover. This was unusual for EDI and saw a total of 13 new controllers trained within 18 months. Usually, EDI would see around one new controller a year. This pace of training required the ANSP to qualify a significant number of the controllers already working at EDI as trainers and a small number of these had little or no previous experience in training new controllers. The ANSP contracted a third-party to provide a trainer's course which was designed and approved in accordance with the requirements in Section 5 of Commission Regulation (EU) 2015/340. The OJTI in this incident was a new trainer who had completed this course.

Training procedures at Edinburgh

According to the Edinburgh Unit Training Plan, the OJTI's responsibilities include:

> *'The safety of the air traffic control service that the trainee is providing under his supervision.*
>
> *Briefing the trainee before and after each session and outlining what is expected of them.'*

On-the-job training is divided into three levels. The differentiation between the levels is primarily in terms of what amount of OJTI support is required for trainee controllers to meet the competency standard.

At the core (first) level, in medium or high traffic or complex conditions, the trainee controller is expected to be able to perform to the required standard with '*some support*' from the OJTI. '*Some support*' is defined as '*The OJTI will direct and prompt as necessary*'.

At the second level, in medium traffic/medium complexity conditions '*minimal*' support is expected. '*Minimal*' means '*minor support where necessary, e.g. make reference to complex problems or ask the trainee to develop a course of action in time.*' In high traffic or high complexity conditions, '*some*' support is expected.

At the final level, the trainee controller is expected to be able to perform all tasks with no input from the OJTI.

At all levels, during LVPs or emergencies, additional OJTI support is expected to be necessary for the trainee to perform at the required standard.

OJTI training

Regulation (EU) 2015/340 required that the training of practical instructors '*Shall include a practical instructional techniques course… including an assessment.'* The training provider and the course must have been approved by a competent authority which, in the UK, is the CAA.

CAP 624 '*Air Traffic Controllers Performance Objectives Part 11 OJTI'* specified the performance objectives required for OJTIs. These included:

- OJT1.2 Determine the student/trainee's current level of ability
- OJT2.1 Conduct a pre-session briefing
- OJT3.1 Conduct the Training Session
- OJT3.2 Monitor the Training Session
- OJT3.3 Correct Errors

There were no EU regulatory requirements for the content of the practical instructional techniques course but Eurocontrol have published guidance[17] which includes a recommended syllabus for OJTI training.

The OJTI completed his practical instructional techniques at a third-party provider. The training provider and course were approved by the CAA. The course content was consistent with the Eurocontrol guidance and was designed to teach new OJTIs to meet the performance objectives specified in CAP 624.

Footnote

[17] Eurocontrol (2009). EUROCONTROL-GUID-133: '*EUROCONTROL Guidelines for ATCO Development Training OJTI Course Syllabus'*. Edition 2.0.

The course included:

- 90 mins classroom session on the briefing.
- 45 mins classroom session on error correction.
- 45 mins computer-based training on post-training session report writing.

It also included seven 45-minute practical exercises with mock trainees who simulated different levels of experience and different attitudes. The 45-minute practical period included time for briefing, de-briefing and assessment of the OJTI and 20 minutes for OJTIs to practice the training and monitoring of mock trainees. Four out of the five days of the course were devoted to such practical exercises. When trainee OJTIs were not doing practical exercises themselves, they observed the other trainee OJTIs doing so.

The OJTI's monitoring was assessed as good on all practical exercises. There was evidence that the OJTI had experienced trainee errors during the exercises and had made corrections or taken control appropriately.

OJTI practice at Edinburgh

Trainee controllers were supervised by a team of OJTIs, working with different people on different training sessions as required. The trainee controllers and the OJTIs were in regular contact and were considered to know each other well. Therefore, there was no expectation that a pre-training briefing would be conducted prior to each session and no time was provided for it.

Reporting procedures

After the training session during which the incident occurred, the OJTI reported the event to the Unit Competency Assessor and later, the Watch Manager. The conclusion from these conversations was that the incident could be reported on a voluntary basis.

The Unit Competency Assessor said that the event was reported to him as a "late landing clearance" which was a common occurrence. Although he recalled that the OJTI had used the word "incident", he was not aware that the landing clearance was given after the aircraft crossed the runway threshold or that another aircraft was involved and so he did not recognise how serious the event was. The Unit Competency Assessor and OJTI agreed that the OJTI should file a voluntary observation report. When they parted, the Unit Competency Assessor believed that the OJTI was on his way to file the report.

The Watch Manager also said that the event was reported to him as a "late landing clearance". He said that the OJTI's concern had been focused on the performance of the trainee controller. The Watch Manager was aware that the OJTI had already spoken to the Unit Competency Assessor and presumed that the Unit Competency Assessor had judged that the event was not serious. He did not follow up by talking to the trainee controller or to the Unit Competency Assessor.

MATS Part 1 specifies that a Mandatory Occurrence Report (MOR) should be filed within 72 hours of a serious incident occurring[18]. It allows an ATSU to use an approved programme for submitting an MOR which puts the report in the correct format for uploading on the database. EDI ATSU uses a programme known as TOKAI[19] for submitting MORs. The changeover of ANSP meant that user access for reporting events via TOKAI changed. The login for TOKAI required an employee email address and password. The OJTI had difficulty logging onto the system as this was the first time since the ANSP changeover that he had needed to do so. This difficulty, combined with days off, meant that the report was not completed using TOKAI for a number of days.

This delay meant that the recollections of the parties involved in the incident were not fresh and they had had time to reflect on the events, which may have altered how they recalled what had happened. It also meant that neither aircraft's CVR was available to the investigation.

Analysis

Introduction

At 0945:55 hrs, the preceding aircraft landed at EDI. At this point EI-FJW was 6 nm from touchdown, which was exactly the spacing required in the EDI MATS Part 2 for gap mode. The trainee controller then preceded to give OE-IVC line up clearance as had been planned for the gap before EI-FJW landed. Due to a combination of factors, the gap rapidly closed and the departing aircraft was at only 60 ft aal when the landing aircraft touched down.

Factors leading to the gap closure

<u>Stop Bar</u>

The airfield was in safeguarding due to the meteorological conditions and, therefore, the Stop Bars were in use. The trainee controller did not have much experience of working in conditions similar to those of the day of the incident and had little experience of using the Stop Bars. The Stop Bar was not turned off expeditiously and, as a result, OE-IVC could not move from the holding point to line up. There are two possible explanations; the trainee controller may have forgotten to do it or may not have activated the Stop Bar controls correctly. Turning off the Stop Bar requires a controller to move a cursor using a mouse and click within a very small box, before moving the cursor to the beginning of the active runway and clicking again. During this process, the cursor may have been mispositioned or the selection may have been performed in the wrong order, leading to the Stop Bar remaining illuminated.

Having been cleared to line up but with the Stop Bar still illuminated, it was natural for the crew of the departing aircraft to then question the illumination of the Stop Bar with the controller. However, before the crew of OE-IVC could do this, another aircraft on the same

Footnote

[18] MATS Part 1 Section 6, Chapter 3.
[19] TOKAI - Tool Kit for ATM Occurrence Investigation.

frequency began a transmission. As a result, there was a 16 second delay between OE-IVC being cleared to line up on Runway 06 and the crew asking the controller to turn off the Stop Bar so they could proceed onto the runway. This delay caused a significant part of the gap closure.

Speed of landing aircraft on approach

EI-FJW had been instructed by EDI approach to maintain a speed of at least 160 KIAS on the approach until 4 nm to assist with the spacing between it and the following aircraft. It would have been more usual for an aircraft on the approach to be instructed to maintain a speed of exactly 160 KIAS until 4 nm from touchdown, so the instruction given to EI-FJW permitted the aircraft to be flown at a higher speed than was normally expected. The crew complied with the instructions and were at 181 kt ground speed at 6 nm when the preceding aircraft touched down on the runway. EI-FJW complied with all the operator's requirements for a stable approach, having begun to slow after they passed 6 nm from touchdown. The higher than normal speed of EI-FJW on the approach may have caught the trainee controller by surprise.

Any speed control given to an approaching aircraft by the radar controller was displayed on the strip information, and the groundspeed was displayed on the radar picture display at the tower controller's station. However, the trainee controller was more familiar with being able to see the aircraft on the approach and to judge the gap visually rather than relying on the screens provided. With the weather conditions, the trainee controller was unable to see the aircraft until it was inside 2 nm from touchdown. The higher speed of the approaching aircraft combined with the less familiar need to refer to the radar display meant that the closure of the gap went unnoticed until the late stages of the approach.

The OJTI, seated or standing behind the trainee controller could not see the screens in detail without making a deliberate attempt to move his position, so the developing situation may also have not been obvious to him.

Time taken for the departing aircraft to take off

The crew of OE-IVC were unaware of the closing gap. They had not been instructed to expedite their line-up, nor had they been cleared for an immediate takeoff. Had either of the tower controllers issued these instructions it is likely that the training captain would have taken control of the aircraft and conducted the takeoff. The training captain estimated that this could have saved 10-15 seconds.

Reaction to the closing gap

EI-FJW

The crew of EI-FJW were familiar with the much busier air traffic environment of LGW, where the aircraft spacing is optimised to allow a large number of movements from a single runway. They were not concerned about the closing gap, as they did not consider it unusual. As the aircraft approached 0.5 nm from touchdown, they could clearly see the other aircraft was still on the runway. PM called the tower controller and was told to expect a late landing clearance. This confirmed in the minds of the crew that the controllers were fully aware of the position of both aircraft.

The crew in EI-FJW consisted of three captains, which, for the reasons given earlier, could make the dynamics of decision making challenging especially when considering that the captain who was PM in the left seat was being assessed before completing his training. There may have been reluctance from all three pilots to voice their concerns for fear of jeopardising the assessment.

The aircraft commander reported he was tired due to the overnight flight and his previous roster that included several transatlantic flights. He had had as much sleep as could be expected given his roster pattern and his flying performance was unlikely to be affected by fatigue. However, his feeling of tiredness may have made him hesitant to go around because this would extend the flight time.

The phenomenon of plan continuation bias may also have added to the crew's reluctance to go around even when they had not received a landing clearance at such a late stage. Plan continuation bias is an '*unconscious cognitive bias to continue* [the] *original plan in spite of changing conditions*[20]'. The bias can cause people to discount cues which indicate the situation requires a different course of action and has a stronger effect on behaviour the closer someone is to the completion of their plan; for example, the closer someone is to landing at the planned destination.

Overall, the above factors came together to contribute to the crew of EI-FJW not making a decision to discontinue the approach and go around.

OE-IVC

The crew of the departing aircraft were unaware of the developing situation and so could not react. The absence of any indication from the tower to the contrary resulted in the aircraft departing as planned. Even after takeoff, they were completely unaware of the situation that had developed and the closeness of EI-FJW behind them.

Controllers

The trainee controller was still relying on techniques more suited for use in better weather conditions. The trainee controller was using a rule-based strategy which checked the gap was sufficient as the preceding aircraft touched down and was not effectively monitoring the aircraft speeds or size of the gap as the situation progressed. All this meant that the trainee controller did not become aware of the gap closure until late and so then had little time to react.

As the crew of EI-FJW called at 0.5 nm, the trainee controller responded by instructing EI-FJW to continue the approach. This call also coincided with the RIMCAS Stage 2 visual

Footnote

[20] Dismukes, K. and Loukopoulos, L. (2004). '*The Limits of Expertise: The Misunderstood Role of Pilot Error in Airline Accidents*'. https://humansystems.arc.nasa.gov/flightcognition/article2.htm [accessed 6 March 2019).

and audible alert which would have continued in the background until cancelled. Both the 0.5 nm call and the RIMCAS Stage 2 alert may have been unfamiliar to the trainee controller. Whilst the trainee controller would have been familiar with the instructions in EDI MATS Part 2 stating that a RIMCAS Stage 2 alert requires the issue of a go-around unless it is ‘*positively known that there is no runway infringement*’, the trainee controller did not have the capacity or experience to immediately make that decision.

The trainee controller had little or no experience of instructing a go-around. This inexperience, together with the short time period available to act after becoming fully aware of what was happening resulted in an inability to recover the situation. The lack of experience probably also caused a reluctance to intervene in such a serious situation immediately without confirmation from the OJTI that it was the correct thing to do.

The OJTI was monitoring the trainee controller but had missed the developing situation. He became aware of the seriousness of the situation when EI-FJW came out of cloud a few seconds before the RIMCAS Stage 2 alert began to sound. He was startled by the suddenness of the situation and this caused a further delay in his reaction. His immediate concern was for the separation of the two aircraft. He could see both aircraft out the window and although they were close he was not concerned about them closing together. He considered that it was too late to stop OE-IVC taking off as he considered its speed was above 80 kt because it had passed the glide path aerials as specified in EDI MATS Part 2. His options were therefore to either instruct EI-FJW to conduct a go-around or allow it to land. His biggest concern was that if he instructed the go-around, he would have two aircraft, which he could see were close, disappear into cloud where he could not visually separate them. He made the decision to allow EI-FJW to land, which he did by giving them landing clearance. He considered that the decision was the safest at that point.

An earlier intervention could have enabled EI-FJW to go around whilst keeping OE-IVC on the ground, preventing the risk of two aircraft in cloud without minimum separation.

Had EI-FJW gone around from the approach, both aircraft would have been airborne with limited lateral separation. Given the TCAS inhibits, neither would have received an RA until reaching 1,000 ft radio altitude (737) or 1,100 ft radio altitude (A320). Whether the aircraft would have received an RA after this point would have depended on the actions of the controller to separate the aircraft, and their relative speeds and climb rates. It is not possible to model the flight paths of the aircraft accurately enough to be able to fully understand whether the TCAS RA would have been activated.

Being an OJTI can be a challenging position which requires experience and sound judgement to decide when and how to intervene with a trainee. The OJTI was relatively inexperienced in the role which would have made intervention decisions more challenging. As a trainee controller progresses through the training programme, OJTIs are encouraged to intervene less and less to allow the trainee controller to develop the skills and confidence required to qualify. With the trainee controller a considerable way through the second of three parts of the training, the OJTI would have been expecting the trainee controller to perform with little or no support from him. He had also had two sessions in the days before the incident during which the trainee controller had performed well. These factors and the difficulty of reading the screens could explain why the OJTI was not monitoring the situation closely once the initial gap had been checked and thus it increased the surprise[21] factor when the seriousness of the situation became clear to him.

Other factors

Training reports

The reporting forms used by EDI ATC for their trainee controllers contained the information required by the regulations. The reports, which were filled in by the OJTI after each training day, contained a comments section which the OJTI could use and a grading for each competency area. The comments recorded by the OJTIs were often quite lengthy but rarely included details of the weather conditions that the trainee controller experienced.

There was no summary to show the gradings for each competency over time. This made it hard for OJTIs to quickly get an impression of a trainee controller's recent experience and performance, and what the areas of focus should be for each session. This made it difficult to provide effective training and support at the right level for the trainee controller.

Pre-training briefing

The CAA performance objectives for OJTIs and the OJTI practical instruction techniques training both include conducting pre-session briefings. However, there was no expectation in EDI that this would occur, and no time was set aside for it. Whilst the OJTIs and the trainee controllers were well known to each other, a pre-session brief would allow both parties to understand the expectations for the session. It would also allow the OJTI to assess the experience level of the trainee controller for the prevalent conditions and to discuss the appropriate use of the information available to them.

Conclusion

A succession of short delays to the departure of OE-IVC and the higher than normal speed approach of EI-FJW led to the rapid closure of the gap between EI-FJW and OE-IVC. The loss of spacing went unnoticed by both the trainee controller and the OJTI until EI-FJW came out of cloud which was just before the crew prompted them by calling at 0.5 nm. At this point the OJTI made the decision that it was safer to land EI-FJW than risk having two aircraft that he could not separate visually close to each other in cloud above the airport.

The crew of OE-IVC were completely unaware of the developing situation as they could not see EI-FJW nor had the trainee controller instructed them either to be '*ready immediate*' or cleared them for an '*immediate takeoff*'.

Footnote

[21] Surprise is an emotional and cognitive response to unexpected events that are (momentarily) difficult to explain, forcing a person to change his or her understanding of the problem. Landman, A., Groen, E.L., van Passen, M.M. Bronkhorst, A. & Mulder, M. (2017) '*Dealing with unexpected events on the flight deck: A conceptual model of startle and surprise*' in Human Factors, Vol 59 pp 1161-1172.

The crew of EI-FJW were confident in the EDI air traffic controllers and were not initially concerned that they had not received a landing clearance. They were used to operations at LGW where traffic levels are significantly greater than EDI. They became concerned enough to prompt the controller at 0.5 nm but the reply only served to reinforce their confidence that the controller was on top of the situation. As a result, they did not decide to perform a go-around and continued to land once clearance was given. This led to a loss of separation between the aircraft at a critical phase of flight.

Safety actions

The ANSP at Edinburgh has taken the following safety actions in response to this incident:

- Published procedures in the Edinburgh MATS Part 2 regarding what events must be entered as MORs on the TOKAI system.
- Conducted a review of High Intensity Runway Operations at Edinburgh.
- Conducted a review of OJTI competency and introduced refresher training for all OJTIs as an outcome of the review.
- Has introduced additional higher OJTI chairs to provide OJTIs with a better view of the trainee, the screens and the trainee interactions with the equipment.
- Has reminded OJTIs of the requirement in the Unit Training Plan which mandates the requirements for a pre-training briefing between the OJTI and the trainee controller prior to every training session or at least every training day.
- Has incorporated a one-sheet overview of trainee ATCO's experience in their training file covering what key conditions and procedures they have experienced (eg fog, wind, go-arounds, significant slot delays, weather avoiding, snow etc).

Published: 30 May 2019.

ACCIDENT

Aircraft Type and Registration:	DHC-8-402 Dash 8 Q400, G-JEDU
No & Type of Engines:	2 Pratt & Whitney Canada PW150A turboprop engines
Year of Manufacture:	2004 (Serial no: 4089)
Date & Time (UTC):	10 November 2017 at 1330 hrs
Location:	Belfast International Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 53
Injuries:	Crew - None Passengers - 2 (Minor)
Nature of Damage:	Forward underside of the nose, front pressure bulkhead, nose landing gear and landing gear doors damaged
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	47
Commander's Flying Experience:	9,112 hours (of which 8,734 were on type) Last 90 days - 208 hours Last 28 days - 40 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was carrying out the third sector of a four-sector day from Belfast City Airport to Inverness Airport. After takeoff, the landing gear was selected UP. Cockpit indications indicated that the main landing gear (MLG) retracted normally but the nose landing gear (NLG) did not. The crew carried out the actions in the relevant abnormal checklists and were unable to lower the NLG. After burning off fuel, the aircraft was diverted to Belfast International Airport where it landed with the NLG retracted. The crew initiated an emergency evacuation.

It was determined that a damaged electrical harness on one of the nose landing gear proximity sensors caused an erroneous signal, which resulted in the forward NLG doors starting to close while the NLG was still in transit to the UP position. The nose landing gear tyres contacted the forward doors, causing the NLG to rotate off-centre. Although the NLG subsequently retracted, the forward doors remained open and the tyres became jammed in the NLG bay. This prevented the nose landing gear from extending when subsequently commanded.

The damage to the harness resulted from a cyclically-driven fatigue failure mechanism, which occurred because the harness had been secured with a non-flexible cable tie which restricted it from flexing during normal nose landing gear operation.

The aircraft manufacturer has taken action to clarify nose landing gear proximity sensor harness routing and attachment instructions in the Aircraft Maintenance Manual, and has published inspection requirements. Following the accident, the operator carried out an inspection of the nose landing gear proximity sensor harness routing on its Dash 8 Q400 fleet and undertook rectification of any anomalies noted. The aircraft and landing gear manufacturers are also working to identify a more flexible harness design; this activity had been initiated before the accident to G-JEDU.

History of the flight

The crew reported for duty at Belfast City Airport at 0550 hrs to carry out a four-sector day flying to London City Airport and Inverness Airport. The first two sectors to London City and returning to Belfast City were flown without incident and with all the aircraft equipment and systems operating normally. Following a normal turnaround and flight preparation, the aircraft was refuelled and the passengers boarded. The weather was good with a surface wind of 260º at 12 kt, CAVOK with an OAT of +8ºC and a dew point of +4ºC. The aircraft was started and taxied for Runway 22, from which it departed at 1118 hrs.

Shortly after takeoff, the landing gear selector lever was selected to the UP position. On the Landing Gear Control and Indication Panel (LGCIP), which is shown in Figure 6, the crew observed that the landing gear green lights extinguished, the three red lights and the amber landing gear door lights as well as the amber light in the landing gear selector lever all illuminated. After a short time, all three red lights extinguished, the left and right DOOR lights extinguished but the nose door light and the light in the landing gear selector lever remained illuminated. The crew kept the airspeed below the 185 kt landing gear limit speed and climbed to 4,000 feet, routing to waypoint Magee to take up the hold whilst they assessed the problem. The aircraft entered the hold at 1132 hrs and the total fuel onboard was 2,800 kg.

Whilst in the hold, the crew initially actioned the 'LANDING GEAR FAIL TO RETRACT' abnormal checklist followed by the 'LANDING GEAR FAIL TO INDICATE LOCKED DOWN' abnormal checklist. The MLG lowered and indicated locked down, but the NLG showed the unsafe indication with the amber nose door light still illuminated. The landing gear inoperative (LDG GEAR INOP) caption also illuminated on the Caution and Warning Annunciator Panel. They actioned the 'ALTERNATE LANDING GEAR EXTENSION' abnormal checklist and made several attempts to operate the nose landing gear alternate release handle but the indications remained the same.

They reviewed the 'EMERGENCY LANDING – ONE OR BOTH ENGINES OPERATING' abnormal checklist and decided to divert to Belfast International Airport. At this stage, the crew did not know if the NLG was up or down. The crew sought advice from their company and this confirmed their decision to go to Belfast International Airport. They reviewed the fuel and decided to leave the hold with 1,100 kg which would minimise the fuel onboard at touchdown but ensure sufficient fuel to carry out a go-around if required.

The Senior Cabin Crew Member (SCCM) was called to the flight deck and the situation explained to her along with a NITS[1] briefing which included the procedure for an emergency evacuation, should it be required. Passengers seated adjacent to the propellers were moved to other seats away from the possible arc of any debris in case the propellers should contact the runway. Following this, the commander briefed the passengers on the problem and his intentions using the PA system.

The cabin crew played the pre-recorded passenger emergency briefing and then walked through the cabin ensuring the passengers were all aware of what was required and that their restraint harnesses were secure. The passengers at the rear of the aircraft were warned of a possible increased drop to the ground from the rear doors due to the nose-down attitude if the NLG was not lowered.

At Belfast International Airport, Runway 25 was in use, the surface wind was 250º at 12 kt, visibility more than 10 km, clouds few at 1,800 feet and scattered at 2,900 feet, temperature +12ºC, dew point +3ºC, and the QNH 1020 hPa. The crew briefed for a radar vectored ILS approach for Runway 25 with full landing flap and an approach speed of 110 kt. They also reviewed the emergency landing actions and reminded themselves where the CVR/FDR circuit breakers were located in order to ensure they were pulled after landing.

The aircraft left the hold at 1320 hrs with 1,100 kg of fuel as planned and commenced the approach. All the normal checks were carried out and at about 4 nm, ATC informed them that the nose landing gear had not extended. The approach was continued as briefed and at 200 ft, the co-pilot gave the 'BRACE' command over the PA and all the passengers were seen to adopt this position.

The aircraft touched down at 1332 hrs on the main wheels and the nose was held off as the speed decayed and gently lowered onto the runway. As the aircraft came to a stop, both engines were shut down and when stopped, the commander ordered the evacuation.

The cabin crew responded and described the passengers as being calm. The forward left door and the rear left and right doors were opened. The forward left door, which has built-in stairs, lay flatter than normal as it could not achieve its full downward travel. This made exiting the aircraft more difficult, but no one fell whilst using it. At the rear, some passengers were reluctant to jump given the door sill height but some of the passengers who had left the aircraft returned and assisted them from below.

Smoke and a smell of burning entered the flight deck and so the flight deck door was opened which allowed it to clear. The flight crew used the 'ON GROUND EMERGENCIES' checklist on the rear of the QRH to ensure they had completed all the required actions before leaving the flight deck and checking there was nobody on the aircraft.

They then vacated the aircraft. The passengers had been gathered together by the Fire Service and were transported to the terminal on buses provided.

Footnote

1 The standard briefing content of; Nature, Intentions, Timings and Special instructions (NITS).

Airfield information

The aircraft had departed from Belfast City Airport which has a single runway orientated 04/22, 1,829 m long and 45 m wide with an asphalt surface. Belfast International Airport has two runways. The main runway is orientated 07/25 and is 2,780 m long and 45 m wide. There is a 'cross' runway orientated 17/35 which is 1,891 m long and 45 m wide. Both runways have an asphalt surface.

Accident site and aircraft examination

Photographs taken as the aircraft landed showed that the nose landing gear was retracted and the forward NLG doors were open. The aircraft touched down on its main landing gear in the Runway 25 touchdown zone, and slightly to the right of the centreline.

Two thin parallel ground marks, corresponding to contact by the lower edges of the forward NLG doors, commenced abeam the point where the Taxiway B centreline joined Runway 25. Thereafter, a single broader ground mark indicated that the lower forward fuselage had contacted the runway surface.

The aircraft had come to rest with its nose on the ground approximately 1,973 m from the Runway 25 threshold (172 m before the intersection with Runway 17/35) and 15 m to the right of the centreline (Figure 1). The left NLG wheel was visible protruding from the NLG bay, but it was not possible to verify from initial examination whether the NLG was uplocked.

The aircraft had suffered abrasion damage to skin panels and structure on the lower surface of the forward fuselage and the VHF antenna. The NLG forward doors had also separated from the fuselage.

Figure 1

G-JEDU on Runway 25 at Belfast International Airport

Examination of the cockpit showed that the landing gear selector lever was in the DOWN position, the overhead MLG release door was opened and the handle was stowed. The guard on the L/G DOWN SELECT INHIBIT switch was lifted and the toggle switch was in the INHIBIT position. The landing gear alternate extension door on the cockpit floor was open. It was evident that the nose landing gear alternate release handle had been pulled. The cable had not retracted into its spool and approximately 12 cm of cable was exposed lying on the cockpit floor (Figure 2). The lock release button was in the UP position.

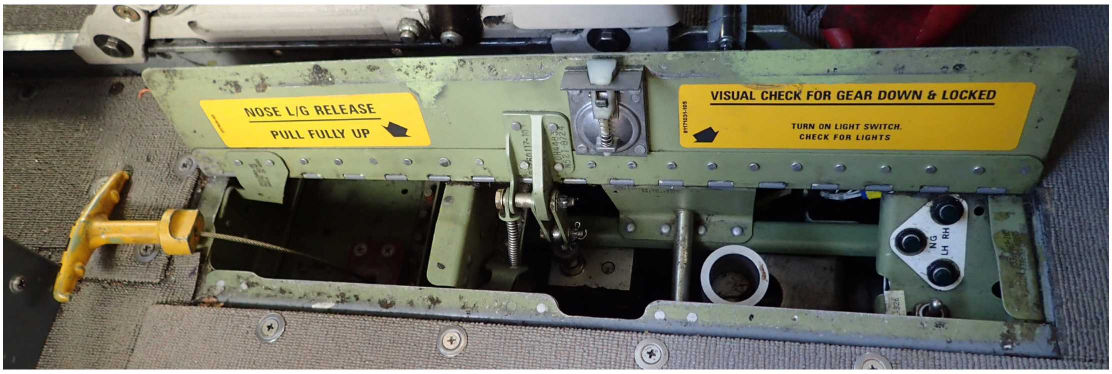

Figure 2

Position of nose landing gear alternate release handle following the accident

The aircraft nose was raised using airbags until a jack could be positioned on the forward jacking point. The NLG remained in the retracted position when the aircraft was lifted. It was evident that the NLG was not correctly centred, instead the wheels were turned to the right. The upper outside surface of the right tyre appeared to be jammed against the wall of the NLG bay (Figure 3).

Figure 3

View looking up and forward, showing nose landing gear retracted and off-centre

The nose landing gear alternate release cable remained jammed despite attempts to pull it using substantial force, however the uplock could be heard releasing when the cable was pulled. A crowbar was used to rotate and centre the NLG, releasing the right tyre from the jammed position; once the gear was centred, it extended under gravity and locked down. Coincident with this the nose landing gear alternate release cable in the cockpit was heard to retract onto its spool.

Examination of the NLG identified evidence of blue paint on the outboard shoulders of both tyres, indicating that each tyre had come into contact with the outer painted surface of the respective forward NLG doors (Figure 4).

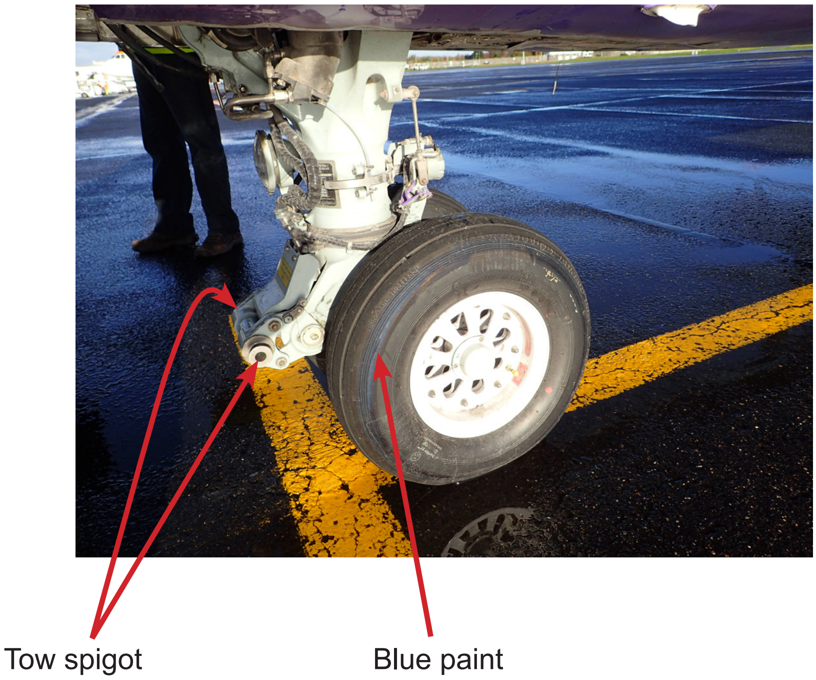

Figure 4

Blue paint on the tyre shoulder of left nose landing gear wheel

Both forward NLG doors exhibited extensive abrasion damage. The rubber seal and metal retaining strip from the lower edge of the forward right door were recovered from the runway. The seal had worn through as a result of ground contact and the attached remnants of the outer door skin showed evidence of tyre contact (Figure 5a). Additionally, the bottom edge of the seal-retaining strip exhibited mechanical damage in one location where a curled lip of metal had peeled upwards (Figure 5b). The location of this damage was approximately in line with the position of the tow spigot on the NLG.

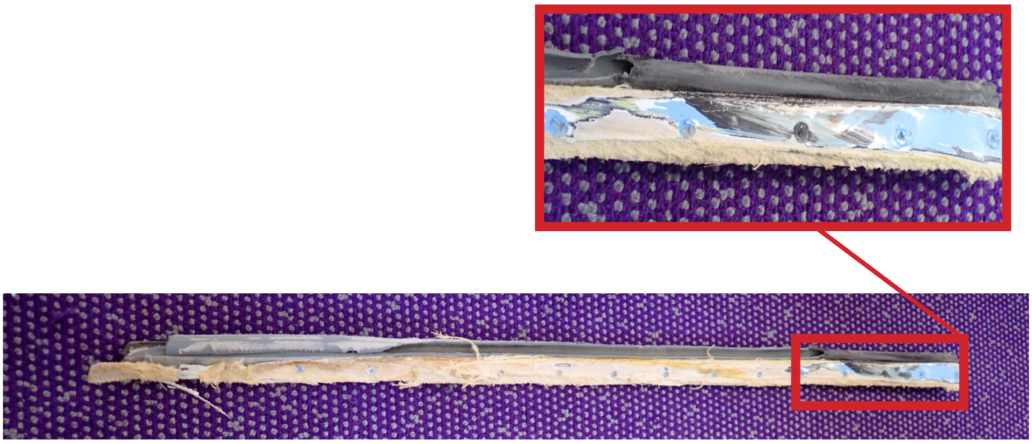

Figure 5(a)

Outer surface lower edge of forward right NLG door,
showing abrasion damage to rubber seal and tyre contact marks

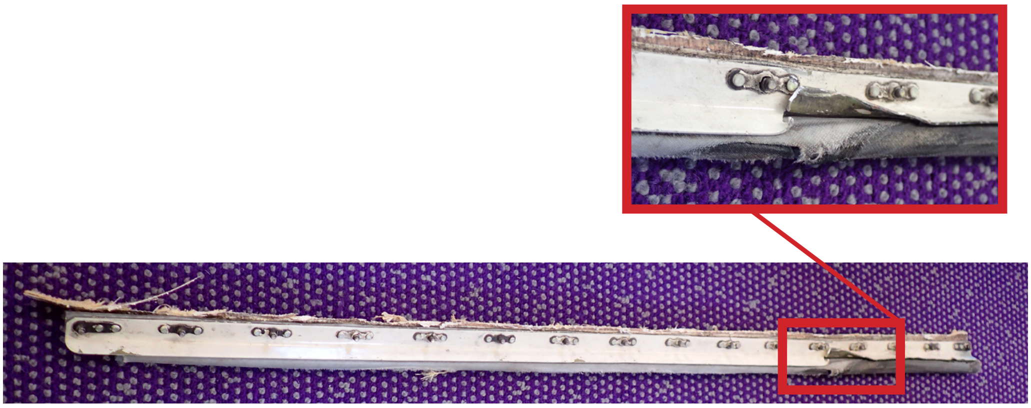

Figure 5(b)

Inner surface lower edge of forward right NLG door,
showing mechanical damage to metal seal-retaining strip

Damage to the aircraft

The aircraft was substantially damaged by deformation and abrasion due to runway contact. This resulted in structural damage to the lower front pressure bulkhead and fuselage skin[2]. The forward NLG doors suffered substantial abrasion damage and were partially detached from the fuselage. The aft NLG doors were in the closed position with portions of the exterior surfaces abraded and worn down to the honeycomb. The nose landing gear trunnion assembly was also damaged.

Footnote

2 The damage was to stringers and frames between frame X-69.40 and X-124.00 and between stringers 30S and 30P.

Previous incidents on G-JEDU

During a go-around at Birmingham International Airport on 1 November 2017, G-JEDU's landing gear failed to retract when selected. The flight crew observed three red landing gear unsafe lights and one amber NLG door light on the LGCIP. The remainder of the go-around was flown with the gear-down and a second approach resulted in a normal landing.

Subsequent inspection identified damage to the lower edge of the forward right NLG door and the door seal. In consultation with the aircraft manufacturer, the operator's contracted maintenance organisation carried out system checks and troubleshooting which included performing a bypass check of NLG door actuator, an inductance check of the proximity sensors, and checks of the NLG centring system. The defect was not replicated during the ensuing gear swings; it was not recorded how many gear swings were performed. The forward right NLG door and the NLG door actuator were replaced and the aircraft was returned to service.

Recorded information

Flight data recorder

The aircraft was fitted with a Honeywell solid-state flight data recorder which recorded over 25 hours of flight data and contained data for 21 sectors, including the accident flight. A review of this data showed that NLG retraction time was typically 5.25 seconds. However, on two occasions on 9 November 2017, and on the accident flight, the NLG retraction time was 9.25 seconds and for one flight, on 7 November 2017, 17.25 seconds. Due to the sample rates of the parameters used to calculate the NLG retraction time these times could be in error by ± 2 seconds.

Quick access recorder

An analysis of quick access recorder data conducted by the operator also indicated that G-JEDU experienced slower than normal NLG retractions (12 seconds) during two sectors on 9 November 2017 and on one sector on 7 November 2017 (20 seconds). Additionally, slower than normal NLG retractions (12 seconds) were noted for the flight on 1 November 2017 where the landing gear failed to retract, and on the previous sector the same day (prior to the beginning of the flight recorder data).

Landing gear system description

General

The landing gear system on the Dash 8 Q400 is electrically controlled, hydraulically operated and mechanically locked. The landing gear is operated by a selector lever in the cockpit. Landing gear and landing gear door position is shown by nine advisory lights on the LGCIP and an amber light in the selector lever (Figure 6). An amber gear door advisory light will illuminate when the related door is open. A green landing gear safe advisory light is illuminated when the respective gear is down and locked. Red landing gear unsafe advisory lights are illuminated when the gear is neither uplocked nor downlocked.

When the gear is up-and-locked, and all landing gear doors have closed, all lights on the LGCIP are extinguished. The amber light in the landing gear selector lever will be illuminated when the actual position of any gear does not match the position of the lever.

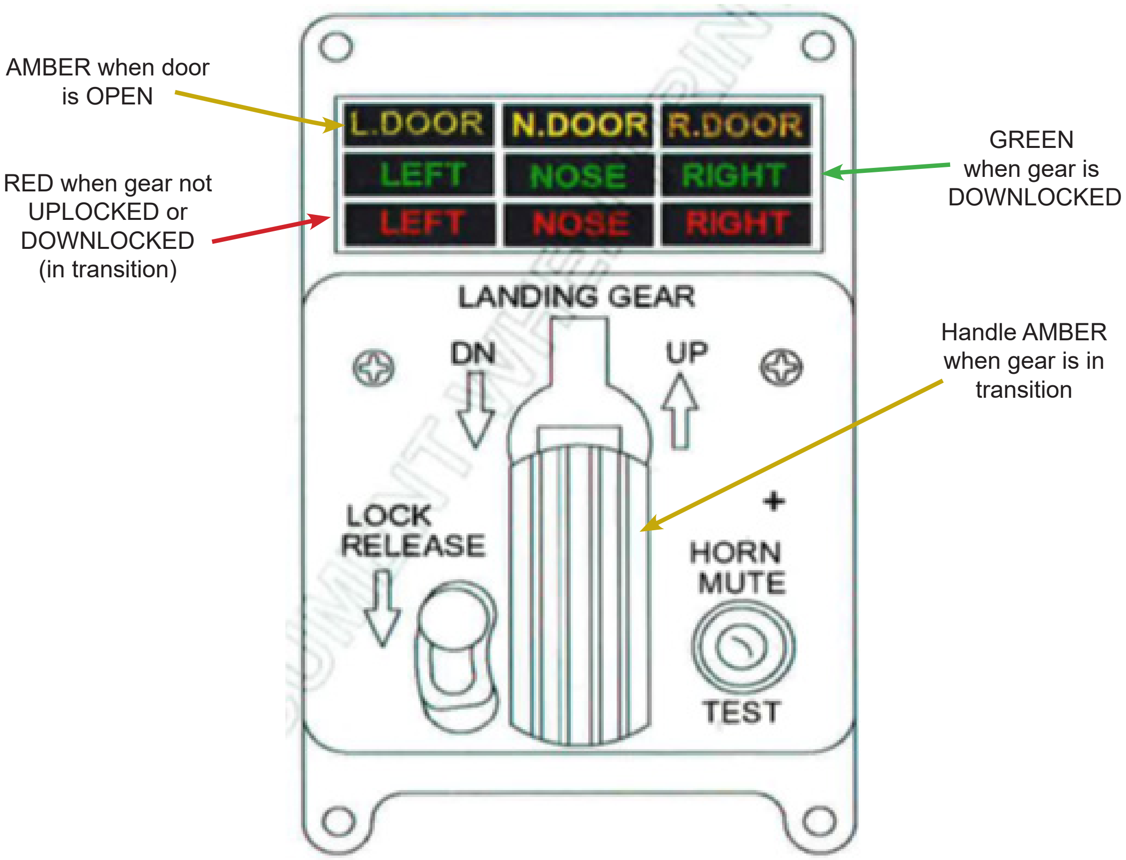

Figure 6

Dash 8 Q400 landing gear control and indication panel

Landing gear proximity sensors

A Proximity Sensing Electronic Unit (PSEU) provides landing gear control, sequencing and status indication. It monitors discrete inputs from the landing gear system, such as the extend and retract commands from the landing gear selector lever and the position of the landing gear components based on readings from 20 landing gear proximity sensors. It uses logic based on this information to generate discrete outputs which govern the landing gear operation.

The proximity sensors are hermitically-sealed devices that contain an inductor. When a ferrous metal target moves into position near the sensor face the inductance[3] of the sensor increases to a value where the PSEU detects a NEAR target condition. When the target

Footnote

[3] Inductance is a property of an electric circuit by which an electromotive force (voltage) is induced by a change of current, either in the same circuit or in a neighbouring circuit. It is an effect caused by the magnetic field of a current-carrying conductor acting upon the conductor. Inductance is the ratio of the induced voltage to the rate of change of the inducing current. The unit of inductance is the henry (H).

moves away from the sensor the inductance decreases to a value where the PSEU detects a FAR target condition. The PSEU uses the NEAR and FAR sensor condition to determine the position of the landing gears and gear doors and the aircraft weight-on-wheels status.

Nose landing gear proximity sensors

There are eight proximity sensors on the nose landing gear. These include a 'nosewheel centred' sensor (NWCENT), a 'nose gear doors closed' sensor (NGDRCL) and a pair of sensors giving primary and alternate indication for each of the following functions: 'nose gear weight-off-wheels' (NGWOFW1 and NGWOFW2), 'nose gear down' (NGDN1 and NGDN2) and 'nose gear locked' (NGLK1 and NGLK2).

The NGWOFW sensors indicate when the nose landing gear is on the ground (FAR) or in the air (NEAR). The NGDRCL sensor is NEAR when the forward NLG doors are closed and the NWCENT sensor is NEAR when the nosewheel is centred.

The NGDN1 and NGDN2 sensors are in the NEAR state only when the NLG is fully extended down; they will transition to FAR early in the nose landing gear retraction sequence and remain FAR until the gear is fully extended again.

The NGLK1 and NGLK2 sensors are in the NEAR state when the NLG is either fully down and locked or fully up-and-locked and are in the FAR state when the NLG is transitioning between these positions.

Nose landing gear retraction sequence

Logic Equation 2[4] governs the operation of the retract selector valve. Logic Equation 3[4] monitors the NGLK and NGDN sensors and governs the nose landing gear door sequence valve, which controls the function of the NLG doors. When landing gear retraction is commanded the PSEU senses that the landing selector lever is in the UP position. For the retraction operation to commence the PSEU must also sense a NGWOFFW and NWCENT signal and that the landing gear inhibit switch is not inhibited. When these conditions are met, the nose landing gear door sequence valve is energised. In parallel, the retract selector valve is 'shuttled' to the 'retract' state and ports system hydraulic pressure to the retract side of the landing gear hydraulic system. The NLG doors open, and the NLG unlocks and begins to retract (NGDN1 and 2 and NGLK1 and 2 transition from NEAR to FAR).

Once the nose landing gear is in the up-and-locked position (NGLK1 or NGLK2 NEAR), the PSEU deactivates the output to the NLG door sequence valve which is de-energised to close the forward NLG doors. The PSEU deactivates the retract output three seconds after the NGDRCL reads NEAR.

The aft NLG doors are mechanically linked to the NLG and open/close with the gear. The retraction sequence normally takes between five and seven seconds, from first door open to last door closed. If the NWCENT signal is lost at any point, the retraction sequence will

Footnote

[4] de-Havilland Dash 8, Series 400 'Interface control document for the proximity sensor system', Revision AB, dated 13 January 2016.

stop within three seconds and if the gear is not in uplock when the retraction sequence is stopped, the gear will extend.

NGLK sensor inductance faults

The PSEU stores current faults in the 'Present Faults' page and fault history for 31 flight legs. There are three types of proximity sensor fault: proximity sensor 'short', proximity sensor 'open', and proximity sensor 'unreasonable'. An open or short circuit can occur in the sensor or the associated sensor wiring and the PSEU will flag the sensor as OPEN or SHORT respectively if the measured circuit resistance is outside of predetermined limits. The PSEU will use the non-faulted sensor and set the faulted sensor to a FAR state.

Sensor 'reasonableness' is evaluated by the PSEU for each of five operating modes: 'air' mode (weight-off-wheels), 'ground' mode (weight-on-wheels), 'gear down and locked', 'gear in transit' and 'gear up and locked'. If a proximity sensor does not match the expected state for the current operating mode (ie if the sensor target is in the wrong NEAR or FAR position) then a reasonableness fault (UNRSNABL NEAR or UNRSNABL FAR) is reported and logged in the Present Faults page. For an NGLK sensor, such a fault would be logged if it was not in the expected state during the 'gear in transit' for a period of 3.5 ± 2 seconds.

For the NGLK sensors, inductance values in the range 8.055 to 9.9 millihenries (mH) correspond to the NEAR state and those in the range 7.1 to 7.73 mH correspond to the FAR state. If the measured inductance is outside the NEAR/FAR operating range (ie below 7.1 mH or above 9.9 mH) for between 0.5 and 1.5 seconds, a fault is logged in the Present Faults page of the PSEU and the default state sensor state (FAR) is reported/used. If the measured inductance drops below the fault threshold within 1.5 seconds, the sensor state will revert back to the live-monitored state. A fault will be logged in the fault history with no associated faults in Present Faults. If the fault condition persists for more than 1.5 seconds, the reported fault is latched and will continue to be logged in Present Faults. The sensor state will be latched in the default (FAR) state and live measurement of inductance and resistance is stopped.

Following a power-on reset or cold start, the latch associated with the sensor fault and sensor status will be removed and live measurement of sensor and resistance is resumed. The sensor will be re-evaluated for correctness/validity and depending on the outcome of this evaluation the fault will either return to being logged in Present Faults or will be logged in the PSEU fault history with no associated faults logged in Present Faults.

Landing gear alternate extension system

A cable-actuated alternate extension system can be used to extend the landing gear if the No 2 Hydraulic system or the PSEU are not serviceable, or if the normal extension system fails to lock the landing gear in the down position. To use the alternate extension system, the landing gear inhibit switch is switched from NORMAL to INHIBIT to isolate power from the landing gear door solenoid sequence valves and the landing gear selector valve.

Pulling the landing gear alternate release handle, which is accessed through the landing gear alternate release door in the ceiling of the flight deck, opens the MLG aft doors and releases the MLG uplocks. The MLG freefalls in to the down position and a hydraulic hand pump can be used to fully extend the MLG if necessary.

A nose landing gear alternate release handle in the flight deck floor is pulled to release the NLG. The first stage of the pull unlocks the NLG forward doors; as the handle is pulled further, a spring-loaded kicker arm rotates until it contacts the pivot tube on the drag strut, which in turn rotates to release the NLG uplock. The NLG then freefalls to the fully extended position. Springs on the NLG drag strut move the lock links into the down and locked position.

Tests and research

Download of PSEU fault history

Following the accident, a review of the PSEU Present Faults showed a NWCENT UNRSNABL FAR fault. The fault history for the accident flight (present leg) also showed a number of faults including one NWCENT UNRSNABL FAR, nine NWCENT PROX SENS OPEN, one NGDRCL UNRSNABL FAR and nine PSEU CHAN A FAIL CHAN INOP faults.

It was determined that the ‘unreasonable’ faults were associated with the off-centre position of the NLG and the forward doors which remained open, while the NLG was up-and-locked. The NWCENT PROX SENS OPEN and PSEU CHAN A FAIL CHAN INOP faults were logged in ‘weight-on-wheels’ mode and considered to have resulted from the abrasion damage suffered by the centring sensor when the NLG contacted the ground during the landing.

There were no faults associated with the NGLK sensors for the accident flight.

Numerous faults were logged for flight leg 30, which corresponded to the slow retraction incident on 1 November 2017. These included UNRSNABL FAR faults for NGLK1 and 2 in ‘gear down and locked’ mode and UNRSNABL NEAR FAULTS for NGLK1 and 2 and NGDN1 and 2 in ‘gear in transit’ mode.

On-aircraft testing - general

Following the accident, a temporary repair was performed on G-JEDU and it was flown on a gear-down ferry flight to the operator’s main base, where testing of the landing gear extension/retraction system was conducted under the supervision of the AAIB. Representatives from the operator, the aircraft and landing gear manufacturers, Transport Canada and the Transportation Safety Board (TSB) of Canada were in attendance.

Based on the observations from the aircraft examination, a test programme was devised by the aircraft and landing gear manufacturers to test all components which had the potential to influence the NLG extension/retraction sequence. In preparation for the testing, the nosewheel centring sensor, which had been damaged in the accident, was replaced, the NLG doors which had been replaced after the accident were removed to avoid potential interference between the NLG and the NLG doors and the aircraft was jacked.

As well as dimensional and rigging checks, multiple landing gear extension/retractions were performed while the indications on the LGCIP and the PSEU display were monitored.

During the first set of ten gear swings the first two retractions happened smoothly, but on the third attempt the forward NLG doors closed while the gear was in transit and the NLG stalled mid-retraction. The doors remained closed and the NLG then extended very slowly as hydraulic pressure dissipated from the system. When the NLG was almost completely down, but before it had reached the downlock position, the forward NLG doors opened[5] and the retraction recommenced swiftly and completed successfully. This behaviour was observed three times during the first set of ten gear retractions. In addition, during one retraction the forward NLG doors began to close and then almost immediately reopened and the NLG momentarily stalled, but the gear proceeded to compete the retraction.

Further landing gear swings were performed and a number of stalled NLG retractions were observed. The PSEU display indications for the NGLK1 and 2 sensors were monitored in real time and it was noted that the NGLK1 and 2 sensor indications appeared to correctly reflect the position of the NLG when in the NEAR state (ie when the NLG was either downlocked or uplocked). However, on those occasions when the NLG stalled mid-retraction, shortly after transitioning from the NEAR to FAR state, the displayed NGLK1 inductance value briefly spiked to a value within the NEAR inductance range before once again going back FAR. While the exact value varied each time, it was observed to be high enough to register a NEAR signal in the PSEU but remained below the 9.1 mH limit, at which the PSEU would fault the sensor. The PSEU therefore considered these inductance spikes to represent a valid NEAR signal and stopped the NLG retraction sequence.

Each time the retraction stalled, the NLG was observed to descend slowly until almost fully extended after which the retraction swing would recommence and successfully complete. Monitoring of the PSEU display indicated that retraction would recommence as both the NGDN1 and 2 sensors transitioned from the FAR to the NEAR state, but before either of the NGLK sensors had achieved the NEAR state indicating downlock.

The PSEU was replaced with a new unit and several gear swings were carried out. The NLG continued to stall mid-retraction at intermittent intervals. The PSEU was therefore eliminated as a potential cause and the original unit was reinstalled.

On-aircraft examination of NGLK1 harness

The NGLK1 harness was unclipped from its routing and progressively flexed along its length, while monitoring the NGLK1 inductance indication on the PSEU display. Inductance spikes were observed when the harness was manipulated at a position approximately 15 cm from the sensor, indicating the possibility of mechanical damage within the electrical harness. The NGLK1 sensor and harness were removed for further examination and replaced. A further 40 gear retractions were conducted with no anomalies noted.

During removal of the NGLK1 harness from the aircraft it was noted that there appeared to be little slack in the harness and there was a tight bend where it entered the airframe connector (Figure 7).

Footnote

5 Although the forward NLG doors had been removed for testing, the door mechanism operated such that the doors would have opened if they had been attached.

Figure 7

NGLK1 harness termination at airframe connector

Computed tomography examination

A subsequent computed tomography (CT) scan of the NGLK1 sensor and harness assembly identified that one of the two conductors in the harness was fractured at a location approximately 15 cm above the sensor. In addition, a number of sites which indicated the initiation of possible similar damage were identified.

Proximity sensor harness additional information

The proximity sensor harnesses are made from a M27500[6] standard cable, comprising a twisted pair of 22-gauge conductors, and these are cut to length for each individual sensor application. Each conductor wire is made from 19 strands of silver-coated copper, covered in a thin layer of insulation (teal-coloured) and a thicker layer of white fluoropolymer insulation. One of the conductors has a blue stripe on the white insulation; this denotes it as the ‘drive’ wire. The other conductor is the ‘sense’ wire.

Footnote

6 M27500 is an aerospace-standard specification, formerly known as MIL-DTL-27500.

The twisted pair are shielded by two layers of woven metal braiding, an inner layer fivestrand metal shield and an outer six-strand layer. This assembly is encased in an outer white fluoropolymer 'jacket' and a corrugated black conduit.

NGLK sensor harness routing

The NGLK sensors are mounted on the aft face of the NLG drag strut and their associated harnesses run vertically up the drag strut, secured by p-clips at two locations (Figure 8). Above p-clip 2, flexible rubber lacing holds both harnesses together. The harnesses then route horizontally aft along the top of the NLG bay, where they are secured to a bracket by a third p-clip, before terminating at their respective airframe connectors on the front pressure bulkhead.

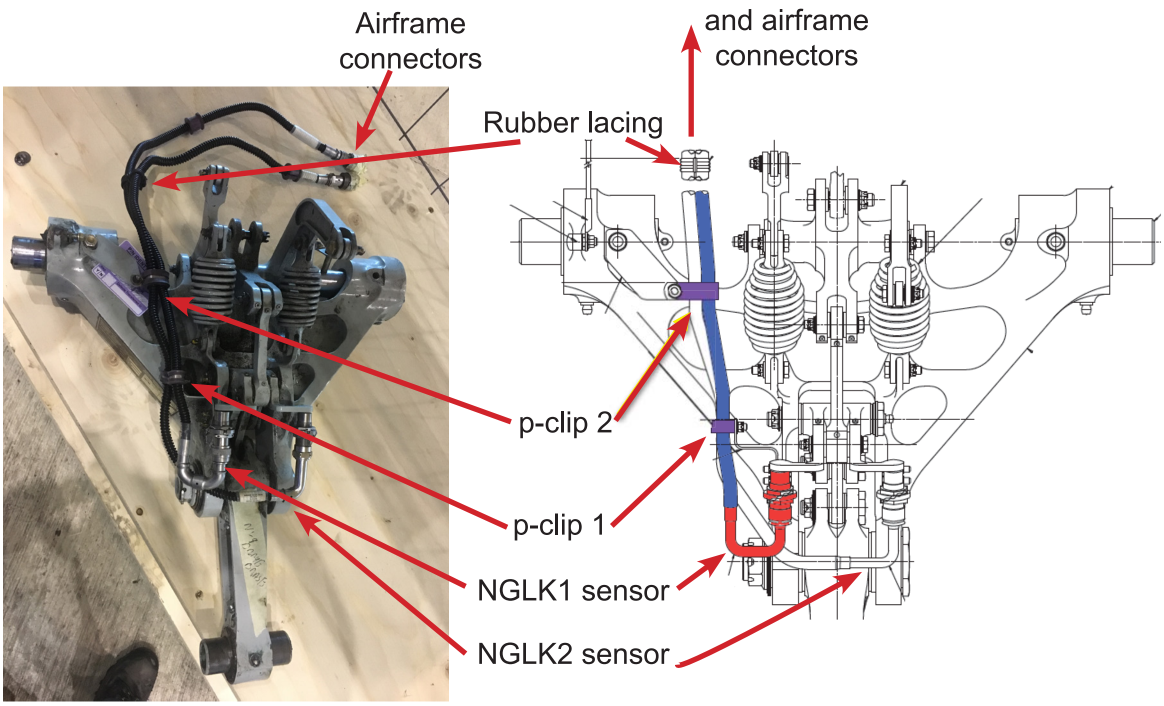

Figure 8

NGLK1 and NGLK2 harness routing on drag strut

Laboratory examination

The NGLK1 harness was subjected to a detailed forensic disassembly and strip examination by the University of Southampton's nC² engineering consultancy. Additional CT scanning of the NGLK1 harness was carried out by the university's MuVis facility.

NGLK1 harness

Visual examination of the harness revealed a distinct bend above the p-clip 2 location. The harness did not lie flat but exhibited a permanent deformation. A kink in the black corrugated conduit was evident at the joint with the airframe connector (Figure 9).

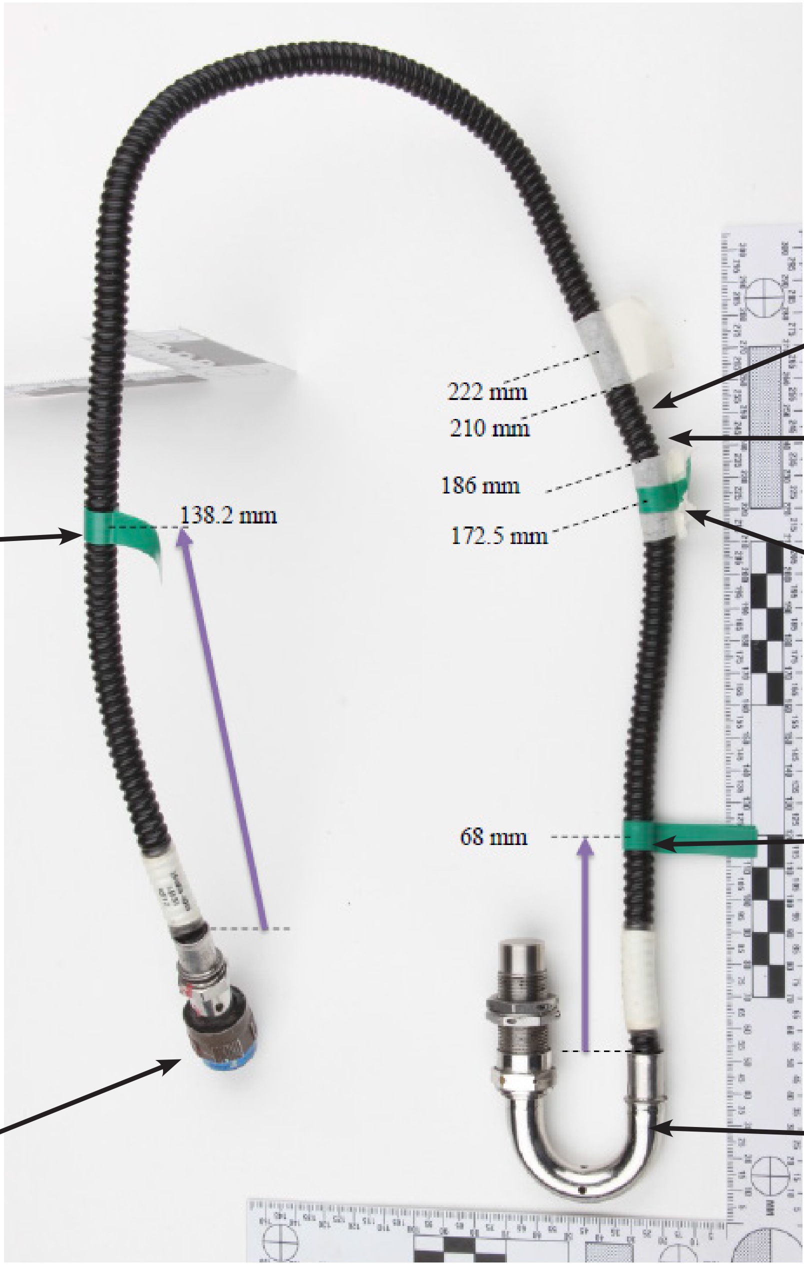

Figure 9

NGLK1 harness. Note: p-clip positions marked with green tape, and the area of damage identified on the initial CT scan was marked with white tape

When the corrugated conduit was removed to expose the cable, a split in the white polymer jacket was apparent (Figure 10), coincident with the concave side of the 'permanent set'[7] bend highlighted in Figure 9. The jacket also exhibited permanent set suggesting it had been held at a tight angle. There was evidence of buckling on the white jacket, either side of the split which was indicative of compressive loading. Broken strands of woven metal

Footnote

[7] Permanent set refers to the permanent change in shape, or plastic deformation, of a material that occurs when the load to which it is subjected causes the elastic limit of the material to be exceeded. The material does not return to its original shape when the load is removed.

braiding were visible protruding through the split and the line of fractures was consistent with the point of maximum compression of the bend. Scratch marks were noted on the inner surface of the corrugated conduit, indicating that the exposed strands had made contact in this area and that the cable was moving relative to the conduit.

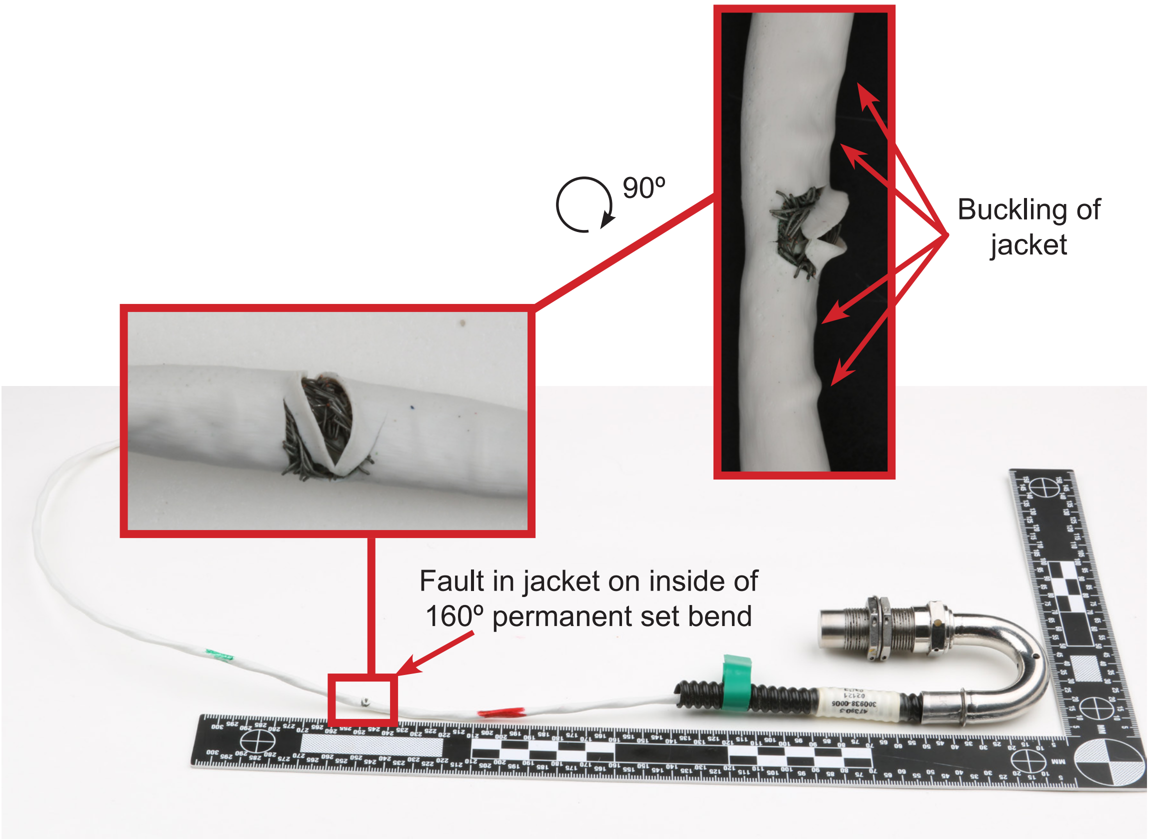

Figure 10

NGLK1 harness partially disassembled showing split in polymer jacket

A 100 mm section of cable was cut from the harness for additional examination, CT scanning and disassembly. The CT scan showed that one of the central multi-stranded conductors (white with blue stripe) had completely fractured at one location including through the two layers of insulation (Figure 11). It also exhibited multiple transverse fractures on individual wire strands either side of the bulk fracture, resulting in numerous short strand lengths. It was apparent that an electrical path could still have existed across the bulk fracture, bridged by short lengths of wire strands. The second wire (white) also displayed many transverse fractures on individual wire strands, predominantly on the concave side of the cable but was still contained within its insulation and was capable of making an electrical circuit.

Examination in a scanning electron microscope (SEM) showed that the fracture surfaces of the broken strands from both layers of metal braiding were corroded but the overall shape was flat and not consistent with ductile overload failure. Under higher magnifications features consistent with fatigue striations were observed between the areas of corrosion. It was not possible to measure striation spacing with any confidence on the failed strands from the outer six-strand layer, however on the inner five-strand layer, striation spacing was approximately 0.3 m, suggesting that over 330 cycles would have been required to fail one strand.

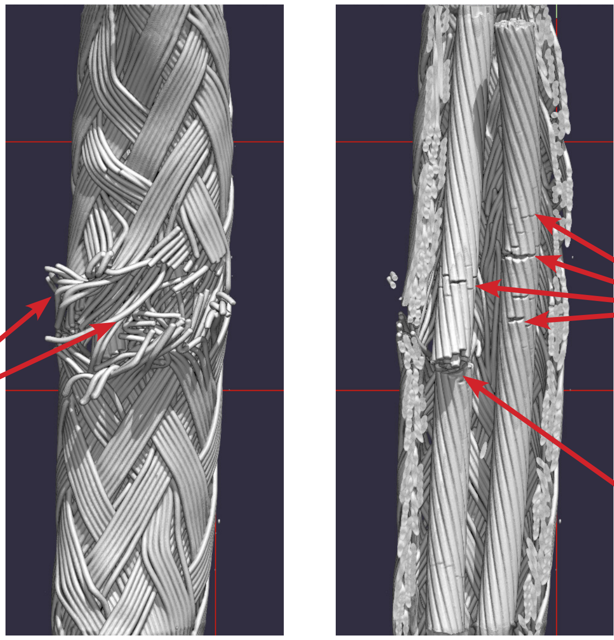

Figure 11

CT images of the concave side of the wire, orientation sensor down.
Left image shows deformation and damage to the metal braiding (with polymer jacket 'virtually' removed).
Right image shows the damage to both conductor (with polymer jacket, both layers of metal braiding and wire insulation 'virtually' removed)

The fracture surfaces of the failed wire strands from both conductors were flat and displayed evidence of fretting damage but were too corroded to find striations. However, the features that were present, including the general flat shape, indications of crack arrest and ratchet marks, were consistent with a cyclically-driven fatigue propagation failure mechanism initiating at sites of fretting damage.

Examination of NGLK2 harness

Based on the results of the NGLK1 examination and the common routing shared by both harnesses, forensic disassembly and strip examination of the NGLK2 harness was also performed. Upon removing the harness cable from the black conduit a visible fault, similar to that observed on the NGLK1 harness, was evident in the white jacketing just above the position of p-clip 2. The fault included a large transverse split in the white polymer jacket at the centre of the concave side of a permanent set bend in the cable, approximately 305 mm from the end of the sensor. The jacketing also displayed permanent set, suggesting it had been held at a tight angle. Both layers of protective woven metal braiding had failed and broken strands were exiting the split in the jacket. The fracture surfaces of the broken strands were flat, indicative of a fatigue failure mechanism. There were signs of localised corrosion on the outer six-stranded layer.

Beneath both layers of woven metal braiding, the two insulated conductors were found to be intact and displayed no macro evidence of failure, however they were not examined in the SEM.

ATP Testing of NGLK1 sensor

The NGLK1 sensor removed from G-JEDU was subjected to the standard Acceptance Test Procedures at the manufacturer's facility and no faults were found.

NGLK1 comparative testing by landing gear manufacturer

The landing gear manufacturer undertook testing on an example NLGLK1 sensor/harness assembly to simulate various fault conditions in the harness wiring while monitoring the reported sensor state, inductance and resistance. The testing confirmed that an intermittent open circuit in either the drive or the sense wire could cause an inductance increase and a momentary sensor state change from FAR to NEAR without isolating an inductance-based (FAR/NEAR) or resistance-based (OPEN/SHORT) fault. The intermittent open circuit was simulated by manually disconnecting and reconnecting the wire rapidly at an approximate 0.5 second interval.

A review of the nose landing gear control laws and logic determined that a state change on the NGLK1 sensor from FAR to NEAR without a fault being isolated, could cause unexpected premature closing of the forward NLG doors, before the NLG was fully retracted.

The landing gear manufacturer advised that filters are used in the system to provide fault tolerance to limited intermittent conditions (resistance) while still allowing sensitivity at the mechanical NEAR/FAR trip points (inductance). As a result, some intermittent failure conditions resulting from rapid changes in resistance might not be detectable prior to associated changes in inductance.

Extension/retraction videos

The aircraft manufacturer installed some video cameras in the NLG bay of a production Dash 8 Q400 and filmed the movement of the NGLK harnesses during landing gear extension and retraction. Analysis of the video footage showed that the drag strut, and hence p-clip 2 and the portions of both NGLK harness attached to the drag strut, rotate through approximately 90º during landing gear retraction and back during extension. A substantial amount of slack is evident in the harnesses between p-clip 2 and 3, and this portion flexes to a large radius as the nose landing gear is cycled through its positions. The movement includes a sudden jolt as the gear comes out of downlock and as it uplocks, due to the over-centre mechanism.

NGLK harness routing on G-JEDU

Further to the findings of the forensic examination, a retrospective review of photographs of the NGLK1 and NGLK2 harness routing on G-JEDU identified that both harnesses had been secured to neighbouring harnesses mounted on the sidewall of the NLG bay using a non-flexible cable tie (Figure 12).

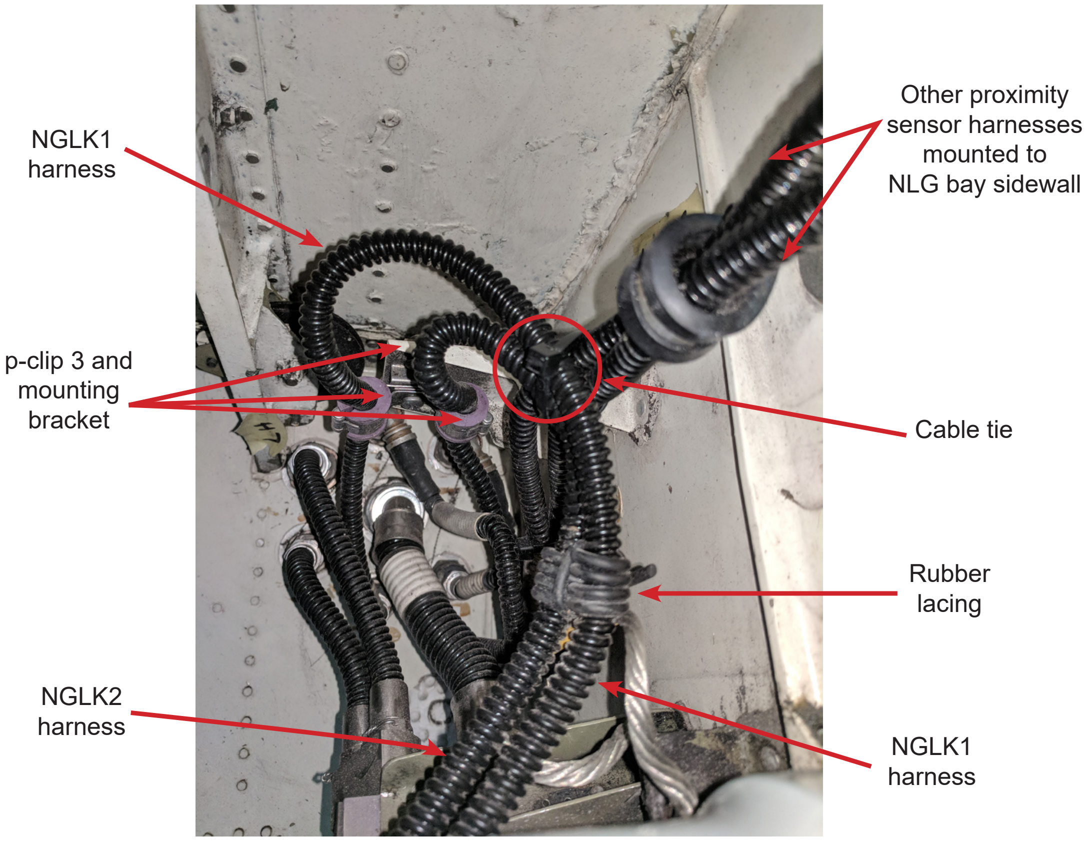

Figure 12

NGLK1 and 2 harness routing on G-JEDU, showing cable tie

Previous problems with NGLK harnesses

In the early 2000s, the aircraft manufacturer received reports of several Dash 8 Q400 operators removing large numbers of NGLK1 and 2 harness assemblies due to broken wires. Investigation at the time identified that the failures had resulted from excess stress developed at the second pclip on the drag strut, where the harness was being kinked, as the NLG rotated towards the up-and-locked position. Reported failures occurred between 3,900 and 5,000 flight cycles.

In 2003, the aircraft manufacturer introduced a modification[8] to revise the attachment method for the NGLK1 and 2 harnesses on the NLG drag strut by replacing the existing attachment bracket on the back of the drag strut. The new installation, introduced as a production change from aircraft serial number (S/N) 4088 onwards, relocated the NGLK1 and 2 harness attachment points approximately 1 cm inboard and 2 cm down from the original position, thus removing the extreme bend between p-clip 2 and 3 and allowing them to bend in a large natural radius. The S/N for G-JEDU is 4089 and it would have had this change embodied during production.

Footnote

[8] ISQ3200004 *'NLG Drag Strut – revised attachment installation of the NLG #1 and #2 down lock harness'*, first issued 12 Mar 2003, and subsequent revisions – currently at Rev F 19 Jan 2006.

The aircraft manufacturer advised that the landing gear proximity sensor harnesses are not tracked items and operators that experience problems tend to discard and replace the harnesses. From the data it did have available, the aircraft manufacturer conducted a history search for events relating to NGLK sensors between 2011 and 2018. It identified seven incidents where the NLG interfered with the forward doors during retraction, two of which were the events which occurred on G-JEDU on 1 and 10 November 2017. In all but one of the events the NGLK sensor harnesses were found to be at fault. In the remaining event, multiple components were replaced but the description of the event and the damage to the NLG forward doors were very similar to that experienced on G-JEDU.

NGLK harness installation - general

A review of the NLG installation drawings and associated Aircraft Maintenance Manual (AMM) tasks relating to the nose landing proximity sensors revealed several inconsistencies regarding the routing and installation requirements for the NGLK sensors. In one instance, an AMM illustration incorrectly showed the NGLK sensor harnesses crossing over each other on the back of the drag strut between p-clip 1 and 2.

As a result of these observations the aircraft manufacturer undertook the following actions:

- In October 2018, issued a Service Letter to inform Dash 8 Q400 operators of the correct routing of the nose landing gear lock (NGLK) sensor harnesses. The Service Letter emphasises that correct routing and retention, using rubber lacing, ensures no interference with surrounding harnesses and structure while maintaining freedom of movement during the retraction and extension. It refers to in-service occurrences where the sensor harnesses have been secured to neighbouring harnesses using cable ties, which have resulted restricted movement and subsequent damage to the harness conduit and the internal sensor wire, which can contribute to poor sensor operation. It includes photographs of correct versus incorrect installation.

- In November 2018, issued Service Bulletin 84-32-157 *'Landing gear – Nose landing gear – Drag strut – Special inspection and rectification – electrical harness re-routing'* to inspect the NGLK sensors for correct routing and signs of wear, abrasion or fretting.

- In January 2019, updated the following AMM tasks: 32-21-11-400-801 *'Installation of the NLG electrical harnesses'*, 32-21-06-400-801 *'Installation of the NLG drag strut'* and 32-21-06-000-801 *'Removal of the NLG drag strut'*. Amendments included clarifying the harness routing on the back of the drag strut, instructions for the location of the rubber lacing, addition of cautions indicating that the harnesses should not be retained or restricted at locations other than the specified p-clips and correcting a routing installation illustration.

G-JEDU aircraft maintenance history

Prior to the accident G-JEDU had accumulated 25,477 flight hours and 29,405 flight cycles. The most recent maintenance check had been a C-check in October 2017, but no work was done on the nose landing gear.

In October 2015, a nose landing gear 'Electrical Connector Care' maintenance work package was performed on G-JEDU. This included disconnecting all the NLG sensor harness electrical connectors at the bulkhead, cleaning and drying them, examination for and removal of corrosion, application of corrosion inhibitor and application of heat-shrink tubing to the connectors. No findings were reported on G-JEDU.

On 9 April 2016, a newly overhauled drag strut assembly was fitted to G-JEDU, at which point the aircraft had accumulated 22,286 flight hours and 25,991 flight cycles. New NGLK1 and NGLK2 sensor/harness assemblies had been fitted to the drag strut at overhaul.

In September 2016, the operator raised an internal Technical Order for removal of the heatshrink tubing on the NGLK1 and NGLK2 electrical connectors on all its Dash 8 Q400 aircraft, due to a concern that the heat-shrink tubing, previously-applied during the connector care programme, may be covering a drain hole on the electrical connectors and trapping water in the harness conduit and causing corrosion. The Technical Order noted that upon removal of the heat-shrink tubing, water might be seen to drip from the harness conduit. This task was accomplished on G-JEDU on 13 September 2016; no water was observed to drip from the harness conduit.

A review of defects between April 2016 and November 2017 did not identify any other defects or entries relating to the NGLK1 sensor or harness.

Failure Mode and Effects Criticality Analysis

The Failure Mode and Effects Criticality Analysis (FMECA) for the Dash 8 Q400 proximity sensing system, conducted as part of the aircraft certification process, identified seven potential failure modes for the NGLK sensors, all of which had a severity classification of 'minor'. These included electrical faults (internal open or short circuit), mechanical faults and inductance drift of the sensors. For each of these faults the documented 'system effect' indicated that the PSEU would identify that the sensor was faulted and refer to the remaining valid sensor, such that the nose landing gear would safely extend or retract. The FMECA did not identify any failure modes relating to erroneous intermittent change of state of the NGLK sensors which did not meet the threshold for the sensor to be flagged as faulted.

Following this accident, the landing gear manufacturer undertook to produce a revised FMECA for all landing gear proximity sensors based on the failure modes identified in this investigation. For the NGLK sensors this resulted in the new failure modes *'NGLK1/2 indicating intermittent NEAR while gear in transit'* being identified for the extension and retraction case. For the retraction case the 'effects of failure' included *'NGLK* [1 or 2] *indicates intermittent near, NLG SSV de-energised intermittently, NLG doors may not completely close'* with the 'end effect' being *'Potential collision between NLG and forward* *doors.'* However, this accident showed that the plausible end effect is failure of NLG to extend following a collision between the NLG and forward doors.

At the time of publication of this report, the revised failure modes had not been fully evaluated. The Functional Hazard Analysis (FHA) for the Dash 8 Q400 landing gear system categorises failure of the NLG to extend as having a severity classification of 'major'[9], so the severity classification of the revised failure modes will not be greater than 'major'.

Proximity sensor harness redesign activity

The aircraft and landing gear manufacturers are aware of other instances of NGLK sensor harness failures in normal operation. During normal retraction, extension and steering operations, the NGLK harnesses are subject to dynamic movement and bending which can result in degradation and breakage of the internal wires. The landing gear manufacturer initiated a product improvement review of the proximity sensor harness with the aim of improving the performance of the landing gear system. The need for this activity was identified prior to the G-JEDU accident, but it has been informed by the findings of this investigation. This activity included a detailed review of harness failures for all proximity sensors throughout the Dash 8 Q400 aircraft, which identified harness stiffness/inflexibility, due to its construction, as a possible cause of failure.

As a result of its findings, the landing gear manufacturer initiated a redesign activity to improve the robustness of the existing harness construction. The current proximity sensor harness is comprised of a double-shielded twisted pair of wires within a convoluted conduit. A new, more robust, high-flex sensor wire, coupled with a more rigid, yet still flexible, conduit design is being explored. This aims to provide further protection for the sensor and wire from damage due to repetitive dynamic movement and external environmental conditions.

In August 2018, the landing gear manufacturer submitted a preliminary design concept to the aircraft manufacturer for review. The implementation plan and project schedule for the new harness will be developed following finalisation of the design concept, which is expected in the first half of 2019.

Operator fleet inspections

As a result of the findings of this investigation, throughout August and September 2018 the operator carried out an inspection of the NLGLK harness routing on the remainder of its Dash 8 Q400 fleet. Minor routing anomalies were noted and rectified on a number of aircraft; the most common finding was the absence of the rubber lacing. Other findings included the use of a cable tie in place of rubber lacing, incorrect p-clips and in one case, a damaged NGLK2 harness.

One of the operator's aircraft experienced a slow landing gear retraction on the third sector after this inspection had been performed. The flight crew reported *'Undercarriage failed to retract for considerable time'*. The routing and security of the harnesses had been found to

Footnote

[9] The FHA describes four levels of severity classification: minor, major, hazardous and catastrophic.

be correct, but the position of the harnesses had been disturbed to facilitate inspection. A review of flight data showed that, following the gear-up command, the landing gear came out of down lock and the retraction commenced but then stalled. The NLG dropped down under gravity and the retraction re-started and completed successfully. The operator considered that the only difference between that incident and the G-JEDU accident was the timing at which the retraction stalled; and therefore, contact between the NLG and NLG door did not occur. The operator replaced the landing gear selector valve, PSEU and both NGLK harnesses and conducted function tests before releasing the aircraft back into service. No detailed examination of the removed NGLK harnesses was undertaken.

Analysis

Operational aspects

After the landing gear retraction, the crew were aware that there was a problem with the nose landing gear. They immediately ensured that they did not exceed the gear limiting speed of 185 kt and decided to enter the hold to assess and deal with the problem. They followed the actions set out in the abnormal checklists but were unable to obtain the nose landing gear down-and-locked indication.

They decided to divert to Belfast International Airport as it had a long runway which was aligned with the surface wind of 250º at 12 kt. A fuel calculation was carried out and it was decided to minimise the fuel on landing and that the aircraft would remain in the hold until 1,100 kg of fuel remained. During the time in the hold, they followed the checklists three times to ensure nothing had been missed.

The commander agreed the plan and actions to be taken with the co-pilot and that he would fly the aircraft for the approach and landing. He briefed the SCCM and the passengers on the situation and the cabin crew prepared the passengers for the landing and played them the pre-recorded tape for an emergency landing.

The crew had a clear plan and enough fuel for a go-around and a second approach if required. The final approach was normal and at 4 nm from touchdown ATC advised them that the nose landing gear was not extended. Their plan had allowed for this and they continued their approach touching down at the normal touchdown point and gently lowering the nose onto the runway. When the aircraft came to a stop, the engines were shut down and the propellers stopped. The evacuation was carried out in an orderly manner and resulted in only two minor injuries to those onboard. The only delay was at the rear doors where passengers were concerned about the drop to the ground due to the aircraft's nose-down attitude.

The crew reported smoke and a burning smell in the flight deck after the aircraft had come to a stop. The exact source was not determined during the aircraft examination however, it was considered likely to have resulted from the abrasion of the lower fuselage structure with the runway surface, during the later stages of the landing roll.

Examination of the aircraft

Following the accident, the nose landing gear was found to be retracted but not uplocked. It was off-centre, having rotated about the shock strut axis and the right tyre was jammed against the sidewall of the NLG bay, preventing the gear from extending. Ground marks and damage to the aircraft indicated that the forward NLG doors had been open at landing.

It was determined that the flight crew had followed all relevant procedures but the way the nose landing gear was jammed meant that the landing gear alternate extension procedures would not have been effective in lowering the NLG. Due to the position of the NLG, it is believed that as the pilot continued pulling the nose gear alternate release handle, the kicker arm was able to pass the pivot tube. This theory could explain why the nose landing gear alternate release cable did not rewind onto its spool. Following the accident, considerable force was required to release and re-centre the NLG before it was free to extend under gravity.

Both NLG tyres and forward doors exhibited evidence of having contacted each other. The position and shape of the mechanical damage on the seal-retaining strip indicated that it had likely been caused by contact with the NLG tow spigot. Retraction logic prevents retraction commencing unless the nosewheel is correctly centred, so it was determined that the nose landing gear rotated off-centre after retraction commenced, most probably as a result of contacting the forward NLG doors.

A review of flight data showed that G-JEDU had experienced several slower than normal nose landing gear retractions prior to the accident on 10 November 2017. One of these was related to an incident on 1 November 2017 when the landing gear failed to retract. Subsequent inspection identified damage to the lower edge of the forward right NLG door and the door seal. Although not identified at the time, it is considered likely this damage was a result of the NLG tyres contacting the forward doors during retraction. Troubleshooting following that incident did not identify the cause, but the forward right NLG door and the NLG door actuator were replaced.

Post-accident testing

In normal landing gear operation, the NGLK1 and 2 proximity sensors are in the NEAR state when the nose landing gear is in either the uplocked or downlocked position, and in the FAR state when the gear is in transit. Post-accident testing identified a condition where an erroneous state change of the NGLK1 proximity sensor from FAR to NEAR while the gear was in transit could cause an unexpected output to the retract selector valve and the nose landing gear door sequence valve, interrupting the retraction sequence. When this occurred the forward NLG doors closed prematurely causing the gear to stall mid-retraction and the retraction would only recommence when the system logic conditions required for retraction were met.

The erroneous sensor state change was evidenced by an inductance spike on the PSEU, which although sufficient for the PSEU to detect a state change, was not high enough for the PSEU to flag the sensor as faulted.

This condition was consistently repeated during testing but occurred only intermittently and not on every retraction. There was variation in the timing at which the sensor state change occurred, its duration and the angle at which the gear stalled but it was evident during some retractions that interference between the NLG tyres and forward doors would have occurred, if the doors had been fitted. Flexing of the NGLK1 harness along its length while monitoring the displayed inductance values identified the possibility of mechanical damage in the harness, and this was subsequently confirmed by a CT scan.

Laboratory examination

Forensic examination of the NGLK1 and 2 harnesses identified that that the white polymer jacketing on both cables had failed on the concave side of a permanent set bend, just above the position of the shared p-clip 2, which attaches both harness to the drag strut. In both cases the shape of the failure suggested that the cables had been forced into and held in a tight bend with small radius.

The two layers of woven metal braiding had failed at the fault location in both harnesses. The fracture surfaces of the individual failed strands were observed to be normal to their own axis suggesting a fatigue failure mechanism. Higher magnification SEM examination of the fracture surfaces on the failed braiding strands from NGLK1 revealed fatigue striations, consistent with a cyclically-driven fatigue propagation failure mechanism. Striation spacing indicated that it would have taken at least 330 loading cycles to fail a single strand of braiding. The aircraft had completed 3,414 flight cycles since the NGLK1 and 2 harnesses were installed. The multiple landing gear retractions conducted during post-accident testing would also have contributed to the loading cycles on the harnesses.

Beneath the woven metal braiding of NGLK2, both insulated conductors were found intact and did not display any macro-indications of failure.

Beneath the woven metal braiding of NGLK1, one of the multi-stranded conductors (white with blue stripe) exhibited a complete through-thickness bulk fracture, including the two layers of insulation, as well as multiple transverse fractures on individual wire strands either side of the bulk fracture. As the conductor was still largely retained within its insulation, it was apparent that an electrical path could still have existed across the bulk fracture, bridged by short lengths of wire strands. The second conductor (plain white) displayed many transverse fractures on individual wire strands, predominantly on the concave side of the bend and although the failure had not progressed to a bulk fracture, it was on the way to creating one. The fracture surfaces from the bulk fracture on the blue-striped wire, and those on individual wire strands from both conductors, displayed flat transverse fractures that were typical of fatigue that propagated away from sites of fretting. The fretting marks suggested relative movement between wire strands, which would be expected on a multi-stranded wire under cyclic loading. The presence of cyclic loading was confirmed by evidence of fatigue striations on the failed braiding strands from NGLK1. Fretting would have produced a local stress-raiser from which fatigue initiated.

NGLK harness routing on G-JEDU

A retrospective review of the harness installation on G-JEDU identified that a non-flexible cable tie had been used to secure the NGLK1 and 2 harnesses to some adjacent non-moving harnesses mounted on the sidewall of the NLG bay, between p-clip 2 and 3.

Examination of video footage taken within the NLG bay of a production aircraft demonstrated the extent to which correctly-routed NGLK1 and 2 harnesses are required to flex between the p-clip 2 and 3 positions, in order to accommodate movement of the NLG during retraction and extension. The permanent set bend just above the p-clip 2 position displayed by the NGLK1 and 2 harnesses from G-JEDU, indicated that they had been restricted from flexing. In addition, the sharp bend-radius observed at the airframe connector on the NGLK1 harness indicated that there was no slack between p-clip 3 and the connector.

It was concluded that the cable tie had the effect of creating an artificial constraint, restricting the freedom of movement of the NGLK1 and 2 harnesses between p-clip 2 and p-clip 3. This removed slack in the harnesses that would otherwise have absorbed the flex associated with normal landing gear operation. In this condition, normal operational of the landing gear would have produced the loading cycles sufficient to create a fatigue-driven failure mechanism in the harnesses.

The drag strut had been replaced on G-JEDU in April 2016 and since then there had been a number of maintenance interventions associated with the nose landing gear proximity sensors. Consequently, it was not possible to identify when or by whom the cable tie had been fitted to the NGLK1 & 2 harnesses.

As a result of the findings of this investigation, the operator undertook an inspection of its Dash 8 Q400 fleet to determine if a similar installation existed. A number of minor routing anomalies were found including the absence of rubber lacing, incorrect p-clips and a damaged NGLK2 harness. In some cases, a cable tie was found to have been used in place of rubber lacing to secure the NGLK1 and 2 harnesses to each other, although not to adjacent harnesses, as in the case G-JEDU.

While carrying out the inspection the operator identified an inconsistency between two AMM drawings regarding the harness routing; these have subsequently been amended.

Accident scenario (effect of failure)

During landing gear retraction, a NEAR signal from the NGLK sensors is the only thing that confirms when the nose landing gear is successfully retracted and uplocked. In the case of a faulty sensor, the retraction logic must rely on the remaining good sensor to ensure that the NLG doors do not stay open after the NLG is uplocked.

Based on evidence from examination of the aircraft and observations from on-aircraft testing and comparative testing to simulate an intermittent NGLK1 fault, the following scenario describes the sequence of events during the accident.

Following the command to retract the landing gear, the NGLK1 and 2 and NGDN1 and 2 sensors became FAR as the NLG came out of downlock and commenced retracting. Shortly after this, the NGLK1 sensor briefly, and erroneously, transitioned from FAR to NEAR but the resulting inductance was not sufficiently high for the PSEU to flag the sensor as faulted. Since the state change on the NGLK1 sensor from FAR to NEAR was intermittent during 'gear in transit' mode, a reasonableness fault was not reported or logged.

The PSEU sensed the erroneous NEAR status of NGLK1, but as the sensor had not been faulted, it considered this a valid indication that the gear was uplocked. The initial effect of the NGLK1 sensor going FAR to NEAR was to de-energise the nose landing gear selector valve. When this happened the forward NLG doors started to close.

If the NLG doors had closed fully before NGLK1 transitioned back to FAR the NRDCL sensor would have sent a NEAR signal to the PSEU, de-energising the retract selector valve and removing pressure from the landing gear retraction-extension hydraulic circuit, so the doors could no longer move.

When the NGLK1 signal transitioned back to FAR, the nose landing gear door selector valve would have become energised once more, putting it in a state to open the doors once the retract selector valve became energised. The NLG would have extended slowly, hydraulic fluid bleeding off through the inline restrictors, until when almost fully extended (NGDN1 and 2 became NEAR), the retract selector valve output from the PSEU once again became active, opening the NLG doors and allowing retraction to recommence.

At some point during the sequence where the NLG doors closed as the NLG was still in transit to the up position, contact was made between the doors and the NLG tyres, either during door closing, or when they began re-opening. Testing showed that the timing of this sequence of events can vary due to system tolerances and when the NGLK1 sensor transitions from far to near and then back to far. Contact with the doors caused the NLG to become off-centred, however although the NWCENT signal would have been lost at this point, a three-second delay in the logic meant that the NLG achieved the up-and-locked position.

If NLG doors had not closed fully before NGLK1 transitioned back to FAR then the NLG doors would have reopened immediately, allowing the NLG to continue retracting after only a short interruption. This is likely to have been the case in some of the slow retraction events experienced by G-JEDU prior to the accident.

Failure modes

Prior to this accident the failure mode of a sensor providing erroneous state information, but below the threshold at which it would declare itself faulted, had not previously been identified. Although the system design includes redundancy within the NGLK sensors, the nature of this failure mode meant that a single-point failure prevented extension of the nose landing gear. Due to the intermittent nature of the fault, maintenance troubleshooting after an incident may not identify the problem. Although the FMECA for the landing gear proximity sensors was revised following the accident to include this new failure mode, it has not resulted in changes to the documented aircraft-level effects or the associated landing gear extension/retraction logic.

The landing gear manufacturer advised that filters used in the system provide fault tolerance to limited intermittent conditions while still allowing sensitivity to detect sensor state changes, but as a result, some intermittent failure conditions resulting from rapid changes in resistance may not be detectable prior to associated changes in inductance.

Subsequent incident

Another of the operator's aircraft experienced a slow landing gear retraction incident some months after the G-JEDU accident. A review of the flight data indicated that that incident was similar to the G-JEDU event in many respects, except the timing of the stalled NLG retraction was such that contact between the NLG and NLG door did not occur, and ultimately the NLG achieved successful retraction. A number of components, including both NGLK harnesses were replaced but as a detailed examination of the removed NGLK harnesses was not undertaken, it was not determined whether mechanical damage to one of the harnesses could have been a factor.

Proximity sensor harnesses failures

Although the use of an unapproved cable tie contributed to the failure of the NGLK1 sensor harness on G-JEDU, the aircraft and landing gear manufacturers are aware of other instances of NGLK sensor harness failures. During normal retraction, extension and steering operations, harnesses are subject to dynamic movement and bending which can result in degradation and breakage of the internal wires. Following a review of harness failures for all proximity sensors throughout the Dash 8 Q400, the landing gear manufacturer initiated a harness redesign to address the effects of repetitive bending and other environmental effects. The new design being explored will incorporate a more flexible sensor wire along with a more rigid conduit. Although initiated prior to the G-JEDU accident as a product improvement activity, this ongoing redesign work removes the need for any Safety Recommendations relating to harness design.

Conclusion

The investigation concluded that mechanical damage within the electrical harness of the primary 'nose gear lock' proximity sensor caused an intermittent and erroneous sensor state change during landing gear retraction. The measured inductance value associated with the sensor state change was not sufficiently high for the sensor to be flagged as faulted, and the erroneous state change was therefore considered valid. This had the effect of interrupting the NLG retraction sequence by causing the forward NLG doors to close prematurely while the NLG was still retracting, such that the tyres came into contact with the doors. When the NLG finally retracted, the tyres became jammed in the NLG bay, preventing it from extending when subsequently commanded. The flight crew followed the appropriate procedures for dealing with the incident, which led to the safe landing and evacuation.

Prior to this accident, the failure mode of an erroneous sensor state change below the threshold at which the sensor would declare itself faulted, had not previously been identified.

The investigation determined that the harness had been secured by a non-flexible cable tie, which restricted it from flexing during normal operation of the nose landing gear. This created loading cycles sufficient to create a cyclically-driven fatigue failure mechanism in the two conductor wires within the harness.

The aircraft manufacturer has taken action to clarify nose landing gear proximity harness routing and attachment instructions in relevant AMM tasks, and has published inspection requirements. The aircraft and landing gear manufacturers are working to identify a more flexible harness design.

Safety action

The following safety actions have been taken:

The aircraft manufacturer has:

- In October 2018, issued a Service Letter to inform operators of the Dash 8 Q400, of the correct routing of the nose landing gear lock (NGLK) sensor harnesses.
- In November 2018, issued Service Bulletin 84-32-157 to inspect the NGLK sensors for correct routing and signs of wear, abrasion or fretting.
- In January 2019, updated three AMM tasks in order to clarify the harness routing, provide instructions for the location of the rubber lacing, to add cautions indicating that harnesses should not be retained or restricted at locations other than the specified p-clips and to correct a routing installation illustration.

Throughout August and September 2018, the operator carried out an inspection of the nose landing gear proximity sensor harness routing on its Dash 8 Q400 fleet and undertook rectification of any anomalies noted.

Published: 16 May 2019.

AAIB Correspondence Reports

These are reports on accidents and incidents which were not subject to a Field Investigation.

They are wholly, or largely, based on information provided by the aircraft commander in an Aircraft Accident Report Form (AARF) and in some cases additional information from other sources.

The accuracy of the information provided cannot be assured.

SERIOUS INCIDENT

Aircraft Type and Registration:	Airbus A319 OE-LQE
No & Type of Engines:	2 CFM56-5B5-3 turbofan engines
Year of Manufacture:	2010
Date & Time (UTC):	30 September 2018 at 0540 hrs
Location:	London Gatwick Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 144
Injuries:	Crew - None Passengers - None
Nature of Damage:	None reported
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	44 years
Commander's Flying Experience:	10,908 hours (of which 8,156 were on type) Last 90 days - 203 hours Last 28 days - 65 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and the Operator's safety investigation report

Synopsis

The flight crew made an undetected error during the transposition of aircraft loading data from a paper form into their loadsheet calculation software application. As a result, the calculated aircraft all-up-weight (AUW) was 1,962 kg lighter than the actual aircraft weight. This incorrect AUW was used as the basis for takeoff performance calculations. The aircraft took off without difficulty and the flight crew reported the incident upon arrival at their destination. As a result, the airline conducted its own safety investigation into the circumstances and planned to review the way it used its Electronic Flight Bags.

History of the flight

As part of the cockpit preparation process, Pilot Monitoring (PM) was responsible for generating the aircraft loadsheet using his Electronic Flight Bag (EFB). He used the application's 'Detailed' mode to input passenger and cargo data from the Loading Form Certificate (LFC) (Figure 1) compiled by the Handling Agent. Pilot Flying (PF) later reviewed PM's data entries. A cross-check of the loadsheet output revealed approximately two tonnes discrepancy between the calculated Zero Fuel Weight (ZFW) and the flight plan's estimated ZFW. With such a significant difference, the crew re-checked their working but could not find any obvious errors and so used the existing loadsheet for their takeoff calculations.

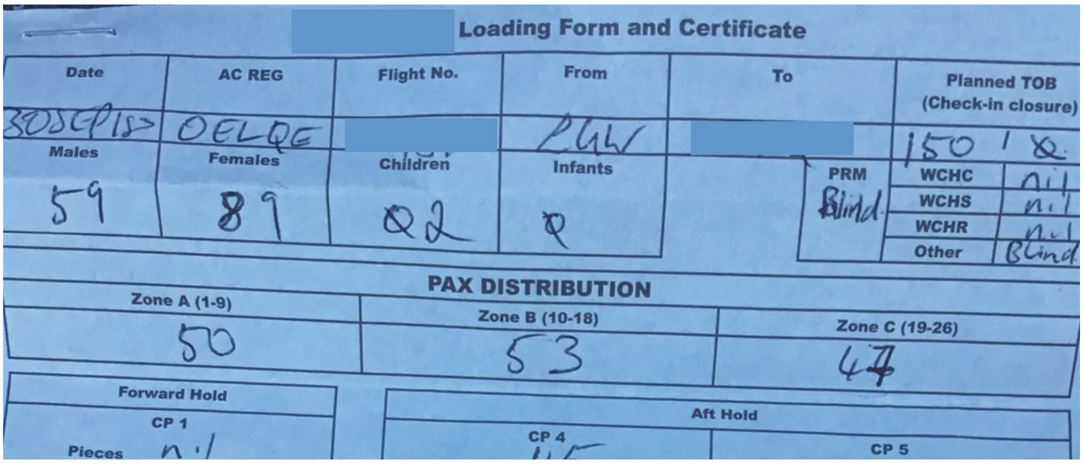

Figure 1

Loading Form Certificate passenger data boxes

Prior to departure, the Handling Agent notified the crew of a Last-Minute Change (LMC) to passenger and cargo numbers. The crew used the application's 'Reduced' mode to update the loadsheet to reflect the change, which reduced the calculated AUW by 384 kg. The new loadsheet did not invalidate the crew's previous takeoff calculations, which were already loaded into the aircraft's flight management system.

Having not fully resolved the ZFW discrepancy, the crew discussed the anomaly while at the runway Holding Point. The takeoff calculations had specified a reduced-thrust departure. The crew resolved that if they had any concerns regarding aircraft performance during the takeoff they would select TOGA thrust (see Aircraft Information paragraph below). The crew based their decision on the fact that the LMC reduced the AUW, and there was a '*central* [CG] *position and excess performance at* [Gatwick]'. The subsequent departure was uneventful.

Once established in the cruise, the crew re-checked their loading calculations. They discovered that the Males, Females and Children data fields in the loadsheet application had been incorrectly populated. They contained the passenger cabin zone distribution figures (Figure 2) rather than the correct gender/age data (Figure 3). The resulting incorrect gender/age profile meant that the total passenger weight was underestimated by 1,962 kg. The flight continued to destination without further incident, whereupon the commander reported the loadsheet error to the Company Duty Pilot.

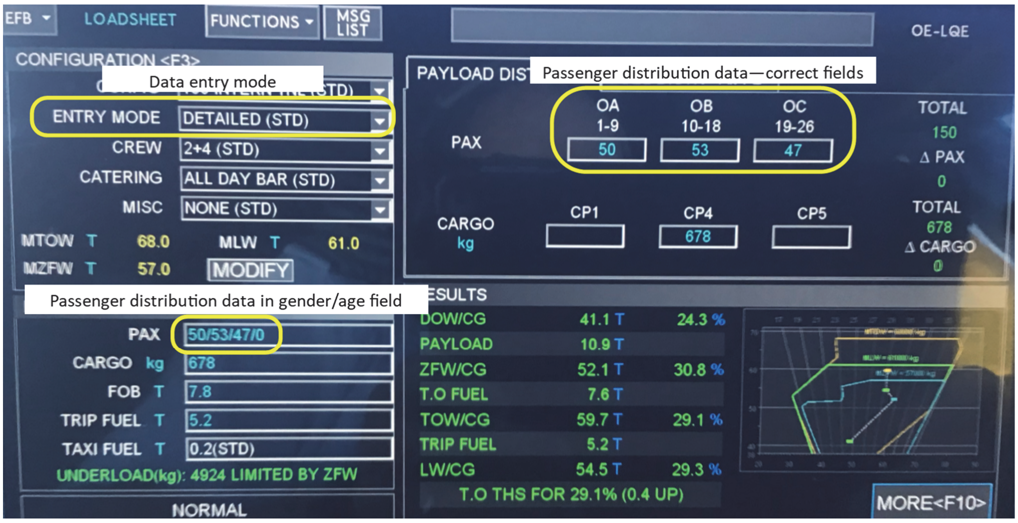

Figure 2

Software screenshot with passenger distribution data in gender/age data box

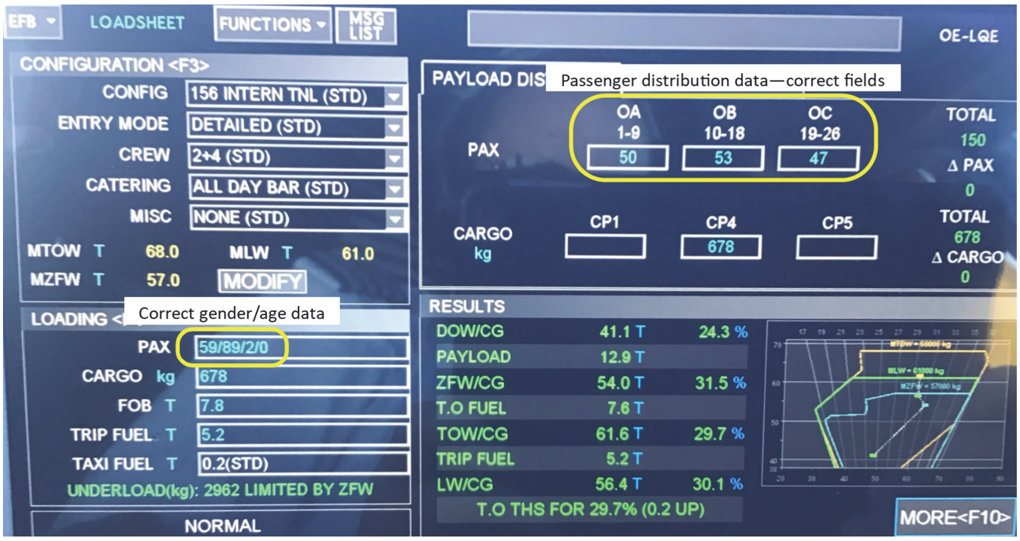

Figure 3

Software screenshot with correct gender/age data as per the LFC

Aircraft information

The Airbus A320 family of aircraft uses software to optimise takeoff parameters. Amongst other outputs, the software application calculates whether full-thrust is required for takeoff or whether it is possible to safely depart with a reduced setting. Reduced thrust departures are the norm for many commercial flights. The application uses an output parameter called the Flex Temperature (FT) to indicate to the pilots that a reduced thrust, 'Flex', takeoff is possible. The FT parameter is entered into the aircraft's flight management computer, which limits takeoff thrust when the thrust levers are advanced to the 'FLX/MCT' detent. Pilots can override the limit by pushing the thrust levers fully forwards to the Takeoff/Go-Around (TOGA) position, whereupon maximum engine thrust is commanded. The maximum allowable thrust reduction for a Flex takeoff is 25%.

Weight and balance

A loadsheet is the commander's legal proof that the aircraft has been loaded correctly. The document must demonstrate that the aircraft will remain within the prescribed CG and weight limits throughout the proposed flight. The application uses known aircraft parameters and variable load data, such as passenger and baggage quantities, when generating a loadsheet. Rather than requiring each passenger and bag to be individually weighed, regulations allow for the use of assumed weights for males, females, children, adults and checked baggage. The application uses these standard weights to calculate the aircraft's payload. If the passenger gender/age profile inputs are incorrect, the loadsheet outputs will be wrong. This is not an error that would be detected by routine flight data monitoring processes.

The Company's investigation noted that the design of the LFC and software application may have contributed to the initial data-entry error. Their report stated:

> *'Inspection of the LFC and EFB formats used for the W&B Data Insertion revealed that the layouts and labelling are not comparable, and do not, therefore support the user in this* [data entry] *task…'*

The crew commented that once they had entered Reduced mode to input LMC data, the passenger gender/age profile information was no longer visible (Figure 4). The commander considered that this was not helpful when trying to find the reason for the ZFW anomaly.

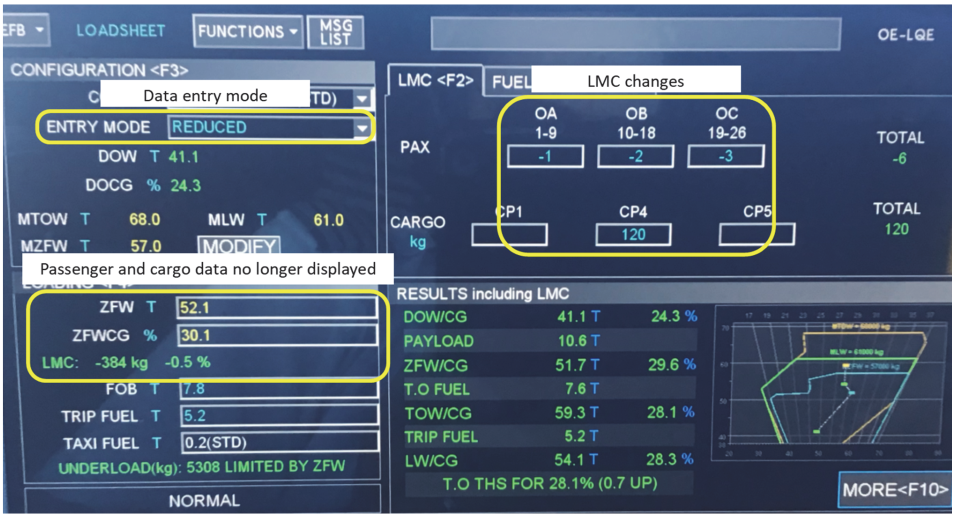

Figure 4

Loadsheet app in Reduced mode

Aircraft performance

The takeoff performance application takes loadsheet AUW and CG data and calculates the optimum takeoff speeds and thrust setting for the runway in use and the reported weather conditions. Correctly calculated takeoff parameters play an important role in the safety assurance for normal and rejected takeoff situations, as well as for safe obstacle clearance on departure and acceptable one-engine inoperative performance. If the pilot-entered data is in error, the takeoff performance optimisation process will produce an invalid output, potentially impacting safety.

Human factors

The AAIB Formal report[1] into a serious incident, where a Boeing 737 (C-FWGH) took off with excessively reduced thrust, contains relevant lessons which can be read across to this event. Specifically, at Appendix B to the Report[2], a Human Factors expert discussed the challenges of cross-checking data entry in electronic systems and detecting abnormal aircraft acceleration.

Regarding identifying data entry errors in electronic systems, the report stated:

> *'The system feedback in relation to the error was quite opaque. Once the FMC page was changed the input was not visible…Once the initial error was made, failure to notice it was predictable and within normal human performance…'*

The parallels with this investigation are that the initial error was incorrect data entry and that, in Reduced mode, the application removed the erroneous data from view.

The pilots' stated intention was to select TOGA thrust if they perceived any performance-related problems during the departure. In the C-FWGH incident, takeoff thrust was inadvertently reduced to 60% of the maximum available, but the report concluded that even at such a low level of thrust the pilots could not be expected to reliably detect the resultant, abnormally low acceleration:

> *'Pilots experience different accelerations on almost every flight due to different runway lengths, loadings and weather, and so do not become accustomed to perceiving a single specific acceleration…it can be confidently concluded that direct vestibular and/or visual acceleration cues would not have alerted a crew to the abnormally low acceleration…'*

The C-FWGH report contained four Safety Recommendations, two of which were aimed at promoting the development of aircraft Takeoff Acceleration Monitoring Systems (TAMS). The intent was that TAMS would automatically detect and alert pilots to abnormally low aircraft acceleration during takeoff.

Organisational information

The Airline's Standard Operating Procedure (SOP) is to use a single EFB to generate the loadsheet. PF and PM transpose calculated loadsheet data into their individual EFBs and

Footnote

1 https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-2-2018-c-fwgh-21july-2017 accessed 11 February 2019.

2 AAIB-commissioned report by Dr Steve Jarvis, "*Human Factors Report for serious incident to Boeing 737-86J, C-FWGH, Belfast, 21st July 2017*".

independently calculate takeoff performance before cross-checking their outputs. The AAIB is aware of at least three different operators who mandate independent calculation of loadsheet as well as takeoff performance data. Independent calculations can be a barrier against incorrect data entry leading to undetected errors but can add to pilot workload.

The Airline had planned an upgrade to their EFB systems in 2019. As part of that project they intended to conduct a thorough review of EFB SOPs and to investigate the potential for automatic data transfer from ground-based load control systems. Recommendations arising from related incidents and outcomes from the Company's participation in a UK CAA-led industry workshop review of EFB SOPs would help inform the process.

Analysis

This serious incident resulted from the error of inputting incorrect data into three fields on the loadsheet application. Once the mistake had been made, human performance limitations reduced the likelihood that the slip would be detected. The crew noticed a ZFW anomaly, but despite looking for an error they could not find one. The lack of commonality between LFC and EFB formats was considered by the operator to be an exacerbating factor, as was the lack of gender/age profile information in the loadsheet application's Reduced mode.

The undetected error led to the departure being flown with incorrect takeoff performance parameters. The crew's decision to use TOGA thrust if they had any performance concerns during takeoff might not have been a reliable risk control because the C-FWGH incident showed that pilots are unlikely to perceive when extra thrust is required.

The C-FWGH report highlighted the challenges of finding data entry errors and the limited ability of pilots to detect abnormally low aircraft acceleration. Procedural barriers, such as parallel EFB calculations, attempt to reduce the likelihood that these types of error occur. Technical barriers to capture the errors once made are still in their infancy.

Conclusion

A data entry error led to an aircraft taking off using incorrect takeoff parameters. The crew noted an anomaly but could not detect an associated error. They continued with a reduced thrust takeoff, agreeing to use TOGA thrust if they had concerns about aircraft performance during the takeoff. Experience has shown, however, that pilots often do not notice the low acceleration associated with insufficient takeoff thrust.

SERIOUS INCIDENT

Aircraft Type and Registration:	Bell 429, M-YMCM
No & Type of Engines:	2 Pratt & Whitney 207D turboshaft engines
Year of Manufacture:	2012
Date & Time (UTC):	25 November 2018 at 1518 hrs
Location:	On approach to Edinburgh Airport
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - 1 (Minor)
Nature of Damage:	Left windshield shattered and damage to interior trim
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	52 years
Commander's Flying Experience:	3,900 hours (of which 800 were on type) Last 90 days - 66 hours Last 28 days - 24 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Whilst on short final to Edinburgh Airport, at approximately 100 kt, the helicopter suffered a bird strike to the left windscreen. The windscreen shattered and debris entered the cockpit, injuring the occupant in the left seat, who required hospital treatment.

The Bell 429 windscreen is not designed to withstand bird strikes and the design certification requirements do not require it to do so. A recent study by the Rotorcraft Bird Strike Working Group has recommended the introduction of bird strike protection requirements for Normal category rotorcraft to minimise the risk of damage or injury.

History of the flight

The helicopter was flying from Blackpool to Edinburgh. It was being flown from the right seat and the left seat was occupied by a passenger, who was also a qualified Bell 429 pilot. Whilst on short final for landing, at a speed of approximately 100 kt, the pilot noticed several birds off the left side of the helicopter. These were not considered to present a threat but he then saw a single bird straight ahead, crossing from right to left. He immediately banked the helicopter to the right but was unable to avoid the bird, which struck the left windscreen. The windscreen shattered and the passenger sustained injuries to his face and hands.

The pilot declared a MAYDAY before successfully landing and the passenger was taken to hospital.

Examination of the helicopter

The left windscreen had shattered and remnants of the acrylic material were found throughout the cockpit and passenger area (Figure 1).

Figure 1
Left windscreen damage

The bird was killed in the impact and was found inside the passenger area. It was identified as a wood pigeon, weighing approximately 640g.

The helicopter manufacturer reviewed photographs of the damaged windscreen and its broken fragments. They concluded: '*that the outcome, based on the size of bird and airspeed, is what was expected and in line with previous events*'.

Helicopter bird strike certification requirements

Normal category rotorcraft

Canadian Airworthiness Manual Chapter 527 defines the specification requirements for Normal category rotorcraft. This includes helicopters with maximum weights of 7,000 lb (3,175 kg) and up to nine passenger seats. The specification does not define any requirements relating to bird strike resistance, but there is a requirement that '*windshields and windows must be made of material that will not break into dangerous fragments*'.

The equivalent design requirements in Europe and the United States of America are CS-27 and FAR-27, respectively. Both these specifications define the same requirements as the Canadian Airworthiness Manual.

Transport category rotorcraft

Canadian Airworthiness Manual Chapter 529 defines the specification requirements for Transport category rotorcraft. This includes helicopters with maximum weights exceeding 7,000 lb (3,175 kg) or more than nine passenger seats. The equivalent design specifications in Europe and the USA are CS-29 and FAR-29, respectively.

All three specifications define a bird strike requirement of 1 kg.

Bell 429

The Bell 429 is certified to the requirements of Canadian Airworthiness Manual Chapter 527 and has no demonstrated bird strike protection.

M-YMCM was equipped with the stretched acrylic windscreens, which the manufacturer indicates offers additional protection over standard acrylic windscreens. Stronger, Polycarbonate windscreens are available as an option.

Previous bird strike incidents

The AAIB has issued three previous reports after similar events on helicopters certified to the Normal rotorcraft category requirements: N109TK (AAIB Bulletin 3/2012), G-ODAZ (AAIB Bulletin 6/2014) and G-BZBO (AAIB Bulletin 11/2016).

Previous safety actions

In November 2010, the National Transportation Safety Board (NTSB) wrote to the Federal Aviation Administration (FAA) with Safety Recommendations following an investigation of a Sikorsky S-76C bird strike accident that resulted in eight fatalities. The S-76C is certified to FAA Part 29, which includes a 1 kg bird strike protection requirement. Acknowledging that Part 27 does not define bird strike protection requirements, the NTSB recommended that it should be amended to include such a requirement.

The FAA assigned the Aviation Rulemaking Advisory Committee (ARAC) the task of providing recommendations regarding bird strike protection rulemaking, policy, and guidance for Normal category rotorcraft, to evaluate existing bird strike protection standards for Transport category rotorcraft, and to provide recommendations for enhancement. In response, the ARAC established a Rotorcraft Bird Strike Working Group.

Rotorcraft bird strike working group

The working group included representatives from aviation regulators and several helicopter manufacturers, including Bell. The group issued a final report in November 2017, which is available from the FAA website[1].

Footnote

[1] Rotorcraft Bird Strike Working Group Recommendations to the Aviation Rulemaking Advisory Committee (ARAC), dated 10 November 2017. [Accessed 28 February 2019] https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/ARAC%20RBSWG%20Final%20Report.pdf [Accessed 28 February 2019]

The working group made several recommendations relating to policy and guidance, both for helicopters already in service and for those requiring new certification.

For newly certificated Normal category rotorcraft, the working group recommended the introduction of a 1 kg bird strike protection requirement. For Normal category rotorcraft already in service, and for newly manufactured aircraft, the working group encouraged operators to implement bird strike safety procedures. These include:

> *Reduce airspeed when practical.* *Training should remind flight crews that more than 3 out of 4 bird strikes (77%) occur during airspeeds greater than 80 knots. No bird strikes have been reported in the NWSD below 55 knots. Therefore, if flight operations allow slower airspeeds in areas known to have a high-density bird population, reduce the airspeed to 80 knots or less, particularly at lower altitudes.*
>
> *Increase altitude as soon as possible and practical, when allowed by other flight variables. Rotorcraft operators should be reminded that there is a 32% decrease of bird strike likelihood with every 1,000 ft gained above 500 ft AGL and that 93% of all strikes occur below 3,500 ft AGL. Fly higher at night when possible, since birds also fly higher at night.*
>
> *Utilize personal protective equipment (PPE) consisting of a helmet and visor, at least for the crew, when practical.*
>
> *Use taxi and / or landing lights in a continuous mode during sunny conditions and at night when practical, and a 2-Hz pulsed mode during partly cloudy conditions, and/or install lighting systems that provide the equivalent.'*

Safety actions

European Union Aviation Safety Agency (EASA)

> In November 2018, the EASA published the European Plan for Aviation Safety (EPAS) for 2019 – 2023[2]. Rule Making Task 0726 is entitled '*Rotorcraft occupant safety in event of a bird strike*'. The document states:
>
> *'Since the 1980s there have been an increasing number of accidents involving rotorcraft bird strikes where the rotorcraft was not certified in accordance with the latest bird strike protection provisions. This has resulted in a number of occurrences where rotorcraft bird impacts have had an adverse effect on safety. The objective of this RMT is to improve rotorcraft occupant safety in the event of a bird strike. This will be achieved by considering the development of new CS-27 provisions for bird strike and also considering proportionate retrospective application of applicable CS-27 and CS-29 to existing fleets and types that are not compliant with the latest provisions.'*
>
> The document indicates that associated timescales are 2024.

Footnote

2 European Plan for Aviation Safety 2019 – 2023 https://www.easa.europa.eu/document-library/general-publications/european-plan-aviation-safety-2019-2023 [Accessed 28 February 2019]

Federal Aviation Administration

In a presentation at the 12th rotorcraft symposium[3], the FAA indicated that their Rotorcraft Standards Branch (RSB) is reviewing the Bird Strike Working Group report. Further FAA study and evaluation will influence potential rulemaking and indications are that the RSB will pursue rulemaking in fiscal year 2020. This will be a multi-year process to achieve a final rule and they will '*coordinate and harmonize to maximum extent with EASA*'.

The FAA indicated that they consider pilots and operators to be the first line of defence. They will consider how to address appropriate rotorcraft flight manual procedures. These are not considered to be flight limitations but '*best practices*'. They will continue discussion and studies with industry. Guidance material such as Advisory Circulars will be issued where appropriate.

Footnote

[3] Presentation number 28 Bird Strike Rotorcraft Protection https://www.easa.europa.eu/newsroom-and-events/events/12th-rotorcraft-symposium#group-easa-downloads [Accessed 28 February 2019]

SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-8Q8, YR-BMF
No & Type of Engines:	2 CFM56 7B24/3 turbofan engines
Year of Manufacture:	1999 (Serial no: 28220)
Date & Time (UTC):	28 July 2018 at 1010 hrs
Location:	Birmingham Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 190
Injuries:	Crew - None Passengers - None
Nature of Damage:	APU drain mast and tail skid components damaged
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	60 years
Commander's Flying Experience:	17,481 hours (of which 7,272 were on type) Last 90 days - 109 hours Last 28 days - 68 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

Prior to departure the aircraft's takeoff data was calculated on an electronic flight bag (EFB) using its zero fuel weight (ZFW) instead of its takeoff weight (TOW). The pilots did not crosscheck or independently calculate the data. During the takeoff the aircraft suffered a tailstrike.

Despite ATC asking the pilots if they had a tailstrike, the error subsequently being noticed in the EFB and a member of the cabin crew hearing a strange noise during the take off, the tailstrike checklist was not actioned. The aircraft continued to its destination and, after landing, damage was discovered on the underside of the aircraft.

The operator has published a safety notice reminding pilots of its procedures when calculating takeoff performance and to refer to the checklist after an unusual occurrence.

History of the flight

The aircraft was on a scheduled flight from Birmingham Airport to Bucharest International Airport, Romania, having arrived from Bucharest. These were the co-pilot's first sectors since passing his line check the day before. The commander was the PF.

During the turnaround the dispatcher informed the pilots that they had an ATC-calculated takeoff time (CTOT)[1] 54 mins after the scheduled departure time. However, they planned

Footnote

[1] If a departing aircraft is issued a CTOT, it is permitted to takeoff up to 5 minutes before and no later than 10 minutes after the time. If this can not be complied with a new CTOT will need to be issued.

to be ready to depart on time, so the co-pilot prepared the FMC and the EFB and the passengers boarded. Due to an issue with the loading of the baggage the load sheet was delayed, so the commander gave the departure brief before the takeoff performance had been calculated.

The load sheet arrived at about the CTOT and "in order to save time" the commander read out the required figures from it to the co-pilot, who entered them into the EFB. The performance data was then entered into the FMC without it, or the load sheet, being crosschecked. The aircraft then received clearance to start and taxi to Runway 15. At the time the wind was from approximately 210° at 14 kt, gusting 31 kt.

A member of ground operations at Birmingham Airport, who witnessed the takeoff, informed ATC that he believed the aircraft may have had a tailstrike, as he saw the tail of the aircraft come very close to the runway. ATC thus asked the pilots if they had had one. Neither of the pilots had noticed anything untoward and after checking the aircraft's systems, including the pressurisation system, they replied they had not. The crew then elected to continue to their destination.

During the cruise, the commander checked the EFB and realised that he had told the co-pilot the ZFW, instead of the TOW, resulting in erroneous takeoff performance data being calculated and used. The commander then asked the cabin crew if they had noticed anything during the takeoff. The cabin crew member stationed at the rear of the aircraft said she had heard a strange noise during the takeoff but could not identify what it was. The aircraft subsequently landed in Bucharest without further event.

After landing the commander asked the aircraft engineers to examine the aircraft for evidence of a tailstrike. They discovered damage to the aircraft's tail skid and APU drain mast (Figure 1).

Figure 1

Damage to underside of aircraft

Recorded information

Information obtained by the operator for flight data monitoring purposes showed that the aircraft started to rotate at about 143 kt and as the aircraft became airborne it reached an attitude of 11.95° nose up, attaining a peak pitch rate of 4.2°/second.

Takeoff data

A comparison between the incorrect and correct takeoff performance data is at Table 1.

	Incorrect performance data	Correct performance data
Takeoff weight (tonnes)	59	71.3
Assumed temperature (°C)	48	31
N_1 (%)	86.3	93.6
V_1	140 kt	152 kt
V_R	140 kt	153 kt
V_2	143 kt	157 kt

Table 1

Comparison of takeoff data

Operations manual

Part B of the operator's operations manual (OM) states:

> *'4.5 Using the On-board Performance Tool (OPT)[EFB]:*
>
> *…*
>
> *WARNING: The performance calculations must be performed independently by both pilots, each using its own EFB and the results (derate, assumed, take-off speeds) must be crosschecked for correctness calculation.*
>
> *…*
>
> *4.6 OPT for take-off*
>
> *…*
>
> *After computing independently, the OPT takeoff data, the crew shall perform a crosscheck of the results.*
>
> *…'*

Aircraft information

The manufacturer's flight crew training manual states that the 737-8's tailstrike pitch attitude is 11.0°. It also states the following:

> *'Rotation and Liftoff - All Engines*
>
> *…*
>
> *For optimum takeoff and initial climb performance, initiate a smooth continuous rotation at VR toward 15° of pitch attitude.*
>
> *…*
>
> *Using the technique above, resultant rotation rates vary from 2° to 3° per second with rates being lowest on longer airplanes. Liftoff attitude is achieved in approximately 3 to 4 seconds depending on airplane weight and thrust setting.'*

Aircraft's Quick Reference Handbook

The aircraft's Quick Reference Handbook (QRH) checklist for a tailstrike states:

Tail Strike ( )

Condition: A tailstrike is suspected.

Caution! Do not pressurize the airplane due to possible structural damage.

1 Pressurization mode selector . . . . MAN

2 Outflow VALVE switch . . . . Hold in OPEN until the outflow VALVE indication shows fully open to depressurize the airplane

3 Plan to land at the nearest suitable airport.

■ ■ ■ ■

Pilots' comments

Commander's comments

The commander commented that he was aware of the tailstrike checklist. He added that as they were not aware of the event there was no need to refer to it.

Co-pilot's comments

The co-pilot commented that on the takeoff the aircraft pitched up "aggressively" and a higher than normal pitch attitude was attained. He added he was not aware of the tailstrike checklist and in future will always ensure the commander crosschecks any performance calculations.

Analysis

During the pre-flight preparation, the commander read the ZFW from the load sheet to the co-pilot, instead of the TOW, and this was entered into the EFB. The takeoff performance data calculated consequently used a takeoff mass of about 12 tonnes less than the aircraft's actual weight. This produced takeoff speeds that were more than 10 kt less than those required. Having flown the takeoff using these slower speeds the aircraft suffered a tailstrike.

It was likely that the incorrect weight was read out, and not crosschecked, as the crew tried to meet the CTOT. However, had the co-pilot crosschecked the load sheet, as required by the operator's SOPs, it is likely this would have been noticed. Also, had each pilot done independent calculations, in accordance with the SOPs, any differing takeoff data would probably have been noticed too.

Shortly after takeoff ATC enquired if the aircraft had sustained a tailstrike; the pilots thought not, as they had no evidence to suggest it. Later, they discovered the error in the EFB and then spoke to the cabin crew member stationed at the rear of the aircraft who heard a strange noise during the takeoff. Despite noticing the EFB error and the other two anomalies from the takeoff, these facts did not cause the pilots any concern and the aircraft continued to destination, without reference to the QRH. However, the commander was likely to have realised that a tailstrike had occurred as he asked the engineers to examine the aircraft after landing.

The *'Tail Strike'* checklist is to be completed if one is '*suspected*'. The enquiry from ATC should have been enough for the pilots to refer to the QRH and take the prescribed actions. Having disregarded this, the additional anomalies should have increased the pilots' suspicion and given them cause to refer to the QRH. Had the QRH been actioned, the aircraft would probably have been able to return to Birmingham or diverted en route. Continuing to destination put the safety of the aircraft and its occupants at an increased risk.

Safety actions

As a result of this event the operator issued Safety Information Bulletin No 7/2018 to its pilots, highlighting the background to it and highlighted the following:

> *'The flight crew members are advised to strictly follow the provisions of OMB 4.6 "AFTER COMPUTING INDEPENDENTLY, THE CREW SHALL PERFORM A CROSSCHECK OF THE RESULTS",*
>
> *When feeding the FMC with data that can affect performance or carrying out a correction, a cross-check shall be initiated before executing the task,*
>
> *To take into consideration the importance of the information provided by the cabin crew and ATC,*
>
> *QRH shall be used any time a non-normal situation occurs (i.e. NNC Tail Strike).'*

SERIOUS INCIDENT

Aircraft Type and Registration:	ERJ 170-200 STD, Embraer 175, G-FBJK
No & Type of Engines:	2 General Electric Co CF34-8E5 Turbofan Engines
Year of Manufacture:	2013 (Serial no: 17000359)
Date & Time (UTC):	11 August 2018 at 0743 hrs
Location:	Dublin Airport, Ireland
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 74
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	7,900 hours (of which 722 were on type) Last 90 days - 103 hours Last 28 days - 23 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

When advised that the takeoff runway had changed the pilots recalculated the takeoff performance from an intersection. This produced a different flap setting, which they did not notice, despite them cross-checking the information. The aircraft subsequently took off with an incorrect flap setting for the calculated takeoff performance data.

The operator is considering three safety actions to strengthen its procedures and prevent recurrence.

History of the flight

The aircraft was scheduled to fly from Dublin Airport, Ireland to Cardiff Airport. This was to be the pilots' second of four sectors for the day. The co-pilot was the PF.

During the turnaround, having noted that Runway 28 was in use, the pilots set up the aircraft's Flight Management System (FMS) and Electronic Flight Bag (EFB) for Runway 28. As the load sheet was not yet available, the co-pilot calculated the takeoff performance data on the EFB using an estimated takeoff weight; this was then cross-checked by the commander. The data, which specified FLAP 1 for takeoff, was then entered into the FMS.

When the pilots obtained the departure clearance, ATC specified Runway 10 for departure. The co-pilot recalculated the performance data for Runway 10 using Intersection Echo 7 (E7), as this was the most limiting normal takeoff distance on this runway. However, she inadvertently selected E7 TMP[Temporary][1] on the EFB, which specified FLAP 4 for takeoff. The EFB was then passed to the commander for cross-checking, during which the dispatcher arrived with the load sheet and load instruction report[2]. The commander noticed a discrepancy with the loading information and discussed it with the dispatcher. Having resolved this, the commander returned to checking the EFB and noticed no anomalies. The data was then entered into the FMS.

While the crew had noticed the takeoff speeds had changed from the Runway 28 calculation, neither noticed that Intersection E7 TMP had been used to perform the calculation, or that it specified FLAP 4. Also, the commander did not crosscheck the EFB-generated speeds and flap setting against the Quick Reference Handbook (QRH), as specified in the operator's standard operating procedures (SOP). Additionally, the co-pilot did not mention she had used Intersection E7 as the basis of the calculations in her departure brief.

The aircraft commenced the takeoff on Runway 10, using the full length, with takeoff speeds for FLAP 4 but with FLAP 1 selected. As the aircraft rotated the co-pilot realised something was wrong when the takeoff speeds annunciated on the Electronic Flight Instrument System's (EFIS) airspeed tape changed colour to amber[3], the Low Speed Awareness Line[4] (LSAL) appeared and the aircraft felt "sluggish". She therefore flew below the pitch attitude commanded by the flight director, in order to maintain a higher speed than commanded until the aircraft reached about 1,000 ft aal, where the flaps were retracted and the climb continued.

In the initial part of the climb, after the co-pilot had reviewed the performance page, she realised what had happened and brought it to the commander's attention. The aircraft landed at Cardiff without further event and the crew notified the operator of the incident. They were subsequently removed from further flight duties on that day.

Pilots' comments

Commander's comments

The commander commented that he did not notice FLAP 4 was specified on the EFB, probably because FLAP 1 was usually specified at Dublin due to the runway length. He added that he had difficulty in distinguishing and identifying the important performance data, on the EFB, as it had a similar size and style of font to most of the information on the page (Figure 1). He also noted that, as he was on his fourth consecutive early start, fatigue may have been a contributory factor.

Footnote

1 The takeoff run available from Intersection E7 TMP on Runway 10 would have been 1,660 m, due to work in progress at the threshold of Runway 28 but was not in use at the time.
2 The load instruction report indicates where the baggage is loaded in the aircraft's hold.
3 The airspeed tape and takeoff speeds change to amber on the pilots' EFIS when the IAS is approaching a low speed situation.
4 The LSAL indicates the aircraft's proximity to its stall speed.

Co-pilot's comments

The co-pilot commented that the turnaround was busy. She felt she had rushed the performance calculations and did not notice the "TMP" suffix to the Intersection E7 selection.

Aircraft performance

The EFB specified the following takeoff speeds for Runway 10 from Intersection E7 TMP with FLAP 4: V_1 119 kt, V_R 119 kt, V_2 123 kt (Figure 1).

The correct takeoff speeds, using the full length of Runway 10 with FLAP 1 were: V_1 145 kt, V_R 145 kt, V_2 147 kt.

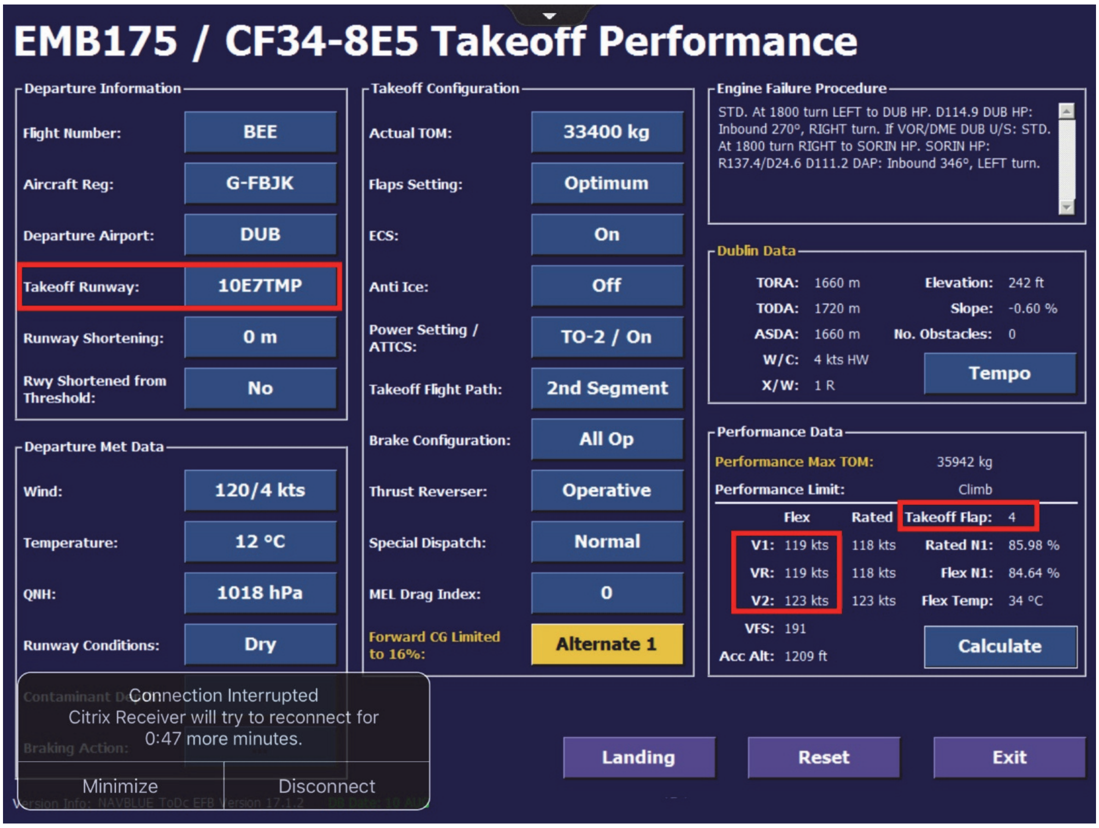

Figure 1

EFB performance data as used by the pilots
(Information relevant to the occurrence are highlighted in red boxes for clarity)

Recorded information

Information obtained by the operator for flight data monitoring purposes showed that the flight departed with FLAP 1 set. The aircraft accelerated along Runway 10 and started to rotate at 133 kt, 12 kt slower than the speed required for FLAP 1. The rotation appeared normal until it stopped at about 10º, with the landing gear still on the runway. Five seconds later the IAS had increased through 145kts (the correct V_R with FLAP 1), the aircraft then became airborne and started to climb.

Cross-checking of takeoff performance

Operator's operations manual (OM)

Part B of the operator's OM states:

> *'**Final Preparation***
>
> *It is important that BOTH crew members check the load sheet to confirm it is correct and appropriate for their flight. As a minimum, the following items must be confirmed by both pilots:*
>
> *…*
> *Confirm the EFB performance calculation and, if necessary, amend the takeoff speeds.*
> *...*
>
> ***CROSS-CHECKING***
>
> *…*
> *It is very important that crews carry out suitable cross-checking of any performance calculation….Finally, the Captain will conduct a gross error check on the Take-off V speeds by use of the performance pages in the QRH,..'*

EASA regulations

EASA's AMC [Acceptable Means of Compliance] 20-25, '*Airworthiness and operational consideration for Electronic Flight Bags (EFBs)*'[5] states:

> *'**F.1.3 Procedures***
>
> *…specific care is needed regarding the crew procedures concerning performance or mass and balance applications:*
>
> *(a) Crew procedures should ensure that calculations are conducted independently by each crew member before data outputs are accepted for use.*
>
> *(b) Crew procedures should ensure that a formal cross-check is made before data outputs are accepted for use. Such cross-checks should utilise the independent calculations described above, together with the output of the same data from other sources on the aircraft.'*

At the time of this event the operator did not require its pilots to calculate takeoff performance data independently, before being cross-checked.

Footnote

5 https://www.easa.europa.eu/sites/default/files/dfu/2014-001-R-Annex%20II%20-%20AMC%2020-25.pdf [accessed April 2019].

Analysis

This serious incident was caused by an ineffective SOP and non-adherence to a SOP. The ineffective SOP was when the commander cross-checked the EFB calculations. The different flap setting was probably missed at this point as he was distracted by a discrepancy with the loading information. The lack of contrast in the size and font on the EFB may have contributed to this.

The pilots did not carry out a gross error check as required by SOPs. Also, had the co-pilot mentioned in her brief that she had calculated the performance data using Intersection E7, it might have drawn their attention to the fact that FLAP 4 was specified.

At the time of the incident it was not a requirement to do independent calculations at the time, as recommended by EASA. However, had the pilots done so, the selected intersection and flap setting would probably have been noticed after they were cross-checked.

The "sluggish" takeoff and low speed awareness cues on the EFIS alerted the co-pilot to the reduced aircraft performance. She responded by reducing the nose-up pitch to below the attitude commanded by the flight director. This allowed the aircraft to accelerate to above the correct V_R with FLAP 1, before getting airborne safely.

Safety actions

The operator has taken the following safety actions:

Changed its SOPs on EFB performance calculation procedures, in OM Part A, to align them with the current EASA regulation where both pilots independently calculate the departure performance and cross-check the other pilots, before being accepted for use.

The operator has introduced the use of a takeoff and landing data card on their Embraer 175 fleet. It believes the process of transferring data from the EFB to the card could potentially act as an additional safety barrier.

The operator is considering the following safety action:

Changing the format, font or colour of the calculated takeoff speeds and flap setting on the EFB to make the calculated data stand out differently from the rest of the inputted data.

This change had not been made at the time of publication.

SERIOUS INCIDENT

Aircraft Type and Registration:	ERJ 190-100 SR Embraer 190, G-LCYZ
No & Type of Engines:	2 General Electric Co CF34-10E5A1 G07 turbofan engines
Year of Manufacture:	2010 (Serial no: 19000404)
Date & Time (UTC):	11 December 2018 at 0655 hrs
Location:	On takeoff from London City Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 86
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	34 years
Commander's Flying Experience:	4,971 hours (of which 4,813 were on type) Last 90 days - 121 hours Last 28 days - 51 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

On departure from London City Airport (LCY) the aircraft commander was Pilot Monitoring (PM). As the aircraft's speed increased through 60 kt on takeoff they noticed that the 'Takeoff 3' (T/O-3) thrust indication was displayed on EICAS[1]. The departure had been planned on the assumption that 'Takeoff 1' (T/O-1) thrust would be selected and available. The T/O-3 engine de-rate setting reduced maximum available engine thrust from 18,500 lbf to 15,450 lbf per engine with all engines operating. Noting the unexpected thrust setting, the commander judged that continuing, rather than rejecting, the takeoff was the safest option at that point. The subsequent climb out was flown without incident.

History of the flight

It was the first flight of the day for the crew and they reported being well-rested. The co-pilot was nominated as Pilot Flying (PF) for the sector. During cockpit preparation both pilots independently calculated takeoff performance figures for the aircraft using their electronic flight bags (EFBs). Having agreed the takeoff settings with PF, PM entered them into the flight management computer. The required engine thrust setting, as determined by the Airline's Standard Operating Procedures (SOPs), was T/O-1.

Footnote

[1] Engine Indicating and Crew Alerting System, an aircraft system for displaying engine parameters and alerting crew to system configuration or faults.

The crew reported that engine start and taxi to the runway were carried out without undue haste. Checklists were followed and the SOP Vital Data Review (VDR) was carried out. Neither pilot could remember if, during the VDR, the displayed T/O-3 setting had been read out incorrectly or whether the call had been misheard as 'T/O-1'.

As the aircraft accelerated through 60 kt on the takeoff roll the commander realised that T/O-3 was displayed on EICAS. Concerned that the incorrect thrust setting invalidated their rejected takeoff stopping distance calculations, the commander deemed that continuing the takeoff was the safest option. As PM, they called V_1[2] at the calculated speed but delayed the V_r[3] call by approximately 5 kt to compensate for the reduced thrust level. PF did not experience any aircraft handling difficulties during the climb-out and the departure was conducted without further incident.

To better understand the safety impact of the incorrect takeoff setting, once above FL100 the crew recalculated their takeoff performance based on T/O-3 thrust. The calculations indicated that, while they would have been able to stop safely up to V_1, climb performance might have been compromised had an engine failed shortly thereafter.

Recorded information

With no appreciable headwind, the aircraft reached V_1 after a ground roll of 560 m, using approximately 41% of the 1,360 m runway length available. Data from a previous departure using T/O-1 at a comparable AUW, but with an unknown headwind component, required a 440 m ground run to achieve V_1.

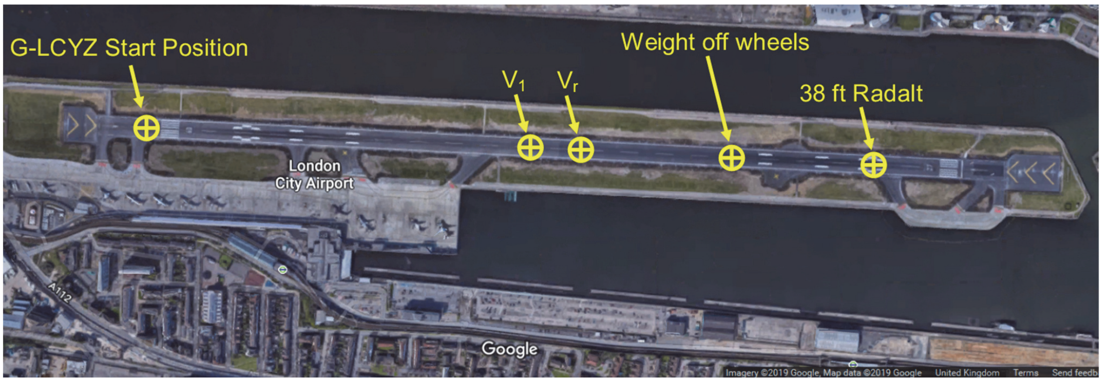

Figure 1

Overview of G-LCYZ's takeoff roll from LCY

Footnote

2 Takeoff decision speed.
3 Rotation speed.

Aircraft information

Performance requirements for commercial aircraft require that an aircraft must be above V_{MCA}[4] before it gets airborne. Reducing available thrust for takeoff reduces the maximum asymmetric yawing moment that would be experienced in an engine failure situation. De-rating the engines can, therefore, reduce V_{MCA} and, consequently, the takeoff ground run required. The Embraer E190 and E170 aircraft have two thrust de-rate settings, 'Takeoff 2' (T/O-2) and T/O-3, which are activated using the MCDU[5].

The aircraft have an Automatic Takeoff Thrust Control System (ATTCS) which can automatically increase thrust to a reserve (RSV) level on the remaining engine should one fail. Had G-LCYZ suffered an engine failure on departure, the ATTCS would have increased the maximum available thrust on the live engine from 15,450 lbf to 17,100 lbf (T/O-3 RSV). With both engines operating normally, advancing the thrust levers from TO/GA to MAX would have commanded T/O-3 RSV on both engines.

Takeoff de-rate settings are automatically cancelled when climb power is selected. Alternatively, they can be manually de-selected through the MCDU. To do so during takeoff would divert PM's attention away from their monitoring role at a critical stage of flight.

Other than the EICAS display, the aircraft was not fitted with any automated system capable of alerting the pilots to an inappropriate takeoff thrust setting.

Weight and balance

The Company SOP takeoff thrust mode for all E170 and E190 flights is 'Optimum', except E190 departures from LCY. For an Embraer E190 departing LCY with a takeoff mass (TOM) above 40,000 kg, T/O-1 thrust is used. At lower masses T/O-2 is standard (Figure 2). Where Optimum is specified, the thrust setting calculated by the EFB performance software is not artificially limited and the EFB calculates the most appropriate engine de-rate for the environmental conditions. On the incident flight G-LCYZ's TOM was 41,118 kg.

Human factors

The crew could not positively say why the slip occurred, nor why it remained undetected. Pilots can fly the Embraer E190 and its smaller E170 variant on a common type rating. In the two weeks prior to the incident, the commander had almost exclusively flown the E170, often using T/O-3 as the required de-rate. The commander believed that this may have led to the initial slip and contributed to confirmation bias when reviewing the information displayed on EICAS. At no stage during the takeoff did the flight crew assess that advancing the thrust levers to command T/O-3 RSV was necessary to assure safe flight.

Footnote

4 Velocity Minimum Control (air) (V_{MCA}): in broad terms, the minimum speed at which directional control can be maintained with the critical engine inoperative and the other delivering takeoff power.
5 Multi-purpose control and display unit.

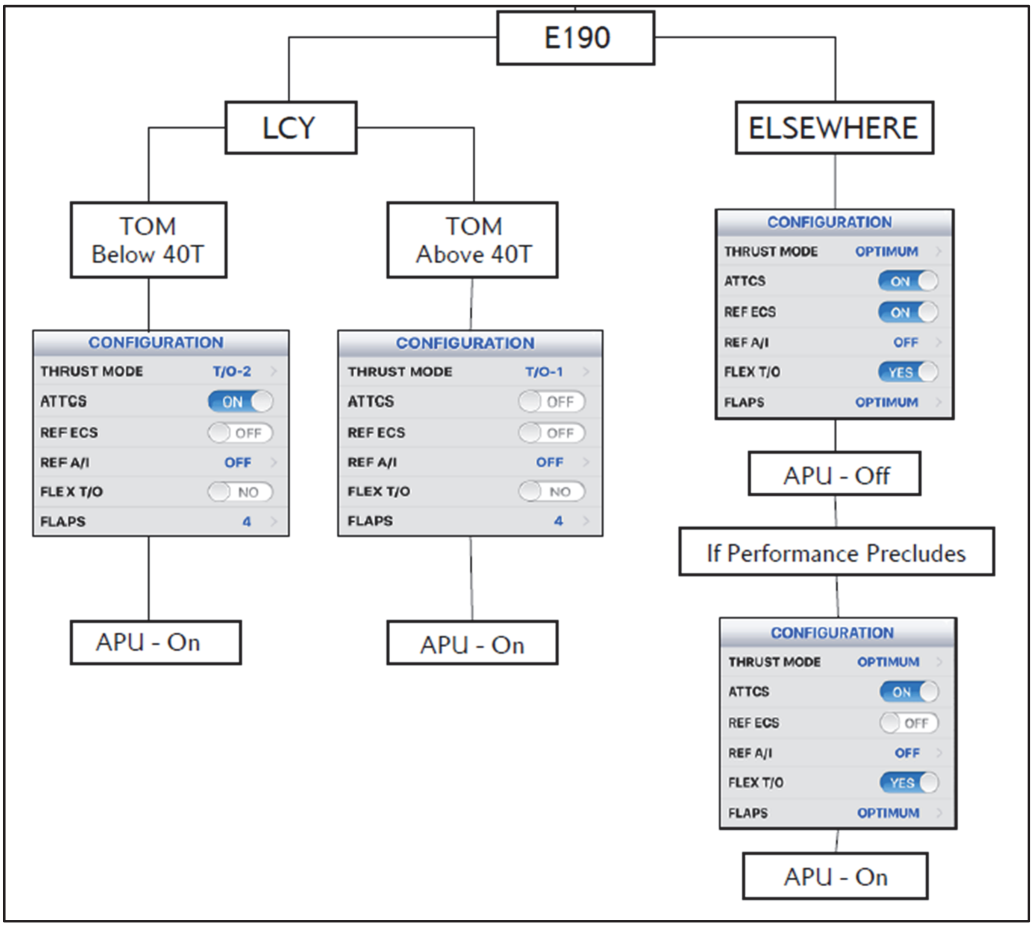

Figure 2

The Airline's SOP takeoff thrust settings for E190 aircraft

Additional information

Performance-related accidents and serious incidents

The AAIB published a Formal report[6] into a serious incident, where a Boeing 737 (C-FWGH) took off with excessively reduced thrust. Appendix A to the report lists 33 performance-related accidents and serious incidents occurring to commercial aircraft during the period 14 October 2004 to 20 March 2018. The report advocates the future development of automated systems to supplement procedural barriers and act as additional risk controls to mitigate against performance-related accidents and incidents. The report also examines various human factors that explain why it may not be instinctive for pilots to advance thrust levers when faced with abnormal takeoff performance.

Footnote

6 https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-2-2018-c-fwgh-21july-2017 accessed 11 February 2019.

Analysis

On balance, the evidence suggests that, following the correct calculation of takeoff performance, T/O-3 was manually selected in error. Normal limitations in human performance are likely to have been contributory factors to the T/O-3 setting remaining undetected during the VDR. Subtle differences associated with operating different variants of a common type appear to have played a part in the error chain. While the aircraft took off without incident, an emergency on departure might have been made more challenging by the reduced thrust available with T/O-3 activated. The commander did not consider manually de-selecting the engine de-rate, either through premature activation of climb thrust or through the MCDU, to be a safe or appropriate course of action at that time. Neither did they consider that T/O-3 RSV thrust was required for a safe climb out.

Performance-related errors remain a threat to the safe conduct of commercial air transport operations. Until technical solutions can be developed, procedural barriers remain a key defence against such events.

Conclusion

Human Performance limitations contributed to the aircraft departing LCY with a power setting that might have had an adverse effect on aircraft handling and performance in the event of an engine failure. Given the known limitations of humans, robust procedural barriers will remain a key defence against mishap until technological solutions are sufficiently mature.

ACCIDENT

Aircraft Type and Registration:	Spitfire Mk.T IX (Modified), G-CTIX
No & Type of Engines:	1 Packard Motor Car Co MERLIN 224 piston engine
Year of Manufacture:	1944 (Serial no: PT462)
Date & Time (UTC):	27 February 2019 at 1255 hrs
Location:	Denham Airfield, Buckinghamshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Broken propeller blades, left undercarriage detached and minor structural damage
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	55 years
Commander's Flying Experience:	12,992 hours (of which 101 were on type) Last 90 days - 113 hours Last 28 days - 43 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The landing gear warning horn sounded during the approach to land. The undercarriage had been selected down and the green light indicating it was safe was illuminated, but the right undercarriage leg collapsed towards the end of the landing ground roll. Neither occupant was injured. The operator has provided additional information to its pilots concerning the landing gear systems on each of its aircraft and the aircraft will be modified to standardise system functionality with its other Spitfires.

History of the flight

The pilot was operating the aircraft at Denham Airfield. A passenger was seated in the rear of the two cockpits.

Surface wind was reported to be from 230° at 5 kt, with visibility more than 10 km and no significant cloud. The runway surface was dry.

In preparation for landing on grass Runway 24, the pilot selected the undercarriage DOWN at an indicated airspeed of approximately 140 mph. The red UP indicator light extinguished, he felt the undercarriage lower and "clunk" into place, and the green DOWN indication illuminated. He then tested the brakes, reduced power and lowered the flaps for landing.

At this point the undercarriage warning horn sounded but the pilot observed that the green undercarriage DOWN indication remained illuminated.

On two previous occasions in G-CTIX, the pilot had heard the undercarriage warning horn sound on takeoff with the undercarriage raised, flaps up and high power selected; a configuration in which the horn would not normally sound. Consequently, he trusted the DOWN indication and the sensation of the gear lowering as evidence that the undercarriage was down, and he continued the landing.

The aircraft touched down in a 3-point attitude[1] and decelerated normally until, at around 30 mph, the pilot noticed the right wingtip lowering. At first he suspected that a seal in the undercarriage oleo had failed, which would result in the wing being lower on that side. However, the wing continued to drop and he realised that the right undercarriage leg was in the process of retracting. He immediately turned off the magnetos to minimise damage to the engine when the propeller hit the ground and turned off the fuel.

At the end of the accident sequence the aircraft slowly tipped forward and gently yawed to the right, coming to rest upright and facing approximately 170º right of the landing direction. As it stopped moving the pilot instructed the passenger to leave the aircraft immediately and turned off the battery switch. He then unstrapped himself, vacated the aircraft, and assisted the passenger to leave the rear cockpit and move away.

Neither occupant was injured. Aerodrome fire and rescue personnel arrived promptly, and there was no sign of smoke or fire.

Aircraft information

G-CTIX was built in 1943 as a single seater Mk HF.IXe. After a period of inactivity it was converted to two-seat configuration and restored to flight in 1987, with a Packard Merlin 224 engine and Mk PR.XI wings.

Undercarriage system

The Spitfire Mk IX is fitted with two main undercarriage legs and a tail wheel. The main undercarriage legs retract outwards by hydraulic actuators mounted within the fuselage on the engine firewall. An emergency gas discharge system is fitted to extend the undercarriage in the event of hydraulic system failure. The system is operated by the undercarriage control lever (Figure 1) on the right side of the cockpit and there is a panel mounted indication system for UP (red) and DOWN (green) (Figure 2).

Footnote

1 In which the aircraft lands on both main undercarriage and the tail wheel simultaneously.

Figure 1
Undercarriage control lever

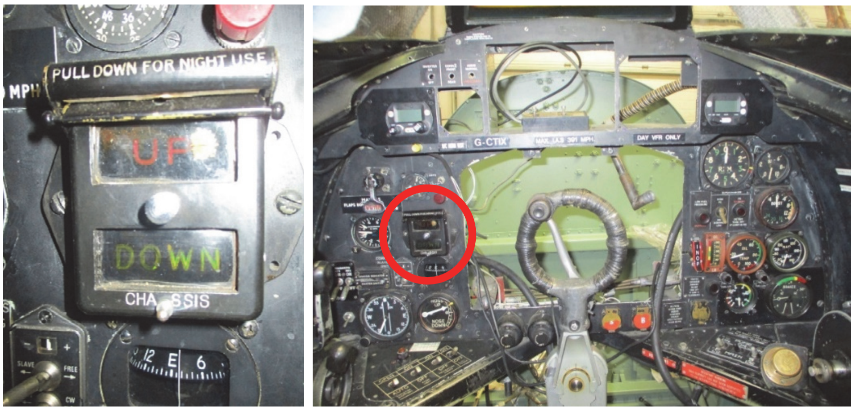

Figure 2
Undercarriage position indicator

Extension / retraction system

To extend the undercarriage the control lever is moved to the left out of a retaining gate and rotated aft by approximately 130º. During this motion the UP side of the hydraulic system is powered to take the weight of the undercarriage off the undercarriage locking pin (Figure 3) so that it can be rotated to the DOWN position. The locking pin is rotated by a series of pulleys, cables and chains connected to the control lever and is sprung loaded so that it can retract and allow either the yoke or eye to disengage or engage as required. A combination of gravity and the DOWN side of the hydraulic system powers the legs until the yoke engages with the locking pin. Once fully down, the hydraulic system pressure increases until a cut-off plunger in the control unit is activated and system pressure is diverted through a bypass circuit and IDLE is indicated on the control lever unit.

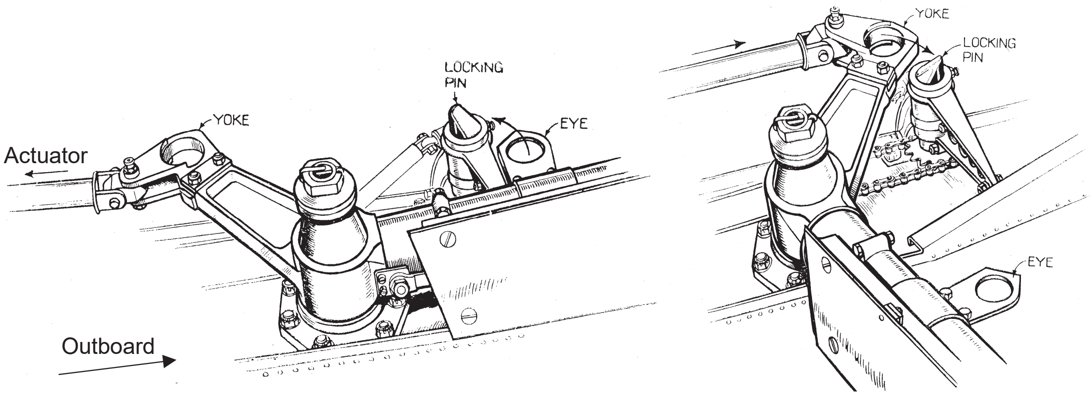

Figure 3

Undercarriage locking pin
Left – Undercarriage UP. Right – Undercarriage DOWN
Source: Haynes Supermarine Spitfire Manual / Crown Copyright

Experience has shown that in certain circumstances it is possible that the undercarriage is not locked down despite indications to the contrary. For example, if the undercarriage is lowered with enough sideslip[2], the airflow on the undercarriage fairing can prevent one leg from engaging with the locking pin and activate the hydraulic cut-off plunger. Additionally, if the control lever is not moved into the DOWN gate properly, the undercarriage will free fall and (one leg) may not lock down, and the hydraulic system will remain at IDLE. In both cases the DOWN indication will not be lit and so the undercarriage should be fully recycled (raised and then lowered) to ensure both legs are fully locked down before landing.

Indication system

There are several switches in the undercarriage bay which are used to indicate to the pilot the undercarriage position. There is a single switch fitted to each locking pin which indicates if the pin is in the fully locked position. Further switches are mechanically activated when the undercarriage leg is either in the fully UP or fully DOWN position (Figure 4). To illuminate the UP caption in the cockpit, the locking pin must be fully engaged and the UP position switch made. Consequently, for the DOWN caption to be illuminated the locking pin must be engaged and DOWN position switch made. When these conditions are not met (ie during undercarriage retraction or extension) no captions will be lit. Each caption is lit by two bulbs in case of bulb failure.

Footnote

[2] A sideslip is an aerodynamic state where an aircraft is moving sideways, as well as forward, relative to the oncoming airflow or relative wind.

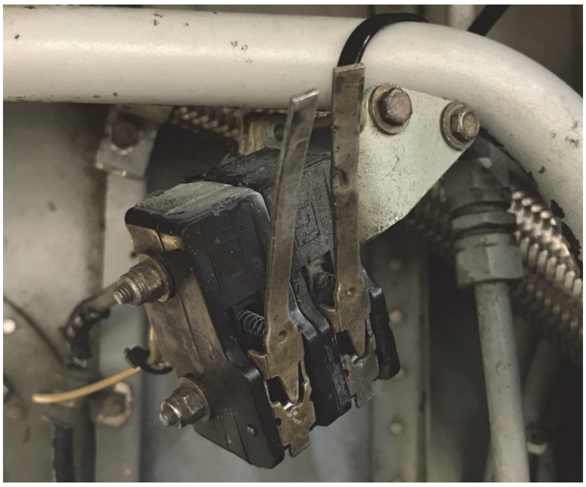

Figure 4

DOWN position and undercarriage warning horn switches (partially disassembled)

Flap system

The trailing edges of both wings are flitted with pneumatically operated flaps for low speed flight. They are operated by an electrical switch on the left side of the instrument panel and there is a warning horn fitted which sounds if the flaps are extended and the undercarriage is not locked DOWN. On G-CTIX there is a second, separate, switch located adjacent to the undercarriage DOWN position switch which is activated by the same mechanical means for the undercarriage warning horn system. There is a modification which has been embodied on some Spitfires to replace the individual undercarriage DOWN and warning horn switches with a single dual-pole switch to increase reliability (Figure 5). The modification was not fitted to G-CTIX.

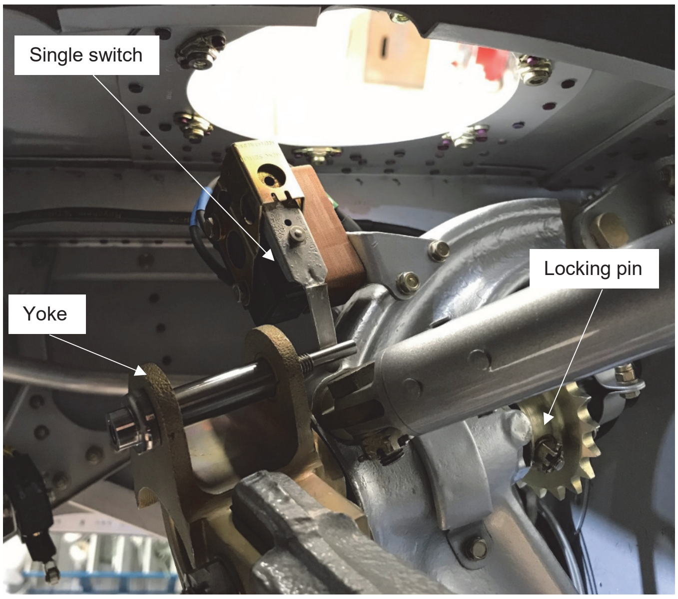

Figure 5

Single dual-pole switch for DOWN position and flap horn (not fitted to G-CTIX)

Some Spitfires are fitted with an additional switch on the throttle control which results in the undercarriage warning horn sounding if the throttle is not closed when the flaps are deployed, and the undercarriage is not locked DOWN (Figure 6). This additional switch was not fitted to G-CTIX.

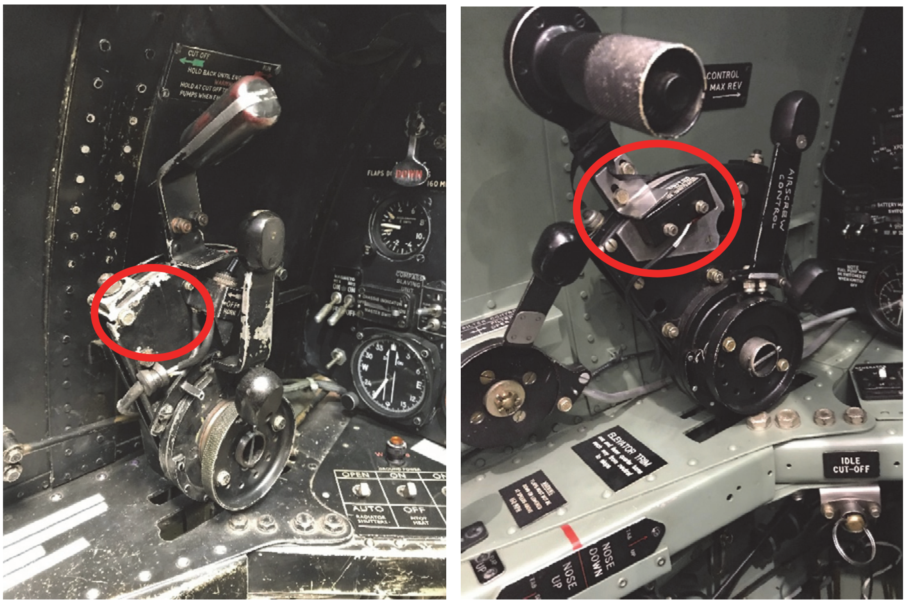

Figure 6

Comparison of throttle controls showing the undercarriage warning switch.
G-CTIX shown in left image

Aircraft examination

At the accident site it was confirmed that the right undercarriage leg was not locked down and subsequently on landing, had retracted back into the wing. The left undercarriage leg had been locked down but the leg had folded underneath the fuselage during the landing sequence. The aircraft came to rest on the left undercarriage leg (Figure 7).

Figure 7

G-CTIX after landing

The aircraft was recovered from Denham Airfield to the Repair Organisation where it was inspected by the AAIB. The primary undercarriage attachment and the locking pin fitting were detached however, as the attachment bolts had failed, there was minimal damage to the wing spar. The inboard end of the left wing had been deformed by the landing leg. There was further damage to the hydraulic retraction actuators and their attachment to the fuselage firewall. The various indication system switches were inspected, and it was found that the DOWN position switch on the right undercarriage was stuck in the closed (DOWN) position. Manipulation of the switch released the switch, but the fault could not be replicated.

Operation

There are several different undercarriage position indicating systems fitted to Spitfires, which may or may not be the same as the systems originally fitted.

The pilot commented that his knowledge of the undercarriage warning horn system fitted to G-CTIX was not complete. The system was not described in the Spitfire Mk T. IX handling notes he used, and the RAF *'Pilots' Notes'* to which he occasionally referred stated:

> *'The horn, fitted in early aircraft only, sounds when the throttle lever is nearly closed and the undercarriage is not lowered. It cannot be silenced until the throttle is opened again or the undercarriage is lowered.'*

Consequently, he viewed the cockpit indicator lights as the "master system" and believed that the horn was dependant on throttle position and undercarriage selector position only, as in other aircraft he had flown. His belief that the gear was down and locked was further reinforced because the horn did not sound when he selected the undercarriage down, but only subsequently when he selected the flaps down. He assumed it had done so spuriously. He considered that, had he known how the horn system on this aircraft worked, he would have discontinued the approach to assess the situation.

Analysis

Following an earlier retraction of the undercarriage, the right DOWN position switch became stuck in the closed (DOWN) position and during the accident landing sequence, the pilot was unaware that the right undercarriage leg was not locked down.

The right locking pin had not been displaced by the yoke and the left leg was fully locked down, resulting in the DOWN indication being lit in the cockpit.

Conclusion

The right main undercarriage was not locked down, and retracted under the weight of the aircraft on landing.

It is likely the undercarriage was serviceable and capable of operating correctly, but excessive air load or incomplete selection of the undercarriage lever to the DOWN position meant that the hydraulic system returned to IDLE before the undercarriage was locked down.

The undercarriage warning horn operated as intended but the right undercarriage DOWN switch was stuck closed, providing an incorrect indication that the undercarriage was safe. The pilot's previous experience and incomplete knowledge of the systems fitted to G-CTIX led him to believe that the green DOWN indication alone confirmed that the undercarriage was safe.

Safety actions

As part of the repairs and return to service, the Operator has taken the following safety action to standardise the operation and functionality of its Spitfires:

> Individual switches for the undercarriage DOWN position and the warning horn have been replaced with a single switch for both purposes.
>
> A switch has been added to the throttle quadrant so that the undercarriage warning horn will sound if the throttle is closed, flaps are DOWN and the undercarriage position switch is not closed.
>
> Having reviewed the circumstances of the accident, the operator held a safety briefing for its pilots aimed in part at improving their awareness of the various undercarriage operating and indication systems fitted to its aircraft.
>
> Recognising the differences between different marks of the same basic design, and the fact that aircraft have been fitted with a variety of systems that are not necessarily original, the operator intends to provide its pilots with handling notes for each aircraft that correctly describe the systems currently fitted to it.

ACCIDENT

Aircraft Type and Registration:	Cessna 195, N1581D	
No & Type of Engines:	1 Jacobs R-755S piston engine	
Year of Manufacture:	1952	
Date & Time (UTC):	3 January 2019 at 1317 hrs	
Location:	Colestocks, East Devon	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Propeller, fuselage and cockpit glazing damaged	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	47 years	
Commander's Flying Experience:	534 hours (of which 1 were on type) Last 90 days - 2 hours Last 28 days - 2 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The aircraft was being flown from Dunkeswell Airfield to Branscombe Airfield in Devon in good weather with the wind calm, CAVOK and QNH 1004 hPa. Shortly after departure, the engine began to lose power from which it recovered briefly before suffering a total power loss at a position where turning back to the airfield was not an option. The pilot flew towards the lower ground to the west and checked the mixture, throttle and fuel pumps. He moved the fuel tank selector to the left, right and then both tanks in turn and recycled both magnetos, all to no effect. He made an approach to a large field, touching down briefly on the soft ground before allowing the aircraft to fly down the gentle slope and touch down again on a gentle upslope. The wheels began to dig in and, on crossing some slightly firmer ground, the pilot thought that the tail was lowering normally. However, the wheels dug in heavily and the aircraft nosed over onto its back. The pilot was uninjured and able to exit the aircraft through the normal door. No cause for the engine problem was identified. The aircraft is shown at Figure 1.

Figure 1
Cessna 195, N1581D with tail wheel configuration

SERIOUS INCIDENT

Aircraft Type and Registration:	Diamond DA42, N648KM
No & Type of Engines:	2 Thietlert TAE 125-02-99 piston engine
Year of Manufacture:	2007
Date & Time (UTC):	27 November 2018 at 1450 hrs
Location:	En route from Retford Gamston Airport to Weston Airport, Dublin, Ireland
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None reported
Commander's Licence:	Private Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	386 hours (of which 103 were on type) Last 90 days - 64 hours Last 28 days - 6 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

While in the cruise at FL100 the left engine fire warning illuminated. A PAN was declared and a diversion to Liverpool initiated with the assistance of Scottish and Liverpool ATC. During the descent, control of the aircraft was lost while in IMC. The aircraft descended rapidly, and control was recovered as the aircraft reached VMC at approximately 800 ft agl. At this juncture, and at the suggestion of Liverpool ATC, the aircraft diverted to the nearby RAF Woodvale where it landed safely.

History of the flight

The aircraft was on an IFR flight from Gamston to Weston, near Dublin. The planned cruising level was FL100 and icing was forecast. The aircraft is equipped with a fluid anti icing system and is cleared for flight into known icing conditions. The pilot stated he replenished the fluid level prior to departure and that pitot heat was on during the climb. The pilot had been cleared to route direct from DESIG to BAGSO. Approximately 39 nm east of BAGSO the left engine fire warning illuminated. The pilot disengaged the autopilot, retarded the left engine control to idle and began to monitor for smoke or flames. The co-pilot contacted Scottish ATC, informed them of the fire warning and declared a PAN. The crew requested a descent and vectors to land at the nearest airfield.

Scottish ATC suggested a diversion to Liverpool Airport and cleared a descent to 5,000 ft. Scottish ATC asked the crew to Squawk 7700 and then handed the aircraft over to

Liverpool ATC. Liverpool ATC offered vectors for an instrument approach to Runway 09 and cleared the aircraft for further descent. Liverpool ATC also asked the crew about their ability to maintain heading and altitude, concerned at manoeuvring that had not been directed by ATC.

The fire warning persisted during the descent until below 5,000 ft when it cleared briefly before reappearing. Apart from the warning, however, there were no signs of fire. At approximately 3,000 ft the pilot stated that he engaged the autopilot, though he confirmed he had become aware subsequently that autopilot use was not permitted for asymmetric flight. The pilot said he then felt a sudden jolt in the aircraft and the autopilot disengaged. Simultaneously, the slip ball moved rapidly to full scale deflection left and the aircraft pitched sharply nose down.

The aircraft descended rapidly. The pilot stated that he applied full left rudder, neutralised the control column and retarded the good engine to idle thrust. Then he gradually pulled back on the control column. The aircraft reached VMC just southeast of Crosby at approximately 800 ft agl and was recovered to level flight.

Liverpool ATC, concerned at the sudden descent, asked if the aircraft was in VMC and the pilot could see the coast. The crew confirmed that they could. Liverpool ATC then suggested a diversion to RAF Woodvale, as it was closer than Liverpool Airport, or a continued diversion to Liverpool by following the Mersey River. The crew accepted the first option and were passed the Woodvale weather and the tower frequency by Liverpool ATC.

The in-use runway at Woodvale was Runway 08. Woodvale ATC had been informed of the diversion by Liverpool ATC and so were alerted to the arrival of the aircraft. The crew called Woodvale Tower shortly before arrival, when the aircraft was on final approach to Runway 03. The weather was poor and, given the circumstances, Woodvale cleared the aircraft to land on Runway 03, although it was out of use due to a degraded surface. The aircraft landed safely and taxied to the apron under its own power.

It was not established why the fire warning was triggered.

Personnel

The pilot had an FAA PPL with an Instrument Rating. His logbook indicated that he had completed the necessary recency training to operate in IMC and that he had completed the requisite biennial check flight.

Human factors

The pilot was in an unfamiliar, high stress and high workload environment. With asymmetric thrust, the handling of the aircraft is much more challenging than normal and effective control of attitude is more difficult. In asymmetric flight any power changes induce yaw and roll effects which must be corrected to control the flight path. In IMC these additional factors increase the risk of spatial disorientation.

Analysis

Following the fire warning the pilot was in asymmetric flight, with the left engine at idle power. With the fire warning emergency, the unplanned diversion in IMC and the higher than usual workload there were many and significant pressures on the pilot's capacity to operate effectively. The autopilot was disengaged after the fire warning occurred, so the descent was being manually flown. Given the high workload and the difficulties in controlling the aircraft the pilot decided to re-engage the autopilot at approximately 3,000 ft. The autopilot has no yaw channel and therefore is unable to control the effects of asymmetry. Shortly after the autopilot was engaged the pilot reported feeling a sudden jolt and the autopilot disengage. The aircraft then went out of control. It is likely that the autopilot exceeded its operating parameters as a result of the asymmetric condition. With the slip ball deflected left, the aircraft was yawing rapidly right. The secondary effect of the yaw would induce a right roll and it is probable the aircraft entered a spiral dive condition. The pilot took appropriate corrective action and the aircraft was recovered to level flight, albeit at low altitude.

The diversion to Woodvale was flown at low altitude and in poor weather, though VMC. The pilot called Woodvale only shortly before his arrival and was positioned on final approach for Runway 03. While this runway was closed by NOTAM, ATC assessed the surface to be safe and, in the circumstances, allowed the aircraft to land on it.

Conclusion

Control of the aircraft was lost during high stress, high workload flight following an engine fire warning. It is probable that the pilot, operating in very challenging circumstances during the descent, became spatially disorientated. His use of the autopilot in an attempt to manage workload, in fact exacerbated the situation. The pilot was able to recover before terrain impact as the aircraft entered VMC at low altitude.

ACCIDENT

Aircraft Type and Registration:	Europa, G-BVOW
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	1996 (Serial no: PFA 247-12679)
Date & Time (UTC):	27 December 2018 at 1330 hrs
Location:	MOD Boscombe Down, Wiltshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to propeller, windscreen, fuselage and wingtips
Commander's Licence:	Private Pilot's Licence
Commander's Age:	60 years
Commander's Flying Experience:	101 hours (of which 6 were on type) Last 90 days - 6 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot planned to perform some circuits on the grass Runway 35. The weather was fine and the wind was calm. During the takeoff roll, as the airspeed reached approximately 40 kt, the tail lifted and the aircraft began deviating to the left. The pilot reported applying right rudder, but the aircraft continued to deviate to the left, transitioning from the grass to a tarmac section, after which it rotated further to the left. The pilot was wearing a full harness and was uninjured.

Figure 1

G-BVOW after the accident

On this aircraft type, the effect of the propeller slipstream means that right rudder is required to maintain the aircraft heading. Once the aircraft lifts from its tailwheel, it balances only on its mainwheel and this slipstream effect becomes more prominent. The pilot considered that his application of right rudder was insufficient or not quick enough to arrest the deviation to the left.

ACCIDENT

Aircraft Type and Registration:	Piper PA-28-140 Cherokee, G-BAKH
No & Type of Engines:	1 Lycoming O-320-E2D piston engine
Year of Manufacture:	1972 (Serial no: 28-7325014)
Date & Time (UTC):	9 September 2017 at 0835 hrs
Location:	Near City Airport, Manchester
Type of Flight:	Private[1]
Persons on Board:	Crew - 1 Passengers - 3
Injuries:	Crew - 1 (Minor) Passengers - 1 (Serious) 2 (Minor)
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	51 years
Commander's Flying Experience:	15,000 hours (of which 10,000 were on type) Last 90 days - 13 hours Last 28 days - 4 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

The aircraft took off above the certified MTOW from a runway with insufficient takeoff distance available for the prevailing conditions. After takeoff it failed to accelerate or climb and in order to miss a set of overhead power lines ahead the pilot made a forced landing with power in a field.

History of the flight

The pilot was planning to fly three passengers from Manchester City Airport to Oban. There had been a significant amount of rain during the morning at the departure airfield leading to patches of standing water forming. The ATIS advised pilots to avoid the centreline and southern part of Runway 26R, the active runway, and a NOTAM had also been issued advising that further heavy rain might lead to the short notice closure of the airport.

The pilot had fully refuelled the aircraft before departure and waited while a further runway inspection was carried out. The inspection confirmed the runway was very wet and these results were relayed to the pilot. The pilot then requested permission to conduct an accelerate and stop run to check he could make rotate speed within the area available.

Footnote

[1] In subsequent legal action by the Crown Prosecution Service it was determined that the flight was being operated illegally on a commercial basis.

He was cleared to do so and stated that, having successfully managed to achieve rotate speed, he then back-tracked along the runway for takeoff.

The pilot was cleared for takeoff and reported he adopted a short field technique that used two stages of flap. He stated that during the takeoff roll he kept the aircraft to the right of the runway centreline, becoming airborne between half and three quarters along its length. The aircraft was seen by a witness to "crawl" into the air in a nose-high attitude. The pilot further stated that, once airborne, the aircraft failed to climb or accelerate and that it was heading towards an overhead power line situated about 1,400 m beyond the end of Runway 26R. In order to miss the power line he began a left turn, in so doing also avoiding the M62 motorway that ran across the normal take-off flightpath about 600 m beyond the end of the runway. The pilot reported he then carried out a forced landing in the only field available.

The field was planted with potatoes and on landing the aircraft landing gear sunk into the soil, causing it to come to an abrupt stop with the pilot and front-seat passenger both hitting their heads on the instrument panel. The rear seat passengers were also injured in the landing, but all the occupants were able to vacate the aircraft unaided. Despite severe disruption of the left wing there was no fire and the emergency services were in attendance within about ten minutes of the accident.

Engine inspection

An inspection carried out by an independent aircraft engineering company found no significant faults with the engine or ancillaries. It did however find some wear of the camshaft which was described as typical for such an engine. The report quoted from tests carried out by the AAIB during another investigation (G-AVRP AAIB Bulletin 10/2008 ref EW/C2007/08/01) involving the same engine type and estimated there would have been a reduction in available power of 5-8%.

Aircraft weight and balance

The aircraft had a basic weight of 1,370 lbs (621 kg). The pilot had refuelled the aircraft so that it had full tanks prior to departure, giving a total fuel weight, according to the published fuel capacity, of 288 lb (131 kg). The pilot, three passengers and their baggage were all weighed after the accident, giving a total weight of 899 lb (408 kg). Items found in the aircraft weighed 19 lb (9 kg) giving a total takeoff weight for the aircraft of 2,576 lb (1,169 kg).

The actual takeoff weight would have been slightly lower, taking into account the fuel used for the taxi, power check and the accelerate-stop manoeuvre performed prior to the final takeoff.

The maximum takeoff weight (MTOW) for this aircraft, as stated in the Airplane Flight Manual, is 2,150 lbs (975 kg).

The aircraft was within its centre of gravity limits.

Aircraft performance

By reference to the Airplane Flight Manual, the factored takeoff distance required (TODR) for the aircraft at its MTOW of 2,150 lb under the prevailing conditions to achieve a screen height of 50 ft was 2,090 ft. Referring to Civil Aviation Publication (CAP) 1535P, *'The Skyway Code',* to allow for the wet grass this figure would increase by a factor of 1.3 to give a revised TODR of 2,717 ft.

An estimate of the TODR, taking into account the additional weight above MTOW, gives a TODR of 3,912 ft (1,192 m). The UK Aeronautical Information Publication gave a declared Take Off Distance Available (TODA) for Runway 26R of 641 m.

Analysis

The aircraft was significantly overweight when it took off. With the four occupants and their baggage on board, the aircraft was already overweight before the uplift of any fuel. The TODR was also nearly double the TODA of the runway in use.

The takeoff technique used is not described in the Airplane Flight Manual although it is a used by some pilots to reduce the takeoff run required. The high nose attitude witnessed and the additional flap selected would have created significant drag and with the aircraft already at slow speed would have made acceleration difficult without reducing the aircraft's attitude, something that may have been counter-intuitive at such a low altitude.

The condition of the engine would have contributed to the aircraft's inability to accelerate and climb, but such was the level of overloading and lack of runway length available it is likely the outcome would have been the same had it been performing without any power loss at all.

It is possible that without the presence of the power line the pilot might have been able to gradually accelerate the aircraft, but this would have led to the aircraft passing low over the adjacent motorway. As it was, the pilot had no practical option other than to turn away from the pylon line and motorway, further reducing the opportunity to accelerate and leading to the forced landing in the field.

ACCIDENT

Aircraft Type and Registration:	Socata TB20 Trinidad, G-BMIX	
No & Type of Engines:	1 Lycoming IO-540-C4D5D piston engine	
Year of Manufacture:	1985 (Serial no: 579)	
Date & Time (UTC):	7 February 2019 at 1734 hrs	
Location:	Dundee Airport	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to left main landing gear oleo	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	59 years	
Commander's Flying Experience:	808 hours (of which 229 were on type) Last 90 days - 5 hours Last 28 days - 1 hour	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Synopsis

The aircraft, whilst taxiing at night at Dundee Airport, departed the right side of Taxiway E at the point where the taxiway curves to the left prior to joining the main apron. The aircraft's left main landing gear oleo was damaged as it rolled over the paved edge of the main apron. A contributory factor in the pilot's loss of situational awareness of his position on Taxiway E may have been his loss of sight of the taxiway edge lights against the brightly-lit main apron. Excessive taxiing speed may have also been a contributing factor.

History of the flight

The pilot, accompanied by one passenger, intended to fly the aircraft from Dundee Airport to Aberdeen Airport. The aircraft was parked outside the maintenance facility on a grass apron and having started the aircraft, the pilot requested taxi instructions. He was instructed by ATC to taxi to the south side of the main apron, via Taxiway E (Figure 1), for pre-departure checks. The pilot was a regular visitor to Dundee Airport and stated that he had used Taxiway E on many occasions. It was dark when the aircraft started to taxi, with sunset having occurred at 1655 hrs.

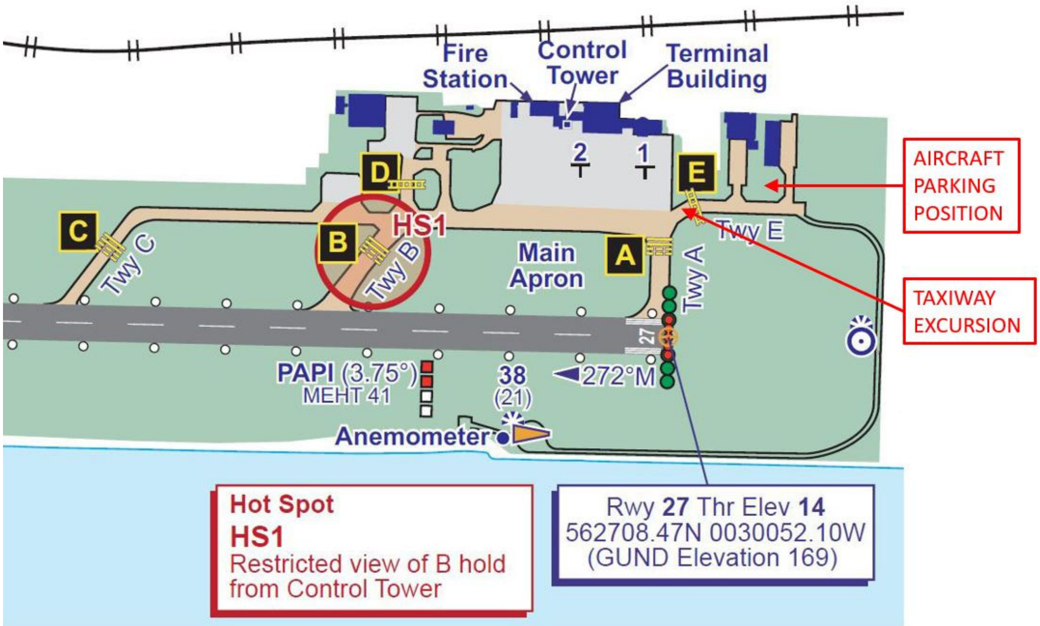

Figure 1

Dundee Airport main apron and taxiway E (adapted from UK AIP)

The pilot taxied from the grass apron onto Taxiway E and proceeded towards the main apron. As the aircraft approached the main apron, the pilot described feeling that the aircraft went over a depression in the taxiway, followed by a loud bang, which he thought was one of the landing gear oleos bottoming out. He continued to taxi to the south side of the main apron when ATC called the pilot to state that they had heard a loud bang from the aircraft. The pilot stopped the aircraft and shut it down to investigate possible damage. The aircraft was attended by members of the AFRS and it was apparent that the left main landing gear oleo was damaged, caused by the aircraft departing Taxiway E and over-running the edge of the main apron.

A witness, who was familiar with both daytime and night aircraft operations on Taxiway E, observed the aircraft taxying and stated that in his opinion, the aircraft's taxying speed was excessive.

Accident site and aircraft damage

Witness marks made by the aircraft as it departed Taxiway E showed that it had continued taxying straight and had not turned left along the curved portion of the taxiway where it met the main apron, Figure 2.

Figure 2

Witness marks made by G-BMIX following departure from Taxiway E
(photo used with permission)

The left main landing gear leg had sunk into the grass beyond Taxiway E and had then been subjected to an overload when the aircraft rode over the paved edge of the main apron. The overload caused the left main landing gear oleo to burst, Figure 3, releasing hydraulic fluid from the oleo. No other damage to the aircraft occurred during the accident.

Figure 3

Damage to the left main landing gear oleo
(photo used with permission)

Airfield information

The layout of taxiways and the main apron area at Dundee Airport is accurately depicted in the UK AIP aerodrome chart. Taxiway E is marked with a yellow painted centreline and the edges of the taxiway are marked with blue edge lights whose spacing and luminance comply with CAA publication CAP168 *'Licensing of Aerodromes'*.

Human factors

The pilot stated that in his opinion, heading towards the brightly-lit main apron area along Taxiway E at night reduced the conspicuity of the blue taxiway edge lights, contributing to a loss of situational awareness of his position on the curved section of Taxiway E. He further stated that in daylight it was clear that the taxiway had a slight left turn as it joins the main apron.

Discussion

The aircraft, whilst taxying at night at Dundee Airport, departed the right side of Taxiway E at the point where the taxiway curves to the left prior to joining the main apron. The taxiway was appropriately marked and the edges lit with blue lights. It is possible that the pilot lost sight of the taxiway edge lights against the brightly-lit main apron, and despite his familiarity of Taxiway E during daylight, that this led to the aircraft continuing to taxi straight ahead and consequently departing from the curved section of taxiway. Excessive taxying speed may have also been a contributing factor.

Safety actions

Dundee Airport conducted an investigation into the event and plan to take two actions resulting from their investigation. A taxi speed limit is to be inserted into the warnings section of the textual data of the AIP document for Dundee Airport. The airport also plans to reduce the severity of the lip between the grass and the main apron surface at the point where Taxiway E joins the main apron.

ACCIDENT

Aircraft Type and Registration:	EV-97 Teameurostar UK, G-CETT
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	2007 (Serial no: 3006)
Date & Time (UTC):	10 April 2019 at 1400 hrs
Location:	Carrickmore Airfield, County Tyrone
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damaged beyond economical repair
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	51 years
Commander's Flying Experience:	220 hours (of which 220 were on type) Last 90 days - 20 hours Last 28 days - 5 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot was making an approach to land on Runway 08 at Carrickmore Airfield when he encountered turbulent air. The aircraft began to sink which the pilot corrected by applying more power. The aircraft then encountered lift before once again sinking towards the runway. Fearing that the aircraft could stall, the pilot pushed the stick forward and the aircraft landed heavily. The aircraft slewed to the right contacting a metal gate post and damaging the aircraft beyond economical repair. Although the pilot felt there was little more he could have done to prevent the heavy landing, he did comment that perhaps committing to a go-around when the sink was first encountered might have been a better option.

ACCIDENT

Aircraft Type and Registration:	Ikarus C42 FB100, G-CIIN	
No & Type of Engines:	1 Rotax 912 ULS piston engine	
Year of Manufacture:	2014 (Serial no: 1407-7344)	
Date & Time (UTC):	23 March 2019 at 1030 hrs	
Location:	Tandragee Airstrip, Craigavon, County Armagh	
Type of Flight:	Training	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to right landing gear and nosewheel	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	63 years	
Commander's Flying Experience:	1,638 hours (of which 1,636 were on type) Last 90 days - 16 hours Last 28 days - 2 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

During a training flight to practice circuits, the instructor reported that the student pilot was having difficulty with rounding out and holding off during landing. He considered that the presence of a slight crosswind may have contributed to the student's difficulties. The instructor decided to demonstrate the correct procedure so that the student could get the correct visual "picture". As the instructor was holding off, the aircraft landed hard and the right landing gear collapsed, causing the aircraft to veer to the right.

The instructor immediately turned off the magnetos to stop the engine and the aircraft came to rest on the edge of a river bank, to the right side of the grass runway. After turning off the master switch and the fuel valve, the instructor and his student, neither of whom had sustained injury, exited the aircraft. Shortly thereafter, the nosewheel collapsed and the aircraft slid a short distance down the river bank. The emergency services were notified by passers-by but did not attend the scene after being assured by the instructor and an off-duty paramedic that there were no injuries or fuel leaks.

The instructor considered that the nosewheel collapse may have been a result of the side loads imposed on it after the right landing gear collapsed or when it entered the soft ground at the edge of the river bank.

ACCIDENT

Aircraft Type and Registration:	MCR-01 ULC Banbi, G-HARD
No & Type of Engines:	1 Rotax 912ULS piston engine
Year of Manufacture:	2007 (Serial no: PFA 301B-14427)
Date & Time (UTC):	18 October 2018 at 0820 hrs
Location:	Eshott Airfield, Northumberland
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Minor) Passengers - N/A
Nature of Damage:	Damage to engine, landing gear, fuselage cockpit, and wings
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	58 years
Commander's Flying Experience:	152 hours (of which 88 hours were on type) Last 90 days - 7 hours Last 28 days - 6 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot took off in G-HARD intending to complete an hour of flying including some circuits at the airfield. On his second circuit, the pilot decided to practise a go-around. Having reduced power for the flare just above the runway, the pilot then applied power for the go-around. The aircraft initially yawed left and failed to climb. The pilot pulled back further on the stick and checked that the engine was delivering power. Before he could adjust the controls further, however, the aircraft struck the ground to the left of the runway. The aircraft came to an abrupt halt and the pilot struck his head on the top of the instrument panel. He was able to vacate the aircraft without assistance although he was bleeding from a head wound.

Examination of the aircraft after the accident revealed that the pilot's seat had partially detached from its mountings, and the shoulder harness had failed at the stitched joint connecting the shoulder straps to the harness' rear restraining belt. The Light Aircraft Association decided to conduct tests into the suitability of this automotive type of seat belt.

ACCIDENT

Aircraft Type and Registration:	Quik GT450, G-PVSS
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	2007 (Serial no: 8302)
Date & Time (UTC):	20 January 2019 at 12:30 hrs
Location:	Northrepps Aerodrome, Norfolk
Type of Flight:	Training
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to wing, fuselage pod and propeller
Commander's Licence:	Student
Commander's Age:	66 years
Commander's Flying Experience:	36 hours (of which 36 were on type) Last 90 days - 3 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

After completing a short flight under instruction, the pilot was authorised to complete a short solo flight. The flight and initial touchdown were uneventful but, after the touchdown, the pilot noticed that the aircraft was turning to the left. The pilot attempted to bring the aircraft back on track but over-corrected, which resulted in the aircraft rolling onto its left side, damaging the wing, the fuselage pod and the propeller. At the time of the accident the pilot had acquired approximately five hours of solo flying time.

ACCIDENT

Aircraft Type and Registration:	Rotorsport UK Calidus, G-CGOT
No & Type of Engines:	1 Rotax 914-UL piston engine
Year of Manufacture:	2010 (Serial no: RSUK/CALS/008)
Date & Time (UTC):	12 February 2019 at 1200 hrs
Location:	Leicester Airport, Leicestershire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Minor) Passengers - N/A
Nature of Damage:	Damage to rotor assembly, airframe and tailplane
Commander's Licence:	Private Pilot's Licence
Commander's Age:	62 years
Commander's Flying Experience:	434 hours (of which 383 were on type) Last 90 days - 11 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot was departing from Leicester Airport having flown in earlier that morning. He taxied along Runway 04 with the intention of stopping at the hold for Runway 28 but overshot, such that the rotor tip was approximately 2/3 m away from the runway.

On contacting the tower for departure information, he was given the wind direction and speed. He checked it was safe to enter the runway and saw an aircraft on final approach to Runway 28. There had been no mention of this aircraft when he was given the wind conditions and he had not heard a final approach call on the radio.

The pilot of G-CGOT heard a radio transmission that the other pilot was intending to perform a touch-and-go before "he made a radio call and berated me for being in the active area and then complained that he now had to go around again".

The pilot of G-CGOT apologised, before checking the approach and transmitting his intention to line up for an immediate departure. He engaged the pre-rotator and applied a small amount of power, but on checking the rotor speed he realised he had applied too much power and the clutch was slipping. The pilot reported that it should have been possible to build up the rotor speed on the runway, but the blades began to sail and struck the ground. The aircraft veered to the left and almost rolled over before coming to rest upright.

Miscellaneous

This section contains Addenda, Corrections and a list of the ten most recent Aircraft Accident ('Formal') Reports published by the AAIB.

The complete reports can be downloaded from the AAIB website (www.aaib.gov.uk).

TEN MOST RECENTLY PUBLISHED FORMAL REPORTS ISSUED BY THE AIR ACCIDENTS INVESTIGATION BRANCH

2/2014 Eurocopter EC225 LP Super Puma G-REDW, 34 nm east of Aberdeen, Scotland on 10 May 2012
and
G-CHCN, 32 nm south-west of Sumburgh, Shetland Islands on 22 October 2012.

Published June 2014.

3/2014 Agusta A109E, G-CRST Near Vauxhall Bridge, Central London on 16 January 2013.

Published September 2014.

1/2015 Airbus A319-131, G-EUOE London Heathrow Airport on 24 May 2013.

Published July 2015.

2/2015 Boeing B787-8, ET-AOP London Heathrow Airport on 12 July 2013.

Published August 2015.

3/2015 Eurocopter (Deutschland) EC135 T2+, G-SPAO Glasgow City Centre, Scotland on 29 November 2013.

Published October 2015.

1/2016 AS332 L2 Super Puma, G-WNSB on approach to Sumburgh Airport on 23 August 2013.

Published March 2016.

2/2016 Saab 2000, G-LGNO approximately 7 nm east of Sumburgh Airport, Shetland on 15 December 2014.

Published September 2016.

1/2017 Hawker Hunter T7, G-BXFI near Shoreham Airport on 22 August 2015.

Published March 2017.

1/2018 Sikorsky S-92A, G-WNSR West Franklin wellhead platform, North Sea on 28 December 2016.

Published March 2018.

2/2018 Boeing 737-86J, C-FWGH Belfast International Airport on 21 July 2017.

Published November 2018.

Unabridged versions of all AAIB Formal Reports, published back to and including 1971, are available in full on the AAIB Website

http://www.aaib.gov.uk

GLOSSARY OF ABBREVIATIONS

aal	above airfield level
ACAS	Airborne Collision Avoidance System
ACARS	Automatic Communications And Reporting System
ADF	Automatic Direction Finding equipment
AFIS(O)	Aerodrome Flight Information Service (Officer)
agl	above ground level
AIC	Aeronautical Information Circular
amsl	above mean sea level
AOM	Aerodrome Operating Minima
APU	Auxiliary Power Unit
ASI	airspeed indicator
ATC(C)(O)	Air Traffic Control (Centre)(Officer)
ATIS	Automatic Terminal Information Service
ATPL	Airline Transport Pilot's Licence
BMAA	British Microlight Aircraft Association
BGA	British Gliding Association
BBAC	British Balloon and Airship Club
BHPA	British Hang Gliding & Paragliding Association
CAA	Civil Aviation Authority
CAVOK	Ceiling And Visibility OK (for VFR flight)
CAS	calibrated airspeed
cc	cubic centimetres
CG	Centre of Gravity
cm	centimetre(s)
CPL	Commercial Pilot's Licence
°C,F,M,T	Celsius, Fahrenheit, magnetic, true
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DME	Distance Measuring Equipment
EAS	equivalent airspeed
EASA	European Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitoring
EGPWS	Enhanced GPWS
EGT	Exhaust Gas Temperature
EICAS	Engine Indication and Crew Alerting System
EPR	Engine Pressure Ratio
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
FAA	Federal Aviation Administration (USA)
FIR	Flight Information Region
FL	Flight Level
ft	feet
ft/min	feet per minute
g	acceleration due to Earth's gravity
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
hrs	hours (clock time as in 1200 hrs)
HP	high pressure
hPa	hectopascal (equivalent unit to mb)
IAS	indicated airspeed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IP	Intermediate Pressure
IR	Instrument Rating
ISA	International Standard Atmosphere
kg	kilogram(s)
KCAS	knots calibrated airspeed
KIAS	knots indicated airspeed
KTAS	knots true airspeed
km	kilometre(s)
kt	knot(s)
lb	pound(s)
LP	low pressure
LAA	Light Aircraft Association
LDA	Landing Distance Available
LPC	Licence Proficiency Check
m	metre(s)
mb	millibar(s)
MDA	Minimum Descent Altitude
METAR	a timed aerodrome meteorological report
min	minutes
mm	millimetre(s)
mph	miles per hour
MTWA	Maximum Total Weight Authorised
N	Newtons
N_R	Main rotor rotation speed (rotorcraft)
N_g	Gas generator rotation speed (rotorcraft)
N_1	engine fan or LP compressor speed
NDB	Non-Directional radio Beacon
nm	nautical mile(s)
NOTAM	Notice to Airmen
OAT	Outside Air Temperature
OPC	Operator Proficiency Check
PAPI	Precision Approach Path Indicator
PF	Pilot Flying
PIC	Pilot in Command
PM	Pilot Monitoring
POH	Pilot's Operating Handbook
PPL	Private Pilot's Licence
psi	pounds per square inch
QFE	altimeter pressure setting to indicate height above aerodrome
QNH	altimeter pressure setting to indicate elevation amsl
RA	Resolution Advisory
RFFS	Rescue and Fire Fighting Service
rpm	revolutions per minute
RTF	radiotelephony
RVR	Runway Visual Range
SAR	Search and Rescue
SB	Service Bulletin
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TAF	Terminal Aerodrome Forecast
TAS	true airspeed
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Collision Avoidance System
TODA	Takeoff Distance Available
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
USG	US gallons
UTC	Co-ordinated Universal Time (GMT)
V	Volt(s)
V_1	Takeoff decision speed
V_2	Takeoff safety speed
V_R	Rotation speed
V_{REF}	Reference airspeed (approach)
V_{NE}	Never Exceed airspeed
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional radio Range

AAIB
Air Accidents Investigation Branch