Serious Incident

Aircraft Type and Registration:	Boeing 737-8K5, G-TAWD
No & Type of Engines:	2 CFM56-7B27E turbofan engines
Year of Manufacture:	2011 (Serial no: 37265)
Date & Time (UTC):	20 October 2023 at 1153 hrs
Location:	Leeds Bradford Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 195
Injuries:	Crew - None Passengers - None
Nature of Damage:	Main landing gear tyres and nosewheel tyres damaged. Left nosewheel inner axle bearing destroyed
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	41 years
Commander's Flying Experience:	14,250 hours (2,800 hours on type) Last 90 days - not known Last 28 days - 88 hours
Information Source:	AAIB Field Investigation

Synopsis

After touching down at Leeds Bradford Airport (LBA) in stormy weather, the aircraft began to yaw left of the runway centreline. When the pilot flying increased the right rudder input to correct the deviation, both pilots reported feeling a significant judder from the nose gear. This prompted the pilot flying to reduce the right rudder input and, although there were repeated brief right pedal inputs, the aircraft continued to deviate from the centreline and left the runway. The aircraft sustained minor damage and there were no injuries.

The investigation found that one of the aircraft's nosewheel bearings had failed, likely during the rollout at LBA. The resultant juddering was unexpected and led the PF to limit his rudder input. However, there was, in fact, no mechanical impediment to the use of additional rudder, and differential braking was also available to maintain directional control.

History of the flight

The crew reported for duty at 0400 hrs for a scheduled passenger flight from Manchester to Corfu, followed by a return flight to Leeds Bradford Airport (LBA). The outbound flight to Corfu was uneventful and the crew did not experience any issues with directional control of the aircraft during landing or take off from Corfu.

The commander was PF for the flight to Leeds. There was inclement weather forecast at the time of their arrival, with high winds expected as part of Storm Babet which was passing through the north of the UK. The crew conducted a comprehensive briefing during the cruise and discussed the increased likelihood of a diversion to Manchester, where the wind direction was forecast to be more favourable.

As the aircraft was in the descent towards Leeds, the crew calculated landing performance using the manufacturer's performance tool and used the wind of 060° at 19 kt that was passed to them. However, they recall that the results of the calculation were outside the aircraft landing performance limits and so requested to enter a holding pattern at the LBA NDB. As they approached the holding pattern, the approach ATCO passed the current wind to be 070° at 21 kt gusting 33 kt and advised the crew that a Boeing 737-800 had just landed at Leeds.

The crew confirmed this wind was in limits and commenced an ILS approach for Runway 14. They were expecting turbulent conditions and reported that they were 'go-around minded'. Both crew members recalled that the conditions were smoother than expected and that the approach was stable with minimal speed fluctuations. The PF configured the aircraft for landing earlier than normal and autobrake MAX was selected. The tower ATCO cleared the aircraft to land as it was descending through approximately 2,000 ft and passed a final wind check of 070° at 23 kt gusting 37 kt, indicating a maximum crosswind component of 35 kt from the left.

The PF de-crabbed the aircraft using right rudder and landed in the touchdown zone. The landing was described by the crew and tower ATCO as smooth. The autobrake engaged one second later, reverse thrust was commanded and deployed as normal, and the target deceleration rate was achieved. There was left control wheel input after touchdown for 5.5 seconds. The PF reduced the right rudder pedal to neutral five seconds after landing and the aircraft began to yaw to the left. In response, the PF made a right rudder input which reduced the rate of yaw to the left. The PF then disconnected the autobrake whilst decelerating through 107 kt, following which there was a period of eight seconds where there was no wheel braking. The reverse thrust was cancelled at approximately 86 kt and there was an increase in right rudder pedal input to 2.5°. The rudder was periodically reduced to 0° and the aircraft continued to yaw to the left.

The crew reported feeling a significant 'judder' when right pedal pressure was applied. The PF reported that the judder was accompanied by an un-commanded yaw to the left. He stated that subsequent right rudder inputs were effective initially but then there was a return to left yaw beyond mid-deflection of the rudder. This repeatedly led the PF to reduce the rudder input and meant that the full range of rudder application was not used to correct the aircraft's drift to the left of the runway centreline. Asymmetric braking was used momentarily, and the crew reported attempting to regain control using the tiller as the aircraft approached the runway edge. Maximum manual symmetric braking was applied three seconds prior to the aircraft reaching the runway edge. The PF recalled using nosewheel steering in an attempt to correct the deviation, but control of the aircraft was not regained, and the aircraft left the runway at a groundspeed of approximately 55 kt.

The aircraft came to a stop six seconds later in muddy ground approximately 150 m beyond the D taxiway exit (Figures 1 and 2). The crew followed normal shutdown procedures to secure the aircraft. There were no injuries reported by passengers or crew.

Figure 1
Aircraft final position

Figure 2
Aircraft ground track

On-site examination

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.

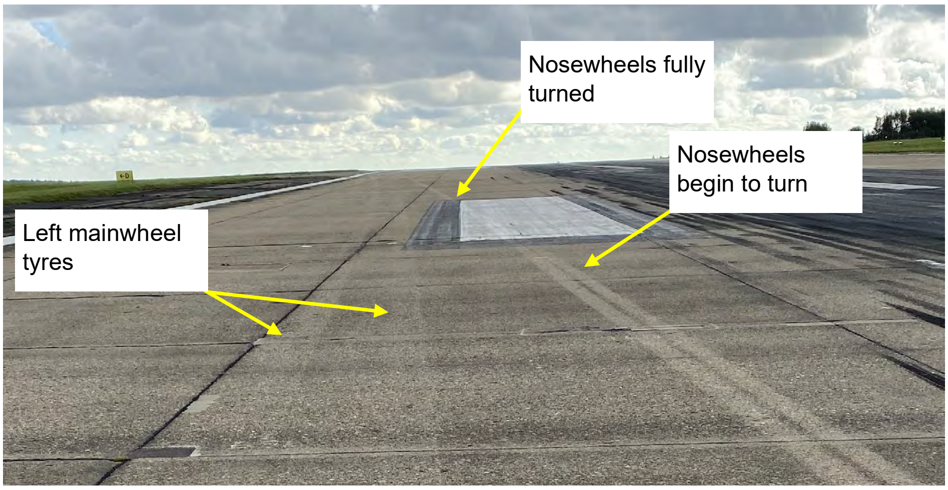

Figure 3
Runway tyre marks in direction of travel

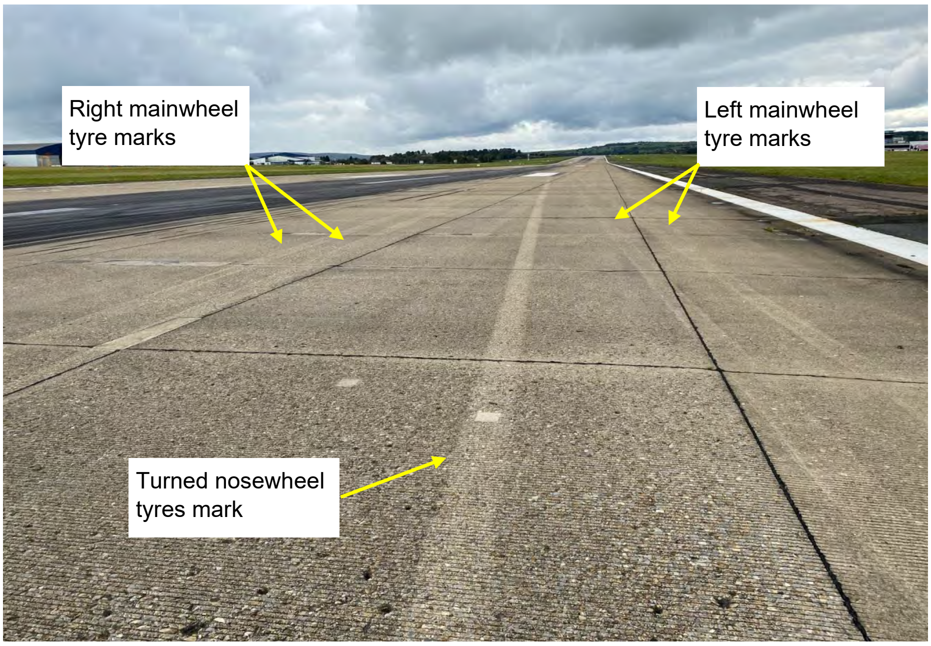

Figure 4
Runway tyre marks facing direction of travel

All times are UTC

Aircraft information

Nosewheel steering

Nosewheel steering on ground is linked to the rudder pedals and a steering tiller on the commander's side. When the rudder pedals are moved to full travel, the nosewheels turn a maximum of 7° in the left or right direction. Rudder pedal steering is used during the takeoff and landing roll, whilst for slow speed manoeuvring, the tiller is used. When the tiller is moved to full travel, the nosewheels turn a maximum of 78° in the left or right direction. Both the tiller and rudder pedals provide input to the same system of cables that control the nosewheels, but tiller input will override any rudder pedal steering input. There is no physical mechanism to prevent use of the tiller at higher speeds, however, the manufacturer's Flight Crew Training Manual (FCTM) and the operator's Operations Manual Part B Volume 1 states that for directional control and braking during landing roll:

> *'Do not use the nose wheel steering wheel until reaching taxi speed.'*

Further guidance is stated that for unusual events:

> *'Upon landing and rollout, if direction 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.'*

Braking system

The left and right main gear wheel brakes are independently controlled by brake pedals mounted on top of the rudder pedals, using toe pressure. The nosewheels do not have a braking system. Each main gear wheel has individual antiskid protection which, when triggered, releases brake pressure until the wheel starts to rotate again. This system provides protection in the event of a skid, a locked wheel, and hydroplaning.

The autobrake system has five settings (OFF, 1, 2, 3 and MAX) that can be used during landing to achieve a pre-selected deceleration rate. Each setting applies an increased amount of braking system pressure up to the MAX setting of 3,000 psi. The setting required is calculated by the manufacturer's Onboard Performance Tool which determines operational landing distance at each setting compared to available landing distance and also takes into account figures input for the runway and weather conditions. Applying manual braking during the landing roll will disable any pre-set autobraking. The maximum pressure available from manual braking is 3,000 psi.

Recorded information

The aircraft was fitted with a FDR and CVR, both of which were downloaded and captured the landing at Leeds Bradford Airport.

Prior to takeoff in Corfu, the flight crew performed a 'full and free' control surface check which included the rudder and control wheel. During this check, the rudder pedals were moved to their full travel which was recorded as 13.4° left to 11.9° right. The recorded rudder surface position followed the pedal demand to a deflection of 30.4° to 30° respectively. Full control wheel travel was to 95° left and 92° right.

At 1252:10 hrs, whilst on the final approach at approximately 1.6 nm from the Runway 14 threshold, the autopilot and autothrottle were disconnected. The approach continued with touchdown at 1252:55 hrs at a recorded vertical acceleration of 1.3 g and Computed Airspeed (CAS) of approximately 140 kt (point A, Figure 5). During the flare, rudder inputs were recorded which reduced the drift on touchdown.

The speedbrakes deployed and autobrake system engaged with the recorded brake pressure rising to approximately 1,600 psi[1] leading to an increase in the longitudinal deceleration[2] to -0.45 g. Additionally, the throttles were moved to the reverse 2 position, and the thrust reversers operated as expected. The aircraft decelerated, during which right rudder pedal inputs were recorded.

Seven seconds after touchdown at a CAS of 107 kt, the autobrake was disengaged and brake pressure reduced (point B, Figure 5). Six seconds later at a CAS of 86 kt, the throttles were returned to the 'Forward Idle' position and the thrust reversers were stowed. Throughout this time, up to 1.8° right rudder pedal continued to be applied (point C, Figure 5) and the Cockpit Area Mic (CAM) recorded what could be described as a juddering/ rattling sound. This was more pronounced from point C onwards.

Once the thrust reversers were stowed, the recorded right rudder pedal deflection periodically returned to zero and the control wheel was progressively increased up to 42° to the right. Three seconds after the reversers were stowed, pedal braking was applied which was the same time the CVR recording captured the commander vocalising concerns (point D, Figure 5). Braking application was briefly asymmetric with a demand for full right braking after which the pedal demand for left braking increased to maximum to match that of the right brake pedal (point D, Figure 5). The aircraft deviated to the left of the runway and the recorded longitudinal and vertical acceleration deviations showed it departed the left side of the runway (point E, Figure 5) at approximately 64 kt CAS (groundspeed 55 kt), stopping six seconds later. Nosewheel steering position was not recorded.

Footnote

1 Recorded brake pressure is upstream of the antiskid system.
2 The target deceleration for autobrake MAX is -0.435 g.

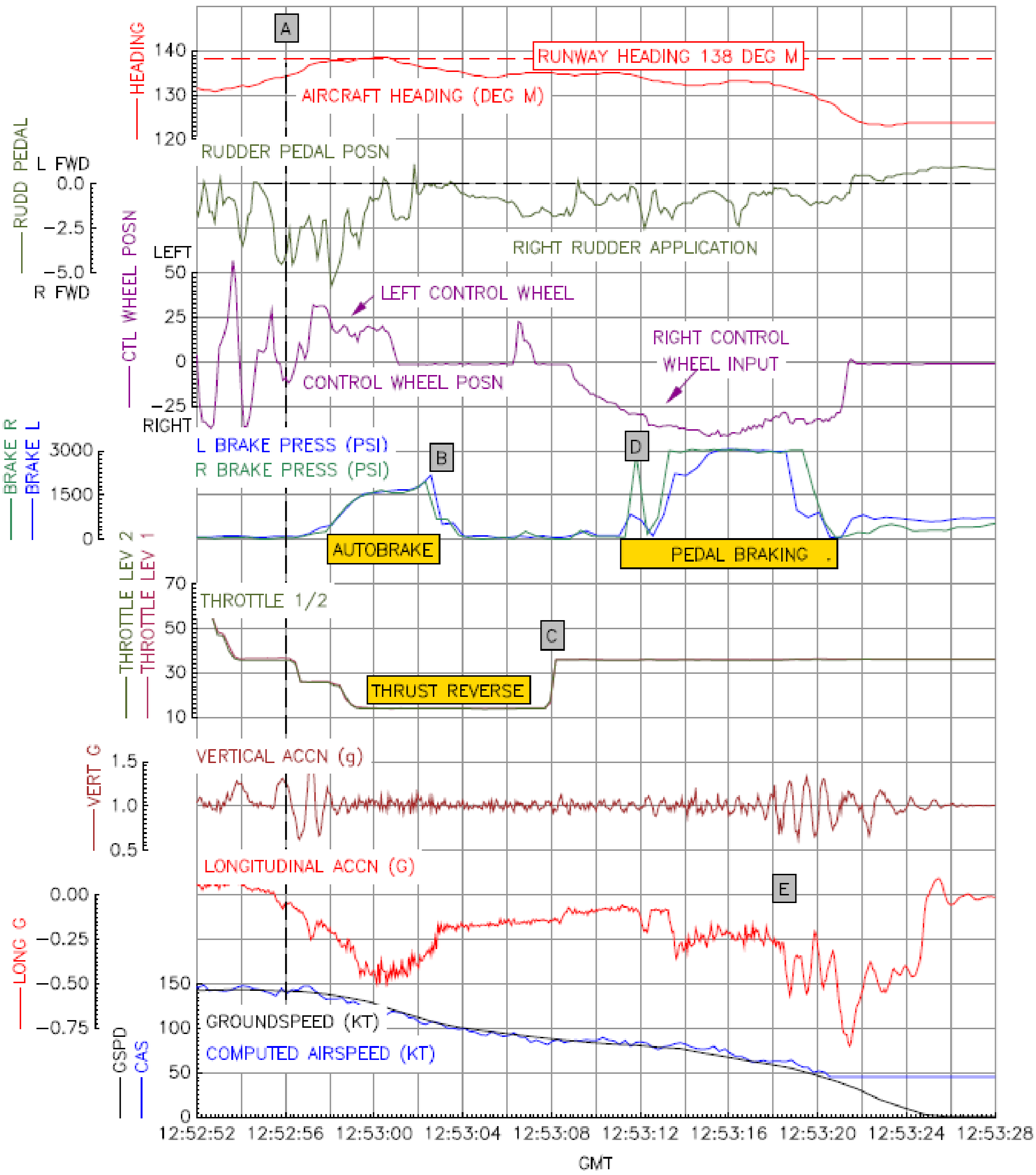

Figure 5

FDR parameters during landing

Manufacturer's data analysis

Ground track analysis

The aircraft manufacturer carried out a ground track analysis of the flight data using a combination of inertial data, localiser deviation and airfield information, cross-referenced against gear marks on the runway and final resting location of the aircraft. This provided a baseline against which further results could be compared.

Calculated airplane braking coefficient

The airplane braking coefficient was calculated for the landing. The coefficient is the ratio of the deceleration force from the wheel brakes (calculated from total aircraft deceleration, minus aerodynamic drag and thrust components) to the normal force acting on the main gear wheels (aircraft weight minus lift). It is an all-inclusive term that incorporates effects due to the runway surface, contaminants, and aircraft braking system (e.g. anti-skid efficiency, brake wear, tyre condition etc.). It is not equivalent to the tyre-to-ground friction coefficient and does not rely on METAR information or reported runway conditions. If the surface friction level reduces to the point that the tyre begins to lock up, the antiskid system should detect this and release the brake to prevent the skid. In such circumstances, the tyre/runway interface is described as being 'friction-limited'.

The manufacturer found that the measured deceleration while maximum autobrakes were selected (0.45 g) was consistent with the expected deceleration (0.435 g). They stated that braking was not friction-limited at any point during the landing.

Landing simulation

A desktop engineering simulation was used to recreate the landing rollout. The simulation was a six-degrees-of-freedom non-linear model updated to match flight data, and it was driven by recorded control positions from the actual landing, along with the METAR data nearest to the time of the event and a runway surface condition of wet. The simulation was used to assess aircraft lateral performance during the landing, and the simulated results were a reasonable match to the aircraft's actual track over the ground (Figure 6).

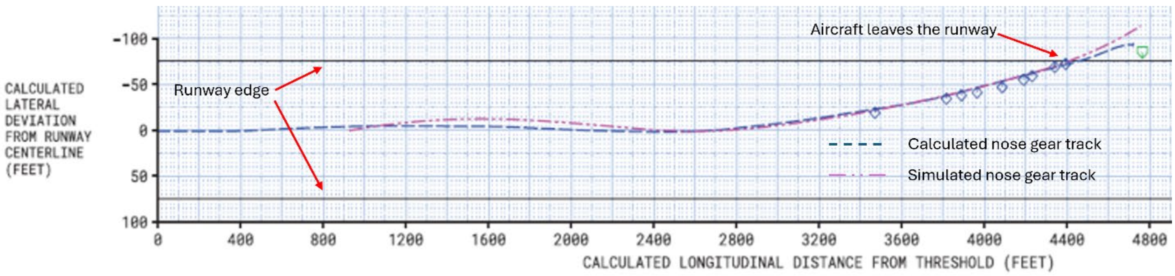

Figure 6

Landing simulation (The Boeing Company)

The model was also used to estimate the magnitude of rudder pedal application during landing that would have kept the aircraft on the runway centreline. The manufacturer stated that:

> *'Under similar crosswind/headwind conditions as indicated in the provided METAR and with the braking assumptions listed, it is expected that approximately 2-3 degrees of right rudder pedal, increasing to 4 degrees by the time that the airplane comes to a stop, would be required to maintain the airplane on the runway centerline'.*

The 2° to 3° of right rudder pedal used in the simulation was a continuous pedal application (rather than application followed by a periodic return to the zero position), increasing to 4°.

The manufacturer commented that:

> *'Throughout the ground roll, there was additional directional control authority at the flight crew's disposal, via rudder and asymmetric wheel braking, that was not utilised.'*

Initially after touchdown, there was left control wheel input, which is normal for landing with a crosswind from the left. As the aircraft decelerated through 86 kt, there was application of right control wheel. These inputs were considered in the simulations and the manufacturer stated that the contribution of this control wheel input to the loss of lateral control was negligible. They also stated that they had observed such control wheel inputs during previous lateral runway excursion events and commented that such inputs may have been instinctive responses.

Aircraft examination

General

The aircraft was examined once it had been recovered to hardstanding. A significant amount of mud had accumulated within all landing gear bays, underneath the wings including flap surfaces, and over the fuselage towards the tail. There was mud within the engine bypass and engine cowlings. The main and nose landing gear appeared to be undamaged and no further apparent structural damage had occurred.

Tyres

The mainwheel tyres all showed some form of damage, comprising either light flat-spotting or from cuts and deep gouges. The latter type of damage typically requires contact with a foreign object to occur and was likely incurred during the recovery process. The No 1 mainwheel tyre had deflated. None of the mainwheel tyres showed damage corresponding to a locked wheel condition or rubber reversion as a result of hydroplaning.

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 7). Neither nosewheel tyre showed damage corresponding to a locked wheel condition or rubber reversion in the un-abraded sections of their surface.

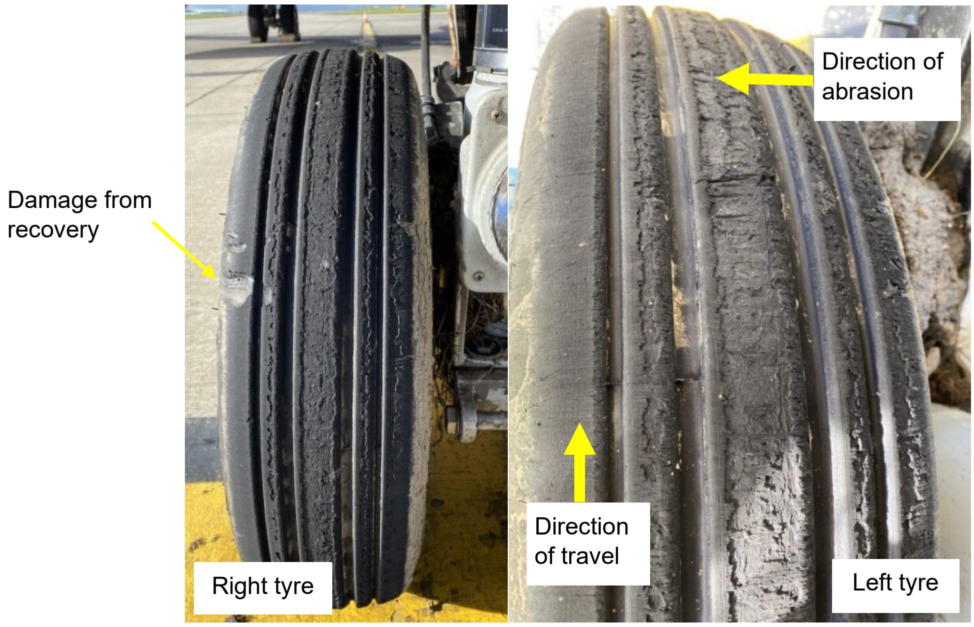

Figure 7
Nosewheel tyre damage

Nosewheel bearing

The left nosewheel was removed which revealed that the inner axle bearing had failed (Figure 7), while the outer axle bearing was undamaged. Each nosewheel has an inner and an outer axle bearing which are replaced on condition and do not have a fixed service life. This bearing was fitted during a routine wheel overhaul in September 2022.

Prior to removal, the left nosewheel had significant play on the axle but was free to rotate. It is probable that the play of the nosewheel on the axle occurred during the recovery process as, had it been present during the landing roll, significant damage to the outer bearing and further damage to the wheel and axle would have been expected.

Figure 8
Left inner nosewheel bearing components

Operator maintenance

The aircraft was subject to inspection and rectification maintenance by the operator prior to its return to service. No further evidence was identified of any system or component failure that could have been contributory to the event.

Meteorology

The weather at Leeds Bradford at 1250 hrs reported a visibility of 4,000 m with light rain and mist at the airfield. The cloud base was at 600 ft with some scattered cloud at 400 ft. The temperature was 10°C. The wind was from 070° at 17 kt with gusts of 32 kt. The final wind check received by the crew from ATC prior to landing was reported at 070° at 23 kt gusting to 37 kt.

The weather forecasts which were available to the pilots (published at 0500 hrs and 1100 hrs) were consistent with these conditions.

Airfield information

Leeds Bradford Airport (Figure 9) has one concrete runway (14/32) which is 2,250 m long. The landing distance available for Runway 14 is 1,801 m and the threshold elevation is 674 ft.

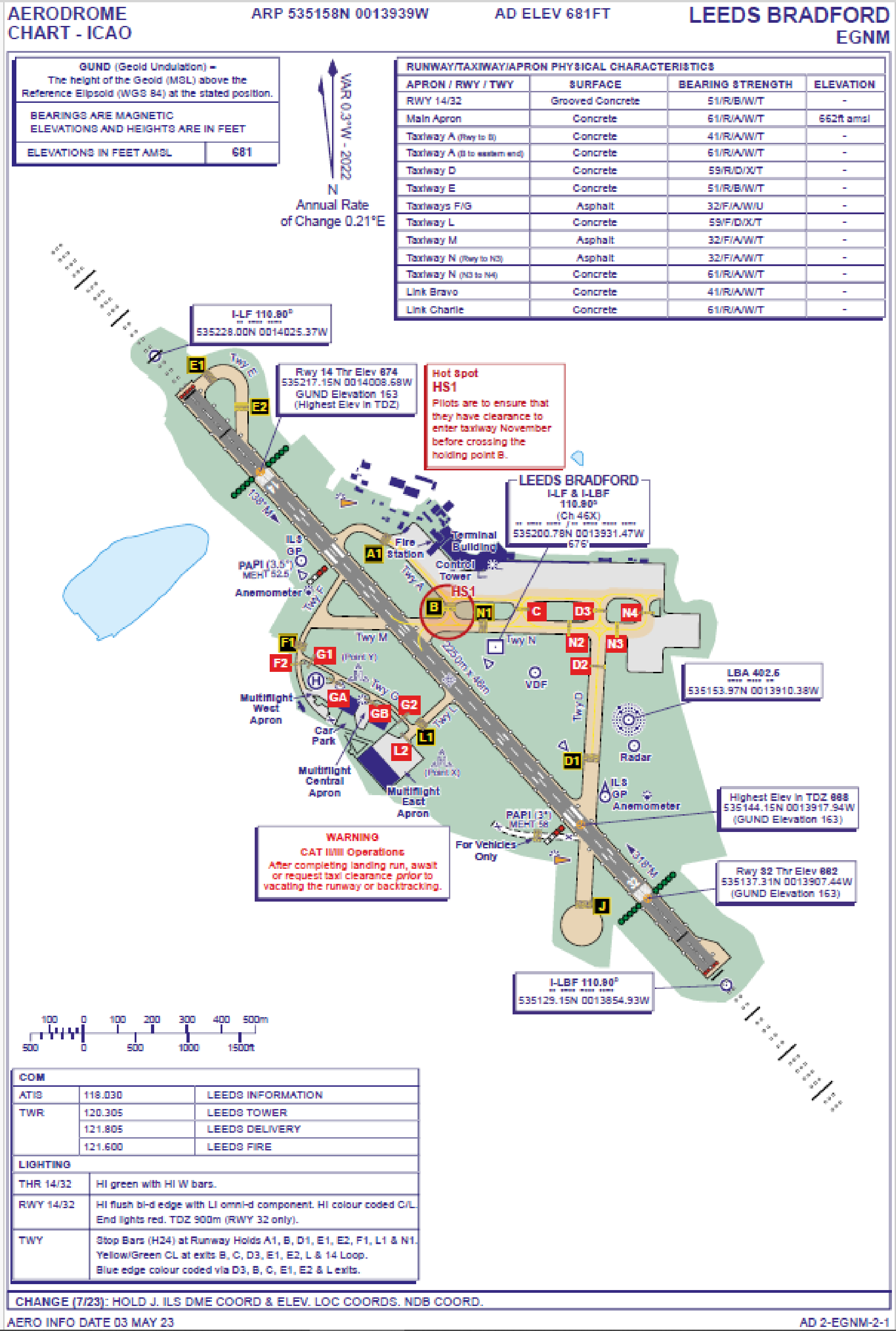

Figure 9

AIP Leeds Bradford Aerodrome chart

Runway type and friction measurement

Runway 14/32 is constructed from concrete with a grooved surface to help disperse water and improve aircraft tyre grip.

A runway surface friction assessment[3] was conducted by airfield operations personnel on 11 October 2023, and again on 21 October 2023 following the incident. Both tests showed some isolated 10 m interval measurements fell below the minimum friction level (MFL) required but concluded that the average values of each section of the runway were above the MFL.

Runway condition

About 30 minutes before touchdown there was a runway inspection (1221 hrs on 20 October 2023) after which the condition was assessed to be WET WET WET over the whole surface (5/5/5). Airport personnel who carried out the inspection were aware of increased risk of runway contamination due to weather conditions. The personnel who carried out the inspection were confident in their assessment that the runway was not contaminated and noted that the rainwater could be seen draining away. This was consistent with other witness descriptions that the runway was wet, although no significant standing water was present. This investigation found no evidence to suggest the reported runway condition was not reflective of the actual runway condition.

Operator manuals

Braking

The Operations Manual Part B (OMB) Vol. 1 'Landing Roll Procedure' details the standard calls to be made by the pilots during the rollout with regard to aircraft braking:

Pilot Flying	Pilot Monitoring
Verify correct autobrake operation.	
By 60 knots, start movement of the reverse thrust levers to reach the reverse idle detent before taxi speed.	Call "60 KNOTS."
Before taxi speed, disarm the autobrake. Use manual braking as needed.	Call "AUTOBRAKE DISARM" when the advisory light illuminates.

The OMB Vol. 1 provides the following description of the braking technique for the aircraft:

> *'Use an appropriate autobrake setting or manually apply wheel brakes smoothly with steadily increasing pedal pressure as required for runway condition and runway length available. Maintain deceleration rate with constant or increasing brake pressure as required until stopped or desired taxi speed is reached[4].'*

Footnote

3 Using a Douglas Mu-Meter, conducting ten adjacent runs along the runway's length measuring surface friction in 10 metre intervals. The values are averaged for inner and outer sections of the runway.

4 FCTM 6.44 Landing roll.

The manufacturer FCTM provides additional guidance:

> *'Rudder control effective until approximately 60 kt. Rudder pedal steering is sufficient for maintaining directional control during the rollout.*
>
> *Use a combination of rudder, differential braking, and control wheel input to maintain runway centreline during strong crosswinds, gusty wind conditions or other situations. Maintain these control input(s) until reaching taxi speeds.'*

The FCTM recommends that autobrake is used when the runway is limited or when landing in a crosswind and that the speed at which manual braking is made will depend on the deceleration rate of the aircraft, runway conditions and stopping requirements.

Guidance on manual braking states:

> *'Immediately after main gear touchdown, smoothly apply a constant brake pedal pressure for the desired braking. For short or slippery runways, use full brake pedal pressure.*
>
> *• do not attempt to modulate, pump or improve the braking by any other special techniques*
>
> *• do not release the brake pedal pressure until the airplane speed has been reduced to a safe taxi speed.'*

Crosswind limits

It is the operator's policy not to include wind gusts in performance calculations. The maximum crosswind component permitted for landing a B737-800 on a wet runway is 37 kt (Figure 10).

737-800			
Runway Surface Condition	**RWYCC**	**Maximum Crosswind Component**	
		Takeoff	**Landing**
Dry	6	33	37
Wet	5	25 / 33*	

Maximum crosswind component can be increased to 33 knots with the following conditions:

- Braking action 'GOOD' or better / RWYCC 5 or better
- Flaps 5 or greater is used
- MACTOW is 25% or less
- Minimum runway width 45 meter

Figure 10

Operator Operations Manual Limit

Reverse thrust operation

The operator OMB Vol. 1 contains the following information on reverse thrust use:

> *'After touchdown, with the thrust levers at idle, rapidly raise the reverse thrust levers up and aft to the interlock position, then to the number 2 reverse thrust detent. Conditions permitting, limit reverse thrust to the number 2 detent.*
>
> *When stopping is assured and the airspeed approaches 60 KIAS start reducing the reverse thrust so that the reverse thrust levers are moving down at a rate commensurate with the deceleration rate of the airplane. The reverse thrust levers should be positioned to reverse idle by taxi speed, then to full down after the engines have decelerated to idle. Reverse thrust is reduced to idle between 60 KIAS and taxi speed to prevent engine exhaust re-ingestion and to reduce the risk of FOD.'*

Figure 11 shows the lever position to select detent no. 2.

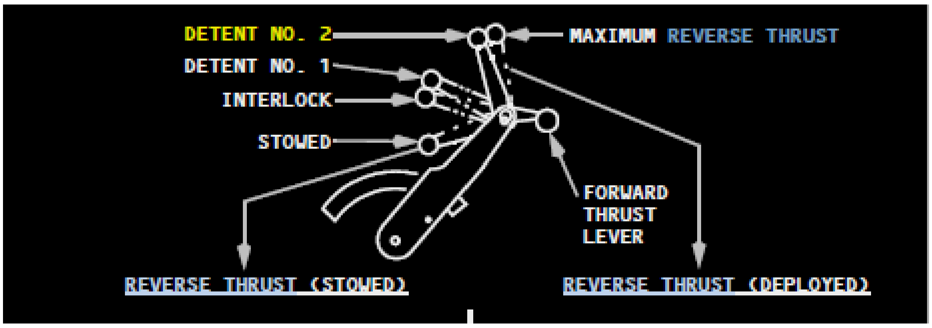

Figure 11
Thrust reverser lever positions

Use of reverse thrust in crosswinds on a slippery runway

Although the indications are that the LBA runway was not slippery, guidance in the manufacturer FCTM for landing in crosswinds on a slippery runway states that if deviation from the centreline occurs during strong crosswinds, pilots should release the brakes and reduce reverse thrust to IDLE to prevent the reverse thrust side force component adding to the crosswind (Figure 12). This guidance is to assist pilots in controlling the aircraft in a crosswind on slippery runways, where the aircraft is blown to the downwind side of the runway.

> *'Releasing the brakes increases the tire-cornering capability and contributes to maintaining or regaining directional control. Setting reverse idle reduces the reverse thrust side force component without the requirement to go through a full reverser actuation cycle.'*

The guidance further advises pilots to use rudder pedal steering and differential braking as required. Once the centreline is regained, maximum braking and symmetrical reverse thrust should be reapplied. It states that using this technique will increase the landing distance required.

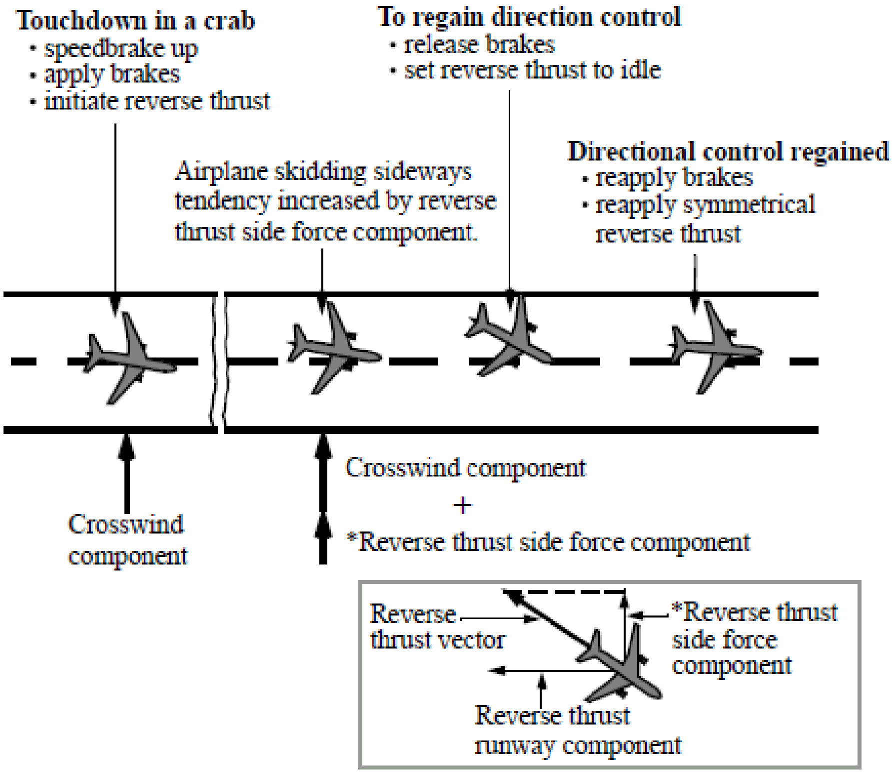

Figure 12

Use of reverse thrust in crosswinds on a slippery runway

Landing performance

Landing performance calculations were carried out by the investigation using the software available to the crew for in-flight performance. The landing distance required (LDR) was within the Runway 14 landing distance available (LDA) at Leeds for the prevailing conditions, using maximum autobrake or maximum manual braking. Landing performance was calculated (Table 1) for a Flap 40° landing and using reverse thrust. There was insufficient landing distance to use AUTO BRK 1, AUTO BRK 2 or AUTO BRK 3 but sufficient for MAX AUTO.

LDA Runway 14	1,800 m
LDR MAX AUTO	1,709 m
LDR MAX Manual	1,599 m

Table 1

Landing performance calculations

Startle and surprise

Pilots may experience unexpected events – such as an interruption from another crew member or unexpected interactions with ATC – on a daily basis, which do not result in a negative outcome. The startle reflex and surprise can play a part in how pilots respond to unexpected events.

Startle reflex is a short, involuntary physiological (heart rate, blinking, muscle tension, distraction) and emotional response to sudden and intense stimulus. The emotional reaction to startle largely dictates how a person will respond. Pilots experiencing the startle reflex can experience task disruption ranging from 100 ms to three seconds for simple tasks, and up to 10 seconds for more complex motor tasks[5].

The physiological response to surprise can be similar to that of startle but onset does not involve an intense stimulus. Rather, surprise is a mismatch between expectation and reality. These effects of surprise are typically longer lasting than startle as the pilot must reassess their reality and their new expectations.

Startle and surprise are normal human reactions to non-normal events and do not normally result in adverse outcomes. Pilots are trained to react to unexpected events, some of which require immediate and accurate response to unexpected circumstances to ensure a safe outcome. Examples of this include responding to TCAS or EGPWS warnings.

Analysis

Approach preparation

The crew carried out a thorough briefing of the expected approach at Leeds, the weather conditions and were well prepared for a diversion to Manchester Airport.

The landing performance was calculated and within limits to land at Leeds with a margin of 91 m[6] when using auto brake MAX.

Landing roll

The aircraft touched down in the touchdown zone and the initial phase of the rollout was normal, with the aircraft reaching the expected deceleration rate. After the PF cancelled the autobrake, there was a period of eight seconds with no wheel braking applied, during which the reverse thrust was also cancelled. The guidance on braking in the operator OMB and FCTM stated that pilots should *'maintain deceleration rate with constant or increasing brake pressure as required until stopped or desired taxi speed is reached'* and '*do not release the brake pedal pressure until the airplane speed has been reduced to a safe taxi speed'.* The reduction in deceleration rate caused by disconnecting the autobrake and cancelling reverse thrust on a wet runway, with a significant crosswind, invalidated

Footnote

5 Research Project: Startle Effect Management, EASA 2015, available at https://www.easa.europa.eu/sites/default/files/dfu/EASA_Research_Startle_Effect_Managements_Final_Report.pdf. [accessed 8 October 2024].

6 Calculations inclusive of the required legal safety margins.

the landing performance calculated by the crew. However, there is no evidence that, as a result, the aircraft did not have sufficient stopping distance available or that the crew assessed this to be the case.

Runway surface

The ‘cleaned’ runway tyre markings are typically only associated with reverted rubber hydroplaning. However, no evidence of reverted rubber was found on the mainwheel or nosewheel tyres, which requires locked wheels to occur, nor were there corresponding ‘melted’ rubber deposits on the runway. The runway marks suggest that the surface temperature underneath all the tyres was high enough to turn some of the water on the runway’s surface into steam but not high enough, nor combined with locked wheels, to cause rubber reversion.

During the period after touchdown when maximum autobrake was used, actual deceleration was as expected. The eight second period after autobrake disengagement, during which there was no wheel braking applied, corresponded to a period when the aircraft’s heading remained broadly constant (although slightly left of the runway centreline). This showed that there was sufficient friction for effective directional control during this period. In addition, the manufacturer assessed that the aircraft was not friction-limited at any point during the landing, so hydroplaning was not considered to be a contributory factor in this event.

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.

Nosewheel bearing

It was not confirmed when the nosewheel bearing began to fail, but it is likely that it occurred during the rollout at LBA and was contributory to the vibration through the rudder pedals, as felt by the crew. Both crew members recalled the “judder” as being significant and unusual, and the CVR recording contained a confirmatory sound during this period. The PF recalled the vibration increasing as he increased right rudder pedal input, effectively limiting the amount of rudder he felt he could apply. However, no evidence was found that the bearing failure did, in fact, limit rudder pedal or rudder movement.

Aircraft handling

After touchdown, the rudder pedal input reduced to zero at 12:53:02 (Figure 5) for two seconds and the aircraft heading began to turn into wind, as would be expected in a strong crosswind. The autobrake was disengaged, and the right rudder pedal input was increased to an average of about 2° over a period of about 10 seconds (from about 12:53:07 to 12:53:17), with a maximum of 2.5°. The increased rudder pedal input stabilised the aircraft’s heading for about six seconds (until 12:53:11), although it was not sufficient to return the aircraft to runway heading. The manufacturer’s report concluded that 2° to 3° of right rudder pedal would be required to maintain the runway centreline initially, increasing to

4° as the aircraft slowed and came to a stop. At 12:53:11, the aircraft had slowed to about 80 kt, the rudder was less effective, and, in the absence of an increase in rudder input to about 4°, the aircraft began to turn progressively into wind until it left the runway at 64 kt. The manufacturer commented that additional directional control was available by using increased rudder (which is effective down to 60 kt) and differential braking.

Differential braking was applied momentarily at 12:53:12, but it was not applied for long enough to have an effect.

The bearing failure was not considered to have physically prevented the application of further rudder. Nevertheless, the PF felt constrained not to apply more rudder than he did because of the vibration it caused and his perception that increasing right rudder pedal beyond mid-application led to left yaw. Had increasing right rudder input led directly to left yaw, it would have been an unexpected aerodynamic response and it is likely that the manufacturer's simulated landing data would have diverged from the recorded data (Figure 6). However, the manufacturer's modelling of the landing was closely correlated with the actual performance of the aircraft, and so the left yaw response reported by the PF was likely to have been an indication that even the increased rudder input was insufficient to counter the left yaw in the strong crosswind.

Landing distance

The guidance for pilots on handling deviations from the runway centreline in high crosswinds and on slippery runways is to release the wheel brakes and cancel reverse thrust, although this technique will increase the LDR. The runway was wet but there was no evidence that the aircraft skidded at any point, nor did the aircraft drift downwind of the runway centreline during the landing roll. It may have been that the pilot cancelled the reverse thrust earlier than normal SOP in an effort to apply a known procedure (Figure 11) in response to the nosewheel judder.

In this event, there was an adequate, but not significant, margin between the landing distance required and that which was available. The recorded data shows there was a significant amount of right rudder input available to the pilot that was not used. The simulation calculated by the manufacturer suggested that the extra rudder and differential braking available would have been sufficient to correct the deviation and prevent the runway excursion without cancelling the autobrake and cancelling reverse thrust.

Startle and surprise

It is possible that the pilot was startled by the sudden onset of vibration of the nosewheel and, as he perceived it, an adverse reaction to increased rudder pedal input. However, the use of rudder to steer an aircraft is an embedded skill for pilots, so any startle response was likely to have been short. Surprise – a mismatch between expectation and reality – can last longer and may have played a role in events. The PF's expectation was that increased right rudder input would correct the aircraft's deviation from the centreline, but it was actually met with vibration and a feeling of left yaw, and he was required to reassess his expectations related to directional control with limited time and in difficult conditions.

Conclusion

The initial phase of the landing roll was normal, with the aircraft touching down in the touchdown zone and meeting the target deceleration rate. The PF disconnected the autobrake and then stowed the reverse thrust early in the landing rollout and a constant deceleration was not maintained.

It was likely that a nosewheel bearing failed during the landing causing an unusual vibration that increased with rudder input. This, combined with the PF's perception that increased rudder input was causing an adverse yaw response, led him to consider that he was limited in the amount of right rudder he could apply. However, the bearing failure did not physically prevent the application of more rudder, and the manufacturer's modelling showed that increased rudder and differential braking would have been effective in maintaining directional control during the landing.

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Note: the original report was amended online on 11 February 2026. The correction is included in AAIB Bulletin 3-2026.