AIRCRAFT ACCIDENT REPORT 2/2018

AAIB
Air Accidents Investigation Branch

Report on the serious incident to
Boeing 737-86J, C-FWGH
Belfast International Airport
on 21 July 2017

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This investigation has been conducted in accordance with
Annex 13 to the ICAO Convention on International Civil Aviation,
EU Regulation No 996/2010 and
The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 2018.

The sole objective of the investigation of an accident or incident under these Regulations is the prevention of future accidents and incidents. It is not the purpose of such an investigation to apportion blame or liability.

Accordingly, it is inappropriate that AAIB reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
aal	above airfield level
ACARS	Aircraft Communication, Addressing and Reporting System
ACC	Area Control Centre
ACMS	Aircraft Condition Monitoring System
ADS-B	Automatic Dependent Surveillance – Broadcast
AEO	all engines operating
AFTN	Aeronautical Fixed Telecommunications Network
agl	above ground level
AMC	Acceptable Means of Compliance
AME	Aircraft Mantenance Engineer
amsl	above mean sea level
ASDA	Accelerate Stop Distance Available
ATC	Air Traffic Control
ATS	Air Traffic Services
ATIS	Automatic Terminal Information System
ATSU	Air Traffic Service Units
BEA	Bureau d'Enquétes et d'Analyses pour la Sécurité de l'Aviation Civile
BITE	Built-in Test Equipment
CAA	Civil Aviation Authority
CAT	Commercial Air Transport
CCTV	closed-circuit television
CDS	Common Display System
cm	centimetre(s)
CDU	Common Display System
CVR	Cockpit Voice Recorder
DFDAU	Digital Flight Data Acquisition Unit
DSB	Dutch Safety Board
DU	Display Units
EAFDM	European Authorities Coordination Group on Flight Data Monitoring
EASA	European Aviation Safety Agency
EEC	Electronic Equipment Compartment
EFB	Electronic Flight Bags
EGPWS	Enhanced Ground Proximity Warning System
EOFDM	European Operators Flight Data Monitoring
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration (USA)
FCOM	Flight Crew Operations Manual
FDR	Flight Data Recorder
FDM	Flight Data Monitoring
FMC	Flight Management Computer
FMCS	Flight Management Computer System
FMC OPS	FMC Operational Program Software
ft	feet
hPa	hectopascal
hrs	hours (clock time as in 1200 hrs)
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
km	kilometre(s)
kt	knot(s)
LIF	Loading Instruction Form
m	metre(s)
MATS	Manual of Air Traffic Services
min	minutes
MCP	Mode Control Panel
MOR	Mandatory Occurrence Report
NATS	National Air Traffic Services
NTSB	National Transportation Safety Board
N_1	engine fan or low pressure compressor speed
OAT	outside air temperature
OEI	one engine inoperative
PCMCIA	personal-computer memory-card interface association
PF	Pilot Flying
PFD	primary flight displays
PM	Pilot Monitoring
QAR	Quick Access Recorders
QNH	altimeter pressure setting to indicate elevation amsl
RE	Runway Excursion
SAE	Society of Automotive Engineers
ScACC	Scottish Area Control Centre
SIB	Safety Information Bulletin
SOP	Standard Operating Procedures
TAMS	Takeoff Acceleration Monitoring System
TAWS	Terrain Awareness and Warning System
TODA	Takeoff Distance Available
TOGA	Takeoff/Go-around
TOM	Takeoff Monitoring
TOPMS	Takeoff Performance Monitoring Systems
TORA	Takeoff Run Available
TODR	Takeoff Distance Required
TSB	Transportation Safety Board (Canada)
UK	United Kingdom
USA	United States of America
UTC	Co-ordinated Universal Time
VFR	Visual Flight Rules
V_1	takeoff decision speed
V_2	takeoff safety speed
V_R	rotation speed
ZFW	Zero Fuel Weight
°C	Celsius
737NG	Boeing 737 Next Generation

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Air Accidents Investigation Branch

Aircraft Accident Report No: 2/2018 (EW/C2017/07/02)

Registered Owner and Operator:	Sunwing Airlines Inc.
Aircraft Type:	Boeing 737-86J
Nationality:	Canadian
Registration:	C-FWGH
Place of Serious Incident:	On takeoff from Belfast International Airport
Date and Time:	21 July 2017 at 1539 hrs (all times in this report are UTC unless stated otherwise)

Introduction

The Air Accidents Investigation Branch (AAIB) became aware of this serious incident during the morning of 24 July 2017. In exercise of his powers, the Chief Inspector of Air Accidents ordered an investigation to be carried out in accordance with the provisions of Regulation EU 996/2010 and the UK Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996 and, subsequently, 2018.

The sole objective of the investigation of an accident or incident under these Regulations is the prevention of accidents and incidents. It shall not be the purpose of such an investigation to apportion blame or liability.

In accordance with established international arrangements, both the National Transportation Safety Board (NTSB) of the USA, representing the State of Design and Manufacture of the aircraft, and the Transportation Safety Board (TSB) of Canada, representing the State of Registration and the Operator, appointed Accredited Representatives to the investigation. The aircraft operator, the aircraft manufacturer, the European Aviation Safety Agency (EASA), and the UK Civil Aviation Authority (CAA) also assisted the AAIB.

Summary

At 1539 hrs on 21 July 2017, a Boeing 737-800 took off from Belfast International Airport (BFS) with insufficient power to meet regulated performance requirements. The aircraft struck a supplementary runway approach light, which was 36 cm tall and 29 m beyond the end of the takeoff runway.

An outside air temperature (OAT) of -52°C had been entered into the Flight Management Computer (FMC) instead of the actual OAT of 16°C. This, together with the correctly calculated assumed temperature thrust reduction of 48°C[1], meant the aircraft engines were delivering only 60% of their maximum rated thrust. The low acceleration of the aircraft was not recognised by the crew until the aircraft was rapidly approaching the end of the runway. The aircraft rotated at the extreme end of the runway and climbed away at a very low rate. The crew did not apply full thrust until the aircraft was approximately 4 km from the end of the runway, at around 800 ft aal.

There was no damage to the aircraft, which continued its flight to Corfu, Greece without further incident. However, it was only the benign nature of the runway clearway and terrain elevation beyond, and the lack of obstacles in the climb-out path which allowed the aircraft to climb away without further collision after it struck the runway light. Had an engine failed at a critical moment during the takeoff, the consequences could have been catastrophic.

The investigation found the following causal factors for this serious incident:

1. An incorrect OAT was entered into the FMC, which caused the FMC to calculate an N_1[2] setting for takeoff which was significantly below that required for the aircraft weight and environmental conditions.
2. The incorrect OAT was not identified subsequently by the operating crew.
3. The abnormal acceleration during the takeoff run was not identified until the aircraft was rapidly approaching the end of the runway, and no action was taken to either reject the takeoff or increase engine thrust.

The investigation found the following contributory factors for this serious incident:

1. The aircraft's FMC did not have the capability to alert the flight crew to the fact that they had entered the incorrect OAT into the FMC, although this capability existed in a later FMC software standard available at the time.

1 See 1.1.3 for further information.
2 N_1: engine fan or low pressure compressor speed.

2. The Electronic Flight Bags (EFB) did not display N_1 on their performance application (some applications do), which meant that the crew could not verify the FMC-calculated N_1 against an independently-calculated value.

3. The crew were unlikely to detect the abnormally low acceleration because of normal limitations in human performance.

The investigation identified other examples of accidents or serious incidents where there was a gross failure of an aircraft to achieve its expected takeoff performance, and found that technical solutions to address this serious safety issue are now feasible.

AAIB Special Bulletin S2/2017[3], published on 20 September 2017, provided initial information on the circumstances of this serious incident, clarification about the reporting of accidents and serious incidents, and made two safety recommendations related to FMC software updates. In this report, the AAIB makes four safety recommendations: one supersedes a recommendation made in Special Bulletin S2/2017; one concerns procedures to verify engine takeoff power settings; and two concern the development of Takeoff Acceleration Monitoring Systems.

3 https://assets.publishing.service.gov.uk/media/59c2302140f0b60d848fd9ad/AAIB_S2-2017_C-FWGH.pdf [accessed September 2018].

1. Factual information

1.1 History of the flight

1.1.1 Background

C-FWGH was registered in Canada but was operating on behalf of a UK tour operator. This was an arrangement between the Canadian operator and the parent company of the UK tour operator which involved Canadian aircraft operating throughout Europe for the summer season. The Canadian operator supplied the aircraft and pilots, and the cabin crew were provided by the UK tour operator.

The flight, TOM 1526, was from Belfast International Airport (BFS) to Corfu International Airport (CFU), Greece. The crew operated the return flight to BFS on the same day.

1.1.2 Pre-flight planning

The flight crew reported for their duty at BFS just before 1315 hrs with a scheduled departure time of 1415 hrs. The cabin crew had already boarded the aircraft and were preparing it for passenger boarding. The pilots were joined in the briefing area by the operator's technical representative in BFS who was a licensed Canadian Aircraft Maintenance Engineer (AME). He was encouraged to travel with the aircraft, sitting on the spare cockpit seat, if time and payload permitted.

The pilots reviewed the paperwork for the flights and decided that the commander would be Pilot Flying (PF) for the outbound sector and Pilot Monitoring (PM) for the return. The pilots and engineer then proceeded to the aircraft.

1.1.3 Flight preparation

On reaching the aircraft, the co-pilot completed the external inspection whilst the commander began the pre-flight preparation in the flight deck. This preparation included programming the FMC and setting up the Mode Control Panel (MCP) for the expected departure routing.

When the co-pilot returned from the exterior inspection, he listened to the ATIS to find out the runway in use and the weather conditions. Using the passenger and baggage figures from the ground handling company, and the weather information from the ATIS, each pilot completed weight and balance, and performance calculations independently on his EFB. These calculations were then crosschecked before the information was entered into the FMC.

The flight crew then completed a taxi and takeoff briefing covering items such as the expected taxi and departure routing and including a discussion on the handling of emergencies during the takeoff and departure.

At some point during the cockpit preparation, a figure of -47°C was entered into the FMC as the outside air temperature (OAT)[1]. The FMC uses the OAT when calculating the value of N_1 which will produce the engine's rated thrust[2]. At a lower OAT, the engine will require a lower value of N_1 to achieve this rated thrust. Therefore, entering an incorrect and abnormally low OAT, causes the FMC to calculate a value of N_1 (and therefore thrust) significantly below that required to produce rated thrust in the actual conditions. Neither pilot noticed the error. Having completed the performance calculations, the crew reduced the takeoff thrust further by entering into the FMC a correctly-calculated assumed temperature thrust reduction of 47°C[3].

At 1412 hrs the aircraft began to push back off the parking stand at BFS for its departure. During the pushback, the ground crew noticed that one of the nose landing gear tyres had a patch of worn rubber which they brought to the attention of the pilots. An engineer was called to look at the tyre and concluded that it needed changing. As a result, the aircraft returned to the parking stand and the engines were shut down. The engineers changed both the nose landing gear tyres, as is standard practice, and the aircraft was again ready to depart at 1521 hrs. During this period the co-pilot updated the weather information from the ATIS and noted that the OAT had increased by 1°C. He recalculated the takeoff performance, which the commander checked before entering the new details in the FMC. He used 48°C to replace the previously-entered value for the assumed temperature thrust reduction but used an incorrect value of -52°C to replace the previously-entered (and incorrect) value for the OAT[4]. The FMC used this information to calculate a thrust setting for takeoff of 81.5% N_1. The aircraft pushed back from its parking stand at BFS at 1521 hrs, and the flight crew started both engines before taxiing for departure from Runway 07.

1.1.4 Incident flight

At 1539 hrs, C-FWGH was cleared for takeoff on Runway 07 from Taxiway D, which gave a Takeoff Run Available (TORA)[5] of 2,654 m[6]. During the takeoff, at a speed of around 120 to 130 kt, the crew realised that the aircraft was not

1 -47°C was the OAT at the first waypoint after the top-of-climb, shown on the pilot's log.
2 In this case, the calculation of N_1 was based upon the rated thrust of the aircraft. In other cases, where a fixed derated thrust is used for takeoff, the calculation of N_1 would be based upon the derated thrust.
3 Assumed temperature thrust reduction is a way of reducing the takeoff thrust to the minimum required for a safe takeoff, thereby conserving engine life. This is achieved by entering a temperature into the SEL TEMP field on the N1 LIMIT page of the FMC which is higher than the actual temperature.
4 -52°C was the top-of-climb OAT shown on the front page of the pilot's log as part of the flight details.
5 TORA – the length of runway declared available and suitable for the ground run of an aircraft taking off.
6 See 1.11.7 for further information on the takeoff.

accelerating normally. They estimated, during post flight interviews, that they reached V_1[7] with around 900 m of the runway remaining and rotated shortly afterwards. The aircraft, which was seen by multiple witnesses, took a significant time to lift off before climbing at a very low rate. After the aircraft lifted off from the runway, one of the aircraft tyres struck a runway light, which was 36 cm tall and 29 m beyond the end of the TORA. Figure 1 shows an overhead view of BFS.

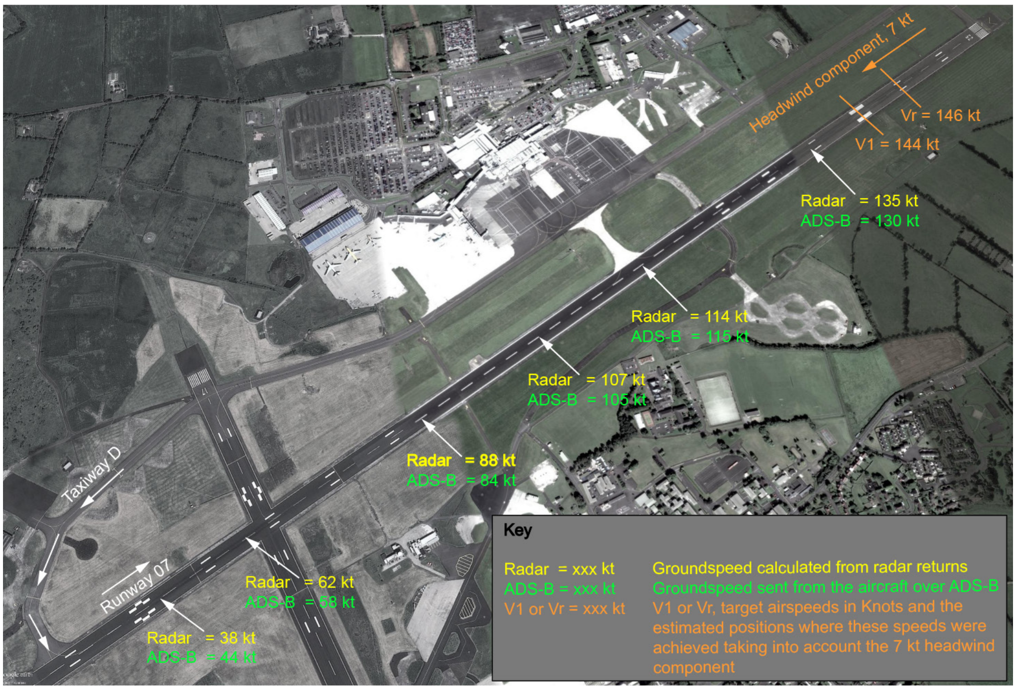


Figure 1

Overhead view of BFS
© 2017 Google, Image © 2017 DigitalGlobe

After takeoff, the crew checked the aircraft's FMC which showed that an N_1 of 81.5% had been used for the takeoff. This figure was significantly below the required N_1 setting of 92.7% (calculated within the EFB and accessed subsequently by the AAIB but not displayed to the pilots).

1.1.5 Notification of the incident

The event was not reported to the AAIB by the aircraft commander, aircraft operator or the tour operator on behalf of which the flight was being undertaken, although it was reported to the TSB in Canada by the aircraft operator. The aircraft commander, the aircraft operator, tour operator and aerodrome authority all had a legal duty to report the event to the AAIB[8].

7 V_1, the takeoff decision speed: the airspeed defining the decision point on takeoff at which, should the critical engine fail, the pilot can elect to abandon the takeoff or continue.
8 See 1.9.3 for further information.

At 2053 hrs on 21 July 2017, ATC personnel at the airport filed a Mandatory Occurrence Report (MOR[9]) and sent an incident signal using NATS Aeronautical Fixed Telecommunications Network (AFTN), and the AAIB was one of the addressees on the signal. This system is only monitored by the AAIB during office hours and the message was not read until 0713 hrs on 24 July 2017 at which time an investigation was begun. The delay introduced by these circumstances meant that information from the Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) was unavailable to the investigation.

1.2 Injuries to persons

There were no injuries to any persons.

1.3 Damage to the aircraft

There was no damage found when the aircraft was inspected in CFU or when a more detailed inspection was conducted on its return to BFS.

1.4 Other damage

One supplementary approach light for Runway 25 at BFS was found damaged (Figure 2). The light was found crushed and lying on the ground having been knocked from its mounting[10].

Figure 2

Supplementary approach light damage

9 Mandatory Occurrence Report (MOR): an occurrence means any safety-related event which endangers or which, if not corrected or addressed, could endanger and aircraft, its occupants or any other person.

10 See 1.10.1 for further information.

1.5 Personnel information

1.5.1 Commander

Age:	38 years	
Licence:	Canadian Airline Transport Pilot's Licence	
Licence Expiry Date:	1 December 2018	
Pilot Proficiency Check:	Valid until 30 April 2018	
Medical certificate:	Valid until 10 April 2018	
Crew Resource Training	Last completed April 2017	
Flying Experience:	Total on all types:	8,234 hours
	Total on type:	2,817 hours
	Last 90 days:	170 hours
	Last 28 days:	45 hours
	Last 24 hours:	0 hours
	Previous rest period:	25 hours

The commander had been off duty the previous day.

1.5.2 Co-pilot

Age:	45 years	
Licence:	Canadian Airline Transport Pilot's Licence	
Licence Expiry Date:	1 May 2024	
Pilot Proficiency Check:	Valid until 30 April 2018	
Medical certificate:	Valid until 07 March 2018	
Crew Resource Training:	Last completed August 2016	
Flying Experience:	Total on all types:	4,423 hours
	Total on type:	1,219 hours
	Last 90 days:	146 hours
	Last 28 days:	52 hours
	Last 24 hours:	0 hours
	Previous rest period:	48 hours

The co-pilot had been off duty the previous day and had completed an early duty the day before.

1.5.3 Engineer

There was an engineer from the operator on the third seat in the flight deck. He was relatively new to the operator and had been encouraged to gain as much experience on the flight deck as possible during his time in Belfast. His role was to act as liaison between the crews, the operator and the contracted engineers.

1.5.4 Crew background, training, experience and duty time

The two pilots had flown together twice before the incident flight.

The maximum allowable flight duty under Canadian regulations was 14 hours. At the time of the incident the pilots had completed 2 hours and 26 minutes of flight duty. Both pilots said that they felt well rested for the flight.

The commander had travelled from North America, arriving in BFS in the morning of the previous day. He had been in North America for the preceding six days and was therefore not acclimatised to UK time, although he commented that he felt well rested. Air travel across time zones can cause disruption to the internal body clock which can lead to jet lag. The International Civil Aviation Organization (ICAO) defines jet lag as:

> *'Desynchronization between the circadian body clock and the day/night cycle caused by trans-meridian flight (experienced as a sudden shift in the day/night cycle). Also results in internal desynchronization between rhythms in different body functions. Common symptoms include wanting to eat and sleep at times that are out of step with the local routine, problems with digestion, degraded performance on mental and physical tasks, and mood changes. Resolves when sufficient time is spent in the new time zone for the circadian body clock to become fully adapted to local time.'*[11]

1.5.4.1 Commander

The commander had been employed by the operator for five years and had been qualified as a commander with the operator since 2015. This was his first deployment to BFS, although the previous summer he had operated out of another European country. The day of the incident was the first time the commander had operated from Runway 07 at BFS.

The commander stated that the takeoff roll seemed normal until 120 to 130 kt when he realised that they were approaching the last 900 m of the runway. He thought he had selected full thrust before lift-off but acknowledged that he may have only pushed the Takeoff/Go-around (TOGA) buttons on the thrust levers (which will not move the levers or adjust the thrust once the aircraft has passed 84 kt on the takeoff roll). He did consider rejecting the takeoff but considered that he did not have enough runway remaining to do so safely. He commented that the takeoff seemed flat and sluggish. He recalled that, after the aircraft got airborne, he asked the co-pilot to select maximum thrust.

11 ICAO Doc 9966 FRMS Manual for Regulators.

1.5.4.2 Co-pilot

The co-pilot had been employed by the operator for two years. This season in BFS was his first time operating in Europe. He thought he might have used Runway 07 at BFS once before but could not be sure.

The co-pilot commented that the takeoff roll seemed normal up to around 80 kt. When the aircraft was in the last 900 m of the runway, he was concerned that the aircraft would not be airborne before the end of the runway. They rotated the aircraft as it reached the red centreline lights, 300 m before the end of the runway. The aircraft entered what the co-pilot described as a “shallow climb”, which he commented felt like when he had practised engine failures in the simulator. He recalled offering the commander a greater thrust setting at the same time as the commander asked him to increase the thrust. The co-pilot selected full thrust, and the aircraft seemed to climb normally once the thrust was increased.

1.5.5 Training and checking

1.5.5.1 Simulator training

Canadian regulations require pilots to complete a proficiency check in the simulator every six months. The operator’s simulator programme did not include a scenario requiring the selection of full thrust once a reduced thrust takeoff roll was underway but neither was it required to do so. Neither pilot had ever selected full thrust during a takeoff roll either in the simulator or the aircraft itself. Since the event in BFS, the operator has included in its simulator training programme a requirement to practise a takeoff where the pilot must move the thrust levers to select full thrust during a reduced thrust takeoff.

1.5.5.2 EFB training

Training on the EFB was provided to both pilots on their initial training course with the operator. This training included the use of the takeoff performance application with examples of the calculations required to calculate the performance for departure.

1.6 Aircraft information

1.6.1 Leading particulars

Manufacturer:	Boeing Commercial Airplanes
Type:	Boeing 737-86J
Engines:	Two CFM56-7B26E turbofans
Date of manufacture:	October 2011
Certificate of Airworthiness:	Canadian transport category issued May 2015
Last maintenance check:	1A/2A, 11 June 2017
Total airframe hours:	19,654 hours
Total airframe cycles:	7,747 cycles
Maximum takeoff weight:	78,999 kg
Takeoff weight (actual):	72,104 kg

1.6.2 Landing gear

The Boeing 737-800 landing gear consists of two main landing gear assemblies located inboard of each engine nacelle and a nose gear assembly located below the aft bulkhead of the flight deck. All three assemblies are fitted with double wheels. The wheelbase is 15.6 m and the track is 5.72 m.

1.6.3 Weight and balance

Details of the baggage and passengers and their distribution within the aircraft was provided to the crew by the handling company, and this information was entered into the EFB to calculate aircraft weight and balance. The calculation was correctly performed and showed that the aircraft was within the allowed weight and balance envelope.

1.6.4 Common Display System and Flight Management Computer System

The Boeing 737-800 is a member of the Boeing 737 Next Generation (737NG) family. On Boeing 737NG aircraft, there are six Display Units (DUs) which, in conjunction with their associated display electronics and control panels, are termed the Common Display System (CDS). The CDS can be upgraded, to support new features or to introduce changes to existing functionality, through a Boeing procedure called a Block Point update.

Boeing 737NG aircraft are also typically equipped, as was C-FWGH, with two FMCs, which are used to optimise and manage the operation of the aircraft. The pilots interact with the FMCs through two Control Display Units (CDUs) which are used for entering and displaying FMC-related information (Figure 3). The overall Flight Management Computer System (FMCS) is referred to as the FMC in this report because that is the term typically used.

The functionality of the FMC can be upgraded during the aircraft's life and this is achieved through revision of the FMC Operational Program Software (FMC OPS). C-FWGH FMC OPS software was at standard U10.8A.

Figure 3

A Control Display Unit

1.6.4.1 EFB description

Each pilot had their own tablet device issued by the operator which performed the functions of the EFB, which were:

- Aircraft weight and balance calculations
- Aircraft takeoff and landing performance calculations[12]
- Access to airport, en-route, and departure/approach charts
- Electronic access to the operator's manuals

12 See 1.11.6.

1.7 Meteorological information

1.7.1 BFS weather at the time of the incident

The weather reported by the BFS ATIS at 1520 hrs showed the wind as 130° at 15 kt, with visibility in excess of 10 km, few cloud at 2,400 ft aal, scattered cloud at 3,000 ft aal, and with a temperature of 16°C, a dewpoint of 11°C and a QNH of 999 hPa. The end of evening civil twilight was at 2131 hrs so all the aircraft movements for the incident flight occurred in daylight.

1.8 Aids to navigation

No relevant information.

1.9 Communications

1.9.1 Description of BFS ATC

BFS ATC offers aerodrome control services for BFS from the visual control room. They also have radar services situated in the same building that offer an approach/departure service for IFR traffic as well as flight information services for VFR traffic. The radar service is known by the callsign Aldergrove Radar.

1.9.2 Scottish Area Control Centre (ScACC)

The airspace of the United Kingdom is divided between area control centres (ACC) which provide air navigation services for IFR traffic departing from and arriving into UK airports as well as international traffic crossing the UK en route for other destinations.

ScACC offers air navigation services to aircraft over Scotland, Northern Ireland, Northern England and the North Sea from 2,500 ft to 66,000 ft. Any aircraft departing BFS is first handed to Aldergove Radar before control of the aircraft is passed to ScACC. ScACC maintains control of the aircraft until its routing takes it into another ACC within the UK or that of a neighbouring country.

1.9.3 The Manual of Air Traffic Services (MATS)

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 by the UK CAA, with Part 2 being produced by the ATSU and approved by the CAA.

MATS Part 1, Section 6, Chapter 3 deals with aircraft accidents and incidents and provides a list of typical incidents which are likely to be considered serious. This list includes '*Gross failure to achieve predicted performance during takeoff or initial climb*'. The list is almost identical to that on the AAIB website and is in accordance with ICAO Annex 13 and Regulation (EU) 996/2010, which is the European Regulation on the investigation and prevention of accidents and incidents in civil aviation.

At the time of this event MATS Part 1 required the senior controller at an aerodrome to ensure that the Watch Manager at the respective Area Control Centre (ACC) and the aerodrome operator were informed of a serious incident, before submitting a Mandatory Occurrence Report[13] (MOR). The Watch Manager at the ACC would then be responsible for telephoning the AAIB and submitting an MOR.

1.9.4 Flight departure communications

The tower controller at BFS and the assistant both observed the aircraft as it taxied out for departure and during its takeoff roll. Both were concerned about the length of runway used by the aircraft during takeoff and were sure that there was a significant problem with the aircraft. They both commented that the aircraft climbed away with a very low rate of climb compared to what they normally observed.

It was normal practice for the flight to be transferred to Aldergrove Radar after takeoff, but the tower controller decided to allow the pilots some time as he was sure they had a problem they were dealing with and that they would call him if they needed anything. However, no such call was forthcoming and so the controller asked them to contact Aldergorve Radar. The crew did not indicate to the tower controller that there was anything abnormal on their takeoff or departure. They contacted Aldergrove Radar and the flight was cleared as normal on the flight plan route.

After the aircraft was transferred to Aldergrove Radar, the tower controller and assistant discussed the departure and agreed that the takeoff was not normal. The fire station watch office, which is located in an adjacent building just below the visual control room, was occupied by an on-duty fireman who also witnessed the takeoff roll. After reporting his concerns to the fire watch manager, he called the visual control room to report what he had seen. The tower controller suggested that a runway inspection should be carried out which the assistant organised with the airport operations department. All three of these witnesses confirmed that they thought the aircraft was still on

13 Mandatory Occurrence Report (MOR): An occurrence means any safety-related event which endangers or which, if not corrected or addressed, could endanger an aircraft, its occupants or any other person.

the ground at the very end of the runway, but the distance prevented them from being able to describe exactly where the aircraft rotated or lifted off.

The runway inspection found one of the Runway 25 supplementary approach lights lying on the ground with substantial damage evident (Figure 2). The damage was reported to the tower and to the duty electrician at 1620 hrs. A discussion between staff in the tower and airport operations concluded that the light had been blown over due to jet blast of the engines. This had happened previously in BFS, although with much larger aircraft and generally at the beginning of the runway behind an aircraft as it began its takeoff roll.

Following a shift change, the new airfield duty manager observed the damage to the light and the rubber deposits on it and suggested that, rather than the light being blown down by jet blast from the aircraft, it had been hit by a tyre. These concerns were reported to the tower by the duty manager. The BFS ATC watch manager then contacted the watch manager at ScACC to request that the ACC try and contact the pilots of C-FWGH. However, the aircraft had long since left ScACC airspace, so the watch manager attempted to contact the operator. The ScACC log showed that, at 1908 hrs, they were told that the aircraft may have hit a light. The watch manager at ScACC contacted the operator in Canada who agreed to contact the crew who had already arrived at their destination.

There were three conversations between BFS ATC and ScACC. The first two were from BFS to ScACC trying to get a message to the pilots regarding the light and the third, from ScACC to BFS, was reporting that the operator would speak to the pilots in Corfu. The watch manager at ScACC did not get the impression that ATC in BFS believed that there had been a serious incident, and did not come to that judgement himself, and therefore did not report the matter as laid out in MATS Part 1. The conversations between BFS and ScACC did not mention reporting a serious incident or the processes that would be followed in doing so.

BFS ATC filed an MOR at 2053 hrs, as per the instructions in MATS Part 1, just over 5 hours after the event. This MOR was received at the AAIB as it was an addressee on the signal. The primary means to inform the AAIB of an accident or serious incident is using a telephone line which is manned 24 hours a day, 365 days of the year. The signal traffic is only monitored during office hours. This signal was sent on a Friday evening, and so was not seen by the AAIB until office hours on Monday morning. The lack of reporting action by the method then prescribed in MATS Part 1 meant that, by the time the AAIB became aware of this serious incident, both the CVR and FDR had been overwritten and their data was unavailable.

1.10 Aerodrome information

1.10.1 Description of BFS and its runways and lighting

Runway 07 at BFS is fitted with high intensity edge and centreline lights. The edge lights are spaced at 60 m with the centreline lights placed every 15 m. The centreline lights are white from the beginning of the runway until the last 900 m when they alternate red and white. From the last 300 m to the end of the runway the lights become all red.

As the aircraft was departing from Runway 07, the lights beyond the end of the runway were the Runway 25 approach lights. These lights consisted of a standard ICAO 5 bar Category 2 and 3 lighting system (Figure 4).

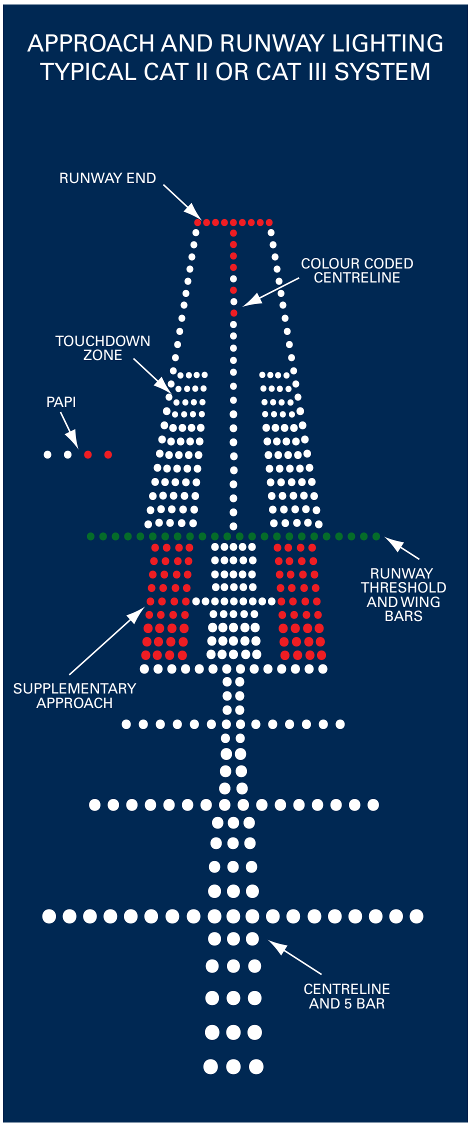


Figure 4

Typical Approach light system illustration from CAA CAP 637 ©CAA

The end of Runway 07 was indicated by a line of red lights. Beyond those lights was 60 m of tarmac – a stopway – which contained some of the approach lights for Runway 25. The ICAO definition of stopway describes a defined rectangular area on the ground at the end of the runway in the direction of takeoff prepared as a suitable area in which aircraft can be stopped in case of an abandoned takeoff. It does not form part of the runway length for the purposes of a takeoff roll.

Within the stopway were two sets of supplementary approach lights for Runway 25. Each of these sets had thirteen lights set out in three groups across the tarmac. These lights were positioned 36 cm above the stopway surface. The first set of lights was 29 m beyond the end of Runway 07, with the stopway ending 60 m beyond the end of Runway 07. The aircraft struck the centre light within the first set of supplementary approach lights. Figure 5 shows the layout of the lights, together with the dimensions of the stopway and indicates the direction of travel of the aircraft and the light the aircraft struck. Figure 6 shows the view from the stopway with the centre light missing.

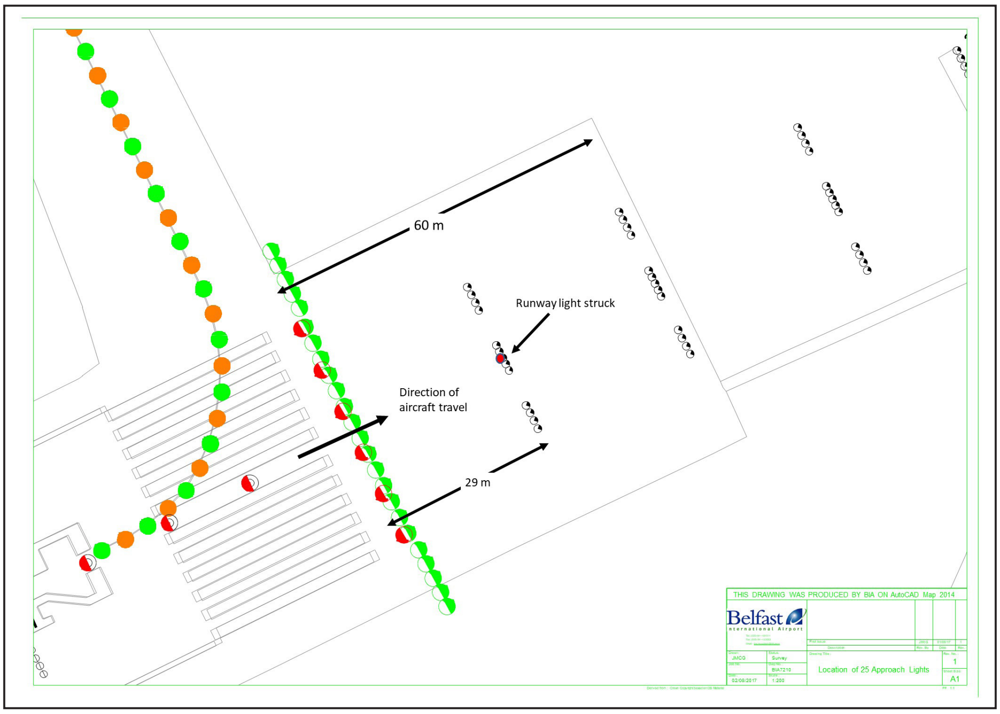


Figure 5

Dimensions of stopway and lighting positions

Figure 6

The view from the stopway showing the centre light missing

1.10.2 Description of terrain on departure from Runway 07 at BFS

BFS has no standard instrument departures, having instead standard routings which have no published required climb gradient. The departure area from each runway has been mapped for obstacles to produce inner, outer and takeoff climb surfaces. The Runway 07 departure area contains very few obstacles. The departure lane from Runway 07 at BFS is benign with no terrain issues and few obstacles.

1.11 Recorded information

The AAIB became aware of this event after C-FWGH departed on its 16th sector since the occurrence, having operated for a further 58 hours. Several conventional sources of recorded information, including the mandatory flight recorders that were fitted to C-FWGH, had been overwritten on the subsequent flights. Therefore, it was necessary to combine data from multiple systems to understand the precise sequence of events that occurred during this event. Each of these systems, and the data that was recovered from them, are documented below.

1.11.1 Mandatory flight recorders

C-FWGH was equipped with both a Cockpit Voice Recorder (CVR) and a Flight Data Recorder (FDR).

The AAIB did not remove the CVR from the aircraft because it would have been overwritten due to the elapsed time since the event.

Power to the FDR was isolated on completion of the aircraft's 17th sector, 60 hours after the occurrence. Subsequently, the FDR was removed from the aircraft and downloaded at the AAIB. The download confirmed that, although the FDR was working correctly, the event had been overwritten because the FDR had a recording capacity of only 25 hours.

1.11.2 Quick Access Recorders

C-FWGH was equipped with two supplementary Quick Access Recorders (QARs). One of these was installed in the cockpit and used in support of the operator's Flight Data Monitoring (FDM), or Flight Operations Quality Assurance (FOQA), programme. However, the operator was troubleshooting this installation and the memory card, when downloaded by the operator one sector after the event, was found to be empty. This was confirmed by an AAIB forensic examination.

The other QAR, located in the Electronic Equipment Compartment (EEC), was a wireless unit which had been installed when the aircraft was with a previous operator. The current operator was not using this installation and the last flight on the unit's internal memory was from 2015.

1.11.3 Aircraft Condition Monitoring System data

C-FWGH was equipped with an Aircraft Condition Monitoring System (ACMS), which is a function carried out by the Digital Flight Data Acquisition Unit (DFDAU) located in the EEC. By utilising relevant data as it passes through the DFDAU, the ACMS continuously monitors the health of various components on the aircraft, such as the engines.

The ACMS analyses DFDAU data and produces summary reports if certain trigger conditions are met. These reports are stored locally and can be transmitted by the aircraft to a ground station by utilising a system called the Aircraft Communication, Addressing and Reporting System (ACARS). A standard report which the ACMS generates is a takeoff report and, following C-FWGH's incident takeoff, one of these reports was received via ACARS by the Belfast ground station. The report was generated at 1540 hrs, as the aircraft accelerated through 153 kt at the upwind end of Runway 07, and showed N_1 values of 81.4% and 81.7% for engine Nos 1 and 2 respectively.

Other ACMS reports received via ACARS confirmed that the correct weights for the aircraft had been entered into the FMC prior to takeoff.

The operator attempted a download of the ACMS system the day after the incident, by removing the unit's PCMCIA card, but the last report stored locally on the card was from the beginning of May 2017. As a subsidiary function, the ACMS can be programmed to store flight data onto the PCMCIA card, but the last flight data stored was from April 2017.

1.11.4 CDU/Built-in Test Equipment data

The CDUs support an interface to Built-in Test Equipment (BITE) for various aircraft systems, including the autothrottle system. The AAIB examined the autothrottle BITE data on the CDUs and this showed that two faults[14] had been logged for the incident sector (see the red box in Figure 7).

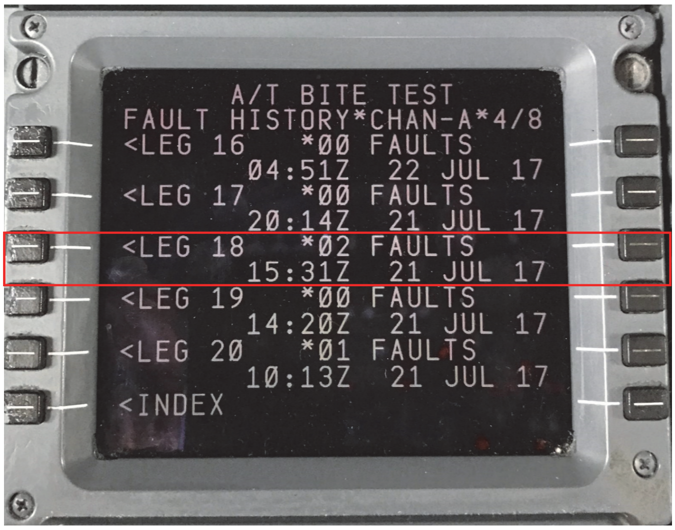


Figure 7

CDU autothrottle BITE history

These faults related to the initial climb-out from BFS, and the CDS pages for them are shown in Figure 8. Both messages relate to an *'N1 Bloom'* and the message identification numbers are highlighted by red boxes in Figure 8.

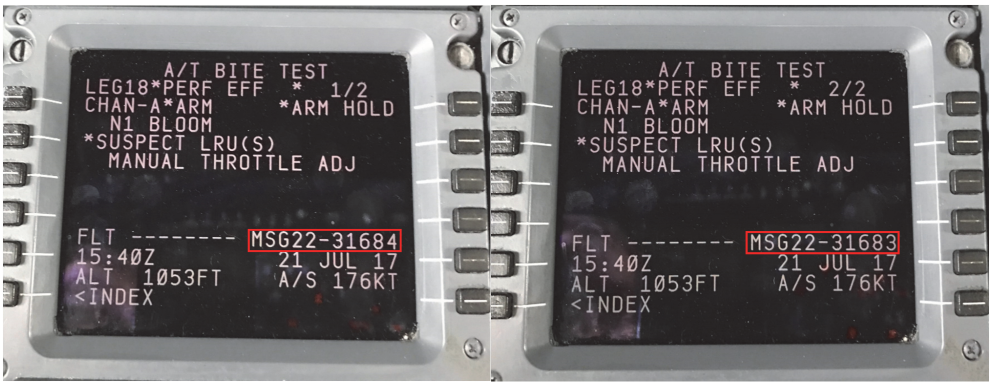


Figure 8

Detailed CDS fault pages for both faults logged

14 Manual throttle adjustment is recorded as a fault on the CDU autothrottle (A/T) BITE TEST page.

The manufacturer's Fault Isolation Manual provided additional information:

> *'MANUAL THROTTLE ADJ (the same as MAN THR ADJ) means that the increase in N_1 was caused by a change in throttle position made by the flight crew.'*

The aircraft manufacturer stated that the messages indicated that the crew has adjusted the throttles for Engine No 1 and 2 during takeoff to a value above the FMC-calculated takeoff target. The increase in thrust occurred at 1540 hrs, when the aircraft was flying at an airspeed of 176 kt and 1,053 ft barometric altitude (based on the Standard pressure setting of 1,013 hPa). At this point, C-FWGH was approximately 4 km from the end of Runway 07, at approximately 800 ft aal.

1.11.5 Enhanced Ground Proximity Warning System

An Enhanced Ground Proximity Warning System (EGPWS) was fitted to C-FWGH and data from the unit was downloaded. An EGPWS provides various protection functions (modes) and the pertinent one for this incident is Mode 3. Mode 3 generates an alert if a loss of altitude after takeoff exceeds a set value dependent on the height the aircraft has attained above ground – for a height of 250 ft above ground, the altitude loss required to trigger an alert is approximately 25 ft. At 500 ft above ground, this value is approximately 50 ft.

C-FWGH's climb-out from Belfast was over ground that sloped away from the airfield and no alerts were generated by the EGPWS. This confirmed that C-FWGH did not descend by more than 50 ft during the aircraft's initial climb-out to 500 ft agl.

1.11.6 EFB data

The EFBs used by both pilots were examined by the AAIB and further examination of the co-pilot's EFB showed that eight performance calculations were made for the takeoff. Three of these calculations were made prior to the aircraft's takeoff time and five afterwards when the aircraft was en route.

For each of these cases, the crew requested the EFB to calculate solutions for both a Runway 07, Taxiway D, and a Runway 25 takeoff. The calculations made prior to departure for a Runway 07, Taxiway D takeoff are summarised in Table 1. For these cases, it was assumed that the runway was dry, bleed air was selected ON and there was no requirement for any wing or engine anti-ice. The use of both air conditioning packs and the use of optimal flap setting was also assumed.

Time of calculation (hh:mm:ss)	14:00:41	14:03:11	15:27:49
Wind direction/ velocity (°/kt)	140/15	140/15	130/15
Outside air temperature (°C)	+15	+15	+16
QNH (hPa)	999	999	999
Gross weight (Tonnes)	71.6	71.9	71.9
N_1 (%)	92.6	92.9	92.7
Assumed temperature (°C)	+48	+47	+48
V_1 (kt)	143	141	144
V_R (kt)	146	146	146
V_2 (kt)	150	150	150

Table 1

EFB Performance calculations made prior to takeoff

Using an assumed temperature of +48°C, the EFB calculated an N_1 target of 92.7% for the takeoff from Runway 07, Taxiway D. This information was not available to the crew, however, because the calculation output page did not display N_1 (Figure 9).

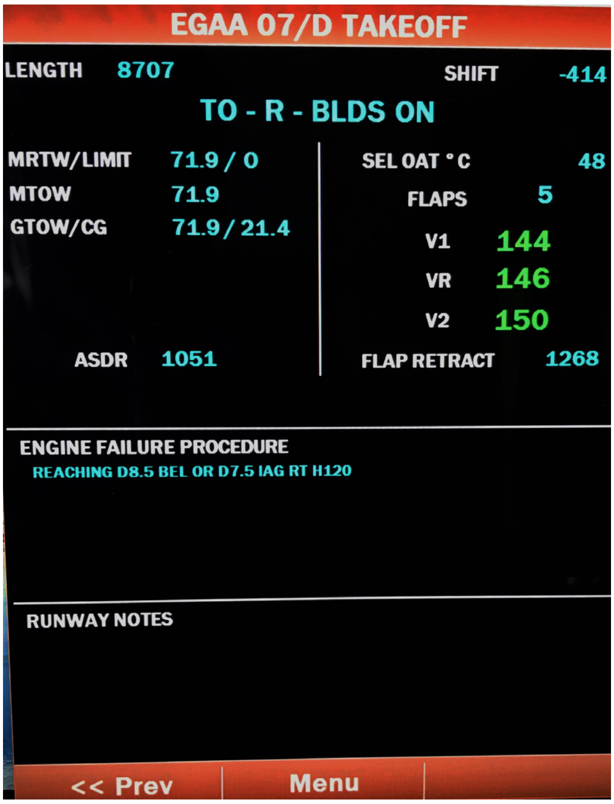


Figure 9

The EFB performance calculation output page

The first calculation made after takeoff (17 minutes into the flight), was also checked and it agreed with the last pre-takeoff calculation.

The EFB manufacturer confirmed that, using the input data for the last pre-takeoff case, its software would calculate an N_1 setting of 92.7%.

1.11.7 Radar and Automatic Dependent Surveillance – Broadcast data

The radar installation at Belfast International Airport tracked C-FWGH along Runway 07 and during initial climb-out, when altitude data also became available from the aircraft's transponder. The radar returns allowed groundspeed for the aircraft to be calculated which was supplemented by both groundspeed and altitude data transmitted from the aircraft over its Automatic Dependent Surveillance – Broadcast (ADS-B) datalink. This data is shown in Figure 10 for the ground roll, where the text in yellow represents calculated groundspeed data from the radar track and, in green, the received ADS-B groundspeeds. Orange lines show the approximate position where the aircraft achieved airspeeds equivalent to the EFB-calculated V_1 and V_R, considering the 7 kt headwind component. V_R would have been achieved approximately 300 m from the end of the runway.

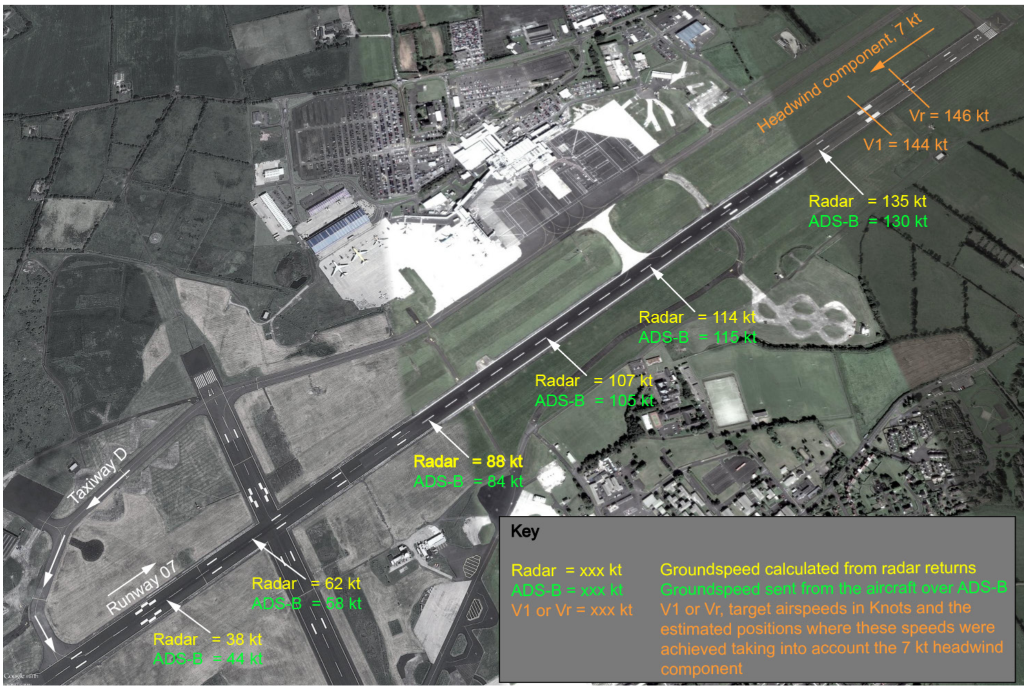


Figure 10

Groundspeed data for the takeoff in relation to the EFB calculated V_1 and V_R
© 2017 Google, Image © 2017 DigitalGlobe

Figure 11 shows spot heights above the elevation of BFS (268 ft amsl) for the aircraft's initial climb, derived from the aircraft's ADS-B reports.

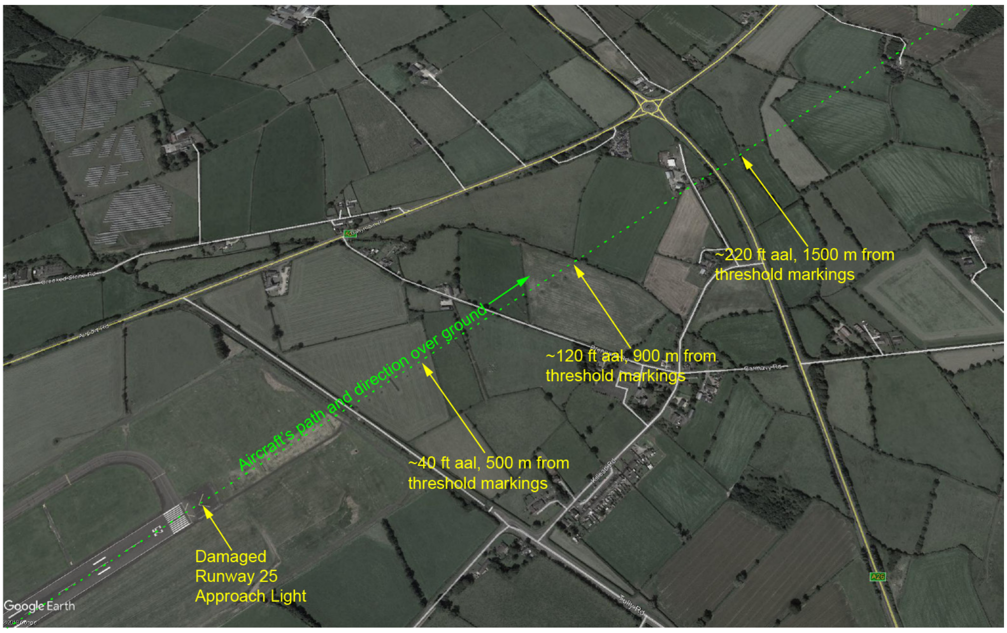


Figure 11

Vertical profile for the initial climb-out
© 2018 Google

1.11.8 Closed-circuit television recordings

The airport operator provided the AAIB with closed-circuit television (CCTV) recordings of C-FWGH's takeoff from two cameras. The first camera's field of view recorded the segment between 1,000 m and 475 m from the departure end of Runway 07. At the end of this segment, C-FWGH had not rotated (Figure 12).

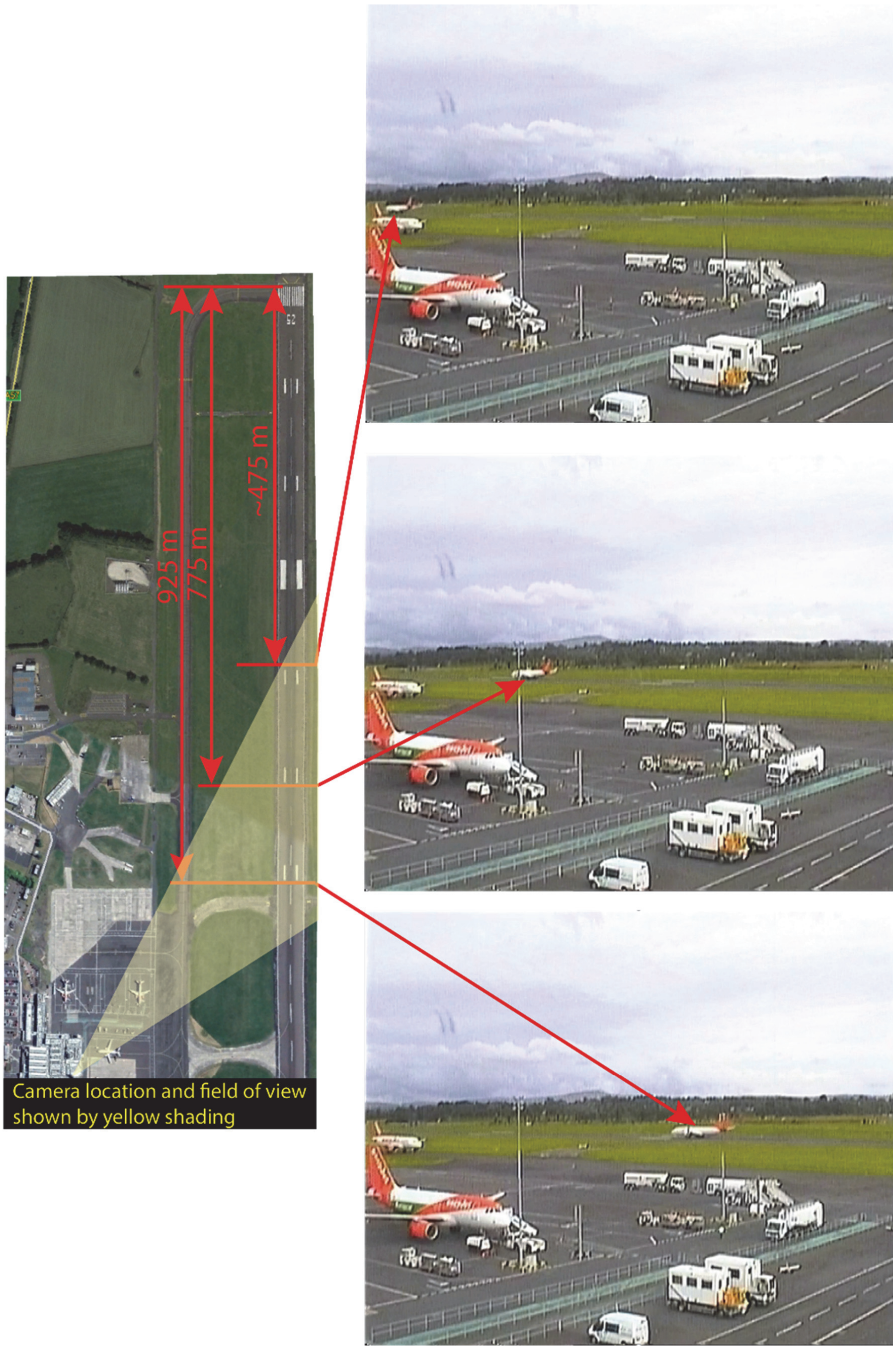


Figure 12

The first CCTV recording showing C-FWGH's takeoff

The second camera captured the rotation, lift off and initial climb-out of C-FWGH. The resolution and sightline angle of this CCTV recording did not allow calculations of distance to be made, but the airport operator provided another CCTV recording from the same camera of an aircraft lined up for departure on the reciprocal Runway 25. Using this recording, and the recording showing C-FWGH's departure, it was possible to confirm that C-FWGH lifted off at the extremity of Runway 07. Figure 13 shows a comparison of these recordings; C-FWGH is shown immediately after lift-off at the top of the figure, compared with the aircraft lined up on Runway 25 ready to depart at the bottom of the figure. In both images, the aircraft have been highlighted by a red circle.

Figure 13

The second CCTV recording showing C-FWGH's lift off at the top, compared with an aircraft lined up for departure on the reciprocal runway at the bottom

1.11.9 Cockpit photo

The engineer travelling in the cockpit took a photo before the aircraft first pushed back from the stand (Figure 14).

Figure 14

Cockpit photo and N_1 display prior to first pushback

In this photo taken prior to engine start, on the upper DU, both reference N_1 readouts in green text show ‘88.2’ and the reference N_1 bugs, represented by the green carets on the N_1 scales, are aligned against this value on both inner scales.

On the Boeing 737NG, the selection of a reduced takeoff thrust is achieved by selecting a fixed derate, and/or entering an assumed temperature into the SEL field, on the N1 LIMIT page on either CDU (Figure 15). These thrust reduction methods can be used in isolation or combined, but the total thrust reduction when using the assumed temperature method is limited to 25% of the reference thrust used (either the full rated thrust or the fixed derate thrust). The operator of C-FWGH typically used the assumed temperature method[15] to reduce takeoff thrust but not the fixed derate method.

15 See 1.1.3, footnote 3.

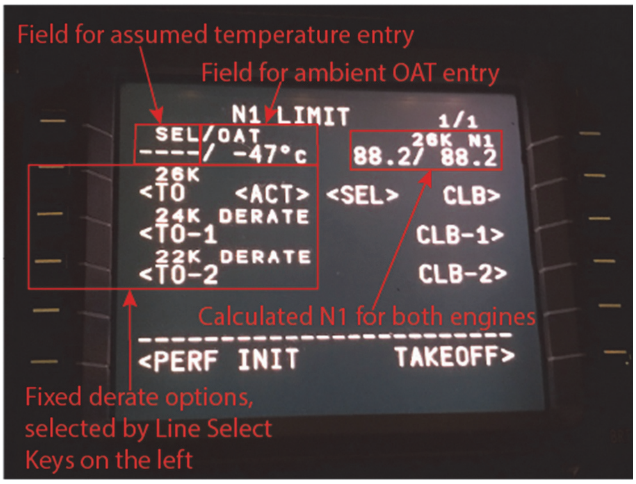


Figure 15

N1 LIMIT CDU page

The text in green showing *'TO'* at the top of the DU (Figure 14) indicates that a fixed derate had not been selected when this photo was taken. Had a fixed derate been selected, the text would have indicated *'TO 1'* or *'TO 2'* dependent on the level of derate selected on the CDU (Figure 15). The text 'TO' also indicates that an assumed temperature thrust reduction had not been selected. If an assumed temperature had been entered, it would have been shown on the DU as *'D-TO'*.

1.12 Wreckage and impact information

1.12.1 Supplementary runway light damage

One of the supplementary approach lights within the Runway 07 stopway was found lying on the ground during the runway inspection. Closer examination revealed that the light had significant impact damage with evidence of black rubber deposits.

When compared with the tread on the tyres on C-FWGH, the pattern of rubber deposits indicated that the light had probably been struck by one of the main gear tyres. Chemical analysis of the rubber deposit was unable to confirm whether a main or nose landing gear tyre struck the light (Figure 16).

Aerodrome lights are designed to be frangible. If stuck by an aircraft they are to break causing minimal or no damage to the aircraft. The crew were unaware that they had struck a runway light and there was no damage to the aircraft structure or tyre from striking the light.

Figure 16

Tread pattern comparison with main gear tyre

1.13 Medical and pathological information

There were no injuries to any persons in the aircraft or on the ground.

1.14 Fire

There was no fire.

1.15 Survival aspects

No relevant information.

1.16 Tests and research

1.16.1 Simulator trials

The AAIB and operator carried out independent simulator assessments of how the incorrect thrust setting might have been programmed into the FMC. Both assessments concluded that the only credible way to achieve a grossly low N_1 setting was to enter an extremely low value into the OAT field on the N1 LIMIT page. It was found that the takeoff N_1 setting used on the flight (81.5%) would be calculated by the FMC if:

a. A figure of -52°C was entered into the OAT field on the N1 LIMIT page; and

b. An assumed temperature of 48°C, as calculated on the EFB, was entered into the FMC.

No other combination of data entries was found which would achieve the same result.

During the simulation carried out by the AAIB, the aircraft's performance was assessed following an engine failure immediately prior to V_1, with the pilot making a decision by V_1 to either abandon or continue the takeoff. In the simulator, the aircraft was able to stop in the runway remaining following a decision to abandon the takeoff, but was unable to climb away following a decision to continue the takeoff.

Simulator assessment by the AAIB of the aircraft handling after takeoff with an N_1 setting of 81.5%, and both engines operating, showed that the aircraft required a significant pull force on the control column to reach the correct pitch attitude for the climb, and that the climb rate was very low.

1.16.2 Manufacturer's performance modelling

The aircraft manufacturer was asked to model the expected performance of C-FWGH using the information summarised in Table 2 below.

Aircraft loading	Planned takeoff weight	71.9 tonnes
Aircraft configuration	Flaps	5
	Engine #1 N_1	81.4%
	Engine #2 N_1	81.7%
	Bleeds[1]	Both air conditioning packs on No wing anti-ice No engine anti-ice
Environmental data	Temperature	+16°C
	Wind	15 kt / 130°T
	Pressure	999 hPa
Operational information	Rolling takeoff performed, Runway 07 entered from Taxiway Delta	

Table footnote:

[1] *Bleeds* refers to the offtake of compressed air from the aircraft's engines, used for ancillary purposes such as cabin pressurisation, heating and anti-ice protection of the aircraft.

Table 2

Data provided to the aircraft manufacturer for the performance modelling work

In response, the manufacturer provided data for the following scenarios:

a) An all engines operating (AEO) takeoff.

b) An AEO takeoff until V_1, at which point an engine was failed and the takeoff was continued with one engine inoperative (OEI).

c) An AEO takeoff until V_1, at which point the takeoff was rejected.

The manufacturer's analysis confirmed that, for case a), the aircraft would have rotated after 2,148 m, 506 m from the end of the TORA. Lift off would have been after 2,501 m, 153 m from the end of the TORA, and the aircraft would have cleared the 35 ft screen height, a regulatory performance requirement, after 2,924 m, 23 m prior to reaching the end of the Takeoff Distance Available (TODA)[16]. The manufacturer's analysis assumed a 0.0% slope for Runway 07, whereas Runway 07 has an upwards slope of 0.7%.

For case b), after an engine failure and without the addition of power on the operating engine or a change in the aircraft's configuration, the manufacturer stated that C-FWGH would not have been able to climb; the gear-down OEI climb gradient was calculated as -1.8%.

In case c), certification requirements do not account for the use of reverse thrust to stop the aircraft. They also allow for a two second delay before action to stop the aircraft is taken. Nevertheless, the manufacturer was asked to assume the use of maximum reverse thrust with no delay in the crew's reaction when calculating the distance it would have taken for the aircraft to stop. The result was a distance of 2,654 m for the aircraft to decelerate to 5 kt groundspeed compared with the Accelerate Stop Distance Available (ASDA)[17] for this departure which was also 2,654 m.

However, this represents an ideal case and, had the crew taken two seconds to react, the manufacturer's data showed that an additional 146 m of distance would have been used to slow down to 5 kt groundspeed. Furthermore, the effect of using reverse thrust on stopping distance is substantial; had the use of reverse thrust not been accounted for, bringing the result for case c) into line with the certification requirements, then C-FWGH would have overrun the end of the TORA at approximately 80 kt.

16 The Takeoff Distance Available, or TODA, equals the TORA distance plus an additional distance over which an aircraft may safely climb-out to the screen height. The TODA for Runway 07 at Belfast Aldergrove, when entering the runway at Taxiway D, is 2,947 m.

17 The Accelerate Stop Distance Available (ASDA), reflects the length of runway defined as available and suitably load-bearing for an aircraft to accelerate and stop within in the case of a rejected takeoff. The ASDA for Runway 07 at Belfast Aldergrove, when entering the runway at Taxiway D, is 2,654 m.

1.16.3 Erroneous entries of OAT into the FMC

1.16.3.1 Previous events

In December 2014, as a result of previous events involving erroneous OAT entries during the programming of the FMC, the manufacturer published a Flight Crew Operations Manual (FCOM) Bulletin. This document discussed three events where incorrect values for OAT had been entered into the FMC. In two of these cases, the incorrect OAT value had been entered through data link from an automated weather reporting system and accepted by the crew, but in the third case the crew made a manual entry error. The bulletin stated:

> *'An incorrect reduced thrust target may result in slower acceleration to V_1, which may invalidate the takeoff performance calculations and/or result in decreased obstacle clearance margins after liftoff.'*

The bulletin also stated that:

> *'flight crews should verify the OAT entry on the N1 LIMIT page is correct.'*

It then described this verification step in further detail instructing crews to:

> *'Confirm the OAT value is correct and reasonable for the ambient conditions.'*

The bulletin also cautioned that:

> *'Flight crews should be particularly vigilant about the plus or minus sign of the OAT entry, since sign reversals are a common pattern in this error and can produce a large effect on takeoff settings.'*

FCOM bulletins are temporary changes which are inserted into the FCOM, and recorded on a bulletin record page within the FCOM, until the next revision of the FCOM is formally issued. However, when this occurs the relevant bulletin is cancelled and, as the FCOM does not detail the background information which was contained within a cancelled bulletin, the circumstances which originally led to its release are not always easily accessible to a crew. Therefore, the details about previous events where erroneous OAT entries had been made, and the significant effect that these entries had on the target N_1 used for takeoff, were not available to the crew of C-FWGH.

1.16.3.2 OAT crosscheck functionality

In addition to the release of the FCOM bulletin, the manufacturer added a crosscheck function to revision U12.0 and later versions of the FMC OPS software. The crosscheck compares the OAT entered by the crew, or accepted by the crew in the case of a data-linked OAT, against either that sensed by the Electronic Engine Controls or, on some older Boeing 737s (including the -100 to -500 series that pre-date Boeing 737NG aircraft), by the aspirated Total Air Temperature probe. The crosscheck runs once, approximately one minute after first engine start, and establishes whether a difference of more than six degrees in temperature exists between the value accepted by the FMC and that sensed by the external temperature sensor. If the difference is more than six degrees, it deletes the OAT entry, removes any assumed temperature or fixed derate that has been selected and deletes the takeoff reference speeds. It also displays two messages and illuminates the *'MSG'* indicator on both CDUs to warn the crew that data has been deleted from the FMC; the messages shown are OAT DISAGREE – DELETED and TAKEOFF SPEEDS DELETED (Figure 17).

Figure 17

CDU messages associated with the FMC OPS U12.0 OAT crosscheck

In addition, the amber FMC light on both autoflight status indicators, situated above each pilot's inner DU, are illuminated.

At the time of the serious incident, C-FWGH had an earlier revision of FMC OPS software installed, U10.8A (Figure 18), which did not include this crosscheck.

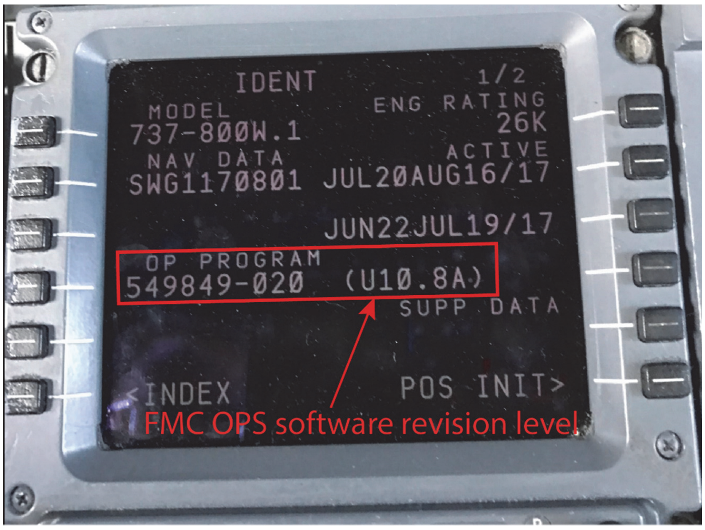


Figure 18

CDU IDENT page of C-FWGH

Revision U12.0 of the FMC OPS software was promulgated to operators in February 2016, via Boeing Service Bulletin 737-34-2600, although U12.0 was embodied on production line aircraft from November 2015. Subsequently, this service bulletin was amended and re-released as Revision 1 on 10 January 2017. Revision 1 of the service bulletin states:

'Boeing recommends that the change given in this service bulletin be done within 24 months after the Revision 1 date of this service bulletin.'

However, the OAT crosscheck functionality also requires Boeing 737NG aircraft to have the Block Point 15 (BP15) update of the CDS installed. This became available to operators, via Boeing Service Bulletin 737-31-1650, on 10 January 2017, having been embodied on production line aircraft since October 2016. This service bulletin states:

'Boeing recommends that the change given in this service bulletin be done within 24 months after the original issue date of this service bulletin.'

Compliance with service bulletins is not compulsory, but each bulletin includes an estimate on the manpower hours required to comply with it. According to the manufacturer, embodiment of both relevant bulletins should take 6.8 hours per aircraft with the parts being supplied at 'nominal cost'. Operators judge whether and when service bulletins should be embodied based on their own assessment of the safety case and the operational and cost impact.

1.16.3.3 Simulator assessment of the OAT crosscheck

The AAIB carried out a simulator assessment of the functionality of the OAT crosscheck in FMC OPS U12.0 to see if it would have detected the erroneous OAT entries, one made prior to C-FWGH first pushing back from the stand and the other made during the nose landing gear tyre change. The AAIB also assessed the effect the deletion of FMC data, by the crosscheck, would then have on the autothrottle operation if an attempt was made to takeoff.

This trial confirmed that, when simulating C-FWGH's first push back from the stand, 60 seconds after the engine start switch returned to OFF after the first engine had been started, the FMC light on both autoflight status indicators illuminated. Being central to the crew's field of view, this drew attention to each CDU. On both CDUs, the MSG light was illuminated and the OAT DISAGREE – DELETED message was displayed. Using either CDU's CLR key removed this first message and exposed the second message, TAKEOFF SPEEDS DELETED. To clear the second message, a further press of the CDU's CLR key was required. The FMC light on both autoflight status indicators could be extinguished at any time by pressing either lit caption but this had no effect on the CDU messages which still required actioning by correcting the original error condition or clearing the messages as detailed above. The crosscheck also cleared the assumed temperature that had been entered and deleted all of the takeoff speeds on the relevant CDU page and on both Primary Flight Displays (PFDs).

After taxiing to the runway, an attempt was made to engage the autothrottle system to perform a takeoff. However, as no N_1 target existed after deletion of the OAT, it was not possible to engage the autothrottle system.

1.16.4 Recent events involving mis-selection of FMC thrust settings

This serious incident, and the previous events reported in the manufacturer's FCOM Bulletin, occurred when incorrect takeoff thrust settings were used following erroneous OAT entries made into the FMC. However, if a takeoff is planned with derated thrust, the setting of the target thrust level also depends on the derate information entered. If either the assumed temperature or the selected fixed derate are entered incorrectly then the target thrust setting will be wrong.

In November 2010, a Boeing 737-700 took off from Southend Airport, England[18] with an incorrect assumed temperature entered into the FMC, resulting in too great a thrust reduction for the runway in use. The Australian Transport Safety Bureau (ATSB) investigated two events, occurring in November 2007

18 https://www.gov.uk/aaib-reports/boeing-737-76n-5n-mji-21-november-2010 [accessed September 2018].

and October 2008, where Airbus A320 aircraft took off with incorrectly entered 'FLEX[19]' temperatures[20].

Following the serious incident to C-FWGH, the AAIB became aware of a further two events worldwide where, from initial information, the potential existed for similar FMC entry errors to have directly affected the takeoff thrust setting.

Appendix A contains other examples since October 2004 of accidents and serious incidents related to abnormal takeoff performance considered by this investigation.

1.16.4.1 N_1 crosscheck

The crew used an EFB to determine their takeoff performance and then transferred this data into the aircraft's FMC. They had calculated the performance correctly in the EFB and transferred the information without error, but made a separate, unrelated data entry error into the FMC which meant that the N_1 setting calculated by the FMC was inadequate for the subsequent takeoff. The EFB did not display the calculated N_1, so the crew could not check it against the FMC-calculated N_1. The aircraft FCOM specified that the N_1 must be verified but did not explain how. Other operators of the Boeing 737 display the calculated N_1 on their EFBs and the verification of N_1 is completed by comparing the EFB-calculated N_1 with the FMC-calculated N_1. If the two N_1 values are the same, it gives the crew confidence that the data they entered into the FMC was consistent with the data entered into the EFB. Some UK based operators introduced such a cross check after this incident.

1.17 Organisational and management information

1.17.1 Operator details

The operator is a Canadian airline which is part of a large Canadian travel group. The airline operates a fleet of over forty Boeing 737 aircraft. The travel group has close links to a European tour operator and provides summer capacity for the tour operator through the lease of aircraft which are then based throughout Europe. The incident aircraft was one of five Boeing 737s operating on behalf of the tour operator for the summer of 2017.

1.17.2 Operator Standard Operating Procedures (SOPs) regarding FMC setup

The operator's FCOM contains technical details of the aircraft as well as amplified procedures for the operation of the aircraft type in the operator's service.

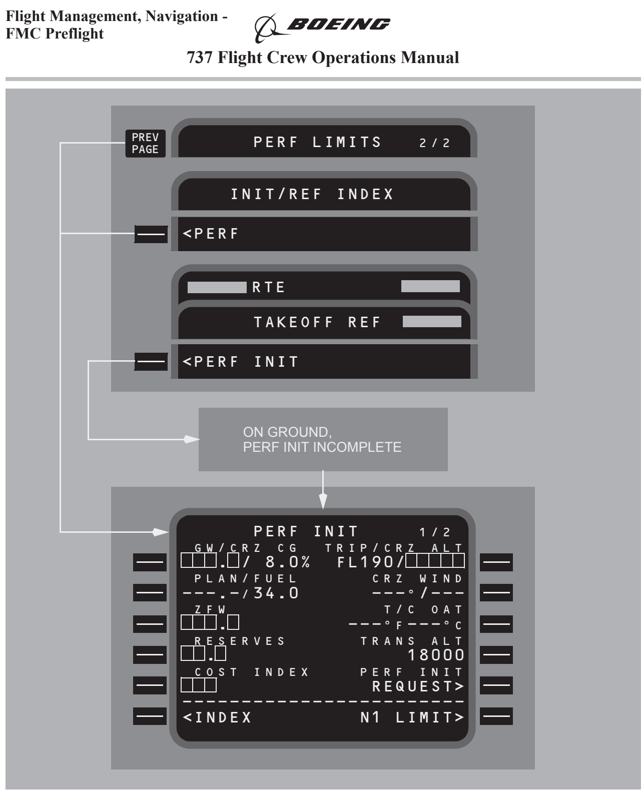
19 The Airbus equivalent of an assumed temperature is called a FLEX temperature.
20 See https://www.atsb.gov.au/media/2229778/ar2009052.pdf [accessed September 2018].

The FCOM amplified procedures state:

> *'Enter or verify OAT. Confirm the OAT value is correct and reasonable for the ambient conditions.'*

1.17.2.1 Pre-flight

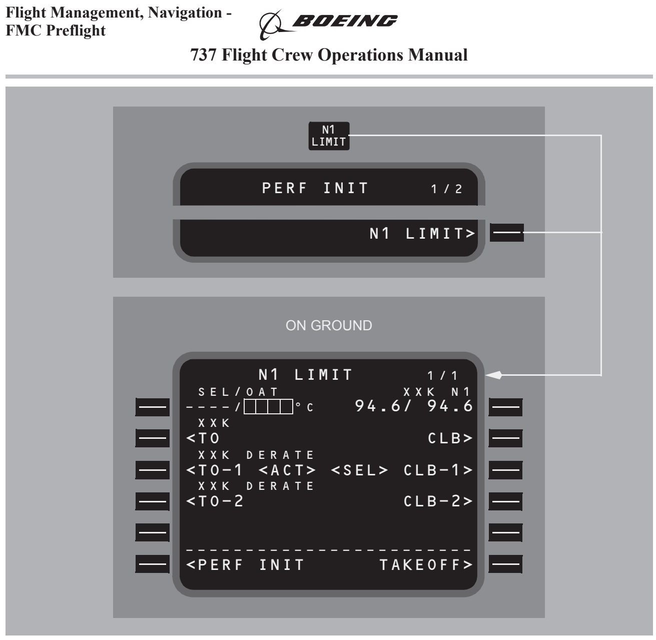
The FCOM states that it is the PF who normally completes the initial setup of the FMC. The PM must verify the entries. The FMC CDU is designed with a sequence of data entry pages with boxes and spaces into which data should be entered, with a prompt at the bottom right of the page to lead the pilot onto the next page requiring entries. The pre-flight setup includes entering a top-of-climb OAT into the T/C OAT field on the right side of the PERF INIT page as shown in Figure 19. The pilot is then prompted to move onto the N1 LIMIT page where they must enter the current airfield OAT value into the OAT field on the top-left of the page as shown in Figure 20. The top-of-climb OAT is obtained from the flight plan and the airfield OAT is obtained from the ATIS broadcast, which the PM had copied down onto the operator-supplied pilot's log (Figure 21).



Copyright © Boeing

Figure 19

PERF INIT page as shown in the Boeing 737-800 FCOM ©Boeing



Copyright © Boeing

Figure 20

N1 LIMIT page as shown in the Boeing 737-800 FCOM ©Boeing

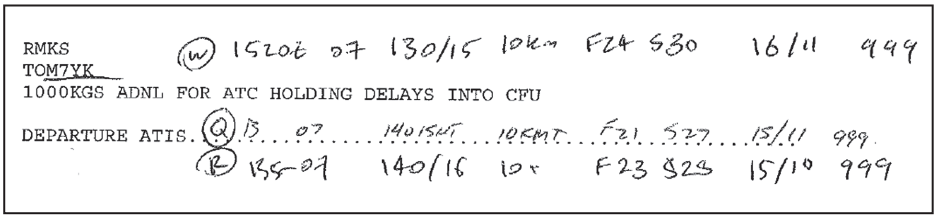


Figure 21

ATIS as recorded by PM on the pilot's log

1.17.2.2 Before start

The crew are supplied with a Loading Instruction Form (LIF) by the ground crew. The LIF includes the passenger numbers and distribution, as well as the details of the baggage. The information is entered into the EFB in order to generate the weight and balance information and, ultimately, the aircraft performance details. The FCOM Before Start Procedure requires both flight crew members to complete the weight and balance, and the performance calculations independently. These calculations are then crosschecked before the PF enters the details into the FMC.

The data which is checked and entered into the FMC at this point includes the aircraft Zero Fuel Weight (ZFW), assumed temperature, climb thrust setting and takeoff speeds. It is the responsibility of the PM to check the veracity of the data entries once completed.

1.17.3 Operator's procedures regarding the performance figures on the pilot's log

The pilot's log contained takeoff and landing performance figures for the planned route. These figures were to be used if the EFB was unavailable or unable to do the calculation (for example, because the airfield was not listed in the database or the EFB batteries were flat). The figures are generated by the same program as that running the EFB performance software.

The takeoff performance in the pilot's log is prepared for each flight based on the forecast environmental conditions at the time the flight plan was produced. It provides for a range of conditions, weights and runways. In this case the performance on the pilot's log for the actual aircraft weight indicated an assumed temperature of 47°C and a takeoff N_1 setting of 93.3%.

As both the pilots had working EFBs and calculated the takeoff performance on them, there was no requirement for them to crosscheck either the EFB performance, or the FMC-calculated takeoff N_1 against the values contained on the pilot's log.

1.17.4 Operator's response to the serious incident

As a result of the initial findings of this investigation into this serious incident the aircraft operator began a programme of upgrading their fleet of B737s to FMC Update 13 and CDU BP15 in order that the OAT alerting function would be available. They also updated their EFB software to display N_1 and included a crosscheck of this figure in their SOPs.

1.18 Additional information

1.18.1 Human factors

The investigation commissioned a report into the human factors of this incident which is at Appendix B. The aim of the report was to consider the human actions and decisions within the incident.

The report looked at three areas:

- FMC input errors
- Recognition of the abnormal takeoff run
- Failure to apply more thrust after recognising the problem

1.18.1.1 FMC input errors

The report considered that there was insufficient information to conclude how the OAT entry error occurred but that there were a number of plausible routes within the cognition process for it to occur. The displayed N_1 thrust setting began with the digit '8' which was not unusual for a crew used to very cold temperatures in Canada. Whilst the figure was indeed low in the conditions, the report concluded that it was unlikely to stand out to the crew as an extreme value.

1.18.1.2 Recognition of abnormal thrust and acceleration

The report described the various methods by which humans detect acceleration and how they were ineffective in this incident. Acceleration can be sensed by the human vestibular system from inertial clues but the difference between the incident flight and any other flight was below the perceptible level. The visual system would have provided much stronger clues to the crew that the aircraft was accelerating but again this system is generally insensitive to the rate of acceleration and has a high threshold. For the crew, this meant they detected the acceleration by the visual texture flow, but it is unlikely that they would have been able to visually detect a slightly slower acceleration rate.

Indirect acceleration clues were available to the crew such as the time to reach V_1 and the visual picture of the end of the runway approaching. During the takeoff roll crews are in a high arousal state and their perception of time is poor as they are concentrating on other matters. This crew's unfamiliarity with BFS, and particularly with Runway 07, meant they were not alerted to the atypical visual picture that began to develop until very late in the takeoff run.

The crew stated that they saw nothing unusual inside the cockpit. The report suggested that the crew's focus during the takeoff roll would have been on ensuring the aircraft was accelerating by checking the airspeed indication and occasionally checking the engine indications to ensure the power demanded was set. For the PF, the majority of his attention is likely to have been concentrated on ensuring the aircraft was straight on the runway, whereas the PM is likely to have been looking both outside and inside. The PM would probably have seen the aircraft accelerating by seeing a large trend arrow on the PFD speed tape. In looking at the engine indications, he would have noted the N_1 was set at the bugged setting. These indications are likely to have seemed the same as any other takeoff, with nothing that would have alerted the pilots to the abnormal acceleration of the aircraft.

Pilots experience different accelerations on every flight due to changes in runways, conditions and aircraft weight. There is therefore no single acceleration rate with which to match aircraft performance.

The report stated:

> *'It is unlikely that a normal crew would have perceived the difference between the lower acceleration and the expected acceleration.'*

1.18.1.3 Failure to apply more thrust after recognising the problem

With hindsight, it would seem strange that neither pilot attempted to increase the thrust to improve the performance of the aircraft. The report detailed why this action might not have been the natural reaction and why many crews would probably have reacted in the same way.

Pilots rarely manipulate the thrust on takeoff due to the use of autothrust. They also remove their hands from the thrust levers at V_1. The use of the autothrust has tended to remove pilots from the action of moving the thrust levers after the start of the takeoff roll, and the action of removing the hand at V_1 means pilots have little or no experience of putting their hand back on the thrust levers after that speed. The pilots of C-FWGH would have had no prepared response for this event.

The closest situation which generates a trained response would be an engine malfunction on takeoff but in this the pilots are trained to continue with a compromised takeoff without putting their hands back on the thrust levers. This situation would have felt similar to that training.

The reason why the end of the runway was fast-approaching was not obvious to the pilots as it occurred. There were other reasons, such as taking off from the wrong intersection or runway, or engine malfunction, that could have caused the situation. Faced with a time critical situation but without knowing why, it is likely the crew would have been reluctant to act. Also, with the end of the runway rapidly approaching, it would not have been the crew's natural and intuitive reaction to increase the speed at which they approached that danger.

The report stated:

> *'The application of more thrust was not a trained, natural or dominant response for a number of reasons as explained, whereas inaction on the thrust levers would be familiar and probably dominant. It is likely that many crews would react in the same way that the incident crew did, given the same circumstances.'*

1.18.1.4 Report conclusion

The report summarised its findings as follows:

> *'Once the initial error was made, failure to notice it was predictable and within normal human performance (it would have occurred to many crews, partly due to the system feedback being opaque in relation to the error). Once the take-off was started, acceleration cues would be unlikely to alert a normal crew to the problem. The view ahead was the first reliable cue, initially creating a recognition-primed cue to the atypical situation. Having noticed the issue, many crews would have reacted in the same way as this crew did, due to normal training and experience.'*

1.18.2 Takeoff Performance Monitoring Systems (TOPMS)

1.18.2.1 Introduction

Since the 1970s and, in particular, following the loss of a McDonnell Douglas DC-8 at Anchorage, USA[21], the aviation industry has recognised the need for tools that can aid pilots' decision making during takeoff. The Anchorage accident, which occurred on 27 November 1970, led to the NTSB recommending that:

> *'The Federal Aviation Administration determine and implement takeoff procedures that will provide the flightcrew with time or distance reference to appraise the aircraft's acceleration to the V_1 speed.'*

Subsequently, following the 1971 takeoff accident at San Francisco International Airport involving a Boeing 747 operated by Pan American World Airways[22], a safety recommendation was made to the Federal Aviation Administration (FAA) that recommended the installation of runway distance markers. In early 1971, this topic, and the use of onboard equipment to assist pilots in judging aircraft acceleration towards V_1, were being discussed by the Air Transport Association of America Flight Operations Committee. However, fearing an increased number of high speed aborted takeoffs both ideas were subsequently discounted.

The NTSB reiterated their safety recommendation to the FAA regarding runway distance markers after the 1982 accident to Air Florida Flight 90[23]. After a McDonnell Douglas DC-10 accident at Boston, USA in 1982[24], the aviation

21 https://www.ntsb.gov/investigations/AccidentReports/Pages/AAR7212.aspx [accessed September 2018].
22 https://www.ntsb.gov/investigations/AccidentReports/Pages/AAR7217.aspx [accessed September 2018].
23 https://www.ntsb.gov/investigations/AccidentReports/Pages/AAR8208.aspx [accessed September 2018].
24 http://libraryonline.erau.edu/online-full-text/ntsb/aircraft-accident-reports/AAR85-06.pdf [accessed September 2018].

industry began actively considering the concept of an automated Takeoff Acceleration Monitoring System (TAMS). The NTSB report into the DC-10 accident, which progressed as industry worked in parallel on the concept of a TAMS, included a safety recommendation addressed to the FAA requesting that they:

> *'Convene an industry-government group which includes the National Aeronautics and Space Administration to define a program for the development of a reliable takeoff acceleration monitoring system.'*

At the time, the Aircraft Division of the Society of Automotive Engineers (SAE) was developing an Aerospace Standard (AS8044) for solutions, varying in technical complexity, that would be able to monitor takeoff acceleration. Recognising the various levels, or classes of functionality these systems offered, the standard used the generic term *'Takeoff Performance Monitor System'*.

The SAE standard AS8044 was first published in 1987.

1.18.2.2 Past research into TOPMS

Several institutions, including the National Aeronautics and Space Administration, the National Aerospace Laboratory of the Netherlands and, more recently, Cranfield University in the UK, have carried out research into TOPMS, beginning in the late 1970s and continuing until about 2009. An extensive summary describing this past research activity is available in the National Research Council of Canada's report entitled *'Takeoff Performance Monitoring Systems'*[25]. In 2007, the original SAE standard AS8044 was reaffirmed.

However, State Accident Investigation Authorities (AIA), including the TSB of Canada, the ATSB in Australia, the United Kingdom AAIB and the Bureau d'Enquétes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) in France continue to investigate occurrences that have involved severely compromised takeoff performance.

One such occurrence, in October 2004, was investigated by the TSB, and involved a Boeing 747-200 colliding with terrain beyond the end of the runway at Halifax Stanfield International Airport, Canada[26]. The report stated:

25 https://nparc.nrc-cnrc.gc.ca/eng/view/object/?id=0fa746bc-edb1-46f9-aa83-af93ee3b2d49 [accessed September 2018].
26 http://www.tsb.gc.ca/eng/rapports-reports/aviation/2004/a04h0004/a04h0004.pdf [accessed September 2018].

> *'Once the take-off began, the flight crew did not recognize that the aircraft's performance was significantly less than the scheduled performance until they were beyond the point where the take-off could be safely conducted or safely abandoned.'*

The TSB recommended as part of this report that:

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

The Canadian Department of Transport (Transport Canada) was the only organisation required to respond and their response was:

> *'It is agreed that if a Take-off Performance Monitoring System could be designed to function as intended, it could provide a significant safety benefit, however in order for Civil Aviation Authorities to establish a requirement for aircraft to be equipped with a take-off performance monitoring system, an acceptable system would have to exist. Transport Canada is not aware of any certified system that is available at this time to meet this recommendation.'*

In 2009, the ATSB undertook a research study titled *'Take-off performance calculation and entry errors: A global perspective'*[27] to review the factors involved in incidents and accidents in the 20 years leading up to 2009. This was undertaken as part of an investigation into a serious incident involving an Airbus A340-500 in March 2009 at Melbourne, Australia[28].

In 2009, the AAIB recommended that EASA develop a TOPMS specification and require fitment of TOPMS on transport aircraft following a serious incident to an Airbus A330 at Montego Bay, Jamaica in October 2008[29]. These Safety Recommendations were reiterated by the AAIB following two further events in December 2008[30] and December 2009[31].

27 https://www.atsb.gov.au/media/2229778/ar2009052.pdf [accessed September 2018].
28 https://www.atsb.gov.au/publications/investigation_reports/2009/aair/ao-2009-012.aspx [accessed September 2018].
29 https://www.gov.uk/aaib-reports/airbus-a330-243-g-ojmc-28-october-2008 [accessed September 2018].
30 https://www.gov.uk/aaib-reports/boeing-767-39h-g-ooan-13-december-2008 [accessed September 2018].
31 https://www.gov.uk/aaib-reports/airbus-a340-642-g-vyou-12-december-2009 [accessed September 2018].

As a result of the AAIB's safety recommendations, in 2012 EASA sponsored the European Organisation for Civil Aviation Equipment (EUROCAE) to set up a working group, WG-94, to:

- Describe the current state of the technology and practical feasibility of TOPMS; and
- Provide guidance and recommendations on the feasibility of publishing technical and/or operational standard(s).

WG-94 issued a draft report in February 2015, concluding that the development of standards to define performance requirements and operational conditions for TOPMS was not possible at the time. This was due to a multitude of factors, including the maturity of the technology, a lack of real-time data including environmental parameters, runway conditions, airport databases and/or suitable aeroplane performance models, and a lack of consensus in design criteria and testing methods. WG-94 activity was therefore concluded at the beginning of 2017, although it was noted that industry would continue investigating technical solutions and a reactivation of WG-94 or a new activity might be launched at a later date.

1.18.2.3 Potential development of a TAMS

During the investigation, the AAIB became aware that a major equipment manufacturer had modified its Enhanced Ground Proximity Warning System (EGPWS), through a firmware update, to perform the additional function of a TAMS. Development of the system had been halted, however, partly because there were no technical standards against which it could be developed.

Worldwide regulations typically mandate the carriage of Terrain Awareness and Warning Systems (TAWS) on commercially operated turbine aircraft with a maximum takeoff weight above 5,700 kg and with more than nine seats. Less capable TAWS systems are also fitted to some piston powered aircraft and lighter, smaller capacity, turbine aircraft operated commercially. Therefore, many aircraft already in commercial operation could, potentially, be retrofitted with a TAWS system offering TAMS functionality.

TAWS, because of their existing role in alerting the crew to their aircraft's proximity with terrain, have access to a wide variety of data about the operation of the aircraft. This includes the aircraft's location which, by comparison with internal data, can be used to establish which airport the aircraft is operating from and, on some units, even which runway the aircraft has entered. Additional runway safety features have also been developed, such as the annunciation of runway length remaining ahead of the aircraft whilst taxiing onto a runway, and warnings should an attempt be made to takeoff on a short runway.

The manufacturer began to develop the TAMS (modified EGPWS) between 2012 and 2013 and development goals included being able to detect different types of takeoff performance problems including:

- Dragging brakes;
- The effects of severe runway contamination;
- Tyre under-inflation;
- Engine under-performance, or the use of incorrectly set thrust; and
- Errors in weight.

By analysing large sets of takeoff data for the Boeing 737, 747, 767 and 777, it was shown that the effect of using derated takeoff settings was to normalise the distance from the end of a runway where an aircraft became airborne. This normalisation was evident across all data sets considered, despite large climatic, airport elevation and takeoff weight variations.

Further analysis of the data for each aircraft type showed that the acceleration required to reach this point on the runway was concentrated around a single value and, when this data was plotted as a histogram, any skew was on the side of higher, not lower accelerations. There were few cases where the acceleration was lower than that expected. This is shown below in Figure 20 for the Boeing 737 data set.

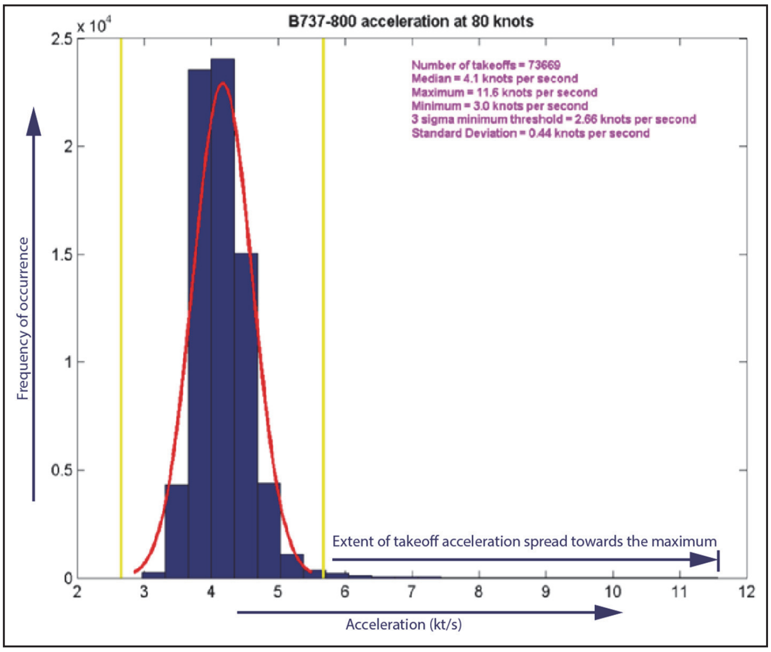


Figure 20

Histogram showing acceleration rates across the Boeing 737 data set
© 2018 Honeywell International Inc.

Factual Information

Although it was found that the minimum expected acceleration was constant for most runway lengths, on shorter runways an increase was noted in its value. For the Boeing 737 data, this is shown graphically in Figure 21.

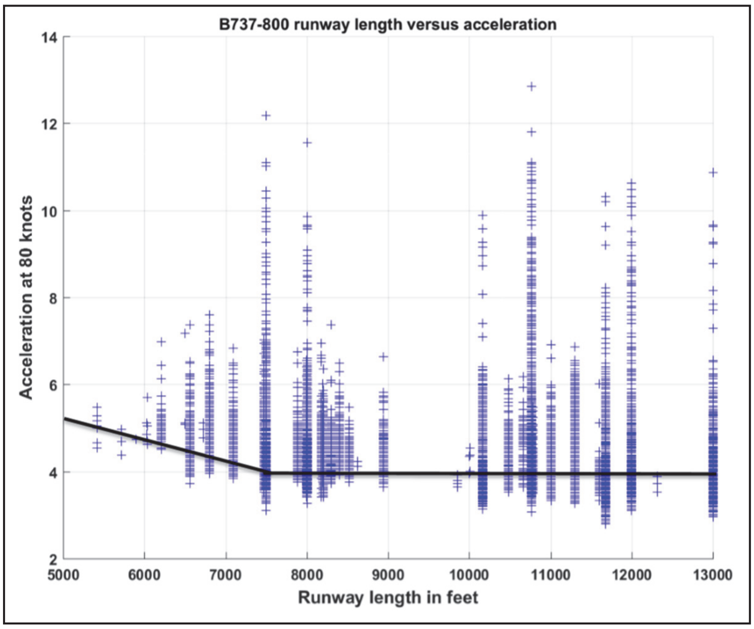


Figure 21

Variation of acceleration rates with weight across the Boeing 737 data set
© 2018 Honeywell International Inc.

The Boeing 737 data set comprised of 73,669 departures, encompassing a weight range from approximately 43 to 78 tonnes representing 93% of the Boeing 737-800 operating weight range. The data set also covered a range of airport elevations from sea level to 1,900 ft amsl and OAT between -1 and 42°C.

Analysis of other data sets showed similar results including the Boeing 777 data set, which covered 60,445 departures from 87 airports worldwide and encompassed a much wider climatic spread, with OAT varying between -27 and 49°C, and airport elevations from sea level to 5,600 ft amsl. During the development of the analysis technique, two events were discovered where abnormal takeoffs had taken place but not been reported.

The TAMS compares actual takeoff acceleration with a minimum expected value of acceleration derived from empirical data as described above. The crew is alerted if actual acceleration is below an alerting threshold when the aircraft groundspeed is within a particular range, typically 70 to 80 kt. This gives time for engine thrust to stabilise, allows for variations in technique in applying power, and allows for circumstances where the aircraft is taxied at higher speeds, such as when backtracking a runway. The alert occurs at a low enough groundspeed to ensure that, if the crew decides to stop the aircraft, the energy absorbed in stopping is low and the risks associated with a rejected takeoff are reduced. However, alerts could be supressed above a certain airspeed to ensure compatibility with an operator's procedures.

This type of system is independent of other aircraft systems such as the FMC and does not rely on any crew-entered data.

1.18.2.4 Simulator assessment of a TAMS (modified EGPWS)

A simulator assessment was undertaken to establish whether a TAMS would have detected the erroneous thrust setting used in this serious incident.

The simulator was fitted with a Honeywell Mk V EGPWS unit running the modified firmware and programmed with the minimum acceleration threshold derived from the Boeing 737 data set. The simulator was set-up to reflect the environmental conditions, configuration and loading of C-FWGH at the time of the serious incident. As the simulator did not have a model for Belfast International Airport, Runway 28 at Dublin Airport was used as both the slope and length of this runway are almost identical to Runway 07 at Belfast International Airport.

Takeoff was commenced using an N_1 of 81.5% on both engines. As the aircraft accelerated through approximately 75 kt groundspeed, the system gave an aural alert, *"CAUTION ACCELERATION ACCELERATION"*, and displayed *'ACCELERATION'* in amber text on both Navigation Displays. The takeoff was rejected immediately, and the aircraft came to rest 1,670 m from the upwind threshold.

Further trials were carried out using higher N_1 values to assess the system's sensitivity. With an N_1 of 83.5%, the system again alerted the crew to low acceleration and a stop was completed with 1,540 m of runway remaining. The trial found that alerts would have been generated by the system up to an N_1 setting of approximately 84.5%, representing an N_1 setting 6% higher in total, than that used for C-FWGH's takeoff.

1.18.2.5 Airbus' Takeoff Monitoring (TOM) system

Airbus developed two systems to help mitigate against takeoff performance errors after in-service data showed that, over a 10-year period, 30 takeoff performance events were reported by Airbus operators. Although Airbus stated that most errors can be avoided by adherence to SOPs, their experience showed that errors still occur, and factors such as time pressure and late changes are often contributory factors. One of the Airbus systems, called Takeoff Monitoring (TOM), works in a similar way to TAMS by warning a crew of abnormally low takeoff acceleration. TOM became available on later Airbus A380 aircraft and is under development for the A350.

The AAIB is not aware of any other aircraft manufacturer that has either developed, or is developing, similar systems.

1.18.2.6 Current regulatory standards and guidance material

One objective of EUROCAE WG-94 was to *'Provide guidance and recommendations on the feasibility of publishing technical and/or operational standard(s)'* for TOPMS. However, the conclusion reached by this group was that:

> *'at the time of writing, it seems that the development of standards to define performance requirements and operational conditions for Takeoff Performance Monitoring Systems is not possible.'*

At the time of writing this report, therefore, there was no technical specification to define the operational performance of such a piece of equipment, or relevant guidance material. The technical complexity of a TAMS is reduced from the more complicated types of TOPMS, which are often predictive in nature. Out of seven areas seen by WG-94 as being potentially problematic, four referred to issues not necessarily faced by TAMS, which are only concerned with acceleration during a takeoff. The four issues were:

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

EASA's European Plan for Aviation Safety covering the years 2018 to 2022[32], which was published in February 2018, included the reduction of Runway Excursions as a strategic priority for Commercial Air Transport (CAT) operations. The term Runway Excursion (RE), is defined by the International Civil Aviation Organization (ICAO), and includes an *'overrun off the runway surface'* whether this occurs on takeoff or landing.

32 https://www.easa.europa.eu/document-library/general-publications/european-plan-aviation-safety-2018-2022 [accessed September 2018].

The EASA document detailed one area of related rulemaking, the *'Reduction of runway excursion'*, where it stated:

> *'The objective of this task is to increase the level of safety by reducing the number of REs through mandating existing technologies on aeroplanes that allow to measure runway left and thus support pilot-decision-making.'*

The UK CAA, concerned about this and other similar events, decided in July 2018 to set up a working group to review incorrect takeoff performance issues. The working group was expected to raise awareness among operators that the main barriers to the types of errors discussed in this report rely on humans and associated processes and procedures. It would seek to agree guidelines around Takeoff Acceleration Monitoring Systems and develop associated technical specifications.

Factual Information

1.18.2.7 Recent TOPMS Safety Recommendations

The Dutch Safety Board (DSB) reported in March 2018 about two serious incidents where Boeing 737-800 aircraft took off with insufficient thrust set. One of these serious incidents occurred in 2014 and was the result of the miscalculation of the takeoff weight on the takeoff data card; the other was in 2015 where take off performance data was based on the wrong takeoff position. As a result, the DSB released a safety recommendation stating that EASA was recommended:

> *'To, in cooperation with other regulatory authorities, standardisation bodies, the aviation industry and airline operators, start the development of specifications and the establishment of requirements for Take-off Performance Monitoring Systems without further delay.'*

In its final response to this recommendation, EASA referred to EUROCAE WG-94 and its conclusion that it was not currently feasible to develop performance requirements and operational conditions for TOPMS[33]. EASA stated that:

> *'… the Agency considers that the overall feasibility of TOPMS has still not been demonstrated, and no specifications can be developed at this stage.'*

33 See 1.18.2.2.

1.18.3 EFB approval and display

1.18.3.1 EFB regulations

ICAO Annex 6 contains the provisions for EFBs, based upon which worldwide regulatory authorities have issued Acceptable Means of Compliance (AMC) for operators to follow. Annex 6 provisions were limited in their scope to allow operators to make use of the rapidly developing technology in the sector. Guidance on the mountings, electrical connections, and non-interference with aircraft systems are detailed and require the approval from the regulatory authorities in the operator's State of registration. Guidance also details the need for a backup system should the EFB be unavailable for any reason.

Guidance on software and applications is limited to proving that any calculations completed are accurate, the display is appropriate for all light conditions, colour use is consistent, and that the entry method for data is straightforward. There is no guidance or regulation on the type, order, content or layout of the displayed information even in safety critical applications such as those calculating weight and balance or performance.

Transport Canada is the regulatory authority for the operator of C-FWGH, and its AMC for EFB[34] closely matches ICAO Annex 6. The operator's EFB would be defined in Canada as a Class 2 EFB with Type B software, that is one which is portable but mounted to the aircraft when in use. Within the Canadian AMC, the operator's EFB required certification approval for the mounting device, power connection and data connectivity but did not require certification approval for its operating system or applications.

1.18.3.2 Operator's EFB

The operator received initial approval from Transport Canada for the use of the EFB in 2013 and this was renewed in 2016. This approval included the use of the performance software.

1.18.3.3 EASA

Within Europe, EASA has recently consulted over increasing its oversight on EFBs and, in particular, the safety critical applications (such as performance and weight and balance programs) that are being used by operators. The proposals are currently in the public domain for consultation with the view to new regulations being introduced in 2019[35].

34 Transport Canada Advisory Circular AC 700-020 Issue 2, Effective date: 19 December 2012.
35 EASA Opinion No 10/2017, Transposition of provisions of electronic flight bags from ICAO Annex 6.

1.18.4 Flight Data Monitoring of takeoff acceleration

1.18.4.1 Introduction

In February 2016, EASA released Safety Information Bulletin (SIB) 2016-02[36], entitled '*Use of Erroneous Parameters at Take-off*'. One of the purposes of this SIB was to:

> *'provide recommendations on the use of the operator's Flight Data Monitoring (FDM) programme to identify precursor events.'*

The SIB reasoned that:

> *'Even if it can be assumed that the vast majority of errors were detected and corrected by the involved personnel, it is likely that several other events have occurred and have not been reported, either because they were uneventful or because the issue had not been identified by the flight crew during the take-off. 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 those events.'*

EASA had conducted a survey on erroneous take-off parameters prior to issuing the SIB, and:

> *'the results suggested that defining and implementing even a few FDM events specific to this issue could help to improve the detection of the frequency and severity of related occurrences and act on the occurrences.'*

One of the recommendations made in the SIB was:

> *'EASA recommends operators to define and implement specific FDM events relevant to the monitoring of take-off performance issues in their FDM programme.'*

The SIB referenced several publications by both the European Operators Flight Data Monitoring (EOFDM) group, as well as the European Authorities Coordination Group on Flight Data Monitoring (EAFDM), to be used as guidance material in defining and implementing FDM events.

36 https://ad.easa.europa.eu/ad/2016-02 [accessed September 2018].

The EOFDM group carried out an analysis of the precursors to a runway overrun scenario. Two different cases were identified for this scenario: one in which a rejected takeoff was carried out and the other where no attempt was made to reject the takeoff. Their analysis of the precursors for the latter case, that most closely matches the serious incident to C-FWGH, is presented in Figure 22.

Increasing "proximity" to the accident →			
Incorrect performance calculation		No liftoff after rotation	
Inappropriate aircraft configuration	Slow acceleration	Slow rotation	Reduced runway remaining at liftoff
CG out of limits		Late rotation	
Reduced Elevator Authority			
Wrong runway or wrong entry point used		Engine power increase	
Aircraft handling			

Figure 22

EOFDM Group precursor analysis of a runway overrun scenario, rejected takeoff not carried out

The precursor, incorrect performance calculation, was defined as: '*erroneous data entry or calculation errors [which] could lead to incorrect thrust settings or incorrect V speeds'.* Precursors from Figure 22 applicable in this event were: incorrect performance calculation, slow acceleration, late rotation, slow rotation, and reduced runway remaining at liftoff.

1.18.4.2 AAIB/UK CAA research project

Acceleration is measurable within an FDM programme but, as it varies over the takeoff roll and can be influenced by piloting technique, for example when setting power, it is challenging to evaluate reliably. Therefore, the AAIB asked the UK CAA FDM team whether it would be possible to use FDM data to identify the required N_1 (or equivalent thrust setting) for any given takeoff. A lower than required N_1 (perhaps following an incorrect performance calculation or a data entry error) would lead directly to slow acceleration.

At the time of writing, this work was at an early stage but the UK CAA was attempting to develop a methodology that could be used to predict the required thrust setting. This could then be used to compare the actual N_1 setting used for a takeoff with the required N_1; any discrepancy above a certain threshold would trigger an FDM event which could then be investigated by the operator. This would allow operators and, if the information was shared, the wider industry to assess the frequency and severity of such occurrences. It would also allow operators, as part of their safety risk management system, to evaluate the effectiveness of existing mitigations put in place within their organisations.

1.18.5 AAIB Special Bulletin S2/2017

Following this serious incident, the AAIB published Special Bulletin S2/2017 in September 2017 and made two Safety Recommendations, shown below and discussed further in 2.2.3.

> **Safety Recommendation 2017-016**
>
> It is recommended that the Federal Aviation Administration, mandate the use of Flight Management Computer software revision U12.0, or later revision incorporating the outside air temperature crosscheck, for operators of Boeing 737 Next Generation aircraft.

The FAA, in its initial response to this recommendation, stated that there might be hardware and fleet compatibility issues and cost implications for some operators which it would need to understand before responding substantively. It undertook to provide an updated response by December 2018.

> **Safety Recommendation 2017-017**
>
> It is recommended that Boeing Commercial Airplanes promulgates to all Boeing 737 operators the information contained within this Special Bulletin and reminds them of previous similar occurrences reported in the Boeing 737 Flight Crew Operations Manual Bulletin dated December 2014.

In response to this recommendation, Boeing stated that it would discuss the issue and remind operators of the existing bulletin at its January 2018 'Fleet Team Call'.

On 13 July 2018, Boeing issued a Multi Operator Message which described the potential for FMC OAT entry errors referring to this, and other serious incidents. The message also reminded operators of the associated service bulletins recommending the installation of revision U12.0 of the FMS OPS software and BP15 update of the CDS[37]. The message reminded operators that the final compliance date for the recommended action was 10 January 2019.

37 See 1.16.3.2.

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2. Analysis

2.1 Introduction

C-FWGH took off from BFS with insufficient thrust to meet regulated performance requirements. The aircraft hit a supplementary approach light for Runway 25, 29 m beyond the end of Runway 07 which was being used for takeoff. The tyre tread pattern indicated that the aircraft struck the light with a main gear tyre, although chemical analysis could not distinguish between nose and main gear rubber to confirm this.

Comparisons of CCTV images of C-FWGH's departure and of an aircraft lined up for departure at the beginning of Runway 25 showed that rotation occurred at the very end of the runway. Airspeed data, calculated from radar and ADS-B data combined with the ATIS winds, confirmed that V_R was reached approximately 300 m from the end of the runway.

The BFS tower controller and assistant, as well as the fire watchman, witnessed C-FWGH lifting off extremely late, with a very shallow climb away from the ground. Data from the EGPWS showed that, if the aircraft did descend during lift off and initial climb, any altitude loss below 500 ft aal was less than 50 ft because it did not trigger an EGPWS Mode 3 alert.

After takeoff, ACARS data confirmed that the N_1 setting used for takeoff was approximately 81.5%, significantly below the required N_1 of 92.7%, and autothrottle data showed that power was not increased until C-FWGH was 4 km from the end of the runway at 800 ft aal.

2.1.1 Risks of the takeoff

According to calculations completed by the manufacturer, the aircraft took off with 60% of maximum thrust set. Analysis of aircraft performance indicated that, had an engine failed once the aircraft reached V_1, it would have been unable to climb if the takeoff had been continued unless additional thrust had been applied. Alternatively, if the crew had immediately rejected the takeoff at $V_{1,}$ the aircraft would have overrun the end of the runway at 5 kt. Regulations require a two second delay to be built into the stopping distance calculation to allow for crew decision-making and no allowance to be taken for the use of reverse thrust. With these criteria applied, the aircraft would have overrun the runway at approximately 80 kt. Therefore, had an engine failed at $V_{1,}$ the most likely outcome would have been either a runway overrun or an attempted takeoff leading to ground impact. Either possibility would be extremely serious and was considered to have the potential to cause significant loss of life.

Safety margins are built into the calculation of the Takeoff Distance Required (TODR) to account for normal variations in operational performance but these margins are unreliable or ineffective as safety controls when there is a data entry error because of the random (and possibly gross) nature of the effect. In this case, it was the benign nature of the runway clearway and terrain elevation beyond, and the lack of obstacles in the climb-out path, which allowed the aircraft to climb away without further collision after it struck the runway light.

2.2 Data entry errors

2.2.1 Human performance

The analysis of human performance at Appendix B showed that there was insufficient evidence to establish why the data entry error was made in programming the FMC, then remade when the FMC was updated on receipt of the new ATIS before the second push back. The error could have occurred in any one of the three stages of cognition that would have been involved in programming the FMC. These were, firstly, selecting the value to enter from the paperwork; secondly, committing that value to the short-term memory; and, lastly, the memory output into the FMC.

The commander had recently returned from North America and, although he felt well-rested, it was considered possible that he was affected by jet lag without realising it. The ICAO description of jet lag states that it can cause degraded performance on mental tasks and it is possible that this might explain the data entry error.

2.2.2 Operational SOPs

Both the manufacturer and the operator required the crew to crosscheck FMC entries. The aircraft took off with an OAT of -52°C entered into the N1 LIMIT page of the FMC instead of 16°C. Neither pilot spotted the error and, in fact, the FMC had been programmed incorrectly before the aircraft pushed back from the stand the first time, only for the error to be remade before the subsequent push back. It was not determined why the crosscheck failed to spot the error, but the human factors analysis suggested that there are many reasons why the crosscheck might have failed such as not completing it when required, performing it with inadequate visual attention or comparing the wrong values.

The crew correctly calculated the aircraft weight and balance using the EFB and generated the correct takeoff performance for the departure from BFS. As required by the operator, both pilots completed the calculation independently before confirming the figures. These figures were then transferred without error to the FMC.

2.2.3 OAT crosscheck

The FMC OPS software installed on C-FWGH was at revision U10.8A, which did not include the automated crosscheck of a manually-entered OAT against the ambient temperature sensed by the aircraft. Had the FMC OPS software been at revision U12.0 or later, and had the CDS BP15 update been embodied, then the OAT crosscheck carried out after the first engine was started would have alerted the crew to their erroneous OAT entry. The software crosscheck would have deleted the erroneous OAT, the takeoff speeds and, as the N_1 target would also have been deleted, the crew would subsequently not have been able to engage the autothrottle at takeoff.

The aircraft manufacturer released two service bulletins, prior to this serious incident, detailing the procedure to update the FMC OPS software and the CDS to the BP15 standard on Boeing 737NG aircraft. The aircraft manufacturer recommends that all Boeing 737NG operators embody both service bulletins by January 2019 but such action is not compulsory.

Therefore, given the potential consequences of departing with an incorrectly set $N_{1,}$ and because this serious incident would have been prevented by the OAT crosscheck, the AAIB made Safety Recommendation 2017-016[1] in Special Bulletin S2/2017. The recommendation asked the FAA to take measures to ensure the OAT crosscheck capability was incorporated into Boeing 737NG aircraft. In its initial response, the FAA stated that it needed to gather more information on the implications of this recommendation before replying more substantively, which it undertook to do by December 2018.

A small number of older Boeing 737 aircraft, which predate the Boeing 737NG series, are also able to implement the OAT crosscheck, so the following Safety Recommendation is made which supersedes Safety Recommendation 2017-016:

Safety Recommendation 2018-012

It is recommended that the Federal Aviation Administration mandate the use of Flight Management Computer OPS software revision U12.0, or later, and the Common Display System Block Point 15 update where this is required, to enable the automated outside air temperature crosscheck on all applicable Boeing 737 aircraft.

1 See 1.18.4.3.

In a related FCOM bulletin released in December 2014, three other incidents were reported where an incorrect OAT was used by the FMC resulting in significant N_1 shortfalls. When an FCOM bulletin is incorporated into the FCOM by revision, the circumstances which originally led to its release are not easily accessible to crews. In this serious incident, the details about previous events where erroneous OAT entries had been made, and the significant effect that these entries had on the target N_1 used for takeoff, were not known to the crew of C-FWGH. Therefore, the AAIB made Safety Recommendation 2017-017[2] in Special Bulletin S2/2017, asking the manufacturer to make Boeing 737 operators aware of this event and to remind them of previous, similar occurrences.

In response to Safety Recommendation 2017-017, Boeing issued a Multi Operator Message highlighting the issues raised in the Special Bulletin and reminding operators that Boeing recommended that, by January 2019, they install revision U12.0 of the FMS OPS software and the Block Point 15 update of the CDS. The AAIB considered that this action met the intent of the Safety Recommendation.

2.2.4 EFB design

The EFB used to calculate the takeoff data complied with the Canadian AMC document and was approved for use as a performance tool. However, there was no requirement to display the calculated N_1, the parameter which defines each engine's thrust and, therefore, determines the aircraft's ability to meet takeoff performance requirements. Had N_1 been displayed on the EFB, it would have allowed the pilots to crosscheck the value of N_1 calculated by the FMC. Had they done so, they would have noticed the significant difference between the two calculated figures and investigated the discrepancy, and this would have probably prevented this serious incident. However, whilst the aircraft manufacturer required the crews to verify the N_1, there was no specified procedure to do so.

An N_1 crosscheck would also highlight other errors that have caused serious incidents and accidents, including selecting the wrong fixed derate and entering an incorrect assumed temperature. Such errors would not be picked up by the automated OAT crosscheck which would only identify erroneous OAT entries. However, the errors would lead to a discrepancy between the EFB-and FMC-calculated N_1 and, if the N_1 figures were crosschecked by the crew, there would be an opportunity for these additional types of errors to be picked up and corrected before they led to an incident or accident. For aircraft not equipped with EFBs, a crosscheck of FMC-calculated N_1 against an alternative, independently-calculated value would increase the likelihood of identifying the error. Therefore:

2 See 1.18.4.3.

Safety Recommendation 2018-013

It is recommended that Boeing Commercial Airplanes give guidance to operators of Boeing 737 aircraft on how they might verify the FMC-calculated value of N_1 against an independently-calculated value.

2.3 Takeoff performance monitoring

2.3.1 Pilots

The human factors analysis in Appendix B suggested that the crew in this serious incident were unlikely to have sensed the abnormal takeoff acceleration. The physical limitations of the human sensory system mean that it is very hard for pilots to distinguish the difference between the acceleration of a normal takeoff and that experienced by the crew in this serious incident. Neither the vestibular system nor the visual system were likely to have been able to detect the difference in acceleration. This, combined with the pilots' unfamiliarity with BFS Runway 07, meant that there was little or no context for the pilots to compare this takeoff with others previously experienced. It was only in the last 900 m of the runway, with the change in centreline light colours and the rapidly approaching runway end, that the crew was alerted that something was wrong.

Cockpit instrumentation did not show anything to the crew during the takeoff roll which was likely to have alerted them to the abnormal acceleration. For the crew, the indications displayed were similar to every other normal takeoff and it would have been extremely difficult to perceive any abnormality from the information displayed.

The response of the crew to the rapidly approaching runway end was the same as could be expected from many crews. They found themselves in a time critical situation but one for which they had no obvious explanation. Pilots are trained to make decisions based on evidence and review rather than reaction, with rapid action in ambiguous circumstances discouraged. Their training would have discouraged them from moving the thrust levers after V_1 and they had no experience of moving the thrust levers to a higher power setting during a derated takeoff. Natural human reaction not to accelerate towards perceived danger may also have made increasing the thrust counter-intuitive as the end of the runway approached.

The acceleration clues in this case were unlikely to have alerted the pilots that there was a problem until the visual clues of the approaching runway end became apparent. Once they realised that there was an issue, their reactions in not increasing thrust were the same as could be expected from many crews.

2.3.2 Technological solutions

Given the limitations of humans in sensing different accelerations, development of a technological solution to this problem is crucial.

Previous work on the subject generally focussed on TOPMS, which are often predictive in nature and which also deal with the continued or rejected takeoff cases, the latter requiring runway condition and other environmental factors to be considered. A TAMS offers a simpler approach which just confirms if the aircraft is accelerating at approximately the correct rate. Such a system would not necessarily detect all types of errors that lead to abnormal aircraft acceleration, nor would it detect errors that cause small changes in the acceleration. However, the EOFDM analysis of precursor events in runway overrun scenarios showed that detecting low acceleration could capture some precursor errors made before the start of the takeoff such as: errors in the performance calculation leading to insufficient thrust; and, in some circumstances, using the wrong runway or intersection for takeoff[3].

The TAMS used in the simulator trial does not rely upon any crew-entered value or selection which could be made in error, and it would have detected the low acceleration in this event and warned the crew at 75 kt groundspeed. If a rejected takeoff had been performed from this speed, the aircraft would have stopped approximately 1,670 m before the end of the runway.

TAMS functionality can be built into existing units, such as TAWS devices, through a firmware modification. TAWS are mandated on most commercial aircraft and so, if TAMS functionality can be added easily, then in-service aircraft and aircraft yet to enter service could be equipped with a TAMS. The work by Airbus on their own TOM system, which works in a similar way to the TAMS, demonstrates that industry is also seeking a technological solution to prevent runway excursions on takeoff.

Previous safety recommendations made by State AIAs focussed on TOPMS. Subsequently, EUROCAE WG-94 concluded that it was not possible to develop such a system because of the lack of: real-time environmental parameters; standardisation in reporting runway conditions; good assessments of runway braking friction and theoretical aircraft performance models. A TAMS, however, which would be based on empirical performance data and would not attempt to account for the continued or rejected takeoff cases, would not have such constraints. It would capture precursor errors in the pre-flight preparation phase, which experience has shown are not always captured by the barriers currently in place and which are vulnerable to typical errors

3 Some circumstances where the actual length of runway remaining is small enough to cause an increase in the low acceleration trigger level (See 1.18.2.3 and Figure 21).

in human performance. A TAMS would add a barrier independent of human intervention which would detect abnormally low acceleration and alert the crew.

EUROCAE WG-94 concluded that it was not possible to develop standards and operational conditions for TOPMS. Based on this, EASA responded to the DSB recommendation on TOPMS stating that, because the feasibility of TOPMS had not been demonstrated, no specifications could be developed[4]. This report has demonstrated the feasibility of TAMS, a simpler system than TOPMS which, nevertheless, has the potential to prevent potentially catastrophic accidents related to incorrectly-calculated takeoff performance. Therefore, the following Safety Recommendation is made:

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.

The aviation industry has been concerned about aiding pilot decision-making during takeoff at least since the accident to a McDonnell Douglas DC-8 at Anchorage, USA in 1970. Following that accident the NTSB made a recommendation related to a crew's ability to '*appraise the aircraft's acceleration to* V_1 *speed'*. Following the accident to a McDonnell Douglas DC-10 at Boston, USA in 1982[5], the industry began actively considering an automated Takeoff Acceleration Monitoring System. Since then, there have been numerous incidents and accidents related to abnormal takeoff performance leading to recommendations from the AAIB in the UK, the ATSB in Australia, the BEA in France, the NTSB in the USA, the TSB in Canada and the DSB in the Netherlands. This is clearly a long-standing safety issue of global concern and therefore:

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.

4 See 1.18.2.7.
5 See 1.18.2.1.

2.4 Reporting accidents and serious incidents

2.4.1 Reporting obligations

The commander, operator, tour operator and aerodrome operator had an obligation to report this event to the AAIB under international protocols, and European and UK legislation. The event was reported by MOR to the Canadian TSB, and the ATSU at BFS filed an MOR and an incident signal as required in the version of MATS Part 1 that was in force at the time, but the event was not reported to the AAIB directly. This meant that much of the flight data was overwritten and unavailable to the investigation. This could have had serious implications on the ability of the AAIB to investigate the event thoroughly.

The ATSU at BFS followed the procedures as laid out in MATS Part 1 at the time but did not make it clear to the watch manager at ScACC that the event was considered to be a serious incident and would therefore need to be reported to the AAIB by ScACC. Neither did the watch manager conclude for himself from the information he was given that this event should be reported to the AAIB.

If MATS Part 1 had required all ATSUs to report to the AAIB as well as the ACC, the AAIB would have learned about the serious incident on the evening it occurred. This would not have been soon enough to allow subsequent access to the CVR, but the FDR data would have been available for download.

Safety Action

After this serious incident, the CAA amended MATS Part 1 such that the senior controllers at ATSUs providing air traffic services at an aerodrome are required to notify the AAIB by telephone as part of their initial reporting actions following an aircraft accident or serious incident.

The CAA also amended CAP 797, *Flight Information Service Officer Manual,* to require air traffic services personnel to notify the AAIB by telephone as part of their initial reporting actions following an aircraft accident or serious incident.

In addition to the action above, a link to Regulation (EU) 996/2010 was put into MATS Part 1 and CAP 797 pointing to typical examples of what are likely to be classified as serious incidents.

Analysis

3. Conclusions

3.1 Findings

1. The crew were properly licensed and qualified to perform the flight.

2. The pilots independently calculated the correct takeoff performance using their EFBs based on the airfield ATIS and the load instruction form.

3. During pre-flight programming of the FMC an incorrect figure (-47°C) was entered into the OAT field of the N1 LIMIT page.

4. The correct figure for the assumed temperature derate (47°C) was entered into the SEL field on the N1 LIMIT page.

5. Following an operational delay and an updated performance calculation, the correct value for the new assumed temperature (48°C) was entered into the FMC, but another incorrect figure (-52°C) was entered into the OAT field of the N1 LIMIT page.

6. Although the commander felt well rested, it was possible that he was suffering from jet lag, which might have had an adverse affect on his performance when programming the FMC.

7. The incorrect value of OAT, when combined with the correct value for the assumed temperature, meant that the FMC calculated a value of N_1 for takeoff which was significantly below the value required for the aircraft weight and environmental conditions.

8. The risk controls in place did not prevent the aircraft from beginning its takeoff run with insufficient power for the aircraft weight and environmental conditions:

   a. Pre-flight performance calculations were performed correctly twice on the EFB.

   b. The FMC was programmed incorrectly twice but a crew crosscheck, if carried out, did not highlight the incorrect value of OAT or the abnormally low value of N_1.

9. The FMC software on C-FWGH was at revision U10.8A, which did not include an automated crosscheck of a manually-entered OAT against the OAT sensed by the aircraft.

Conclusions

10. Two manufacturer's service bulletins were available which installed FMC software revision U12.0 and which introduced an OAT crosscheck that would have alerted the crew to their erroneous OAT entry. Service bulletins are not mandatory, but Boeing recommends compliance with these bulletins by January 2019.

11. The risk of this type of error leading to a serious incident or accident would be reduced if the N_1 calculated by the FMC was crosschecked with the N_1 produced by an independently-assured source, such as a performance application on an EFB.

12. There is no requirement for EFB performance applications to display N_1 on the performance calculation output page (EFBs are not regulated), and not all operators use EFBs.

13. The low takeoff thrust meant that the takeoff was abnormal in terms of:

    a. Low acceleration.

    b. Distance along the runway to achieve V_1 and V_R.

    c. Low rotation rate.

    d. Low climb rate.

    e. Marginal ability of the aircraft to stop during an RTO from V_1.

    f. Inability of the aircraft to continue the takeoff following an engine failure at V_1 without increased thrust.

14. Once the aircraft began its takeoff run with insufficient thrust, the risk controls in place did not alert the crew to act to recover the situation because, in general:

    a. Pilots are unlikely to recognise that actual acceleration is below a threshold value for a particular runway.

    b. The use of autothrust de-couples pilots from the thrust levers.

    c. Pilots are disposed only to reduce thrust to idle during takeoff (in case of RTO).

    d. Pilots remove their hands from the thrust levers at V_1.

    e. Pilots do not have to increase thrust during a takeoff in the event of an engine failure.

15. The takeoff run was significantly longer than expected and the aircraft lifted off at the extreme end of Runway 07.

16. The aircraft struck a Runway 25 supplementary approach light which was in the stopway, 29 m beyond the end of the Runway 07.

17. Thrust was not increased until the aircraft was approximately 4 km from the end of the runway and 800 ft aal.

18. Once the thrust was increased the aircraft climbed away normally and the flight proceeded to CFU without further incident.

19. There was no damage to the aircraft.

20. There were no injuries.

21. The investigation found no faults with the aircraft which could have contributed to this serious incident.

22. Had the crew of C-FWGH been alerted to the abnormally low acceleration while still at low speed, the takeoff could have been rejected and the aircraft brought to a halt well before the end of the runway.

23. Previous attempts to develop technical specifications for TOPMS have failed because the work tended to focus on the more sophisticated options, which were complex in nature.

24. TAMS reduces the complexity of the problem by only considering acceleration during the early stages of a takeoff, and the solution is data-driven.

25. The TAMS trialled in this investigation would have alerted the crew to the abnormally low acceleration during this takeoff.

26. There is currently no technical specification or certification standard for either TOPMS or TAMS.

27. Safety margins built into TODR calculations, which cater for normal variations in operational performance, are rendered unreliable or ineffective when there is a data entry error because of the random (and possibly gross) nature of the effect.

28. It was the benign nature of the runway clearway and terrain elevation beyond, and the lack of obstacles in the climb-out path, which allowed the aircraft to climb away without further collision after it struck the runway light.

29. Staff at BFS ATC attempted to contact the crew through the watch manager at ScACC. The crew were finally contacted by the operator when the aircraft was on the ground in CFU.

30. Although BFS ATC filed an MOR, neither the commander, aircraft operator, nor tour operator informed the AAIB directly as they were required to do for a serious incident of this nature.

3.2 Causal factors

1. An incorrect OAT was entered into the FMC, which caused the FMC to calculate an N_1 setting for takeoff which was significantly below that required for the aircraft weight and environmental conditions.

2. The incorrect OAT was not identified subsequently by the operating crew.

3. The abnormal acceleration during the takeoff run was not identified until the aircraft was rapidly approaching the end of the runway, and no action was taken to either reject the takeoff or increase engine thrust.

3.3 Contributory factors

1. The aircraft's FMC did not have the capability to alert the flight crew to the fact that they had entered the incorrect OAT into the FMC, although this capability existed in a later FMC software standard available at the time.

2. The Electronic Flight Bags did not display N_1 on their performance application (some applications do), which meant that the crew could not verify the FMC-calculated N_1 against an independently-calculated value.

3. The crew were unlikely to detect the abnormally low acceleration because of normal limitations in human performance.

4. Safety Recommendations and Actions

4.1 Safety Recommendations

Two Safety Recommendations were made in Special Bulletin S2/2017, published in September 2017, which are reproduced below along with the response from the addressee:

> **Safety Recommendation 2017-016**
>
> It is recommended that the Federal Aviation Administration mandate the use of Flight Management Computer software revision U12.0, or later revision incorporating the outside air temperature crosscheck, for operators of Boeing 737 Next Generation aircraft.

The FAA, in its initial response to this recommendation, stated that there might be hardware and fleet compatibility issues and cost implications for some operators which it would need to understand before responding substantively. It undertook to provide an updated response by December 2018.

The AAIB classified this response as: Superceded.

> **Safety Recommendation 2017-017**
>
> It is recommended that The Boeing Company promulgates to all 737 operators the information contained within this Special Bulletin and reminds them of previous similar occurrences reported in the Boeing 737 Flight Crew Operations Manual Bulletin dated December 2014.

On 13 July 2018, Boeing issued a Multi Operator Message which described the potential for FMC OAT entry errors referring to this, and other serious incidents. The message also reminded operators of the associated service bulletins recommending the installation of revision U12.0 of the FMS OPS software and BP15 update of the CDS[1]. The message reminded operators that the final compliance date for the recommended action was 10 January 2019.

The AAIB classified this response as: Adequate – Closed.

Safety Recommendations

1 See 1.16.3.2.

The following Safety Recommendation is made in this report, which supersedes Safety Recommendation 2017-016:

Safety Recommendation 2018-012

It is recommended that the Federal Aviation Administration mandate the use of Flight Management Computer OPS software revision U12.0, or later, and the Common Display System Block Point 15 update where this is required, to enable the outside air temperature crosscheck on all applicable Boeing 737 aircraft.

The following additional Safety Recommendations are made in this report:

Safety Recommendation 2018-013

It is recommended that Boeing Commercial Airplanes give guidance to operators of Boeing 737 aircraft on how they might verify the FMC-calculated value of N_1 against an independently-calculated value.

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.

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.

4.2 Safety Action

This report presents the following safety action:

Safety Action by the aircraft operator

As a result of the initial findings of this investigation into this serious incident the aircraft operator began a programme of upgrading their fleet of B737s to FMC Update 13 and CDU BP15 in order that the OAT alerting function would be available. They also updated their EFB software to display N_1 and included a crosscheck of this figure in their SOPs.

Safety Action by the UK CAA

After this serious incident, the CAA amended MATS Part 1 such that the senior controllers at ATSUs providing air traffic services at an aerodrome are required to notify the AAIB by telephone as part of their initial reporting actions following an aircraft accident or serious incident.

The CAA also amended CAP 797, *Flight Information Service Officer Manual,* to require air traffic services personnel to notify the AAIB by telephone as part of their initial reporting actions following an aircraft accident or serious incident.

In addition to the action above, a link to Regulation (EU) 996/2010 was put into MATS Part 1 and CAP 797 pointing to typical examples of what are likely to be classified as serious incidents.

Appendix A

Examples of accidents and incidents involving problems with takeoff performance

Date of occurrence	Investigating Agency (State)	Aircraft type	Synopsis	References
14 October 2004	Transport Safety Board (Canada)	B747-200SF	The incorrect takeoff weight was used in EFB calculations.	1
24 August 2005	Civil Aviation Administration of China	A340-300	The zero fuel weight was used instead of the takeoff weight for performance calculations.	2
12 July 2006	Transport Safety Board (Canada)	E190	The incorrect fuel weight was used in EFB calculations.	3
10 December 2006	BEA (France)	B747-400	The zero fuel weight was used instead of the takeoff weight in EFB calcualtions.	4
22 March 2007	Transport Accident Investigation Commission (New Zealand)	B777-300ER	Take off on a reduced runway length, due to runway maintenance works, using the full runway length performance figures.	5
28 March 2007	BEA (France)	A340	An error was made in entering the rotation speed, V_R.	-
April 2007	Australian Transport Safety Bureau	B767	The wrong performance manual was found on the aircraft which had been used to operate the previous 2 sectors.	6
2 June 2007	Air Accident Investigation Bureau of Singapore	B747-300	Performance data was used for the full runway length and not a shortened runway which was in effect due to ongoing works.	7
9 September 2007	Swedish Accident Investigation Authority (SHK)	MD83	The actual weather conditions were not used for the performance calculations and the weight of a number of bags were omitted on the aircraft's loadsheet.	8
September 2007	Australian Transport Safety Bureau	B737	The takeoff data was not revised after a change in ATC clearance.	6
November 2007	Australian Transport Safety Bureau	A320	An incorrect FLEX temperature was used for departure.	6
March 2008	Australian Transport Safety Bureau	A320	An incorrectly transposed takeoff reference speed, V_2, was used on departure.	6

Appendix A (cont)

Date of occurrence	Investigating Agency (State)	Aircraft type	Synopsis	References
May 2008	Australian Transport Safety Bureau	A320	The crew used take off data for an A321 in error.	6
September 2008	Australian Transport Safety Bureau	B747	An incorrect zero fuel weight was entered into the FMC.	6
28 October 2008	Air Accidents Investigation Branch (United Kingdom)	A330-200	The incorrect takeoff weight and takeoff reference speeds were used on departure.	9
October 2008	Australian Transport Safety Bureau	A320	An incorrect FLEX temperature was set for departure.	6
13 December 2008	Air Accidents Investigation Branch (United Kingdom)	B767-300	The incorrect takeoff weight was used for performance calculations.	10
20 March 2009	Australian Transport Safety Bureau	A340-500	An incorrect takeoff weight was entered into the EFB and used for departure.	6
31 August 2009	Dutch Safety Board	B777-300ER	The incorrect thrust and takeoff reference speeds were used for departure.	11
12 December 2009	Air Accidents Investigation Branch (United Kingdom)	A340-600	The estimated landing weight was used instead of the planned takeoff weight for the performance calculations and departure.	12
21 November 2010	Air Accidents Investigation Branch (United Kingdom)	B737-700	An incorrect assumed temperature was entered into the FMC and used for departure.	13
14 April 2012	Air Accidents Investigation Branch (United Kingdom)	B737-300	The incorrect takeoff weight was used in EFB calculations.	14
21 June 2013	Australian Transport Safety Bureau	E190	The takeoff performance calculations used for departure were performed for the incorrect runway intersection.	15
7 July 2013	Dutch Safety Board	B777-300ER	The incorrect thrust and takeoff reference speeds were used for departure.	11

Appendix A (cont)

Date of occurrence	Investigating Agency (State)	Aircraft type	Synopsis	References
1 October 2013	Swiss Transportation Safety Investigation Board	A320	The crew took off from an intersection using the full runway length performance figures.	16
18 September 2014	Dutch Safety Board	B737-800	An incorrect takeoff weight was used for departure.	17
6 October 2014	Swiss Transportation Safety Investigation Board	A320	The crew took off from an intersection using the full runway length performance figures.	18
25 June 2015	Air Accidents Investigation Branch (United Kingdom)	A319	An incorrect runway was used for EFB calculations.	19
16 July 2015	Air Accidents Investigation Branch (United Kingdom)	A320	The crew took off from an intersection using the full runway length performance figures.	20
3 December 2015	Dutch Safety Board	B737-800	The takeoff performance was calculated for an incorrect runway/takeoff position due to an EFB input error.	17
14 April 2016	CIAIAC (Spain)	A319	The Incorrect runway was used in EFB calculations.	Not investigated
23 December 2017	Australian Transport Safety Bureau	A330	During takeoff, the aircraft took longer than expected to become airborne. A takeoff data calculation error is suspected.	Under investigation
28 March 2018	Air Accidents Investigation Branch (United Kingdom)	B787-9	Reported to the AAIB by the UK CAA. The aircraft was observed commencing takeoff from the wrong position.	Under investigation

References in the table above:

1. http://www.tsb.gc.ca/eng/rapports-reports/aviation/2004/a04h0004/a04h0004.pdf
2. http://multimedia.jp.dk/archive/00062/Klevan-rapporten__pd_62785a.pdf
3. http://www.tsb.gc.ca/eng/rapports-reports/aviation/2006/a06a0096/a06a0096.pdf
4. https://www.bea.aero/fileadmin/documents/docspa/2006/f-ov061210/pdf/f-ov061210.pdf
5. https://taic.org.nz/sites/default/files/inquiry/documents/07-001.pdf

6. https://www.atsb.gov.au/media/2229778/ar2009052.pdf
7. https://www.mot.gov.sg/docs/default-source/about-mot/investigation-report/2-jun-2007.pdf
8. https://www.havkom.se/assets/reports/RL2009_14e.pdf
9. https://assets.publishing.service.gov.uk/media/5422f05640f0b613420002ad/Airbus_A330-243__G-OJMC_11-09.pdf
10. https://assets.publishing.service.gov.uk/media/5422f6a6ed915d13740005e5/Boeing_767-39H__G-OOAN_07-09.pdf
11. https://onderzoeksraad.nl/uploads/phase-docs/1244/3759582bd5c0ovv-kwartaalrapportage-luchtvaart-kw-i-2016-en.pdf?s=29E2A83CC6BD3EC4DD6F1C13AA193A0B4972B816
12. https://www.gov.uk/aaib-reports/airbus-a340-642-g-vyou-12-december-2009
13. https://assets.publishing.service.gov.uk/media/5422ff9140f0b61346000aad/Boeing_737-76N__5N-MJI_10-11.pdf
14. https://www.gov.uk/aaib-reports/boeing-737-33a-g-zapz-14-april-2012
15. https://www.atsb.gov.au/media/4356252/ao-2013-112_final.pdf
16. https://skybrary.aero/bookshelf/books/3551.pdf
17. https://www.onderzoeksraad.nl/uploads/phase-docs/1736/dc88ab83e9f820183230-engelse-b-rapportage-onvoldoende-vermogen-ingesteld-voor-de-start-interactief-180309.pdf?s=F06FFBE8E79E6CF407F391DEFF66DEC2FB14FDF8
18. https://skybrary.aero/bookshelf/books/3440.pdf
19. https://assets.publishing.service.gov.uk/media/5714f19840f0b60388000062/Airbus_A319-111_G-EZAA_05-16.pdf
20. https://assets.publishing.service.gov.uk/media/5714f256e5274a14d9000069/Airbus_A319-111_G-EZIV_05-16.pdf

All references accessed September 2018.

Appendix B

Human Factors Report for serious incident to Boeing 737-86J, C-FWGH, Belfast, 21 July 2017

Author: Dr Steve Jarvis

Introduction

This report discusses the human factors implications for three areas:

1. FMC input error
2. Recognition of the abnormal take-off run
3. Failure to apply more thrust after recognising a problem

1. FMC input error

It has been established that an incorrect figure of -47 degrees was entered into the Outside Air Temperature (OAT) field of the PERF INIT page of the FMC CDU before the aircraft returned to the stand for a tyre change. This figure subsequently became -52 degrees, which was also incorrect.

There is insufficient evidence to establish at which stage of cognition the error was generated, from three plausible possibilities:

1. At the selection stage. For example selecting the wrong figure from the flight plan, such as the OAT for the top-of-climb, which was -47.
2. In the short-term memory. This buffers values verbally despite the transfer being from print to manual output, meaning that the assumed temperature of 47 degrees could have promoted this.
3. At the output stage. Inputting the wrong figure into the system (i.e. a basic slip) or putting the right figure in the wrong field (for example entering T/C OAT into the OAT field in error).

Additionally, the error could have occurred as a combination of the above, or through crew interaction, whereby the figures were communicated between pilots.

There are many reasons why cross-checking fails to pick up errors, particularly FMC entry errors. These include checks not being performed, checks being performed verbally without sufficient attention to the visual elements, and checks being performed against the wrong values. However there is insufficient evidence to know what specifically occurred in this event.

The system feedback in relation to the error was quite opaque. Once the FMC page was changed the input was not visible. The observable indirect indication of the error was the take-off thrust setting. However the position of the bugs on the N1 gauges was not far from normal, and the N1 thrust setting began with the figure 8 (because it was in the low 80s)

Appendix B (cont)

which would make it less likely to stand-out as an extreme value given a low-attentional (unprocessed) single glance. Hence, without a deliberate (conscious) check, it would be understandable that a crew would not notice the issue in the course of their subsequent takeoff preparations.

2. Recognition of the abnormal take-off run

Pilots do not to consciously monitor acceleration cues on takeoff. In order to notice the acceleration issue, a perception that the situation was atypical was required. 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. The acceleration felt in the event was only marginally lower than the normal band with which the crew would have been familiar.

Although the vestibular system is able to perceive accelerations from inertial cues, the lower acceleration during the event (compared to a normal band) would have been effectively undetectable by this vestibular system. Visual cues are a significant factor in the perception of self-acceleration, and will overwhelm the feeling of self-acceleration created by inertial motion cues (Ishida et al, 2008). As an example, visual take-off cues successfully counteract vestibular cues in motion simulators (i.e. the wash-out algorithm). Hence, the situation is unlikely to have been perceptible by the vestibular system, and given the additional presence of visual cues, the crew had very little chance of noticing the slightly lower acceleration from the inertial cues.

The main direct visual cue to acceleration would have been the horizontal translation (e.g. texture flow), however the visual system has a general insensitivity and higher detection thresholds to the perception of acceleration, being less sensitive to acceleration than to constant speed (Mueller and Timney, 2016). It has been demonstrated that to perceive a visual change in velocity (acceleration) a moving target must instantly accelerate by between 17 and 30% (Watamaniuk, 2003). Against this background of insensitivity to acceleration from visual cues, it was clearly unlikely that the pilots would have been visually drawn to notice that the acceleration was slightly lower than normal, particularly given that the pilots were not expecting to experience particularly high acceleration on this take off.

From the discussion above, it can be confidently concluded that direct vestibular and/or visual acceleration cues would not have alerted a crew to the abnormally low acceleration experienced in this event.

However, indirect acceleration cues were also available to the crew, including the time taken to achieve V1, and any atypical visual scene that resulted from the slower acceleration (such as the runway end appearing closer than anticipated).

The crew probably did not notice the extended time taken to reach V1 because accurate perception of time in high arousal states (such as take-off) is poor, and both pilots would be concentrating on other matters.

question why neither crew member reacted by manually increasing the thrust. However, whereas increasing thrust appears the obvious reaction in hindsight, it is explainable why it might not naturally have occurred to the pilots to do so in those moments.

Firstly, pilots rarely manipulate thrust on take off (due to the use of auto-thrust) and so become used to the system performing this function for them.

The time-critical situation that the pilots found themselves in meant that actions could only have been taken as a result of recognition-primed decision-making or skilled performance. Hence in order to advance the thrust levers, the pilots would have had act without much conscious scrutiny of action, despite the situation being unexpected and not fully understood. Taking quick actions under seemingly ambiguous circumstances is not generally encouraged in modern flight training, and so pilots become familiar with the feeling of not reacting immediately when faced with critical events.

There are a number of further reasons why such an action (moving the thrust levers forward) would have been de-sensitised.

1. The use of the auto-thrust will, over time, have the effect of distancing the thrust control element from the skill set, making such a reaction slower or less likely to dominate given the situation.
2. The action of pilots removing their hand from the power levers at V1 (SOP) has safety advantages, but it can also reinforce an unconscious message that after V1 the power levers are not to be used, even though consciously all pilots would recognise that this only applies for retarding thrust levers. This makes the unconscious reaction of putting the hand back on the thrust lever less likely. Additionally, the pilots would have had little experience or practice of putting their hand back on the thrust levers after removing them at V1 (even in the climb, cruise and descent).
3. The pilots would have no prepared response to this specific issue. However due to engine malfunction training, the closest trained and prepared response would be to act as they did in the incident. For an engine malfunction after or at V1, the pilots would be familiar with continuing a compromised take-off without putting their hands back on the thrust levers (despite the take-off and climb acceleration being slower than usual). Therefore, although in hindsight it appears a strange reaction for the pilots not to have advanced the thrust levers in the incident, it is exactly what the pilots would have been used to experiencing in training when faced with almost all situations that felt similar to this one.
4. It is improbable that on seeing the danger ahead in the direction of travel the naturalistic and intuitive reaction of a person would be to increase speed towards the danger. The initial naturalistic reaction would likely be to decelerate (especially being unable to steer away from that danger), and this means that advancement of the thrust levers would need to counter a contrary intuitive reaction.

Appendix B (cont)

5. Although the pilots probably became aware that the runway end was approaching too early in relation to their speed, it was not obvious to them that the cause was a low thrust setting, despite this appearing obvious in hindsight. There are a number of reasons that could have led to this circumstance as well as low thrust setting, including taking-off from the wrong intersection, computing the take-off using the wrong intersection, engine malfunction, and others. With time criticality, without knowing obviously why the situation was occurring, the pilots would have been reluctant to act quickly.

In summary, the application of more thrust was not a trained, natural or dominant response for a number of reasons as explained, whereas inaction on the thrust levers would be familiar and probably dominant. It is likely that many crews would react in the same way that the incident crew did, given the same circumstances.

Conclusion

Once the initial error was made, failure to notice it was predictable and within normal human performance (it would have occurred to many crews, partly due to the system feedback being opaque in relation to the error). Once the take-off was started, acceleration cues would be unlikely to alert a normal crew to the problem. The view ahead was the first reliable cue, initially creating a recognition-primed cue to the atypical situation. Having noticed the issue, many crews would have reacted in the same way as this crew did, due to normal training and experience.

References

Klein, G (1988) *Sources of Power*. MIT Press.

Ishida M, Fushiki H, Nishida H, Watanabe Y (2008) *Self-motion perception during conflicting visual-vestibular acceleration.* Journal of Vestibular Research, 18(2008), 267-272.

Jarvis (2017). Unpublished industry research.

Mueller A S, Timney B (2016). *Visual Acceleration Perception for Simple and Complex Motion Patterns*. Department of Psychology, University of Western Ontario, London, Ontario, Canada.

Nakayama R and Motoyoshi I (2017) *Sensitivity to Acceleration in the Human Early Visual System*. Frontiers in Psychology, 2017; 8 : 925.

Watamaniuk, S N J (2003). *Motion Perception*. In Encyclopedia of Optical Engineering, Volume 2, Driggers (Ed. Marcel Dekker Inc, New York. PP 1383.

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References

Klein, G (1988) *Sources of Power*. MIT Press.

Ishida M, Fushiki H, Nishida H, Watanabe Y (2008) *Self-motion perception during conflicting visual-vestibular acceleration.* Journal of Vestibular Research, 18(2008), 267-272.

Jarvis (2017). Unpublished industry research.

Mueller A S, Timney B (2016). *Visual Acceleration Perception for Simple and Complex Motion Patterns*. Department of Psychology, University of Western Ontario, London, Ontario, Canada.

Nakayama R and Motoyoshi I (2017) *Sensitivity to Acceleration in the Human Early Visual System*. Frontiers in Psychology, 2017; 8 : 925.

Watamaniuk, S N J (2003). *Motion Perception*. In Encyclopedia of Optical Engineering, Volume 2, Driggers (Ed. Marcel Dekker Inc, New York. PP 1383.

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Unless otherwise indicated, recommendations in this report are addressed to the appropriate regulatory authorities having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action is taken. In the United Kingdom the responsible authority is the Civil Aviation Authority, CAA House, 45-49 Kingsway, London WC2B 6TE or the European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany.

Aircraft Accident Report 2/2018

Report on the serious incident to
Boeing 737-86J, C-FWGH
Belfast International Airport
on 21 July 2017