SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-800, G-JZHL
No & Type of Engines:	2 CFM CFM56-7B26E turbofan engines
Year of Manufacture:	2016 (Serial no: 63568)
Date & Time (UTC):	1 December 2021 at 1452 hrs
Location:	Kuusamo Airport, Finland
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	44 years
Commander's Flying Experience:	7,459 hours (of which 3,344 were on type) Last 90 days - 204 hours Last 28 days - 47 hours
Information Source:	AAIB Field Investigation

Synopsis

This investigation was delegated to the AAIB by the Safety Investigation Authority of Finland.

During takeoff from Kuusamo Airport in Finland the flight crew inadvertently left the thrust set at the 70% engine run-up setting rather than the 89% required for takeoff. The aircraft became airborne with 400 m of runway remaining and climbed away slowly. At 250 ft agl the flight crew realised they had insufficient thrust and applied the correct power. The flight continued without further incident.

The thrust was not set correctly because the TOGA button was not pressed. It was not pressed because the co-pilot was startled by the aircraft starting to move when he set 70% power against the brakes. The aircraft started to move because the co-pilot applied insufficient brake pressure. The commander was distracted by a radio call and neither he, nor the co-pilot, checked the thrust was correctly set.

The AAIB has investigated several takeoff performance incidents across the industry. This incident is further evidence that the current barriers designed to prevent these events are not fully effective, and improved reliability is likely only through the introduction of a technical barrier. A Safety Recommendation is therefore made to develop technical specifications and, ultimately, certification standards for a technical solution.

A Safety Recommendation is also made to improve the detection of takeoffs with compromised performance, to support the prompt reporting of occurrences.

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History of the flight

The crew were scheduled to operate return flights from London Stansted Airport to Kuusamo Airport (Kuusamo) in Finland. Neither pilot was working on the day prior to the flights but each took time to revise the cold weather and contaminated runway procedures and read the briefing material for Kuusamo. On the day of the incident the crew reported at Stansted at 0915 hrs.

The outbound flight was uneventful. The flight crew used some quiet time during the cruise to discuss the departure from Kuusamo. The weather in Kuusamo was a light wind from the north-east, light snow and a temperature of -8°C. The runway was covered with 3 mm of dry snow and the airfield was reporting a Runway Condition Code (RWYCC) of 4[1]. The aircraft landed on Runway 30, arriving on stand a few minutes ahead of schedule.

Once the passengers had disembarked the crew prepared for the return sector. There were no passengers for the return flight leaving just the two pilots and four cabin crew onboard. As the wind was still across the runway, they planned to depart from Runway 12 using intersection A (Figure 1). The takeoff weight was 52,100 kg with 9,600 kg of fuel. The airfield conditions were unchanged so the crew completed a takeoff performance calculation using medium to good braking action and derated takeoff thrust. The calculation gave Flap 5, an N_1 of 89.0%, a V_1 of 93 kt, a V_R of 122 kt and a V_2 of 131 kt which was loaded into the FMC and Mode Control Panel (MCP). The crew obtained their clearance and briefed for the takeoff whilst the aircraft was de-iced. The clearance was, after departure, to route via waypoint IBEVU and climb to FL400. The co-pilot was to be the pilot flying. As the ramp was contaminated with snow the crew planned to taxi with the flaps up, selecting them before lining-up on the runway. The conditions required a pre-takeoff engine run-up to clear any ice from the engines. This required the engines to be accelerated to 70% N_1 on the runway for 30 seconds whilst the aircraft was held on the brakes.

Kuusamo Airport either provides an Air Traffic Control service (ATC) or a Flight Information Service (FIS) depending on the expected volume of traffic. During the initial arrival an ATC service was provided but this switched to a FIS shortly before the aircraft landed. A FIS was still being provided when the aircraft departed.

The crew started the engines on stand and, once all the checks were completed, requested taxi instructions. They were instructed to taxi onto the runway and asked to report ready for departure. The commander taxied the aircraft the short distance from the parking position to the runway whilst the co-pilot completed the before takeoff procedure and checklist including selecting the flaps to 5. Once lined-up on the runway the commander handed control to the co-pilot. The crew reported they were ready for departure and the Flight Information Service Officer (FISO) replied the runway was clear and reported the surface

Footnote

[1] Runway Condition Code is part of the new Global Reporting Format for assessing and reporting runway surface conditions. RWYCC 4 means that braking deceleration or directional control is between Good and Medium; and pilot reports of runway braking action are Good to Medium. For further information, see: https://www.caa.co.uk/commercial-industry/airports/safety/runways/new-contaminated-runway-reporting-system/ [accessed July 2022].

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wind. The co-pilot then advanced the thrust levers to 70% N_1 whilst holding the toe brakes. However, as he did this, he felt the aircraft start to slide and yaw. The crew had briefed that this might happen and had agreed that if it did, they would release the brakes and continue the takeoff. The co-pilot recalled saying something like "it's sliding" and the commander replied with words like "let it go". The co-pilot recalled that he was startled by how readily the aircraft had slid and yawed and by the proximity of the snowbanks to the side of the runway. He released the brakes and focused on steering the aircraft down the runway. He remembered working quite hard with the rudder pedals to keep the aircraft straight.

Figure 1
Kuusamo Airport

As the co-pilot was advancing the thrust levers to 70% the commander had selected the secondary engine instruments to be displayed on the lower centre screen (with his right hand). He held his finger over the button ready to clear the display after the run-up was complete. At the same time, he was ready to start his timer with his left hand to time the 30 second run-up.

To set the takeoff thrust, the operator's Standard Operating Procedures (SOPs) require the co-pilot to press the TOGA button then immediately remove their hand from the thrust levers. The commander is then required to place their hand on the thrust levers until V_1. On this occasion, due to the startle of the aircraft sliding, the co-pilot omitted to press the TOGA button and removed his hand from the thrust levers leaving the thrust set at 70% N_1.

Whilst this was happening and as the aircraft was starting to move, the FISO made a transmission to the aircraft asking for them to confirm they would be turning right after departure. The commander replied to confirm they would, but this exchange distracted him and he omitted to check that the thrust was correctly set and did not make the "thrust set" standard call. The co-pilot was focussing on steering the aircraft along the runway and, similarly, did not confirm the thrust was set.

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By this stage the aircraft was approaching 80 kt. The commander reported that he was aware that something was not right but could not resolve what was wrong. He felt the acceleration was slightly low but thought that might be due to the contamination on the runway. The crew made the normal calls at 80 kt and this was shortly followed by V_1 at 93 kt. The takeoff continued and both pilots reported being aware that something was not right. The co-pilot initiated the rotation at V_R but recalled the aircraft was "very heavy" in pitch. As he looked down to the Primary Flight Display (PFD), he realised there was no vertical flight director so he focused on flying a pitch attitude to maintain airspeed. He recalled the aircraft was not climbing normally and the airspeed was hovering around V_2, he described that "it felt like flying an engine failure on takeoff in the simulator". The co-pilot remembered saying "we need more power". At this stage the commander realised they did not have takeoff power set and manually advanced the thrust levers to 89% N_1. On reaching 2,400 ft amsl they selected N1 on the MCP to reduce to climb power then, as the aircraft passed 3,900 ft amsl, started to accelerate and retract the flaps. Once clean they selected LVL CHG[2] which restored the vertical flight director. The remainder of the flight to Stansted continued without further incident.

Recorded information

G-JZHL was fitted with a CVR capable of recording the last two hours of the flight but, due to the length of the return flight, the recording would have been overwritten before the aircraft landed at Stansted. However, data was available from both the FDR and Quick Access Recorder, which were downloaded. The data showed that the crew had correctly loaded the FMC for the derated takeoff, resulting in a target engine N_1 of 89%.

Figure 2 shows salient data from the FDR for the takeoff and second segment climb. It shows that, although the maximum system braking pressure is 3,000 psi, a brake pressure of only 600-700 psi was applied before the thrust levers were slowly advanced for the pre-takeoff engine run-up. Twelve seconds later, as the engines were spooling up towards 70% N_1, and with 600-700 psi brake pressure still applied, the recorded longitudinal acceleration shows that G-JZHL began to move. The brakes were then released, and the engines stabilised at 70% N_1. G-JZHL accelerated and, on passing 6 kt groundspeed, a radio transmission was made from the aircraft, followed by another transmission at 53 kt airspeed. At 80 kt airspeed, G-JZHL was accelerating at approximately 0.12g, or 2.25 kt/second, and attained $V_{1,}$ with the engines still at 70% $N_{1,}$ 32 seconds after brake release. At V_R, the aircraft was rotated for takeoff, leaving the ground six seconds later and establishing a 600 ft/min rate of climb in which the airspeed settled around V_2. However, G-JZHL did not accelerate any further, despite the pitch attitude of the aircraft being reduced and the retraction of the landing gear, until 250ft agl when the thrust levers were advanced to 89% N_1, the correct power setting for the takeoff.

Footnote

[2] Level Change: an autopilot flight director mode for changing altitude or Flight Level.

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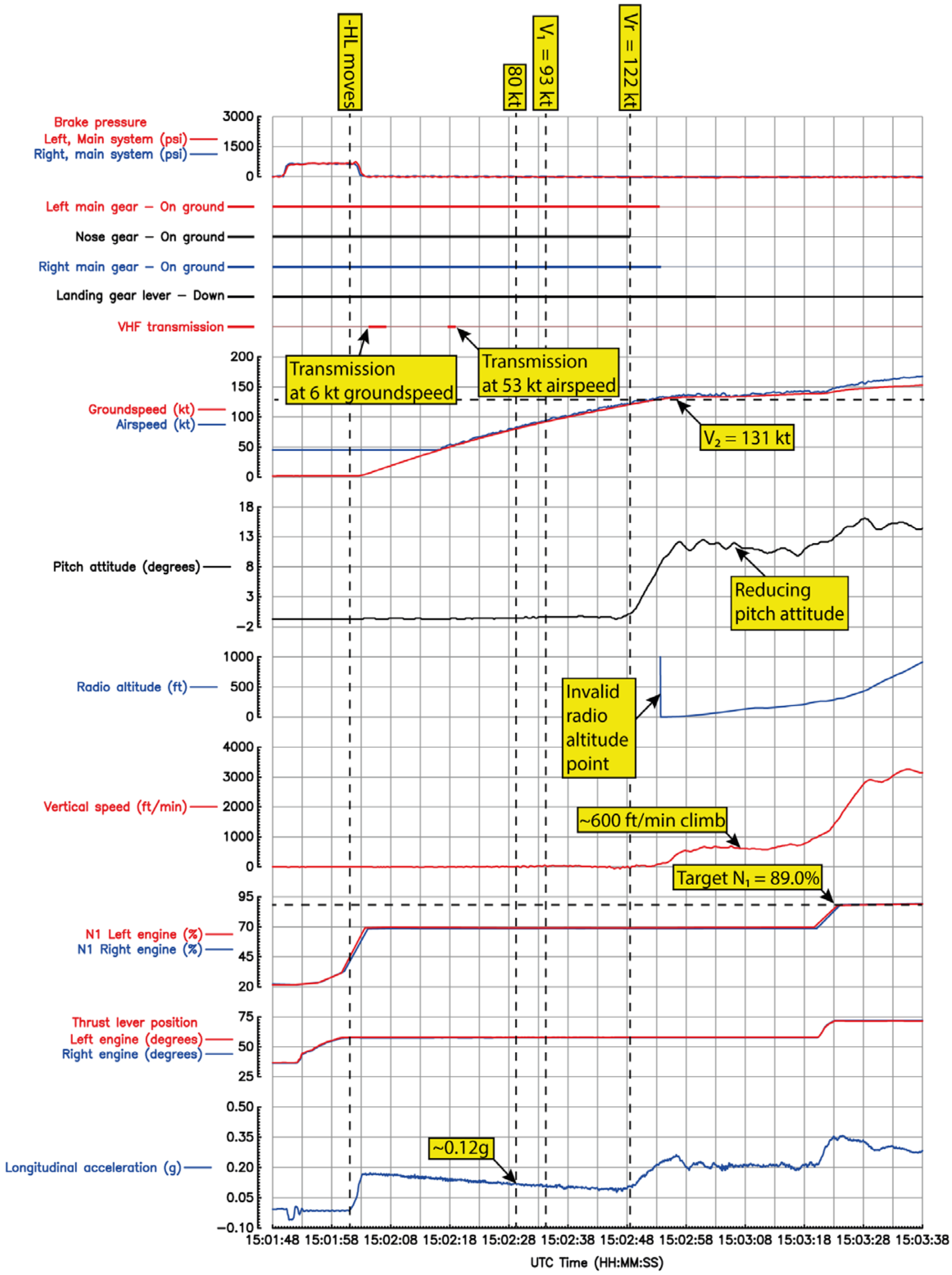

Figure 2

FDR data for G-JZHL's takeoff and second segment climb

Figure 3 shows the takeoff and second segment climb in plan view. The distance from where G-JZHL performed the pre-takeoff engine run-up until the end of the runway is 2,330 m. G-JZHL passed 80 kt with 1,790 m of runway remaining ahead of the aircraft and, at V_1, 1,510 m remained ahead of the aircraft. G-JZHL became airborne 400 m from the end of the runway, and the thrust was restored to 89% N_1 approximately 1,800 m after G-JZHL lifted off.

The FDR data also showed that no EGPWS cautions or warnings were triggered.

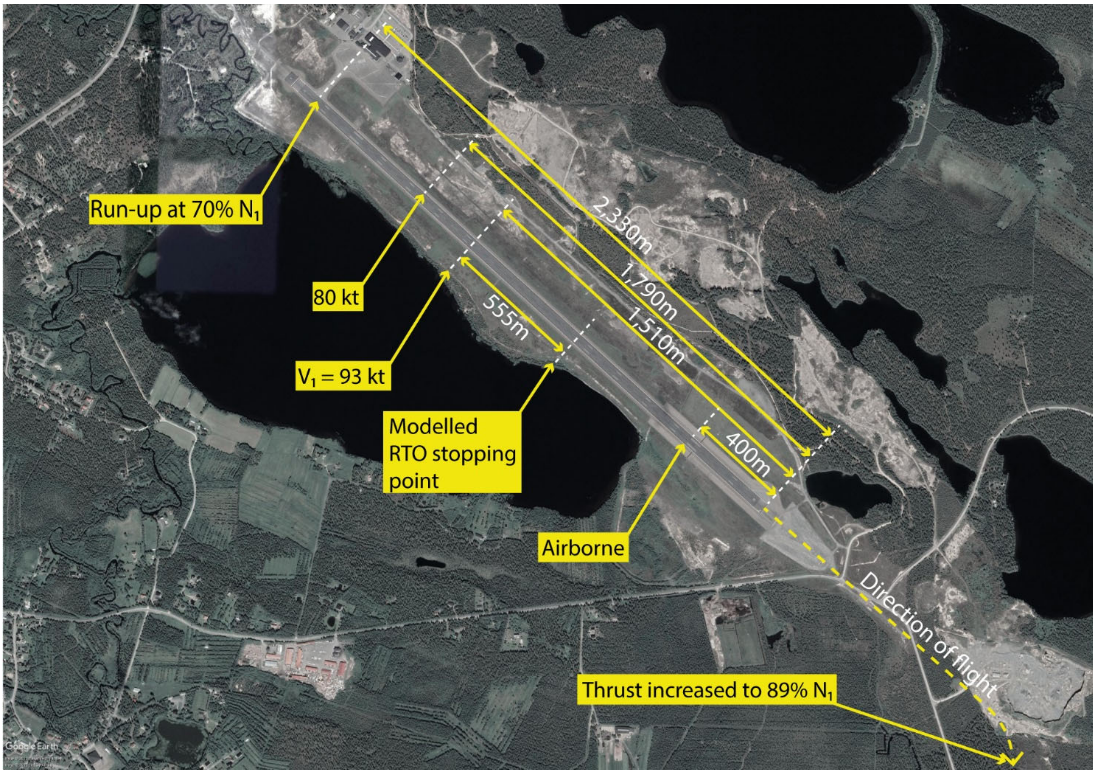

Figure 3

Plan view of G-JZHL's takeoff and second segment climb

No radar or RTF recordings were available for G-JZHL's departure, as Kuusamo Airport is not equipped with a local radar installation and their RTF recording equipment had not been working since 23 September 2021. The RTF recording equipment was subsequently repaired on 9 December 2021, and the maintainer introduced weekly serviceability checks.

Manufacturer's performance modelling

Wheel speed is not a parameter recorded by the FDR, so the aircraft's manufacturer was asked to estimate the brake pressure needed, given a RWYCC of 4, to stop the wheels from rotating against an engine power setting of 70% N_1, the power setting used for the pre-takeoff engine run-up. The manufacturer responded that for G-JZHL, which was equipped with carbon rather than steel brakes, 1,000-2,000 psi would be required dependent on the brake temperature and, to a lesser extent, the humidity of the air. This range of values is substantially higher than the braking pressure observed during G-JZHL's run-up. Furthermore, the manufacturer commented that given the aircraft's weight and centre of gravity and the runway condition, it is unlikely that the tyres would have slipped on the runway's surface.

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The manufacturer also carried out several performance studies and these confirmed that in the event of a rejected takeoff (RTO), commenced at V_1 and using maximum braking effort, the aircraft would have been able to stop within 555 m, leaving 955 m of remaining runway ahead of the aircraft.

However, if G-JZHL had suffered an engine failure close to V_1 and continued the takeoff without any further adjustment to the engine power setting, the aircraft would have left the end of runway, having not attained the scheduled rotation speed, at a groundspeed of 115 kt.

The manufacturer's studies also showed that using 70% N_1 resulted in a total engine thrust at the start of G-JHZL's takeoff roll of approximately 22,800 lbf, or 53% of the 42,800 lbf expected if 89% N_1 had been used – little more than the thrust of a single operative engine.

Airfield and air traffic service information

Kuusamo Airport has a single runway, which is orientated 12/30 and is 2,500m long. The parking apron is at the north-western end of the runway and is accessed via intersection A. The airport elevation is 868 ft amsl.

The insert in Figure 1 shows the location of the airport, which is approximately 10 nm from the boundary between Helsinki and St Petersburg Flight Information Regions (FIR). Figure 4 is an extract from the IFR plates used by the operator. The chart shows the proximity of the border (in green) and the waypoint IBEVU which the crew were cleared to route via after departure. There is a restricted area (R100) along the border and a danger area to the north (D200). These are depicted on the IFR chart (Figure 4) but are shown more clearly in Figure 5 (this was not available to the flight crew in flight). The danger area exists from the surface to 1,000 ft agl, but the restricted area covers all altitudes.

During the incident departure the airport was providing a FIS. The service provided changes between ATC and FIS depending on the expected volume of traffic. NOTAMs are issued to inform flight crews which service to expect.

Generally, a FISO can only provide advice and information useful for the safe and efficient conduct of a flight. A FISO is not permitted to issue instructions or clearances to an aircraft in flight of their own volition (they can pass on clearances issued by other agencies). However, they can issue instructions to aircraft on the apron. At Kuusamo Airport, the FISO could instruct the aircraft to taxi to the runway but could not issue a takeoff clearance. Instead, they report the runway is clear, the commander can then takeoff at their discretion.

On the incident flight, when the flight crew advised they were ready for departure, the FISO told them the runway was clear and the flight crew replied that they were taking off. The FISO expected the flight crew to confirm their intended routing after takeoff, but as they did not do this, she asked the flight crew to confirm they would turn right.

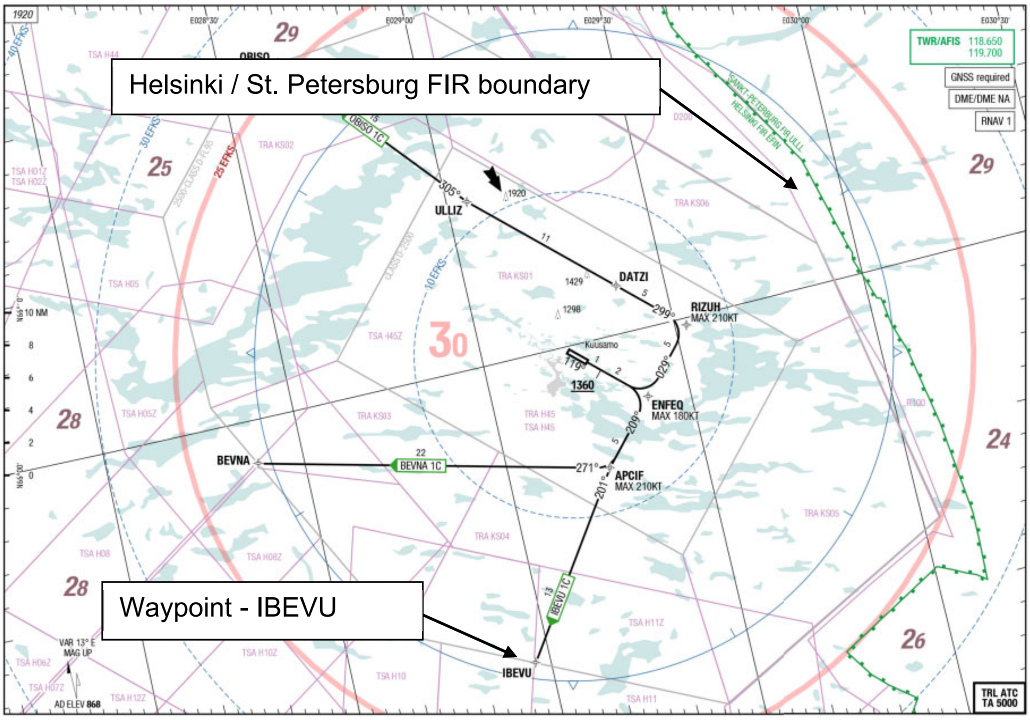

Figure 4

IFR Departure Chart for Kuusamo Airport

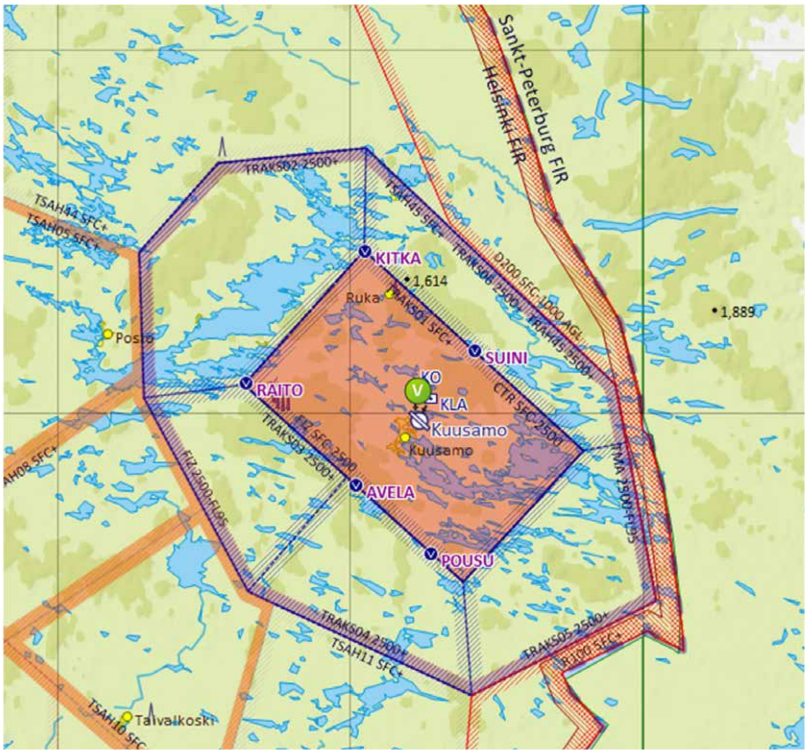

Figure 5

Airspace surrounding Kuusamo Airport

The Airport Operational Information section of the operator's IFR charts for Kuusamo contains the note '*aircraft with a MTOW exceeding 2000kg: after TKOF from RWY 12 turn right'* (the note is extracted from the Finnish Aeronautical Information Publication (AIP)). The flight crew had also been cleared via a waypoint to the south of the airport. They, therefore, intended to turn right but were not aware of any obligation or requirement for them to report this to the FISO.

The Standardised European Rules of the Air (SERA)[3] Section 3, *General rules and collision avoidance*, (SERA.3225) states:

> *'An aircraft operated on or in the vicinity of an aerodrome shall:* […] *(c) except for balloons, make all turns to the left, when approaching for a landing and after taking off, unless otherwise indicated, or instructed by ATC.'*

The Finnish AIP[4] Part GEN 3.3 contains information about air traffic services. Section 3.1 describes operations at Finnish airport where Aerodrome Flight Information Services (AFIS) are provided. Section 3.1.4.1 stated that:

> *'Departing aircraft shall report* […] *the planned route or the flight track and a possible intention to make a right turn.'*

This is followed by a note which states:

> *'According to The Rules of the Air, an aircraft may make turns to the right after takeoff* […] *where Aerodrome Flight Information is available providing that this can be done without hazard to other air traffic and the intention to turn right is reported to the AFIS unit.'*

The FISO reported that local flight crew who regularly fly to Kuusamo always confirm they will turn right when they report they are taking off. The FISO's understanding was that, because the SERA rules states that aircraft should normally turn left after takeoff and the Finnish AIP states that aircraft must report their intentions if they plan to turn right, the commander would report that he intended to turn right. When the commander did not report this, the FISO felt she was required to clarify his intentions, in part due to the proximity of the restricted and danger area ahead and to the left.

Once the aircraft is airborne, the FISO is not allowed to issue any instruction to the aircraft and, as there is no radar at Kuusamo and it was dark, there is no way for them to confirm the aircraft's routing. When an ATC service is being provided the controller can clear an aircraft to fly a particular standard instrument departure (SID). This removes any ambiguity about the aircraft's routing after departure. However, a FISO is not able to issue a SID clearance.

The FISO reported that they could see that the aircraft had commenced its takeoff roll (view from the tower at a similar time of day is shown in Figure 6).

Footnote

3 SERA regulations are available at https://www.easa.europa.eu/document-library/easy-access-rules/easy-access-rules-standardised-european-rules-air-sera [accessed September 2022]

4 Finnish AIP is available at https://ais.fi/ais/eaip/en/ [accessed August 2022].

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Figure 6
View from the ATC Tower

The ICAO Aeronautical Telecommunication Procedures manual (ICAO Annex 10 Volume 2) contains the following rule:

> *'5.2.1.7.3.1.1 Except for reasons of safety, no transmission shall be directed to an aircraft during takeoff, during the last part of the final approach, or during the landing roll.'*

When interviewed after the incident the FISO clearly understood the rule and the importance of avoiding distracting the flight crew at a critical stage of flight. However, at the time she considered it was necessary to confirm the aircraft would turn right after takeoff.

The FISO held a valid licence and had 10 years' experience providing a FIS. She had participated in virtual classroom refresher training in 2020 and simulator refresher training in autumn 2021.

Meteorology

At the time of the incident the airfield was reporting a surface wind from 040° at 5 kt, visibility of 6 km, it was snowing, cloud was scattered at 3,100 ft agl, temperature was -8°C, dewpoint was -10°C and sea level pressure was 983 hPa. The surface wind gave a 5 kt crosswind on Runway 12 with no head or tail wind.

The runway conditions were reported as a 100% covering of 3 mm dry snow with a RWYCC of 4 for all sections of the runway.

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Takeoff performance calculation

Using the operator's runway condition assessment matrix with 3 mm of dry snow gave a RWYCC of 5. However, as the airfield was reporting a RWYCC of 4 the crew used this as the worst case. The flight crew used the operator's approved iPad app to calculate the takeoff performance.

After the incident, the calculation was verified with the assistance of the operator. The FDR data also confirmed the data was correctly loaded into the FMC and MCP.

Flight crew

Both flight crew held valid licences and medicals to operate the B737-800. Their total flight hours and recent experience is shown in Table 1.

	Commander	Co-pilot
Age	44	41
Total Time	7,459 hrs	4,582 hrs
On Type	3,344 hrs	2,399 hrs
Last 90 days	203 hrs	139 hrs
Last 28 days	47 hrs	32 hrs

Table 1

Flight crew age and experience

Both pilots felt they were current and did not think that recency was a factor in the incident. They both reported they were well rested prior to the flight.

Neither pilot had operated to Kuusamo before. They both reported they had limited experience of cold weather operations. The commander had some experience from a previous operator and the co-pilot's only experience was from simulator training. However, they both felt well prepared for the flight from the training they had received and from their pre-flight revision of the operator's manuals.

Takeoff procedure

Figure 7 shows the takeoff procedure as detailed in the operator's Flight Crew Operations Manual (FCOM).

The procedures require the commander's hand to be on the thrust levers during the takeoff roll so that they can rapidly initiate a rejected takeoff if required. The operator has added an additional note to the takeoff procedure specified by the manufacturer (marked as note 1 in Figure 7) to clarify the exact point at which the co-pilot must remove their hand. The note states that the co-pilot must remove their hand immediately after pressing TOGA. The commander will then place their hand on the thrust levers as they advance.

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Captain	First Officer	
Verify that the brakes are released. Align the airplane with the runway.		
Verify that the airplane heading agrees with the assigned runway heading.		
	When cleared for takeoff, set the FIXED LANDING/LANDING (as installed) light switches to ON.	
Select Chronograph to Start and Elapsed Time to RUN.		
Pilot Flying	**Pilot Monitoring**	
Advanced the thrust levers to approximately 40% N1. Allow the engines to stabilise.		
Push the TO/GA switch. Note: If the F/O is PF their hand should be removed from the thrust levers immediately after the TO/GA switch is pushed. The Capt should then keep one hand on the thrust levers as they advance.		1
Verify that the correct takeoff thrust is set		2
	Monitor the engine instruments during the takeoff. Call out any abnormal indications. Adjust takeoff thrust before 60kts as needed. During strong headwinds, if the thrust levers do not advance to the planned takeoff thrust, manually advance the thrust levers before 60 knots. Call "THRUST SET"	2
After takeoff thrust is set, the Captain's hand must be on the thrust levers until V1.		
Monitor airspeed. Maintain light forward pressure on the control column.	Monitor airspeed and call out any abnormal indications.	
Verify 80 knots and call "CHECK".	Call "80 KNOTS".	
Note: If the "80 KNOTS" call is delayed, the PM calls the speed passing, e.g. "90 KNOTS".		
Verify V1 speed	Call "V1".	
At VR, rotate toward 15° pitch attitude. After lift-off, follow F/D commands.	At VR, call "ROTATE" Monitor airspeed and vertical speed	

Figure 7

Takeoff procedure extracted from the operator's FCOM
(blue numbers added to link to the discussion in the following narrative)

The operator advised that this note was added to provide clarity about when the co-pilot's hand should be removed and to ensure the commander was holding the thrust levers as the power increased so that they could always abort the takeoff if required.

Engine run-up

When operating in icing conditions (visible moisture, ice, snow, slush or standing water) and the temperature is 3°C or less a pre-takeoff engine run-up is required. The procedure states (described in the FCOM supplementary procedures):

> *'Run-up to a minimum of 70% N1 and confirm stable engine operation before the start of the takeoff roll. A 30-second run-up is highly recommended whenever possible.'*

The commander reported that he usually displayed the secondary engine instruments during the 30 seconds so that he could monitor the engine indications. He would then clear the secondary display prior to starting the takeoff. Displaying secondary engine instruments requires a single press of the ENG button in the centre of the instrument panel, they are cleared by pressing the button a further two times. During the 30 seconds the captain would hold his finger over the button ready to clear the display.

There is no requirement to display the secondary engine instruments during a run-up but similarly there is no guidance not to display them. However, if any engine parameter is out of limits the display will automatically pop-up.

Following this incident, the operator sought further guidance from the aircraft manufacturer about conducting a take-off with an engine run-up. The operator has incorporated this guidance in their FCOM, highlighting the importance of applying sufficient brake pressure and clarifying actions to be taken should the aircraft start to move during the run-up.

Thrust set check

During the takeoff roll, prior to 80 kt, both pilots are required to verify the correct takeoff thrust is set (marked as note 2 in Figure 7). This requires the pilots to verify the actual N_1 display on the upper centre display matches the target N_1 (Figure 8). The actual N_1 and the target N_1 are shown in digits and on a rotary dial. The lower images in Figure 8 show the indications with the correct thrust set (left image) and with approximately 70% N_1 set (right image).

PFD indication

The top section of the PFD contains the Flight Mode Annunciator (FMA). The FMA tells the pilot which autothrottle, flight director and autopilot modes are armed or active. Figure 9 shows the PFD prior to the takeoff as it was set up on the incident flight. The autothrottle is armed (ARM in white in the left column of the FMA), the flight director roll mode has LNAV (lateral navigation system) armed (LNAV in white in the centre column) and the pitch mode (right column) is blank.

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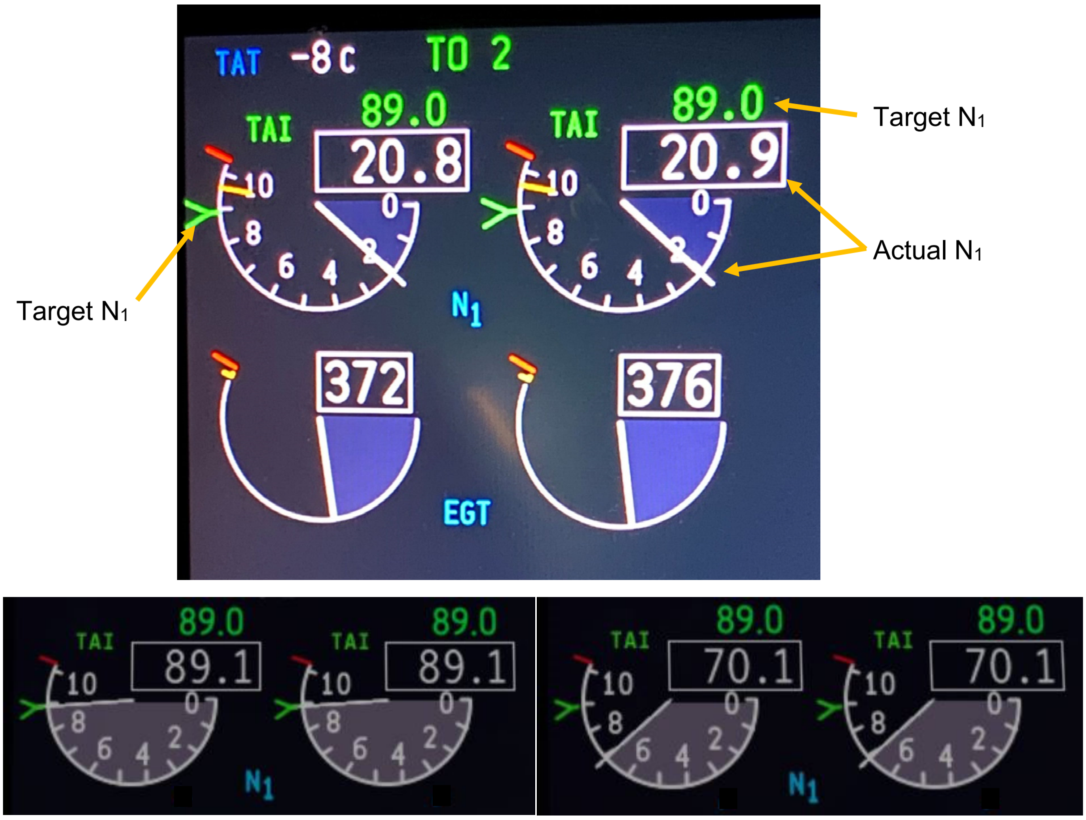

Figure 8

Primary engine instruments shown on the upper centre screen
(images captured in a simulator)

Figure 9

PFD prior to starting the takeoff
(image captured in a simulator)

During a normal takeoff FMA's would change as shown in Table 2

Prior to takeoff	ARM	LNAV	
When TOGA is pressed	N1	LNAV	TOGA
Passing 84 kt	THR HLD	LNAV	TOGA
Passing 50 ft aal	THR HLD	LNAV	TOGA

Table 2

FMA changes during a normal takeoff

In addition to the FMA changes the flight director command bars would appear on the PFD when the TOGA button is pressed.

Table 3 shows how the FMA behaves if the TOGA button is not pressed during the takeoff.

Prior to takeoff	ARM	LNAV	
TOGA press omitted	ARM	LNAV	
Passing 84 kt	THR HLD	LNAV	
Passing 50 ft aal	THR HLD	LNAV	

Table 3

FMA changes during takeoff when TOGA is not pressed

If TOGA is not pressed, the flight director command bars will not be displayed until the aircraft passes 50 ft agl and LNAV engages. At this stage the roll bar will appear but the pitch bar will remain off until a pitch mode is selected.

The PFD speed tape shows a trend arrow, and the top of the arrow predicts what the speed will be in 10 seconds at the current acceleration rate. Figure 10 shows the difference in the trend arrow with 89% N_1 set and 70% N_1 set.

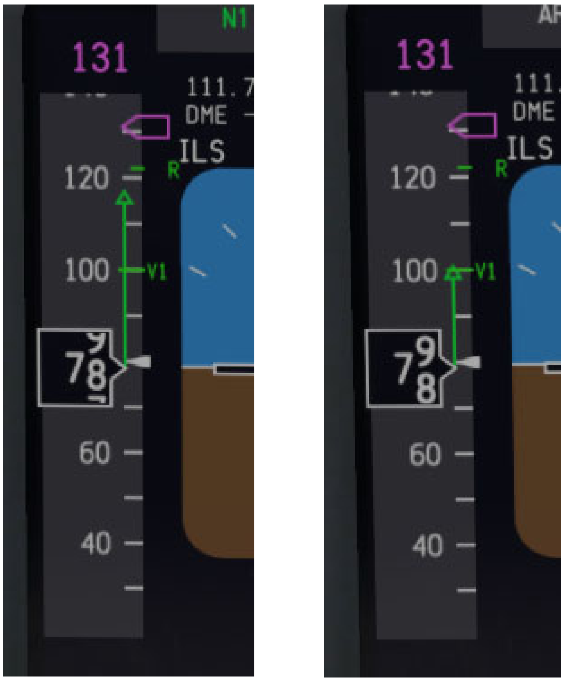

Figure 10

PFD Speed Tape trend arrow (left image with 89% N_1, right image with 70% N_1)
(images captured in a simulator)

Operator's investigation into brake pressure

After the incident, the co-pilot had the opportunity to experiment with the brakes in a simulator and found the brake pedals have significantly more travel than he had previously been using.

The operator reviewed their historic Flight Data Monitoring (FDM) data and found two previous events where it is likely that insufficient brake pressure was applied during static run-ups.

The operator issued a flight crew general notice to all their flight crew highlighting the issue and began monitoring FDM data to detect any future issues. A static run-up was also included in one of the line-orientated evaluation (LOE) sectors used in the operator's next simulator check. The LOE also included some distraction during the start of the takeoff roll.

Previous events

The AAIB has investigated several serious incidents where the takeoff performance of large commercial aircraft was severely compromised.

Most notably, in 2017, the AAIB investigated an event where Boeing 737-800, C-FWGH, carrying 179 passengers and six crew, took off from Belfast, Northern Ireland[5], with

Footnote

[5] AAIB Aircraft Accident Report AAR2/2018 – C-FWGH, 21 July 2017, available at: https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-2-2018-c-fwgh-21july-2017 [Accessed 30 May 2022].

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insufficient thrust for the environmental conditions. This led to the aircraft hitting a runway light, which was 36 cm high, 29 m beyond the end of the runway, before climbing away very slowly.

Frequency of occurrence

Following the 2017 event, the AAIB began compiling a list of subsequent takeoff performance incidents from operators' safety reports, MORs and validated occurrences from online aviation websites. This list, which should not be considered exhaustive, is attached at Appendix A in a de-identified form and shows that a total of 32 events have occurred in just under 5 years, including this incident to G-JZHL.

The most recent event occurred in April 2022 to an Airbus A330-900 departing from Luanda Airport in Angola. In this instance, the aircraft was carrying 148 passengers and 10 crew and departed from Intersection E of Runway 23 using performance data appropriate for a full-length departure. Consequently, the performance data that was used was appropriate for a runway approximately twice the length of that available for the aircraft's departure. Fortunately, the crew saw the end of the runway approaching and applied full power. Six seconds later the aircraft became airborne having reached the extreme end of the runway.

Events relevant to this investigation

The AAIB's list shows that on 15 July 2018, an A220 took off from Porto[6] with insufficient thrust, after the crew did not advance the thrust levers far enough for the autothrottle to engage. This was a similar incident to the event on G-JZHL although, in the Porto case, the crew advanced the thrust levers late in the takeoff roll. On 28 November 2009, an MD-11F was lost at Shanghai[7], with three fatalities, after the crew did not advance the thrust levers far enough for the autothrottle to transition into the correct mode and, as a result, provide the correct takeoff thrust.

Recognition of degraded aircraft performance and intervention

Of the 32 events recorded in Appendix A, 12 were investigated by the AAIB and, of these, 10 resulted in a significant shortfall in the acceleration of the aircraft. In nine of these events the crew did not recognise the reason for the lack of aircraft performance and either abort the takeoff or increase engine power before becoming airborne.

The histogram in Figure 11 shows the acceleration at 80 kt for a sample of 73,669 Boeing 737-800 takeoffs, gathered by a US avionics manufacturer to support development of a technological barrier to detect significant shortfalls in acceleration on takeoff[8].

Footnote

6 STSB Final Report No. 2355, available at: https://www.sust.admin.ch/inhalte/AV-berichte/2355_e.pdf [Accessed 30 May 2022].

7 Avient Aviation MD11 at Shanghai on 28 November 2009, overran runway on takeoff, available at: https://avherald.com/h?article=423638d8 [Accessed 30 May 2022].

8 For more information on this data and analysis, see the AAIB report into C-FWGH's takeoff (Footnote 4).

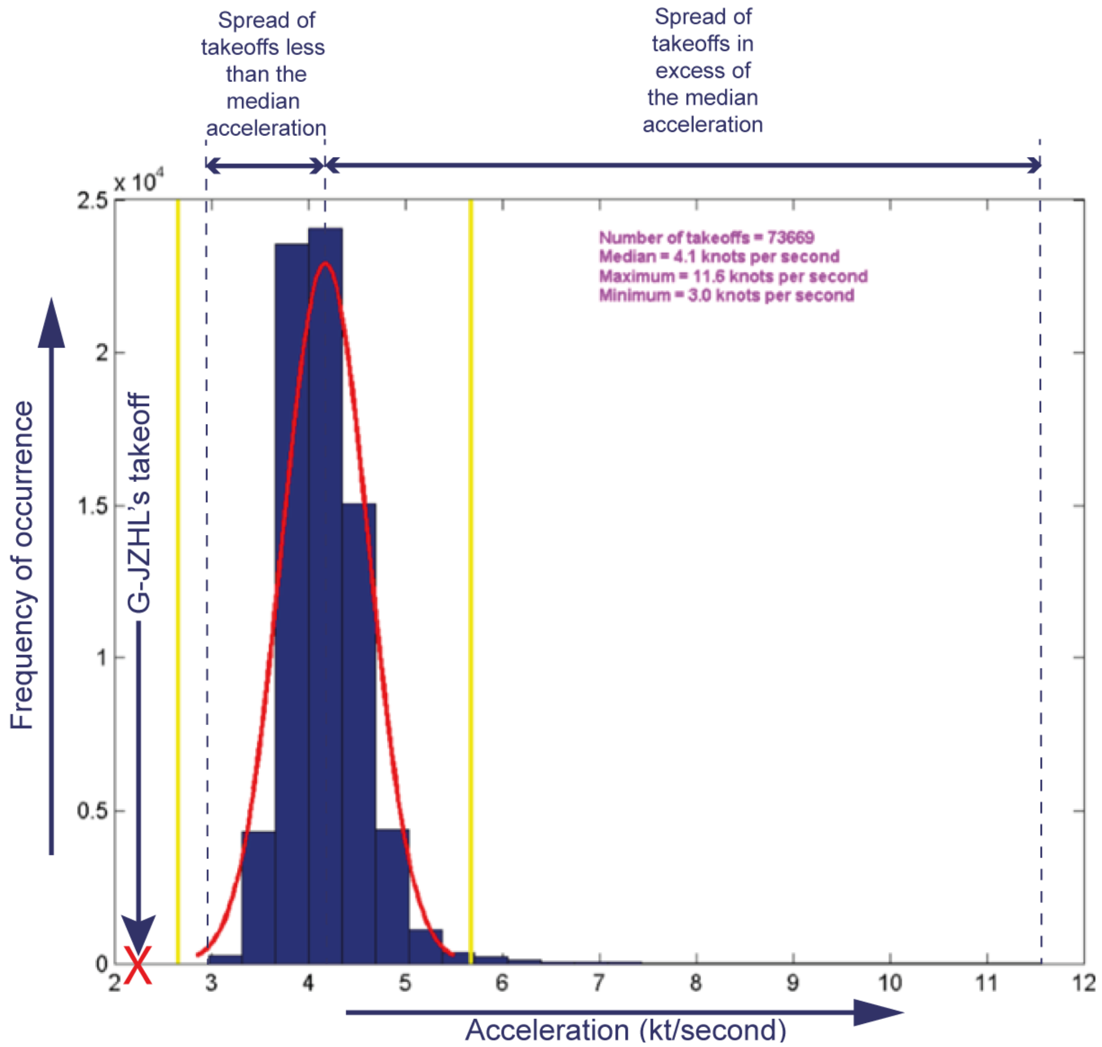

Figure 11

G-JZHL's acceleration on takeoff compared with other 737-800 takeoffs.
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The data encompasses a weight range of 43 to 78 tonnes, representing 93% of the Boeing 737-800 operating weight range, and covers both a range of airport elevations, from sea level to 1,900 ft amsl, as well as outside air temperatures of between -1 and 42°C.

This data shows that the minimum acceleration seen on takeoff from the 73,669 takeoffs was 3.0 kt/second and that the median, the midpoint of the frequency distribution shown on the histogram by the peak of the red line, was 4.1 kt/second. The yellow lines represent three standard deviations, or the bounds which enclose 99.7% of the data.

By comparison, G-JZHL was accelerating at 2.25 kt/second, as it passed through 80 kt airspeed. This value is shown on Figure 11 by the red cross.

In this event, which happened at night, both pilots reported that they were aware that something was not right but continued with the takeoff and did not increase engine power before becoming airborne. In the 2017 Belfast incident, despite the prevailing good visibility

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and daylight conditions, neither pilot recognised that the aircraft was accelerating slowly until nearing the end of the runway, well past the calculated V_1, and engine power was not increased until the aircraft was 4 km from the airport. Both crew members reported that all procedural cross-checks had been completed, yet the data entry error was made and was not detected.

Perception of acceleration

As part of the investigation of the 2017 Belfast Incident, the AAIB commissioned a human factors report which is included in full as an appendix to that AAIB report (see Footnote 4). The human factors report described human perception of longitudinal acceleration and pilots' ability to recognise abnormal acceleration during takeoff. Pilots are unlikely to recognise abnormal acceleration for the following reasons:

- Acceleration is not explicitly monitored during takeoff.
- Pilots become accustomed to different rates of acceleration.
- Perception of motion is primarily governed by visual rather than vestibular cues, and the visual system has a high detection threshold and general insensitivity to acceleration.
- The visual cues in slower acceleration do not differ enough for pilots to detect until presented with an atypical visual scene (such as the end of the runway approaching).

Reliability of checks conducted by humans

Human performance is variable, and no task undertaken by humans is performed completely accurately on every occasion. Because of this, there are numerous requirements for people to check their own work or for someone's work to be checked by a co-worker. Such checks are either intended to prevent errors or to catch any errors made before they have a safety consequence. They contribute to the overall safety of the system but are prone to being missed out or being completed but not detecting errors. A NASA research paper[9] published in 2010 examined the frequency of deviations from prescribed procedures, checks and monitoring on 60 normal flights in three operators. They observed 194 deviations in checklist use and 391 in monitoring. 14% of checklist deviations and 6% of monitoring deviations were caught and corrected by the flight crew. Most deviations observed resulted in a small reduction in efficacy of safeguards but no adverse outcome for the flight. Although the number of deviations was high, when considering the number of items to be checked and monitored the overall rate of deviations compared to the opportunity for deviation was less than 1%. This is similar to the error rate observed for many types of skilled human performance and difficult to improve upon further in a cockpit environment.

Footnote

[9] Dismukes, R. K. and Berman, B. (2010) *Checklists and monitoring in the cockpit: why crucial defences sometimes fail*, NASA.

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Takeoff acceleration monitoring

The histogram in Figure 11 is heavily skewed, showing a much larger spread of takeoffs where the acceleration exceeded the median value of 4.1 kt/second than for accelerations below the median. The maximum recorded value (11.6 kt/second) is 7.5 kt/second above the median, whereas the minimum value (3.0 kt/second) is only 1.1 kt/second below the median.

Because the range of low acceleration takeoffs to the left of the median value in Figure 11 is so sharply defined and there are so few low acceleration takeoffs, technology could be used to alert flight crew, early in a takeoff roll, to acceleration that is grossly low but which may not be recognised as such by them. Such a system, termed a Takeoff Acceleration Monitoring System, is fully described in the report into the Belfast incident (see Footnote 4).

Takeoff Acceleration Monitoring Systems (TAMS) are inherently less complicated than solutions that compare actual aircraft performance against predicted aircraft performance, or those that extend this prediction to include stopping after rejecting a takeoff or continuing with a takeoff following, for example, an engine malfunction. These solutions typically rely upon crew input, which despite the presence of data entry cross-checks, may be in error thereby invalidating the predictions. Further, an industry working group that last looked at these more technically complicated solutions found several areas of concern, including:

- The lack of real-time environmental parameters and/or parameters derived from navigation and airport databases or service providers.
- A lack of standardisation in reporting runway conditions.
- A lack of good assessments of runway braking friction.
- A lack of suitable aircraft performance models.

These concerns do not apply to TAMS, which use empirical data on takeoff performance and are only concerned about the acceleration of the aircraft on the runway.

The reporting of takeoff performance events

The CAA mandates occurrence reporting through Regulation (EU) No 376/2014[10] (EU 376/2014), '*On the reporting, analysis and follow-up of occurrences in civil aviation',* which requires any organisation established in the UK to report safety related occurrences to the CAA in a Mandatory Occurrence Report (MOR).

In Article 4 of EU 376/2014, *'takeoff and landing-related occurrences'* are listed as events that must be reported, and in Commission Implementing Regulation (EU) 2015/1018, '*laying down a list classifying occurrences in civil aviation to be mandatorily reported according to* [EU 376/2014]*',* the following example occurrences are listed:

Footnote

[10] Regulation (EU) No. 376/2014 as retained (and amended in UK domestic law) under the European Union (Withdrawal) Act 2018.

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> *'Use of incorrect data or erroneous entries into equipment used for navigation or performance calculations which has or could have endangered the aircraft, its occupants or any other person.'*

and

> *'Inability to achieve required or expected performance during takeoff, go-around or landing.'*

Furthermore, ICAO Annex 13, which contains the Standards and Recommended Practices for aircraft accident and incident investigation, defines the term *'Serious incident'* and lists in Attachment C examples of events that could constitute such an incident. They include:

> *'Gross failures to achieve predicted performance during takeoff or initial climb'*

Serious incidents are reportable to the State of occurrence (usually the Safety Investigation Authority (SIA)) independently from the mandatory reporting scheme.

However, an analysis of events that occurred in UK airspace, from the AAIB's list of validated takeoff performance occurrences since mid-2017, showed that in many cases MORs were not submitted and, when they were reported, the report was often significantly delayed. Furthermore, in only a few cases was the AAIB promptly notified of the occurrence.

During this investigation, the CAA stated its intention to promote awareness among AOC holders and pilots of the causes and safety implications of compromised takeoff performance, and the importance of pro-active reporting.

FDM detection of takeoff performance events

In February 2016 the EASA published a Safety Information Bulletin (SIB), entitled *'Use of Erroneous Parameters at Takeoff'*, to alert operators and flight crew to the safety issue and to recommend the implementation of operational mitigation measures[11]. The SIB, which followed a survey of operators, recognises that under-detection of takeoff performance events is a potential industry-wide issue and states:

> *'it is likely that other events have occurred but were not reported, either because they were uneventful or because the issue was not identified by the flight crew during the takeoff or through the Flight Data Monitoring (FDM) programme. It is therefore important that this safety issue is monitored more closely and that operators collect more data in order to gain better awareness and understanding of the frequency and potential severity of these events, as well as to monitor associated trends and to assess the effectiveness of any remedial action.'*

Footnote

[11] EASA Safety Information Bulletin No. 2016-02R1, available at: https://ad.easa.europa.eu/ad/2016-02R1 [Accessed 30 May 2022].

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It goes on to state that:

> *'implementing even a few specific FDM event algorithms or measurement algorithms could help to improve the detection of related events and assess their frequency and severity...and consequently, to evaluate the effectiveness of the risk mitigations put in place in their organisation.'*

The SIB suggests that there is under-reporting, perhaps because the outcomes were '*uneventful*' or because the crew did not notice anything abnormal at the time. Data entry errors can lead to unpredictable outcomes. They can have a significant effect on acceleration that is not noticed but may, at the same time, profoundly undermine the validity of the takeoff performance calculation. Day-to-day variability in performance calculation output due to the use of optimised takeoff performance calculations, and the use of intersection takeoffs, degrade flight crews' abilities to distinguish performance on a particular takeoff from the norm.

The SIB goes on to say that the European Operators Flight Data Monitoring (EOFDM) forum has produced guidance for the implementation of FDM to identify precursors to these types of events[12]. They note that this may require the recording or computing of flight parameters that are not readily available, as well as designing new FDM events or measurement algorithms, but it is thought these precursors could be implemented by the majority of operators. The SIB makes the following recommendation:

> *'EASA recommends operators to implement specific FDM event algorithms (or FDM measurement algorithms) that are relevant to the monitoring of takeoff performance in their FDM programme and to analyse events and adverse trends detected by these algorithms.'*

The AAIB is aware of a European operator that routinely analyses whether the takeoff data entered into the aircraft's flight management system matches that calculated by the flight crew prior to departure using their performance tool. Used alone, this technique would not capture all events – such as if erroneous data was initially entered into the performance tool – but it does show an additional approach that would complement a robust set of FDM algorithms.

However, despite EASA's recommendation on the use of FDM to monitor takeoff performance events and the publication of the EOFDM's guidance material, the AAIB is aware that very few operators, including in the UK, have fully implemented FDM algorithms to detect relevant precursors for takeoff performance events. This was confirmed, in part, in a survey carried out by the EOFDM group in early 2022, which showed that only one out of 19 respondents had implemented FDM algorithms for one of the key precursors.

Footnote

[12] EOFDM Working Group B, *Guidance for the implementation of flight data monitoring precursors*, available at: https://www.easa.europa.eu/downloads/119200/en [Accessed 30 May 2022].

Several reasons have been suggested for this including a lack of resource within operators' FDM teams, especially after the Covid-19 pandemic; the lack of interoperability of IT systems involved in computing takeoff performance; and, for some of the more complicated FDM algorithms, the ability to establish and program the algorithm into the operators' FDM system.

Analysis

During a pre-takeoff engine run-up the thrust was increased to 70% N_1 as required by the supplementary procedure. However, the thrust was not subsequently increased to the required 89% N_1 and remained at 70% throughout the takeoff roll. This occurred because the co-pilot did not press the TOGA button and neither pilot checked the thrust was correctly set during the takeoff roll. Several factors contributed to these omissions, which are discussed below. The low thrust was not detected until after the aircraft was airborne.

The aircraft became airborne with 400 m of runway remaining. If the aircraft had suffered an engine failure after V_1 it would not have been able to safely get airborne with the thrust of 70% N_1 on the operative engine.

TOGA button

The co-pilot reported that he omitted to press the TOGA button because he was startled by the aircraft starting to slide and drift toward the snowbanks.

It is likely that the aircraft was rolling rather than sliding as the co-pilot was applying insufficient brake pressure to hold the aircraft stationary against the 70% N_1. Co-pilots at this operator do not taxi the aircraft so are rarely required to use significant brake pressure. This meant the co-pilot did not have any experience of applying significant brake pressure. During simulator training after the incident, the co-pilot discovered the brake pedals have significantly more travel than he had been using.

After the incident the operator reviewed their FDM data and discovered several previous events where insufficient brake pressure had been applied during engine run-ups. The operator took safety action to alert pilots to the issue and is using FDM data to monitor further trends.

Whilst the subsequent analysis showed the aircraft was rolling, in the moment the co-pilot's perception was that the aircraft was sliding. The pilots had briefed that the aircraft might slide and that, if it did, the co-pilot would release the brakes and continue the takeoff. So, when they perceived that the aircraft was sliding, they did as they planned and the co-pilot released the brakes. It is possible that because they were primed that the aircraft may slide, when it started to move, they were more likely to think it was sliding rather than considering insufficient braking. Briefing what may happen is generally very helpful but, in this case, it may have primed the crew to expect a particular outcome.

The co-pilot reported that he was startled by how readily the aircraft started to slide and by the aircraft starting to drift towards the snowbanks. A startle response can be defined as '*a* *complex, involuntary reaction to a sudden unanticipated stimulus*'[13]. It is a '*brief, fast and highly physiological reaction to a sudden, intense or threatening stimulus*'[14]. He perceived that the threat was the aircraft sliding towards the side of the runway and his attention was drawn to controlling the aircraft. NASA's technical memorandum titled '*Effects of acute stress of aircrew performance*'[15] describes how a threatening stimulus can cause a pilot to focus their attention on addressing that threat and can lead to errors or omissions in other concurrent tasks. It is likely that, in the moment of the startle, suddenly faced with a threatening situation, the co-pilot's attention was solely drawn to controlling the aircraft and this caused him to omit to press the TOGA button.

The operator's SOPs require the co-pilot to remove their hand from the thrust levers '*immediately*' after TOGA is pressed (the operator had added an additional note to the manufacturer's standard takeoff procedure to state exactly when the co-pilot's hand should be removed). This normally occurs at the start of the takeoff roll as the aircraft starts to accelerate, so the co-pilot would be used to having both hands on the control column as the aircraft travels down the runway. During this incident, as the aircraft started to move, with his attention focused on controlling the aircraft, it would have felt natural to move his hand from the throttles to the control column.

'Thrust set' check

The takeoff procedure requires both pilots to check that the correct takeoff thrust is set. Once the pilot monitoring has checked the thrust, they are required to call 'thrust set'.

During a normal takeoff, with the co-pilot handling, the commander will place their hand on the thrust lever as soon as the co-pilot presses the TOGA button. They can then watch the N_1 gauges increasing until the actual N_1 matches the target and then call 'thrust set'. However, during the incident takeoff, this normal sequence was interrupted.

As the co-pilot started to advance the thrust levers to 70% N_1, the commander was expecting a 30 second stationary run-up. He had the secondary engine instruments displayed and was ready to start his timer. As the aircraft unexpectedly started to move, he had to clear the secondary engine instruments, start his timer and place his hand on the thrust levers. As this was happening, the commander made a radio transmission (as the aircraft accelerated though 6 kt) which was probably him confirming they were taking off. The FISO then made a further transmission to the aircraft asking them to confirm if they would be turning right after departure. By the time the commander had replied to the FISO the aircraft was passing 53 kt. The commander reported that it was this distraction that caused him to omit the thrust set check and call.

Footnote

13 Reber, A. (1985) *The Penguin dictionary of psychology*, Penguin.

14 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.

15 Dismukes, R. K., Goldsmith, T. E., Kochan, J. A. (2015) *Effects of Acute Stress on Aircrew Performance: Literature Review and Analysis of Operational Aspects*, NASA.

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When an action is normally cued by a sequence of preceding events, if those events are changed or if a distraction occurs during those events, people are vulnerable to omissions. Having missed the action, with the normal cues now passed, it is unusual for a person to remember to return to the omitted item, particularly in a time limited situation. A report published in Aero Safety World in December 2008[16] discussed how common this is and how it has caused previous accidents.

Having omitted the thrust set check after answering the radio call, the commander had seven seconds until the aircraft passed 80 kt, a further five seconds until V_1 then a further 25 seconds before V_R. During the takeoff roll the pilot monitoring would normally be monitoring the aircraft for any abnormal indications. There were several indications on the flight deck which might have alerted him that the thrust was not set correctly and that TOGA had not been pressed. The needles on the N_1 gauges would not have been aligned with the target bugs and the digits would have been different from the target digits (Figure 8). With hindsight these indications may seem obvious, but it is common for humans to see what they expect to see or 'look without seeing' (Footnote 8). This is more common with an indication which is normally correct. Experienced pilots who have seen hundreds of takeoffs will nearly always have seen the thrust correctly set. On the one occasion when it is not set, it is possible that they will not see it, they will just see what they expect to see.

The PFD also had indications to tell the pilots that something was abnormal. The FMAs at the top of the PFD were subtly different to a normal takeoff and the flight directors were not displayed. There is no requirement for the pilots to check the FMAs during the takeoff roll so they may not have looked at them. Even if they did notice the FMAs were abnormal or saw the lack of flight directors, it may not have been immediately obvious why. The pilots had not seen a takeoff without TOGA being pressed before so it may have taken some time to understand why the indications were abnormal. The length of the trend arrow on the speed tape would also have been smaller than on a normal takeoff, but there is no requirement to check the trend arrow on the takeoff roll and this difference from normal may not have been sufficient to be detected. The trend arrow is also dynamically calculated and therefore can fluctuate significantly with wind gusts on the takeoff roll making it hard to interpret.

The co-pilot is also required to check the thrust is correctly set during the takeoff roll. However, having been startled by the unexpected aircraft movement, his focus was on controlling the aircraft. His visual attention would have been outside the cockpit ensuring the aircraft was tracking down the runway centreline. It is likely that the effect of the startle and with his attention captured by controlling the aircraft, the co-pilot did not have the capacity to check the thrust.

Footnote

16 'Deadly Omissions' Aero Safety World December 2008, available at https://flightsafety.org/wp-content/uploads/2016/12/asw_dec08_p10-16.pdf [Accessed 25 February 2022]

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Radio transmission during the takeoff roll.

During the takeoff roll the FISO made a transmission to the aircraft which distracted the commander. The FISO was expecting the flight crew to confirm their routing when they reported they were taking off. When the flight crew did not do this, the FISO felt she was required to ask for confirmation before the aircraft took off.

From the flight crew's perspective, they had been cleared to route via a waypoint to the south of the airport and their charts included an instruction to turn right. Therefore, they intended to turn right but were not aware of any requirement for them to report this.

From the FISO's perspective, there is no clearance between the airport and the first waypoint so an aircraft's commander could take any routing at their discretion. The rules of the air state that aircraft should normally turn left after takeoff, but if they intended to turn right, they must report this intention. The requirement to do this is also stated in the Finnish AIP. Therefore, the FISO expected the commander to report his intention to turn right.

The FISO felt she must obtain this confirmation before the aircraft was airborne because:

1. Kuusamo does not have radar, so once the aircraft was airborne, with limited visibility at night and in snow, the FISO would not have been able to determine the aircraft's routing.
2. Once the aircraft is airborne the FISO is not able to issue any further instructions to aircraft.
3. The FISO needed to confirm the restricted area to the east of the airport along the FIR boundary would not be infringed.

The FISO was aware of the requirement not to call an aircraft during the takeoff, but because of the proximity of the restricted area she believed she was required to obtain confirmation of the intended turn direction.

The operator subsequently included in their OM C the requirement to report direction of turn to the FISO for all Finnish airports.

When a radio transmission is made to an aircraft on a takeoff roll it is difficult for flight crew to ignore the message. The message could contain vital information (for example, informing the commander of smoke coming from the aircraft, or a blocked runway), so the crew must listen to the message and understand what they are being told. It was therefore difficult for the commander, on this takeoff, to avoid being distracted by the radio transmission.

Lack of acceleration

Both pilots reported that something was not right during the takeoff but, at the time, neither could resolve what was wrong. They felt the acceleration and the cadence of the takeoff was slightly slow but thought this might be due to the runway contamination. The feeling was not compelling enough for them to abort the takeoff.

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This is in common with many of the previous takeoff performance incidents that the AAIB and other SIAs have investigated. Human perception of acceleration in combination with the nature of the takeoff task means that pilots are generally not able to recognise when the acceleration is slower than required, even when the difference in acceleration is significant.

Takeoff Acceleration Monitoring Systems

During this incident, the takeoff performance was correctly calculated and correctly loaded into the FMC. The incident occurred because the planned takeoff thrust was not set. There is a barrier in place to detect this error, in the form of a human check, but this incident shows this check is vulnerable to distraction.

The AAIB and other SIAs have investigated many takeoff performance incidents which have resulted in aircraft taking off with insufficient thrust. The circumstances of each incident differ but the outcome is the same. The human checks currently in place do not always stop these incidents occurring. Learning from past events and research shows that, whilst they are effective in many cases, such checks are occasionally omitted or fail to detect errors. Operational interventions maximise crew performance as far as possible but there is a limit to the reliability that can be achieved with any human task. Higher levels of reliability are likely to require a technological intervention. TAMS could detect these events and alert the flight crew at a low speed and enable them to safely reject the takeoff.

Following the Belfast incident, the AAIB made the following Safety Recommendation to EASA and the FAA:

Safety Recommendation 2018-014

It is recommended that the European Aviation Safety Agency, in conjunction with the Federal Aviation Administration, sponsor the development of technical specifications and, subsequently, develop certification standards for a Takeoff Acceleration Monitoring System which will alert the crew of an aircraft to abnormally low acceleration during takeoff.

As the issue of monitoring takeoff acceleration affects civil aviation worldwide, the following Safety Recommendation was made to ICAO:

Safety Recommendation 2018-015

It is recommended that the International Civil Aviation Organization note the conclusions of this report and introduce provisions addressing Takeoff Acceleration Monitoring Systems.

EASA's response to Safety Recommendation 2018-014 stated that:

'The safety issue "Entry of aircraft performance data" was included in the agency's safety risk portfolio for commercial air transport fixed-wing in 2016.'

and they also published SIB 2016-02R1, discussed earlier, to alert operators and flight crew to the safety issue and to recommend the implementation of operational mitigation measures. The SIB largely focused on flight crew training including recovery techniques in the event of a takeoff performance issue, data entry procedures, and management of the operator's exposure to the risk through their Safety Management System. The recommendation to sponsor the development of technical specifications has not been addressed, however, and the AAIB has not received any further information to say that it is under active consideration. The Safety Recommendation, therefore, remains open.

Safety Recommendation 2018-014 was published when the UK was part of the European Union (EU) and so the recommendation was made to EASA and not directly to the CAA. The UK left EU institutions when it left the European Union and therefore:

Safety Recommendation 2022-018

It is recommended that the UK Civil Aviation Authority, in conjunction with other regulatory authorities, develop a set of technical specifications and, subsequently, develop certification standards for an on-board system that will alert the crew of an aircraft to abnormally low acceleration during takeoff.

ICAO's response to Safety Recommendation 2018-015 stated the topic would be discussed with ICAO's Flight Operations Panel Working Group and, although this meeting did take place, the consensus was to look at making procedural improvements, rather than to look to technological aids, so this Safety Recommendation also remains open.

Reporting of takeoff performance events

In this event, the flight crew of G-JZHL recognised that a takeoff performance event had occurred and submitted a safety report. The operator filed an MOR with the UK CAA and contacted the AAIB. The AAIB then liaised with the Safety Investigation Authority of Finland who delegated the investigation to the AAIB.

However, the AAIB's analysis, across all operators, suggests that for many cases that have occurred in UK airspace, MORs are not submitted and, when they are, the report is often significantly delayed. Furthermore, in only a few cases have the AAIB been promptly notified of the occurrence. If, as is likely, this type of event is under-reported, the associated risk will be underestimated, thereby undermining the basis upon which any risk-based decisions are taken on potential mitigating action. It is therefore important that UK AOC holders report the example takeoff-related occurrences referred to earlier in this report[17] and contained in EU 2015/1018. The CAA stated that it intended to promote awareness of the causes and safety implications of compromised takeoff performance and the importance of pro-active reporting.

FDM events can also be used to monitor the frequency of occurrence of takeoff performance events and to ensure they are reported appropriately. EASA has published guidance material on the subject and has recommended that operators implement in their FDM programmes

Footnote

[17] See: *The reporting of takeoff performance events.*

specific algorithms to detect precursors relevant to the monitoring of takeoff performance. However, very few operators have implemented such algorithms and, therefore:

Safety Recommendation 2022-019

It is recommended that the UK Civil Aviation Authority encourage all UK Air Operator Certificate holders to implement into their flight data monitoring programme algorithms to detect the precursors relevant to the monitoring of takeoff performance detailed in the European Operators Flight Data Monitoring Document, *Guidance for the implementation of flight data monitoring precursors.*

Conclusion and recommendations

The aircraft took off with insufficient thrust set because the TOGA button was not pressed. It was not pressed because the co-pilot was startled by the aircraft moving as he commenced the run-up against the brakes. The aircraft started to move because insufficient brake pressure was applied. Human checks designed to detect the insufficient thrust were ineffective because both pilots were attending to other tasks. The commander was responding to a radio call from the FISO during the start of the takeoff roll. Neither pilot detected the low thrust until after the aircraft was airborne.

The AAIB and other SIAs have investigated numerous previous takeoff performance incidents, and this incident provides further evidence that the current barriers in place to prevent such incidents are not always effective. A Safety Recommendation is therefore made to establish technical specifications and, ultimately, certification standards that would allow a technical barrier to be developed.

Takeoff performance-related incidents are likely to be under-reported, and a Safety Recommendation is made to encourage operators to implement FDM algorithms that identify precursor signals associated with compromised takeoff performance so that they can be reported.

Safety action

The operator:

- Issued a flight crew general notice highlighting the importance of applying sufficient brake pressure during a pre-takeoff engine run-up.
- Began to monitor FDM data to detect any further issues with brake pressure during pre-takeoff engine run-up.
- Included a pre-takeoff engine run-up and distraction during the takeoff roll in an LOE sector during their next simulator cycle.
- Updated their FCOM procedure of pre-takeoff engine run-ups.
- Updated their OM C for all Finnish Airports to include a requirement to report the intended direction of turn to the FISO before takeoff.

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Appendix A

Known takeoff performance incidents since mid-2017

Date	Aircraft type	Location of incident	What happened?
15/07/17	B747-8F	Tokyo/Narita	Took off from Runway 16L using a correct assumed temperature, but the fixed derate applicable to a Runway 16R departure.
21/07/17	B737-800	Belfast	Took off from Runway 07 using an incorrect thrust setting – the result of entering the OAT for the cruising level, instead of the field-level OAT combined with an assumed temperature derate.
16/11/17	B737-700	Seletar, Singapore	Took off using an incorrect assumed temperature of 67 degrees, resulting in a thrust setting of 90.4%, not as required 102.5%.
28/03/18	B787-900	Gatwick	Took off from Runway 26R displaced threshold and not from the start of Runway 26R. TODA effectively reduced by 417 m.
29/03/18	B787-900	Tel Aviv	Took off using a ZFW 40t lower than the actual ZFW.
10/06/18	B737-800	Amsterdam	Took from Runway 09 at intersection N4 using the performance for Runway 09, intersection N5.
15/07/18	A220-300	Porto	Took off with insufficient thrust (AT armed but didn't engage as throttles not advanced to the required position). Crew realised at 90-100 kt and advanced the throttles. Spoilers were also deployed due to low thrust setting.
18/07/18	E170	Prague	Flap 1 used to takeoff instead of Flap 4.
28/07/18	B737-800	Birmingham	Took off from Runway 15 with the performance calculated for the ZFW instead of the TOW.

Appendix A (cont)

Date	Aircraft type	Location of incident	What happened?
18/09/18	A320-200	Sharjah	Took off in the wrong direction (Runway 12 rather than Runway 30), after lining-up on the runway from an intersection. Commander selected TOGA and changed flap setting, aircraft received minor damage and became airborne some 20-40 m after the end of the runway.
02/10/18	B787-900	New York	Took off from Runway 22R using the performance for Runway 22L.
11/12/18	E190	London City	TO3 thrust setting used to takeoff instead of TO1.
April 2019	B737-800	Toulouse	Took off from Runway 32R at intersection N4 using data for intersection N2. Thrust was not increased.
05/08/19	B737-800	Moscow/ Domodeovo	Overran Runway 32L, damaging lights & tyres, but climbed away safely. Suspected weight entry error.
24/04/19	A320-200	Lisbon	Took off from Runway 21, intersection U5 (TORA 2410 m) using the full-length performance figures (TORA 3805 m).
07/05/19	A320-200	Lisbon	As the 24/04/19 event.
07/06/19	A319-100	Marrakech	Took off using Flap 1 but performance calculated for Flap 2.
17/06/19	B787-900	Johannesburg	Took off using the performance for Runway 03R on Runway 03L.
29/08/19	A319-100	Nice	Took off using the performance for Runway 04R, intersection Q3 but actually from intersection B3.
30/08/19	A320-200	Basle	Took off from an intersection (slot pressure) without valid performance data.
16/09/19	A320-200	Lisbon	As per the 07/05/19 event.

Appendix A (cont)

Date	Aircraft type	Location of incident	What happened?
20/09/19	A350-1000	Shannon	Incorrect runway inserted into the FMS. Believe the aircraft performance was not compromised. Low speed RTO performed upon ECAM message.
02/10/19	A319-100	Heathrow	Took off using the performance for Runway 27L, intersection N2W but actually from intersection N4E.
17/11/19	B737-800	Paphos	Takeoff performance compromised, as headwind changed into a tailwind, and due to a lengthy ground roll as thrust stabilised.
24/11/19	A321-200	Glasgow	Flex of 79° used instead of 49°. Error not detected. TOGA applied.
28/02/20	B737-700	Gatwick	Flight crew did not enter V speeds into the FMC, derate information was correct.
21/07/20	B737-800	Birmingham	Incorrect assumed weights used for adult female passengers – assigned child weights instead due to a computer glitch. Invalid V speeds and derate, 1.2-ton error in TOW.
03/03/21	B737-800	Lisbon	As per the 16/09/19 event. *This was the aircraft operator's third almost identical event at Lisbon in less than five months.* Took off from runway intersection U5 (TORA 2410 m) using the full-length performance figures (TORA 3805 m).
23/07/21	B737-800	Yerevan	Unknown, but confirmed as a performance error.
01/12/21	B737-800	Kuusamo	70% N_1 used for takeoff, as aircraft slipped during ice shedding procedure and the throttles weren't advanced from 70% N_1 until the aircraft was airborne.

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Appendix A (cont)

Date	Aircraft type	Location of incident	What happened?
04/03/22	B787-900	Brussels	GW entered into the FMC ZFW box instead of ZFW. Approx. 10-ton error. Multiple distractions on ground.
12/04/22	A330-900	Luanda	Took off from runway intersection E (TORA 1900 m) using the full-length performance figures (TORA 3700 m), resulting in a flex to 85% N_1. Crew applied TOGA power and rotated just before the end of the runway.

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