Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

ACCIDENT
Boeing, 737-8AS, EI-DHH
Runway 28L, Dublin Airport

9 April 2023

An Roinn Iompair
Department of Transport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

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

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[1] **Annex 13**: International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.

[2] **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.

[3] **Statutory Instrument (SI) No. 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of SI No. 460 of 2009, on 9 April 2023, the Chief Inspector of Air Accidents appointed Paul Farrell as the Investigator-in-Charge to carry out an Investigation into this Accident and prepare a Report.

Aircraft Type and Registration:	Boeing 737, 8AS, EI-DHH	
No. and Type of Engines:	2 x CFM56-7B26	
Aircraft Serial Number:	33817	
Year of Manufacture:	2005	
Date and Time (UTC)[4]:	9 April 2023 @ 16:30 hrs	
Location:	Dublin Airport (EIDW), Runway 28L	
Type of Operation:	Commercial Air Transport	
Persons on Board:	Crew – 6	Passengers – 172
Injuries:	Crew – Nil	
Nature of Damage:	Substantial	
Commander's Licence:	Airline Transport Pilot Licence (ATPL), Aeroplane (A), European Union Flight Crew Licence, issued by the Irish Aviation Authority (IAA)	
Commander's Age:	60 years	
Commander's Flying Experience:	22,969 hours, of which 16,771 were on type	
Notification Source:	Duty Manager, EIDW	
Information Source:	AAIU Field Investigation Report Forms submitted by the Flight Crew	

[4] **UTC**: Co-ordinated Universal Time. All times in this report are quoted in UTC unless otherwise stated; local time was UTC + 1 hour on the date of the accident.

SYNOPSIS

EI-DHH, a Boeing 737-8AS aircraft, was on a scheduled passenger flight from Liverpool Airport, in the United Kingdom (EGGP), to Dublin Airport, in Ireland (EIDW). Following an uneventful flight, the aircraft touched down on Runway (RWY) 28 Left (L) at EIDW, in crosswind conditions, with a crab angle of approximately three degrees to the left, relative to the runway magnetic heading of 277 degrees. The aircraft tracked towards the left edge of the runway before turning back through the runway centreline and eventually coming to a stop at a runway exit on the right-hand side of the runway. During the ground roll, the aircraft nosewheels were severely damaged with one wheel and tyre departing the aircraft completely, and the other wheel being ground down to its axle, while its tyre also suffered significant abrasion and loss of material. There was damage to the airframe due to debris. There were no injuries and there was no fire. The passengers and crew disembarked the aircraft through the left rear (L2) door using mobile stairs and were taken to the terminal buildings by bus. The Investigation determined that the probable cause of the occurrence was the use of the tiller to steer the nosewheel assembly at a speed higher than that prescribed by the Aircraft Manufacturer.

NOTIFICATION AND RESPONSE

The Duty Manager at EIDW contacted the AAIU on the Unit's 24-hour phone number and advised the Inspector-On-Call about the occurrence. A team of three Inspectors of Air Accidents deployed to the airport, arriving there at approximately 18:00 hrs.

1. FACTUAL INFORMATION

1.1 History of the Flight

EI-DHH, with six crew and 172 passengers on board, departed EGGP on a scheduled flight to EIDW. On this sector, it had been agreed that the First Officer (FO) would be the Pilot Flying (PF) and the Commander would be the Pilot Monitoring (PM).

The accident flight was the first of four scheduled flights (sectors) for the Crew on the day of the accident. The Commander and the FO, who had flown together previously, met in the crew room and decided, *inter alia*, on their fuel plans for the different sectors, before going to the aircraft.

The Investigation interviewed the Commander on the evening of the occurrence. He stated that he was the PM for the accident sector and that he completed the aircraft walk-around inspection prior to departure from EGGP, with no findings. He recalled that there were no entries (of concern) in the Aircraft Technical Log (ATL), and the aircraft was '*off blocks*' five minutes ahead of schedule.

The Commander noted that the weather report for EIDW was indicating a crosswind on RWY 28L. The Commander explained that due to the FO's low hours, he (the FO) was subject to a company operating restriction on crosswind speed. The Commander said that they checked this and that the forecast crosswind was within the limitation prescribed for the FO.

The Commander said that the crosswind had been discussed in the briefing, and that it had been decided that the landing would be a Flap 30 landing because the aircraft was light, the runway was long enough, and Flap 30 meant that the aircraft would be easier to control in a crosswind.

The Captain stated that the Instrument Landing System (ILS) approach to RWY 28L was '*well flown*'. The autopilot was disconnected below 1,000 ft and the Precision Approach Path Indicators (PAPI[5]) were visible to provide guidance at that stage. The Commander said at about 100 ft, the aircraft was a little to the left of the runway centreline but that it was not sufficient to cause concern.

Touchdown was described by the Commander as '*soft but positive*' and he recalled that when the nose-gear was lowered to the runway it was not '*a thump*' but that it was later than usual in the landing manoeuvre. He recalled that the aircraft was pointing to the left and going towards the left edge of the runway, so he called '*my controls*' as he thought that an aircraft tyre had burst. The Commander did not recollect any aircraft bounce. He noted that there was some shaking in the aircraft and also noise, which he believed was originating from the nose-gear.

The Commander's recollection was that he used pedals, and very little braking to regain the centreline and that after he had regained the centreline, he used the tiller[6] to control the aircraft. The Commander did not remember the exact speed at which the tiller was used during the landing ground roll but he indicated that the tiller could not be used above 60 kt.

The Commander elected not to deploy the thrust reversers due to concerns that tyre debris could enter the engine, and because the runway length allowed him to do this. He said that he only used slight braking action and was able to manoeuvre the aircraft towards a runway exit although he recalled that as the speed was reducing the noise was increasing; at this point the Commander realised that the noise, which he had at first thought was originating from outside the aircraft, was in fact coming from the aircraft itself. When the aircraft came to rest, the FO selected Flap 40 and the Commander set the parking brake; this was consistent with the Operator's procedures.

The Air Traffic Control (ATC) tower was contacted to ask if they could see any smoke or fire; ATC replied that they could see nothing now but that there had been sparks observed earlier in the landing roll. The Commander was aware that an evacuation could result in casualties, and decided that an evacuation was not necessary, and the Aerodrome Rescue and Firefighting Service (ARFS) was contacted. The ARFS advised that they could not observe any fire, and this led the Commander to confirm his decision that an evacuation was not required. The ARFS did an inspection of the aircraft and advised the Flight Crew that the only issue that was identified was that the nose landing gear was damaged. The Commander stated that the Flight Crew made a '*Standby*' call to the Cabin, and shortly thereafter the Flight Crew had confirmed with the Cabin Crew that everything was safe in the cabin and briefed the Cabin Crew that an evacuation was not required.

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[5] **PAPI:** A system consisting of four light boxes arranged perpendicular to the edge of the runway projecting a pattern of red and white lights that provide visual approach slope information for landing aircraft.
[6] The tiller is located on the cockpit left-hand sidewall, adjacent to the commander's seat, and is used to steer the nose wheels during ground manoeuvring.

A Passenger Address (PA) was made by the Commander advising passengers of the situation. Subsequently, the passengers and crew disembarked the aircraft through the left rear (L2) door using mobile stairs, and were taken to the terminal buildings by bus.

1.2 First Officer's Interview

The FO began his type rating with the Operator on 6 June 2022, and his first operational flight on 30 September 2022. He had been based at Liverpool since March 2023, and conducted his first flight from that base on 11 March 2023. He recalled that he had flown with the Commander on several previous occasions. Prior to the accident flight, he met the Commander in the Crew Room and discussed the planned flight including Notices to Airmen (NOTAMs), weather, and the FO's crosswind landing restriction as an inexperienced FO. The FO did not recall any weather issues forecast for the time of the accident flight, although he did note that the weather information indicated gusts later in the day; he also noted that, while enroute, the Automatic Terminal Information Service (ATIS[7]) did not provide any matters of concern regarding weather. The Commander decided that the FO would fly the sector to Dublin, the Flight Crew's first sector of the day, and the FO was content with that decision. The FO remarked that as an inexperienced FO, until he reached 500 hours of flying experience on type, he was subject to a 15 kt crosswind Operator restriction—he recalled that the forecast wind was 12 kt, while the ATIS was quoting a wind at 170 degrees of 14 kt (i.e. a crosswind from the left, when landing on RWY 28L).

The FO said that during the flight, the crew carried out a Threat and Error Management (TEM) briefing which did consider the wind but as it was within the limits permitted for the FO, it was deemed acceptable.

The FO stated that when the '*automatics*' were disconnected at around 300 to 500 ft, he got a good feel for the aircraft and did not notice anything abnormal. He recalled that the PAPIs indicated that the approach path was satisfactory, while he made a slight correction to the right for a drift to the left of the RWY centreline. He could not recall if the aircraft was de-crabbed[8] in the flare. Everything felt normal to him and he said that the touchdown was with main gear first. He estimated the aircraft was one to two metres to the left of the RWY centreline, and that the nose gear touched down slightly left of RWY centreline.

He thought that as the aircraft touched down, he may have put in a correction to the left for the crosswind which may have placed the nose a little to the left of the runway centreline, at which point he recalled the Commander saying '*I have control*'. As the nosewheel touched down, the FO felt a vibration and heard a '*rasping*' metallic noise. He recalled that at that point the aircraft was to the left of RWY centreline, with corrections towards the runway centreline being made by the Commander. He said that they (the Flight Crew) believed that it was a minor gear malfunction and that the aircraft could be taxied off the RWY at runway exit S5.

[7] **ATIS:** The automatic provision of current, routine information to arriving and departing aircraft throughout 24 hours or a specified portion thereof; the ATIS at EIDW is an automated voice service, broadcast on a pre-defined frequency.
[8] **De-crab:** A manoeuvre during a crosswind landing that removes an aircraft's crab angle and aligns the aircraft fuselage with the landing runway orientation.

1.3 Injuries to Persons

No injuries were reported to the Investigation.

1.4 Damage to Aircraft

There was substantial damage to the Nose Landing Gear (NLG) assembly and wheels (**Photo No. 1**)

Photo No. 1: NLG assembly as the aircraft came to rest

While the damaged right-hand wheel and tyre remained loosely attached to the NLG assembly, the left-hand wheel and tyre were found to have separated from the assembly early in the landing roll.

A large portion of the left-hand wheel was found on the left shoulder of the runway (**Photo No. 2**).

Photo No. 2: Portion of left-hand wheel at runway edge

The left-hand tyre, and sections of the left-hand wheel, were subsequently recovered from the grass margin to the left of the runway at a distance of approximately 150 metres (m) from the runway edge (**Photo No. 3** and **Figure No. 1**).

Photo No. 3: Left-hand tyre and section of wheel hub

Figure No. 1: Location at which left-hand tyre was recovered

A large number of fragments of various parts of the NLG assembly were recovered from along the runway surface and margins, between the area where the NLG first touched down and where the aircraft came to a stop: these comprised fragments of hub material; tie-bolts, ground on a constant angle; bearing rollers, races and cages; locking wire; an inflation valve with cap in-situ; tyre fragments; axle nuts and washers. A sample of these items is shown in **Figure No. 2**.

Figure No. 2: Sample of the fragments recovered from the runway

It was noted that the axles that had remained attached to the NLG assembly had been ground down to approximately half of their original circular profile (**Photo No. 4**).

Photo No. 4: Ground down axle

There was paint transfer evidence that a separated section of a NLG wheel had impacted, and punctured, the outer skin of the fuselage in the area underneath the left side of the cockpit (**Photo No. 5**). There was no damage to internal systems inside the fuselage.

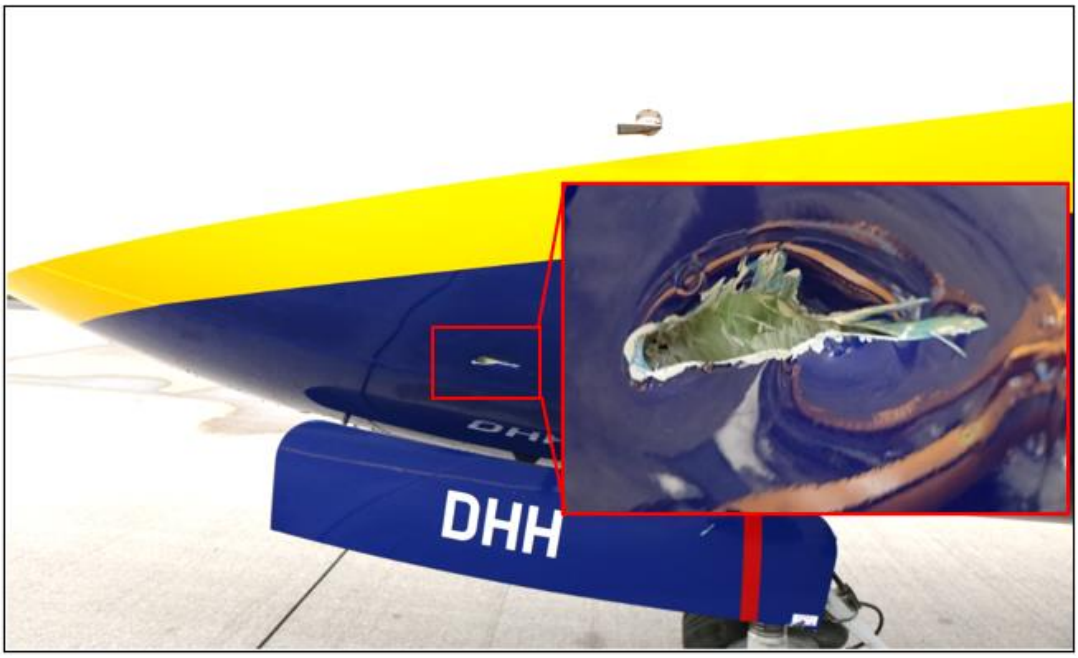

Photo No. 5: Punctured fuselage skin on left side of aircraft

There was damage to various parts of the aircraft including the fuselage, the fan blades of both engines, the undersides of the wings, and the tail surfaces as a result of impact from debris from the nosewheels and NLG.

Examination of each of the nosewheel tyres revealed significant abrasion damage throughout the full available circumference of each tyre in a direction across the tyre ridges/grooves (**Figure No. 3**). The angle between the tyre grooves (thread pattern), which indicate the normal direction of rotation, and the majority (preponderance) of the abrasion marks was in the order of 70 degrees (values up to 72 degrees were observed).

Figure No. 3: Examples of the abrasion marks on the left (top) and right (bottom) tyres

The Investigation notes that such abrasion marks, across the entire tyre face, and throughout the entire tyre circumference, were not present on the aircraft's main wheel tyres (**Photo No. 6**)

Photo No. 6: Main wheel tyres

1.5 Runway Surface Marks

The Investigation conducted a survey of the runway surface to identify marks associated with the aircraft's ground roll. **Figure No. 4** shows the identified NLG-related markings overlaid, in red, on an image of the runway surface.

Figure No. 4: NLG-related runway marks (in red, overlaid on Google Earth imagery)

The Investigation noted that, in addition to the very pronounced NLG-related marks, tyre tracks from the two main landing gear (MLG) tyres were also apparent on the runway surface (**Photo No. 7** and **Photo No. 8**).

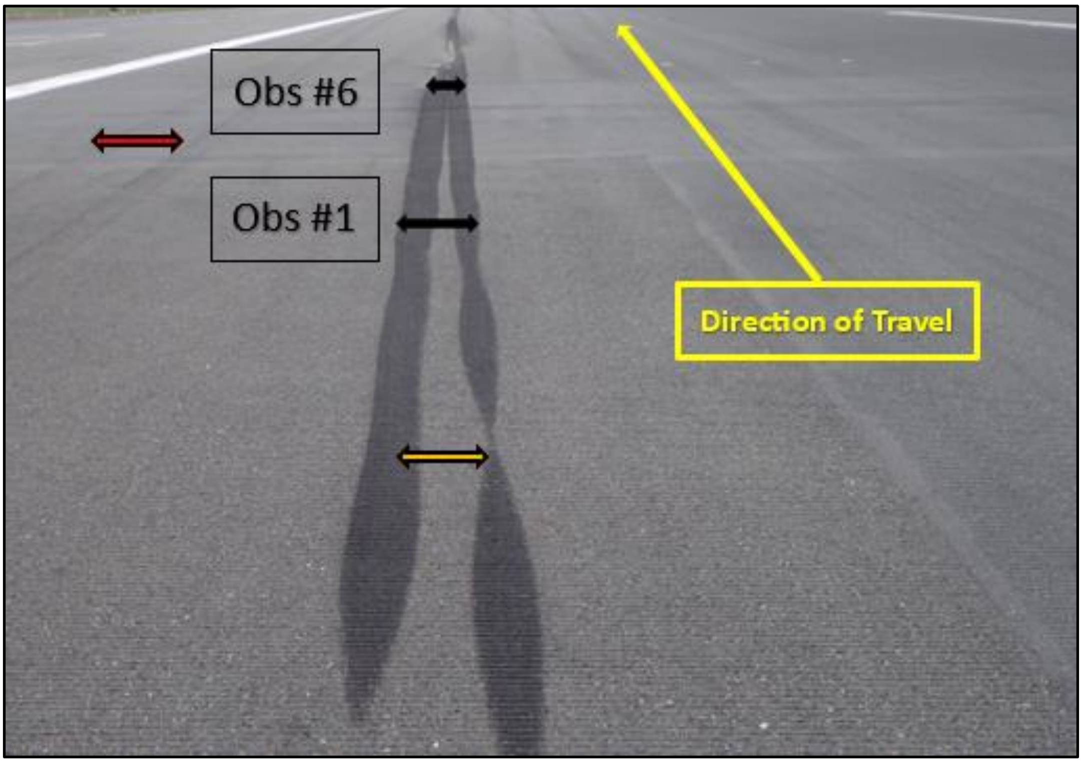

Photo No. 7: Initial NLG-related marks (orange) and left MLG marks (red)

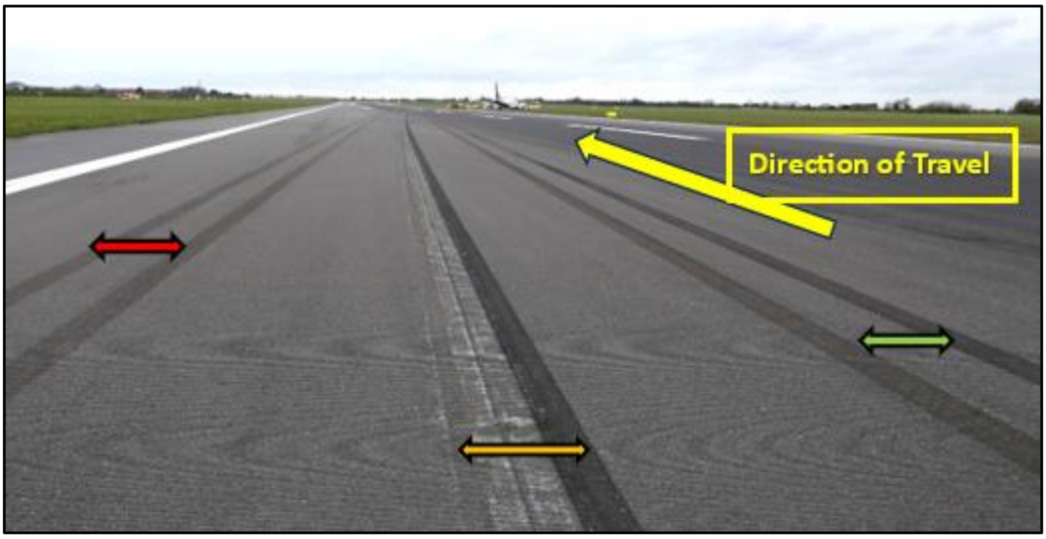

Photo No. 8: Runway marks — NLG-related (orange), left MLG (red) and right MLG (green)

The Investigation carried out a detailed survey of the initial NLG-related marks; a composite of six observations is provided at **Figure No. 5**. The Investigation tabulated these observations in **Table No. 1**.

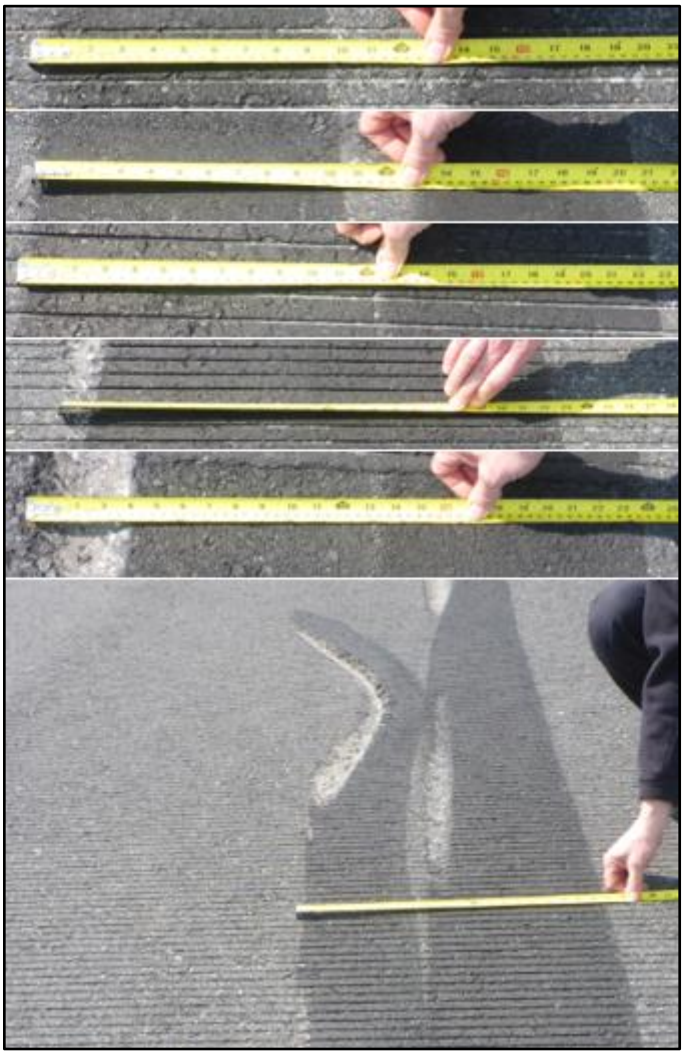

Figure No. 5: Composite of six observations progressing (top to bottom) along initial marks

Obs No.	LH Track Width (Inches)	RH Track Width (Inches)	Note
Obs #1	9.5	6.5	LH > RH
Obs #2	10.5	7.5	LH > RH, both increasing in width
Obs #3	12	10.5	LH > RH, both increasing in width
Obs #4	Single track, 22.5 wide		Start of wheel rim gouge mark on the outside of the LH track
Obs #5	single track, 24 inches wide		Deep, wide wheel rim gouge mark on the outside of the LH track
Obs #6	Diverging gouge of LH wheel, start of RH wheel gouging. Also shows LH track 8 inches wide and RH track 12 inches wide.		

Table No. 1: Observations related to initial MLG-related marks

1.6 Personnel Information

1.6.1 Commander

The Commander held an ATPL (A) issued by the IAA which contained a valid B737 300-900 Type Rating (and Instrument Rating) with an expiry date of 31 January 2024. The Commander's Class 1 Medical Certificate was valid until 18 May 2023. The Commander's Flying Experience is outlined in **Table No. 2**.

Total all types:	22,969 hours 00 minutes
Total on type P1:	16,771 hours 00 minutes
Last 90 days:	221 hours 30 minutes
Last 28 days:	89 hours 30 minutes
Last 24 hours:	3 Hours 23 minutes

Table No. 2: Commander's Flying Experience

1.6.2 First Officer

The FO held a Commercial Pilot Licence (CPL) Airplane (A) issued by the IAA which contained a valid B737 300-900 Type Rating (and Instrument Rating) with an expiry date of 29 February 2024. The FO's Class 1 Medical Certificate was valid until 18 September 2023. The FO's Flying Experience is outlined in **Table No. 3**.

Total all types:	513 hours 36 minutes
Total on type:	331 hours 48 minutes
Total on type P2:	331 hours 48 minutes
Last 90 days:	150 hours 54 minutes
Last 28 days:	30 hours 36 minutes
Last 24 hours:	7 Hours 54 minutes

Table No. 3: First Officer's Flying Experience

1.7 Aircraft Information

1.7.1 General

EI-DHH is a Boeing B-737-8AS aircraft with a wingspan of 35.79 m, a length of 39.5 m and a total height of 12.57 m. It is fitted with two CFM 56-7B26E turbofan engines. Its maximum take-off mass is 79,015 kilograms. The aircraft was manufactured in 2005. It had a valid Certificate of Airworthiness (CoA), issued by the IAA on 21 May 2008, and an associated Airworthiness Review Certificate (ARC) that was valid until 2 December 2023.

The 737 Flight Crew Operations Manual (FCOM) AFM Limitations section for this airplane indicates that the Maximum Takeoff and Landing Tailwind Component is 10 kts with 15 kts for approved airfields only.

1.7.2 Aircraft Spoilers and Automatic Speedbrake System

Each aircraft wing is equipped with six spoilers attached to the upper surface. On each wing two of these spoilers, the innermost and outer most, are called '*ground spoilers*', while the other four are called '*flight spoilers*'. Flight spoilers are deployed symmetrically in flight, to act as speed brakes. Also in flight, the flight spoilers deploy asymmetrically to assist roll control (when control wheel[9] displacement exceeds approximately 10 degrees)—the flight spoilers rise on the wing with the upward deflected aileron while the opposite wing's flight spoilers remain faired (undeployed). On the ground, flight and ground spoilers are deployed symmetrically to reduce lift and increase braking effectiveness.

The aircraft incorporates an automatic speedbrake system which operates during landing when certain conditions are met, namely: Speed brake lever in the armed position; speed brake armed light illuminated; radio altitude less than 10 feet; main landing gear strut compressed; both thrust levers retarded to idle; and MLG wheels spun up to more than 60 kt. Compression of either landing gear strut will deploy the flight spoilers; however, the ground spoilers will only deploy when the right MLG strut is compressed.

1.7.3 Nosewheel Steering System

The nose wheel steering system supplies ground directional control of the aircraft. Steering inputs are from the steering wheel (tiller) or the rudder pedals. When the steering wheel is moved to full travel, the nose wheels turn a maximum of 78 degrees in the left or right direction. When the rudder pedals are moved to full travel on the ground, the nose wheels turn a maximum of 7 degrees in the left or right direction. Steering inputs from the steering wheel or rudder pedals go to the metering valve through a cable loop.

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[9] In this Report the term '*control wheel*' is used to refer to the wheel mounted on the control column that the pilot uses to control the rolling of the aircraft; the term '*steering wheel*' (also referred to as the '*tiller*') is used to refer to the device mounted on the left wall of the cockpit (beside the pilot seat) and used to steer the nosewheels during ground manoeuvring.

The aircraft Manufacturer provided the Investigation with details of the Nosewheel Steering (NWS) System. A schematic of the system is presented at **Figure No. 6**.

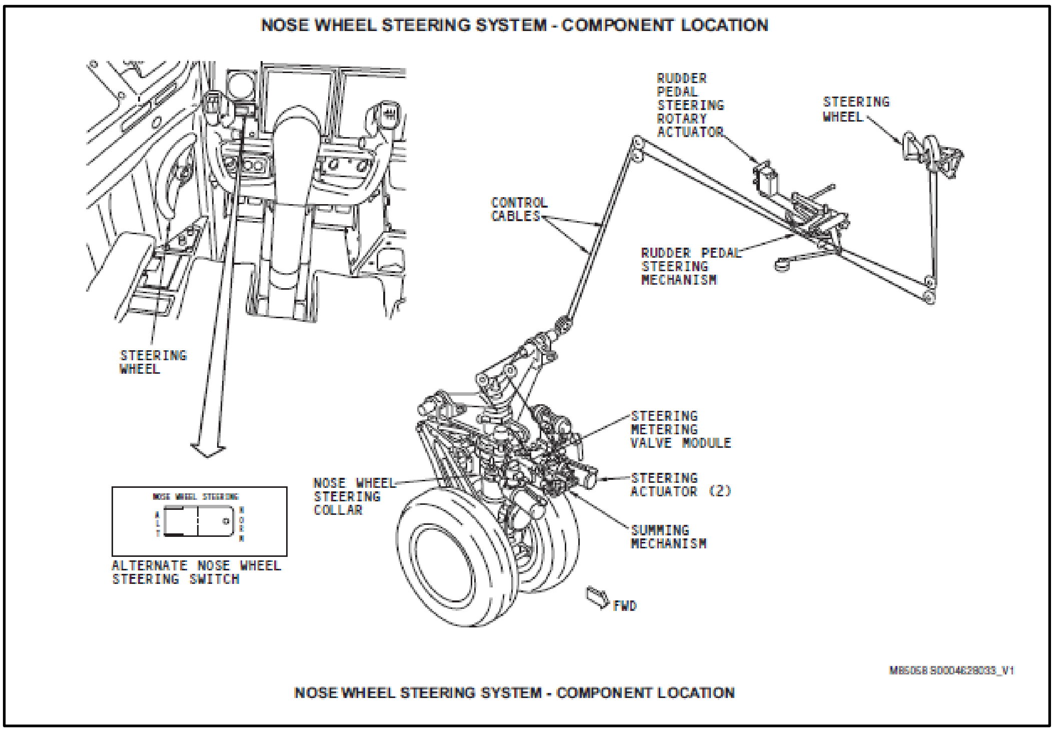

Figure No. 6: NWS system
(Copyright © Boeing. Reprinted with permission of The Boeing Company.)

The rudder pedal steering mechanism:

- Mixes the steering inputs from the rudder pedals and the steering wheel
- Prevents rudder pedal inputs when the airplane is in the air
- Supplies centering forces.

The rotary actuator engages the rudder pedal steering when the nose gear is on the ground and disengages it in the air; this prevents rudder pedal inputs from moving the nose wheel steering control cables whilst the aircraft is in flight. The system is hydraulically driven with cable inputs and there is no steering wheel (tiller) position feedback from or speed inputs to the steering system.

1.8 Aircraft Controls

When an aircraft is at a crab angle for landing, the primary flight control used to adjust the aircraft heading to align with the runway heading for landing is the aircraft's rudder. Specifically, pressing the left or right rudder pedal in the cockpit has the effect of deflecting the rudder surface at the tail of the aircraft, thereby generating a sideways aerodynamic force which, acting about the aircraft's vertical axis, causes the aircraft to yaw in the desired direction. As with other flight controls, there are secondary effects which must also be managed. In the case of the rudder, the yawing of the aircraft gives rise to asymmetric lift due to a higher airspeed being experienced by one wing (the advancing wing); this wing lift asymmetry gives rise to a rolling moment which can be counteracted by an appropriate control wheel input towards the advancing wing, i.e. opposite to the direction of yaw. As with all flying control surfaces, the effectiveness of any control surface reduces with diminishing airspeed.

1.9 Directional Control During Landing

The Manufacturer provided the Investigation with the following Flight Crew Training Manual (FCTM) extracts that provide guidance on directional control during landing, and the use of the NWS system while taxiing:

'*Taxi speed should be closely monitored during taxi out, particularly when the active runway is some distance from the departure gate. Normal taxi speed is approximately 20 knots, adjusted for conditions. On long straight taxi routes, speeds up 30 knots are acceptable, however at speeds greater than 20 knots use caution when using the nose wheel steering wheel to avoid overcontrolling the nose wheels. When approaching a turn, speed should be slowed to an appropriate speed for conditions. On a dry surface, for turn angles greater than those typically required for high speed runway turnoffs, use approximately 10 knots.*

Directional Control During Landing Ground Roll

Unusual events adversely affecting airplane handling characteristics while airborne may continue to adversely affect airplane handling characteristics during landing ground roll. Aggressive differential braking, use of rudder pedal steering and/or use of asymmetrical reverse thrust. in addition to other control inputs. may be required to maintain directional control.

Upon landing and rollout, if directional control cannot be maintained by normal control inputs. careful use of nose wheel steering control wheel may be necessary.

Note: Use of nose wheel steering control wheel is not recommended until reaching taxi speed.

Directional Control and Braking during Landing Roll

If the nose wheels are not promptly lowered to the runway, braking and steering capabilities are significantly degraded and no drag benefit is gained. Rudder control is effective to approximately 60 knots. Rudder pedal steering is sufficient for maintaining directional control during the rollout. Do not use the nose wheel steering wheel until reaching taxi speed. In a crosswind, displace the control wheel [yoke] *into the wind to maintain wings level which aids directional control. Perform the landing roll procedure immediately after touchdown. Any delay markedly increases the stopping distance.*

Use a combination of rudder, differential braking, and control wheel input to maintain runway centerline during strong crosswinds, gusty wind conditions or other situations. Maintain these control input(s) until reaching taxi speeds.

Stopping distance varies with wind conditions and any deviation from recommended approach speeds.'

1.10 Crosswind Landing Techniques

The Manufacturer's FCTM provided the following guidance on Crosswind Landing Techniques:

'*Three methods of performing crosswind landings are presented. They are the de-crab technique (with removal of crab in flare), touchdown in a crab, and the sideslip technique. Whenever a crab is maintained during a crosswind approach, offset the flight deck on the upwind side of centreline so that the main gear touches down in the center of the runway.*

De-Crab During Flare

The objective of this technique is to maintain wings level throughout the approach, flare, and touchdown. On final approach, a crab angle is established with wings level to maintain the desired track. Just prior to touchdown while flaring the airplane, downwind rudder is applied to eliminate the crab and align the airplane with the runway centreline.

As rudder is applied, the upwind wing sweeps forward developing roll. Hold wings level with simultaneous application of aileron control into the wind. The touchdown is made with cross controls and both gear touching down simultaneously. Throughout the touchdown phase upwind aileron application is utilized to keep the wings level.

Touchdown In Crab

The airplane can land using crab only (zero sideslip) up to the landing crosswind guideline speeds. (See the landing crosswind guidelines table, this chapter).

On dry runways, upon touchdown the airplane tracks toward the upwind edge of the runway while de-crabbing to align with the runway. Immediate upwind aileron is needed to ensure the wings remain level while rudder is needed to track the runway centreline. The greater the amount of crab at touchdown, the larger the lateral deviation from the point of touchdown. For this reason, touchdown in a crab only condition is not recommended when landing on a dry runway in strong crosswinds.

Sideslip (Wing Low)

The sideslip crosswind technique aligns the airplane with the extended runway centerline so that main gear touchdown occurs on the runway centerline. The initial phase of the approach to landing is flown using the crab method to correct for drift. Prior to the flare the airplane centerline is aligned on or parallel to the runway centerline. Downwind rudder is used to align the longitudinal axis to the desired track as aileron is used to lower the wing into the wind to prevent drift. A steady sideslip is established with opposite rudder and low wing into the wind to hold the desired course.'

The Operator's Line Training Student Notes (LTSN) States:

> '[…] *we use the de-crab during flare and the touchdown with crab techniques, FCTM 6.46, for crosswind landings.*
>
> *De-crab during Flare*
>
> *The objective is to maintain wings level during approach, flare and touchdown.*
>
> *During the approach a crab angle is established with wings level in order to maintain the desired track. During the flare downwind rudder is applied to eliminate the crab and align the aircraft with the centre-line. At the same time apply upwind aileron in order to maintain wings level. These cross controls are maintained throughout the landing phase and the aileron during the landing roll.*
>
> *Touchdown with Crab*
>
> *It is recommended to use this method when landing on slippery runways as it reduces drift on touchdown and allows for rapid deployment of the spoilers and autobrake as all main gear have touched down simultaneously. However, rudder and aileron inputs to de-crab after touchdown must be applied in order to maintain proper directional control.*
>
> *This method is not recommended on dry runways as on landing the aircraft will tend to track upwind until the correct de-crab technique is accomplished. This lack of initial directional control is undesirable.*'

1.11 Bounced Landing Management Techniques

The Manufacturer's Flight Crew Training Manual provided the following guidance on dealing with bounced landings:

> '*If higher than idle thrust is maintained through initial touchdown, the automatic speedbrake deployment may be disabled even when the speedbrakes are armed. This can result in a bounced landing. During the resultant bounce, if the thrust levers are then retarded to idle, automatic speedbrake deployment can occur. This results in a loss of lift and nose up pitching moment which can result in a tail strike or hard landing on a subsequent touchdown.*
>
> *If the airplane bounces during a landing attempt, hold or re-establish a normal landing attitude and add thrust as necessary to control the rate of descent. Thrust need not be added for a shallow bounce or skip. If a high, hard bounce occurs, initiate a go-around. Manually advance thrust levers to go-around thrust, and verify speedbrakes are retracted. Do not retract the flaps or landing gear until a positive rate of climb is established because a second touchdown may occur during the go-around. When safely airborne continue with the Go-Around and Missed Approach procedure as prescribed in the FCOM/QRH.*'

1.12 Examination of NLG Assembly

An examination of the nosewheel tyres did not identify any evidence of overloading or burst damage on either tyre.

The NLG assembly, and the various fragments of material, tyres, etc. that had been recovered, were sent to the Aircraft Manufacturer for initial examination and thereafter relevant elements were sent for further examination by component manufacturers.

Examination and testing of the NWS metering valve assembly determined that the '*the NWS module passed all functional tests within the limits for an in-service unit.*'

With the assistance of the United States National Transportation Safety Board (NTSB), an examination was carried out of a large amount of the material recovered from the runway, and the failed components of the NLG assembly. The examination comprised:

- Visual examination of the parts
- Optical and Scanning Electron Microscopy (SEM) of the wheel sections to determine fracture mode when possible
- Abrasive cleaning of the surface of the bearing cages to determine the extent of the corrosion observed on the cages (the corrosion was found to be surface corrosion that had occurred in the post-event period)
- Chemical analysis, using Fourier Transform Infrared Spectroscopy (FTIR), of samples of grease from a number of components

The examination was carried out by the Manufacturer's Research and Technology group and it concluded that '*the fracture mode of the wheel sections examined was determined to be ductile separation in all regions it could be confirmed, consistent with a single event.*' It further concluded that '*No other anomalies contributing to the fractures were observed*.'

1.13 Meteorological Information

Met Éireann, the Irish meteorological service, was asked to provide details of the weather conditions prevailing at Dublin Airport at the time of the accident. Details from the report received are reproduced in **Table No. 4**.

Meteorological Situation:	Ireland lies in a generally fresh to strong southerly airflow generated by a depression centred to the southwest of Iceland, associated fronts and troughs move eastwards across the country.
Surface Wind: **Wind at 2,000 feet (ft):** **Surface to 300 ft:**	South-easterly, 12-15 kt, gusts 16-22 kt South to south-west, 35-40 kt Varying between south-east and south-west, 15-25 kt
Visibility:	25 km
Weather:	Cloudy
Cloud:	Few (1-2/8ths oktas[10]) with bases at 1,300ft, scattered (3-4/8ths) clouds with bases at 2,000ft and a broken (5-7/8ths) layer with bases at 2,600ft.
Surface Temperature: **Dew Point:**	12 degrees Celsius 9 degrees Celsius
Mean Sea Level (MSL) Pressure:	1009 hectopascals (hPa).
Freezing Level:	6,000 ft
Other Comments:	METAR EIDW 091630Z 15012KT 9999 FEW013 SCT020 BKN026 12/09 Q1009 NOSIG= TAF EIDW 091100Z 0912/1012 16014KT 9999 FEW014 SCT018 TEMPO 0912/0915 17015G26KT BECMG 0915/0917 19013KT TEMPO 0918/0921 21015G25KT BECMG 0923/1001 22010KT TEMPO 1000/1003 -SHRA BKN012 BECMG 1001/1003 26013KT BECMG 1003/1005 23010KT PROB40 TEMPO 1006/1012 -SHRA FEW018CB=

Table No. 4: Weather conditions at EIDW at the time of the occurrence

The weather information that was provided to the Flight Crew by the Operator was stored within an Electronic Flight Bag[11] (EFB), and subsequently provided to the Investigation (**Figure No. 7**).

[10] **Oktas:** An estimate of cloud coverage in the sky on a scale from 0 to 8; completely clear sky is described as 0 oktas, while completely overcast sky is described as 8 oktas.
[11] **EFB:** A portable electronic device used on the flight deck to store (and display) a range of aviation data and/or perform aircraft performance and fuel calculations.

DESTINATION AIRPORT
EIDW / DUB
SA 091530Z 17014KT 140V200 9999 FEW015 SCT018 BKN023 12/08 Q1010 NOSIG
FT 091100Z 0912/1012 16014KT 9999 FEW014 SCT018
TEMPO 0912/0915 17015G26KT
BECMG 0915/0917 19013KT
TEMPO 0918/0921 21015G25KT
BECMG 0923/1001 22010KT
TEMPO 1000/1003 -SHRA BKN012
BECMG 1001/1003 26013KT
BECMG 1003/1005 23010KT
PROB40 TEMPO 1006/1012 -SHRA FEW018CB

Figure No. 7: Extract from EFB for weather at EIDW

1.14 Aerodrome Information

Dublin International Airport, EIDW, is located 10 KM (5.4 NM) N of Dublin City. RWY 28L has a true bearing of 275.27 degrees. The runway surface is grooved asphalt and is 2,637 m long, 45 m wide, and has 7.5 m wide asphalt shoulders. The runway threshold elevation is 203 ft. In 2023, the magnetic variation at EIDW was 2 degrees W, accordingly the magnetic heading for RWY 28L was 277 degrees.

1.15 Flight Recorders

The aircraft was equipped with a Solid-State Flight Data Recorder, and a Cockpit Voice Recorder. Both devices were downloaded by the Investigation.

1.15.1 Flight Data Recorder

The FDR data indicates that at time 16:27:20, the aircraft was at a radio altitude of approximately 1,200 ft (Above Ground Level, AGL) and configured for landing; flaps were set to 30 degrees, airspeed was 150 kt, autopilot channel B and auto throttle were engaged, and the landing gear was in the extended position.

The FDR data indicates that at time 16:27:58 the autothrottle and autopilot were disengaged. At this time, the aircraft was at approximately 600 feet AGL and at an airspeed of 149 kt.

Figure No. 8 shows a plots of a selection of parameters, as recorded by the FDR between times 16:28:18 and 16:29:18, during which the aircraft descended from approximately 300 ft radio altitude, and landed on RWY 28L. The Investigation notes the following:

- At time 16:28:34, the aircraft was at 50 ft radio altitude (height above ground), with an airspeed of 149 kt, a groundspeed of 158 kt, and a magnetic heading of 275 degrees.

- At time 16:28:36, the aircraft was at 30 ft radio altitude and a nose-up control column input was made from two to eight degrees over one to two seconds. The magnetic heading decreased to 274 degrees and the drift angle[12] increased to six degrees. Also at this time, a 20-degree right turn input was made using the control wheel (yoke).

- At time 16:28:38, the left main gear air/ground discrete changed momentarily from '*air*' to '*ground*', and then returned to '*air*' and the speedbrakes deployed.

- At time 16:28:39, a 10 degree nose up column input was made, and the left and right main landing gear air/ground indications both changed to '*ground*' status (and remained there) while the nose gear air/ground indication remained at '*air*' status. Normal[13] acceleration at touch-down was 1.6 g. At this time, the aircraft magnetic heading was 274 degrees, and the aircraft pitch angle began to increase.

- At time 16:28:41, the aircraft pitch angle continued to increase, and the column input began to decrease (towards two degrees). One second later, the aircraft pitch angle had reached approximately seven degrees, and a right rudder pedal input began at this time. Also at time 16:28:41, there was a brief recording of thrust reverser movement. The Aircraft Manufacturer noted that with the exception of a momentary movement, the thrust reversers were not deployed on landing.

- At time 16:28:42, the airspeed decreased to 138 kt, with a groundspeed of 148 kt. The aircraft pitch angle began to reduce rapidly at an instantaneous/average rate of approximately four to six degrees per second. Right rudder pedal input increased to a maximum travel of 10 degrees, and the rudder trailing edge deflected 28 degrees to the right. The magnetic heading began increasing.

- At time 16:28:43, the nosewheel air/ground discrete indicated that the nose gear was in contact with the runway, and the drift angle began to decrease. There was a momentary increase of N1 (engine fan speed) from 32% to 39% on both engines before N1 reduced to a value of 20%. The aircraft magnetic heading then was approximately 280 degrees.

[12] **Drift Angle:** the angular difference between aircraft's track and the aircraft's heading.

[13] **Normal Acceleration:** the acceleration measured perpendicular to the longitudinal axis of the aircraft.

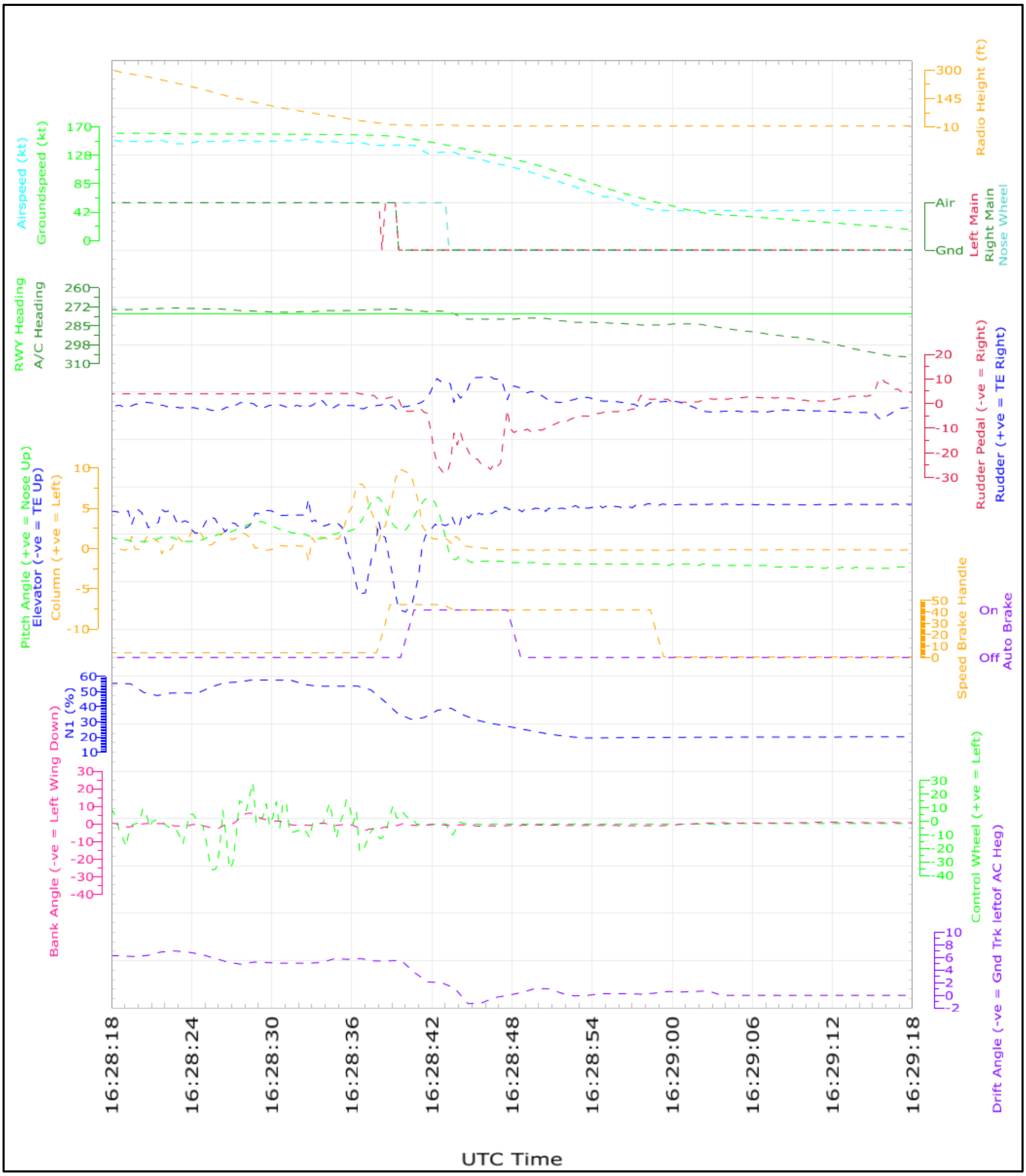

Figure No. 8: Selected FDR parameters around the time of landing

The Aircraft Manufacturer generated a ground track (from the FDR data) to show the aircraft's path during the final approach and landing rollout. Longitudinal and lateral distances were calculated using a combination of inertial data (ground speed, drift angle, heading), glideslope/localizer deviation, and airport information (runway dimensions, taxiway dimensions, etc.). The distances were then referenced to the runway based on the estimated touchdown point from the final resting location identified by the Investigation.

The resulting ground track analysis was consistent with the ground scar information from the Investigation's survey of runway marks.

Neither the nosewheel turning angle, nor the nosewheel tiller position are recorded parameters on the FDR.

1.15.2 Cockpit Voice Recorder

A review of the CVR recording for the accident flight indicated that communications throughout the flight were consistent with expected cockpit discipline and briefing requirements.

The CVR recorded the ATIS broadcast giving surface wind at EIDW as '*one seven zero degrees one four knots varying between one four zero and two zero zero degrees*'. The CVR also recorded other weather information transmissions from Dublin Air Traffic Services immediately prior to the accident (**Table No. 5)**

Time	ATC Information	Note
16:26:26	*surface wind one six zero degrees one two knots*	to the subject aircraft, acknowledged by crew
16:27:38	*surface wind one five zero degrees ten knots*	to a departing aircraft
16:28:30	*surface wind one five zero degrees ten knots gusting one seven minimum five*	to an aircraft approaching after subject aircraft
16:28:38	*surface wind one five zero degrees ten knots gusting one seven minimum five*	to the subject aircraft as part of landing clearance; landing clearance was acknowledged by crew

Table No. 5: Weather conditions from ATC transmissions on CVR

The CVR records the Commander announcing '*my controls, my controls*' two seconds before the sound of the nosewheel contacting the runway surface.

Once the aircraft came to a stop the Commander assessed the need for an emergency evacuation and determined that it was not warranted. ARFS vehicles attended the aircraft. The Commander liaised with ATC and ARFS to ensure that the aircraft was safe and thereafter to arrange the orderly disembarkation of all passengers who were then conveyed to the terminal buildings using buses.

1.16 Operator's Procedures and Guidance for Operating with Inexperienced FOs

The Operator's Operations Manual, Part A (OMA) defines an '*inexperienced*' co-pilot as one who has less than 500 hours flight time with the Operator. The OMA required inexperienced co-pilots to advise the Commander prior to operating. The OMA also states '*Inexperienced co-pilots shall not conduct the landing when the crosswind is in excess of 15 kt during normal operations. This restriction does not preclude the co-pilot from flying a monitored approach.*'

The OMA provides the following advice for Commanders:

> '*Co-pilots generally have less experience than Commanders who will therefore exercise judgement in deciding which sectors to offer the Co-pilot particularly when the conditions are challenging at the destination airfield. This choice shall be a premeditated one by the Captain who will advise the Co-pilot to allow timely adjustment and re-arrangements of functions. The Commander obviously retains the prerogative to change his decision if circumstances change or deteriorate*. *The advice also seeks to pre-empt non-judgemental complacent routines such as "leg and leg about" from developing.*'

1.17 Events Involving Other 737 Aircraft

The Investigation identified published reports on two other 737 lateral runway excursion events involving different operators to the subject occurrence. Each of these reports included details of nosewheel-related runway marks that were similar to those observed in the subject event. One of the reports also include details of tyre damage similar to that observed in the subject event. Furthermore, each of the other reports noted that the commander in each case had attempted to avoid a runway excursion by using the tiller at speeds higher than those recommended by the Manufacturer.

1.17.1 Odesa Aerodrome, Ukraine

On 21 November 2019, after touchdown at '*Odesa*' Aerodrome in Ukraine, a B-737-800 aircraft veered off of the runway to the left onto the cleared and graded area; there were no injuries but the aircraft damage was such that the aircraft was not returned to service.

The National Bureau of Air Accidents Investigation of Ukraine Investigated the accident and published a final report (https://nbaai.gov.ua/wp-content/uploads/2020/11/turkish_tc-jgz.pdf); that final report contains a photograph of the tyre tracks from the NLG showing the two individual tyre tracks merging into one wider continuous track marked with red arrows (**Photo No. 9**).

Photo No. 9: Event involving another operator's aircraft at '*Odesa*' Aerodrome

The final report into the '*Odesa*' accident noted:

'*In his Statement, the PIC notes that, having realized ineffectiveness of the rudder deflection, he took decision to apply "Nose wheel steering" to large angles up to 78º, although FCTM does not recommend using this mode at speeds higher than the steering speed. Despite the fact that the nose landing gear was hydraulically rotated through a significant angle (almost perpendicular to the aircraft movement), this did not allow the aircraft reaching the centreline or position parallel to it. The turned wheel of the nose landing gear began to skid, as seen in the photo, when two black stripes from the tires of the nose landing gear merge into one continuous stripe*'.

1.17.2 Leeds Bradford Airport, UK

On 20 October 2023, a Boeing 737-8K5, G-TAWD, was involved in a lateral runway excursion at Leeds Bradford Airport (LBA) in the UK. In October 2024, the UK AAIB published a Final Report on the occurrence which stated, *inter alia*:

'*The mainwheel and nosewheel tyres left light 'cleaned' marks on the runway surface which became visible after the surface had dried (Figures 3 and 4). The marks began approximately level with taxiway Lima, and continued until G-TAWD left the runway. The nosewheel track changed from two clear tyre marks to a single tyre mark at approximately 840 m after touchdown, where it continued for more than 200 m until the aircraft left the runway. The change in mark indicates that the nosewheels were turned to one side instead of in the direction of the aircraft's travel.*

'Steam-cleaned' tyre marks can indicate the presence of reverted rubber hydroplaning.

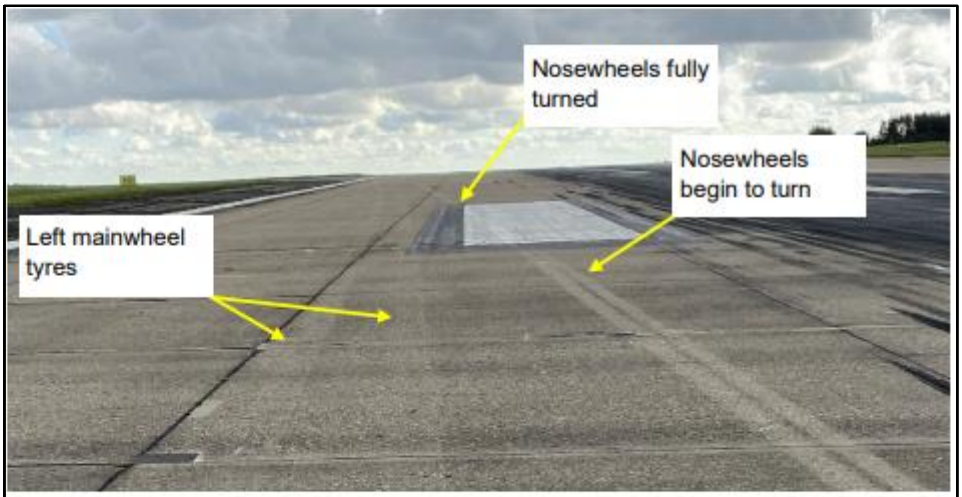

Figure 3

[…]

Both nosewheel tyres had abrasion surface damage around their entire circumference. The type, direction and quantity of damage indicates it occurred when the nosewheels were turned nearly perpendicular to the direction of travel (to the right), and that the wheels were still rotating (Figure 6). Neither nosewheel tyre showed damage corresponding to a locked wheel condition or rubber reversion in the un-abraded sections of their surface.

Figure 6
Nosewheel tyre damage

[…]

The nosewheel tyre damage is consistent with abrasion scrubbing from being turned to an angle nearly perpendicular to the direction of travel whilst the tyres were rotating and in contact with the runway; also demonstrated by the runway marks left by the nosewheel tyres. The angle of the nosewheels could only be achieved by use of the tiller rather than rudder pedal steering alone, and this corresponds with the commander's account of events.

[…]

The nosewheel tyre damage is consistent with abrasion scrubbing from being turned to an angle nearly perpendicular to the direction of travel whilst the tyres were rotating and in contact with the runway; also demonstrated by the runway marks left by the nosewheel tyres. The angle of the nosewheels could only be achieved by use of the tiller rather than rudder pedal steering alone, and this corresponds with the [LBA] *commander's account of events*.'

1.18 CCTV Footage

The Dublin Airport Authority (DAA) provided the Investigation with copies of CCTV footage from nine different cameras with various vantage points around the aerodrome, each of which had captured some imagery of the accident aircraft's landing sequence.

In particular, the aircraft landing and ground roll was captured in a head-on view in the footage from a camera located at the western end of RWY 28L, while another camera captured oblique side-views of the aircraft landing.

The Investigation extracted corresponding head-on (**Figure No. 9**) and oblique side-view (**Figure No. 10**) images showing the aircraft when the right MLG contacted the Runway.

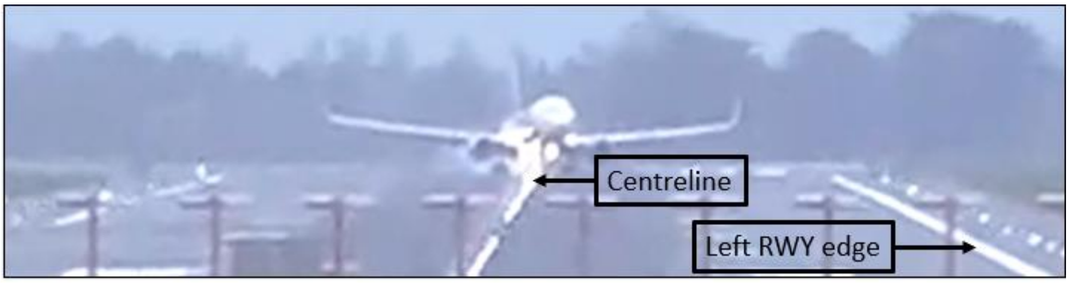

Figure No. 9: Head-on view of right main landing gear runway contact

Figure No. 10: Oblique side-view of right main wheel runway contact

The Investigation extracted corresponding head-on (**Figure No. 11**) and oblique side-view (**Figure No. 12**) images of the aircraft when the nose landing gear contacted the Runway.

Figure No. 11: Head-on view of nosewheel runway contact

Figure No. 12: Oblique side-view of nosewheel runway contact

The Investigation also extracted an image from the head-on CCTV footage which showed the left main wheels outside of the marked runway pavement area (**Figure No. 13**). A Runway Excursion is defined by ICAO's Accident/Incident Data Reporting (ADREP) taxonomy as '*A veer off or overrun off the runway surface*'.

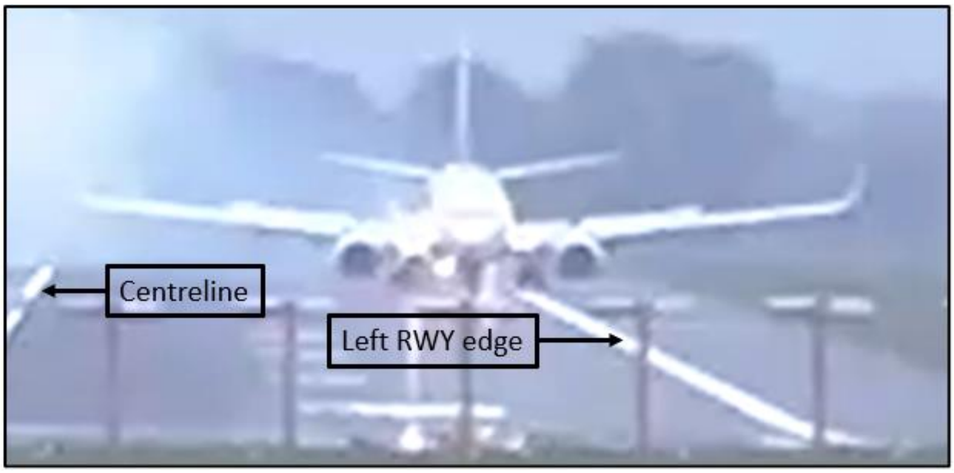

Figure No. 13: Left main wheels outside of marked runway area

2. ANALYSIS

The aircraft, with six crew and 172 passengers on board, departed EGGP on a scheduled flight to EIDW, with the FO acting as PF and the Commander acting as PM. During the approach to land at EIDW on RWY 28L the aircraft was subject to a quartering tailwind from the left. The landing clearance wind report provided to the aircraft stated '*surface wind one five zero degrees ten knots gusting one seven minimum five*': without gusting, this wind would result in a 6 kt tailwind component and an 8 kt crosswind component approximately; with maximum gust, the tail wind component would be 10.2 kt and the crosswind component would be 13.6 kt. A tail wind component of 10.2 kt would have marginally exceeded the AFM limitation of 10 kt documented in the 737 FCOM for this aircraft.

2.1 The Accident Sequence

Following an uneventful flight, at time 16:27:20, the aircraft was configured for landing at a radio altitude of approximately 1,200 ft AGL, flaps set to 30 degrees, airspeed was 150 kt, and autopilot channel B and auto throttle were engaged. The FDR data indicates that at time 16:27:58, the autothrottle and autopilot were disengaged, at which time the aircraft was at approximately 600 feet AGL, with an airspeed of 149 kt.

At time 16:28:34, the aircraft was at 50 ft radio altitude, with an airspeed of 149 kt, a groundspeed of 158 kt, and a magnetic heading of 275 degrees. This indicates a possible nine kt tailwind component—this was less that the AFM limitation of 10 kt documented in the 737 FCOM for the aircraft. Also at this time, the magnetic heading was 275 degrees, which indicates a two-degree crab angle to the left relative to the runway magnetic heading of 277 degrees.

At time 16:28:36, when the aircraft was at 30 ft radio altitude, a nose-up column input was made from two to eight degrees over one to two seconds— this indicates the start of the flare manoeuvre. At the same time, the magnetic heading decreased to 274 degrees, the drift angle increased to six degrees, and a 20-degree right turn input was made using the control wheel (yoke). Therefore, at this time the aircraft still had a crab angle and was drifting to the left of the runway centreline, while a right turning control wheel input was being made.

At time 16:28:38, the left main gear air/ground discrete changed momentarily from '*air*' to '*ground*', and then returned to '*air*'. This indicates that an element of a bounced landing may have occurred although the Commander did not recall any sensation of a bounced landing. Compression of the left MLG triggered the automatic speedbrake system to deploy the flight spoilers symmetrically; the Manufacturer's FCTM guidance that speedbrake [spoiler] deployment can result in a nose up pitching moment suggests that the flight spoiler deployment may have been a factor in the subsequent pitching up of the nose of the aircraft during the landing sequence.

At time 16:28:39, a 10 degree nose-up column input was made, and the main landing gear left and right air/ground indications both changed to ground status (and remained there) while the nose gear air/ground indication remained at in-air status. At this time, the aircraft magnetic heading was 274 degrees, which meant that the aircraft had a three-degree crab angle to the left relative to the runway magnetic heading of 277 degrees. Normal acceleration at touch-down was 1.6 g, and the aircraft pitch angle began to increase in response to the column input.

At time 16:28:41, the aircraft pitch angle continued to increase, and the column input began to decrease (towards two degrees). It is about this time that the CVR records the Commander saying '*my controls, my controls*', and a right rudder pedal input began at this time probably to return the aircraft to the runway centreline. A second later, the aircraft pitch angle had again reached approximately seven degrees.

At time 16:28:42, the airspeed had decreased to 138 kt, with a groundspeed of 148 kt, which indicates a possible increase in the tailwind. Also at this time, the aircraft pitch angle began to reduce rapidly at an instantaneous/average rate of approximately four to six degrees per second. The right rudder pedal input increased to a maximum travel of 10 degrees, and the rudder trailing edge deflected to a maximum of 28 degrees to the right. The magnetic heading began increasing, indicating that the aircraft was turning to the right as the aircraft rolled along the runway.

At time 16:28:43, the nosewheel air/ground discrete indicated that the nose gear was down (in contact with the runway), and the drift angle began to decrease. There was a momentary increase of N1 from 32% to 39% before N1 reduced to a value of 20%. The aircraft heading at this time was approximately 280 degrees magnetic. Thereafter, the aircraft heading increased in stages until the aircraft exited the runway.

2.2 Landing Technique

The Operator's LTSN state that '*we use the de-crab during flare and the touchdown with crab techniques*'. The LTSN goes on to say that touchdown with crab is '*is not recommended on dry runways as on landing the aircraft will tend to track upwind until the correct de-crab technique is accomplished. This lack of initial directional control is undesirable.'* The runway surface was dry, therefore, according to the Operator's LTSN, de-crab during flare was the appropriate landing technique to use.

In this occurrence, the aircraft touched down with crab. A consequence of touching down with crab on the dry runway was that there was, as described in the LTSN, an initial lack of directional control which prompted the Commander to take control. In addition to the LTSN, the manufacturer's guidance for '*Touchdown In Crab*', explains that '*On dry runways, upon touchdown the airplane tracks toward the upwind edge of the runway while de-crabbing to align with the runway*'— which appears to be what occurred in this case.

2.3 Runway Marks and CCTV Footage

The NLG-related runway marks (**Figure No. 4**), and the associated left MLG marks(**Photo No. 7**), along with the CCTV images (**Figures 5** to **9**), and the aircraft manufacturer's FDR-data-generated ground track (which agreed with the Investigation's survey of runway marks), all indicate that the aircraft touched down with a crab angle of three degrees to the left relative to the runway magnetic heading of 277 degrees. The aircraft made the approach with a crab angle because of the prevailing wind, which meant that there was a crosswind component that had to be compensated for during the approach. As the wind direction was actually from the left side of the aircraft, and behind it, in addition to the crosswind component, the aircraft was subject to a tailwind component, of 9 to 10 kt which meant that the aircraft's ground speed was higher than its airspeed at touchdown. The higher ground speed and lack of de-crab during the flare meant that once the main wheels touched down, the time available to intervene and prevent a lateral runway excursion was reduced.

2.4 Nosewheel Assembly and Tyre Marks

Examination of the damaged nosewheel components did not identify any pre-existing conditions or failures that might have contributed to the accident sequence. An examination of the nosewheel tyres did not identify any evidence of overloading or burst damage on either tyre. However, **Figure No. 3** shows abrasion marks in the order of 70 degrees (values up to 72 degrees were observed) to the thread pattern and the normal direction of wheel rotation; these marks were in evidence throughout the available circumference of both tyres indicating that the wheels were rotating about their axles at the same time as the nosewheel assembly was being steered to the right. Similar tyre markings were recorded in the UK AAIB's report into a lateral runway excursion at LBA. In that case the AAIB noted that:

> *'The nosewheel tyre damage is consistent with abrasion scrubbing from being turned to an angle nearly perpendicular to the direction of travel whilst the tyres were rotating and in contact with the runway; also demonstrated by the runway marks left by the nosewheel tyres. The angle of the nosewheels could only be achieved by use of the tiller rather than rudder pedal steering alone*'.

In the LBA occurrence, the flight crew recalled that the tiller had indeed been used to attempt to prevent a lateral runway excursion. In the subject occurrence, the AAIU is similarly of the opinion that the tyre marks are consistent with tiller use and could not have been caused by rudder pedal steering alone.

Photo No. 7 show that the initial nosewheel track mark comprised two parallel tracks, one from each nosewheel tyre, which then merged to one track, wider than the normal contact width of a nosewheel tyre. Thereafter there is impact marking in the runway surface consistent with contact between the runway surface and the metal wheel hub and a divergent runway gouge likely due to left wheel separation. The Investigation noted the similarity between the track marks in **Photo No. 7** and those that were documented in relation to the Odesa and LBA occurrences as outlined in Section **1.17** — (**Photo No. 9**). The final report for the Odesa occurrence stated that '*having realized ineffectiveness of the rudder deflection,* [the PIC] *took decision to apply "Nose wheel steering" to large angles up to 78º, although FCTM does not recommend using this mode at speeds higher than the steering speed*'. The final report for the LBA occurrence stated that '*The angle of the nosewheels could only be achieved by use of the tiller rather than rudder pedal steering alone, and this corresponds with the commander's account of events.*' The AAIU Investigation is satisfied that in the subject occurrence, the tyre and skid marks, are consistent with the nosewheels being steered to the right at a speed higher than recommended by the manufacturer, and in the absence of any pre-existing conditions or failures of the NLG assembly or tyres, that this steering of the nosewheels was due to the tiller being used.

2.5 Operator's Guidance

The FO had less than 500 hours of flying experience with the Operator and was therefore considered to be an inexperienced co-pilot. As an inexperienced co-pilot, the FO was subject to a 15 kt crosswind limit which the Commander was aware of during the pre-flight briefing. The forecast winds, and the inflight wind checks, did not identify crosswinds that would exceed the FO's limitation.

The Operator's guidance required commanders to make a premeditated decision regarding which sectors to offer a co-pilot particularly if conditions at the destination airfield were considered to be challenging. The Commander had previously flown with the FO, and during the pre-flight briefing made the decision to offer the sector to the FO, which the FO accepted. The Investigation notes that the Operator's guidance seeks to avoid complacency in Commander's decisions about sector/leg allocation to FOs – in this case, the evidence is that the guidance was followed.

The Commander recalled that during the pre-flight briefing, the crosswind had been identified and that he had decided that Flap 30 would be used for landing because the aircraft was light, the runway was long enough, and Flap 30 meant that the aircraft would be easier to control in a crosswind. The parameters of the wind checks provided to the accident aircraft did not significantly differ from those that the crew had planned for, nor did they exceed the FO's 15 kt crosswind limitation.

Therefore, the evidence indicates that the Operator's guidance to avoid complacency was followed, that the crosswind had been identified and addressed during the pre-flight briefing, and that the wind check information provided to the flight crew did not exceed the FO's limitation.

2.6 Investigation's Observation

While neither the nosewheel turning angle, nor the nosewheel tiller position are recorded parameters on the FDR, the Commander's recollection when interviewed was that he used rudder pedals and very little braking to regain the centreline, and that after he had regained the centreline he used the tiller to control the aircraft. While he did not recall the exact speeds during the landing ground roll, he indicated that the tiller could not be used above 60 kt.

The manufacturer provides guidance which states, inter alia '*Do not use the nose wheel steering wheel until reaching taxi speed*'. The manufacturer's guidance also states:

> '*Taxi speed should be closely monitored during taxi out, particularly when the active runway is some distance from the departure gate. Normal taxi speed is approximately 20 knots, adjusted for conditions. On long straight taxi routes, speeds up 30 knots are acceptable, however at speeds greater than 20 knots use caution when using the nose wheel steering wheel to avoid overcontrolling the nose wheels. When approaching a turn, speed should be slowed to an appropriate speed for conditions. On a dry surface, for turn angles greater than those typically required for high speed runway turnoffs, use approximately 10 knots.*'

In the absence of any pre-existing conditions or failures of the NLG assembly or tyres, and noting the similarity of tyre track marks between the subject accident and the occurrences in Odesa and LBA, which involved different operators, the Investigation is of the opinion that use of the nosewheel tiller at a high speed caused the left-hand nosewheel to separate from the aircraft, and thereafter, as the ground roll progressed, further NLG damage occurred.

When the Commander assumed control of the aircraft, and lowered the nose, the aircraft was tracking towards the upwind edge of the runway and a runway excursion into the grass to the left of the runway may have appeared imminent. A right rudder input was made to turn the aircraft back towards the runway centreline and as is evident from the nosewheel tyre marks, it is likely that the tiller was also used, probably instinctively, in an attempt to augment the turning action of the aircraft and avert a lateral runway excursion. In the event, while a lateral runway excursion did technically occur when the left main wheels traversed the asphalt shoulder outside of the main runway area (**Figure No. 13**), a more serious lateral runway excursion involving the aircraft departing the paved asphalt area was avoided.

3. CONCLUSIONS

3.1 Findings

1. Both flight crew members' licences and medicals certificates were valid.

2. The First Officer was deemed an inexperienced co-pilot and was subject to a landing crosswind limitation of 15 kt.

3. The First Officer's landing crosswind limitation was discussed during the pre-flight briefing and neither the forecast not the actual winds exceed the limitation.

4. The First Officer was the designated Pilot Flying.

5. No pre-existing conditions or failures that might have contributed to the accident sequence were identified.

6. The Operator's normal procedure for landing on a dry runway called for the aircraft to be de-crabbed in the flare prior to touch down.

7. The aircraft touched down with a crab angle of three degrees to the left relative to the runway magnetic heading of 277 degrees.

8. Following an initial runway contact with the left MLG, the automatic speedbrake system deployed the flight spoilers.

9. The quartering tail wind was challenging for the handling pilot, and increased the aircraft's groundspeed.

10. The aircraft then landed on both main wheels and tracked towards the left edge of the runway.

11. The Commander took control of the aircraft, lowered the nose and made a right rudder input to bring the aircraft back towards the runway centre line.

12. Nosewheel skidmarks on the runway, and associated tyre damage, indicate that the tiller was also used to steer the aircraft.

13. The tyres and wheels of both nosewheel assemblies and their respective axles suffered substantial damage.

14. The aircraft came to a stop at the runway exit and was attended by ARFS vehicles and personnel.

15. There was no fire or reported injuries, and an emergency evacuation was not required.

3.2 Probable Cause

Use of the tiller to steer the nosewheel assembly at a speed higher than that prescribed by the Aircraft Manufacturer.

3.3 Contributory Cause(s)

1. Landing with a crab angle on a dry runway.

2. Aircraft tracking towards the left edge of the runway following touch down of the main landing gear.

3. A quartering tail wind which proved challenging for the handling pilot, and which increased the aircraft's groundspeed.

4. SAFETY RECOMMENDATIONS

This Report does not sustain any Safety Recommendations.

- END -

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

Produced by the Air Accident Investigation Unit

AAIU Reports are available on the Unit website at www.aaiu.ie

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