Bulletin Correction

AAIB File:	AAIB-29685
Aircraft type and registration:	Boeing 737-8K5, G-TAWD
Date and Time (UTC):	20 October 2023 at 1153 hrs
Location:	Leeds Bradford Airport
Information Source:	AAIB Field Investigation

AAIB Bulletin No 12/2024, page 3 refers

The AAIB received representations regarding this report and, as a result, the following changes have been made along with changes to Figure numbers required as a consequence.

Synopsis

Original text of the second paragraph of the synopsis:

> The investigation found that one of the aircraft's nosewheel bearings had suffered a catastrophic failure, likely during the rollout at LBA. The resultant juddering was unexpected, and the crew were uncertain as to its impact. However, the investigation found that there was in fact no mechanical impediment to the use of additional rudder and braking to prevent the runway excursion.

Amended text:

> 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

Original text of the first sentence of the final paragraph on page 4:

> The full range of rudder application was not used to correct the drift, as the crew reported feeling a significant 'judder' when the right pedal pressure was applied which led the PF to reduce the rudder input repeatedly.

Amended text:

> 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.

Manufacturer's data analysis

Original text:

The flight data was provided to the aircraft manufacturer who were asked to assess the landing using their aircraft model. The data allowed an assessment of how well the braking system could achieve deceleration from the runway conditions and the lateral controllability of the aircraft.

The amount of braking force the braking system can apply is dependent on the normal load on the tyre and the surface friction. If the surface friction level reduces to the point that the tyre begins to lock up, the antiskid system should detect this and will release the brake to prevent the skid and, for this case, the tyre/runway interface is described as being 'friction-limited'.

A measure of the amount of friction available is the braking coefficient[1] which the manufacturer calculated for this landing roll. They confirmed that for this landing, the aircraft was not friction-limited at any point and that *'the airplane likely achieved a braking action commensurate with DRY'.* This can be seen in the initial braking phases where the autobrake system achieved the target deceleration for the MAX setting.

The manufacturer was also able to use their six degree of freedom non-linear engineering simulation to assess the lateral performance during the landing. They used data from the FDR recording along with METAR data from the time of the event and a runway surface condition of wet.

They 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° degrees 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°.

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 all 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

Footnote

1 Braking coefficient is defined as the ratio of deceleration force from the wheel brakes relative to the normal force acting on the wheels.

that they had observed such control wheel inputs, which may have been an instinctive response, during prior lateral runway excursion events.

Amended text:

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).

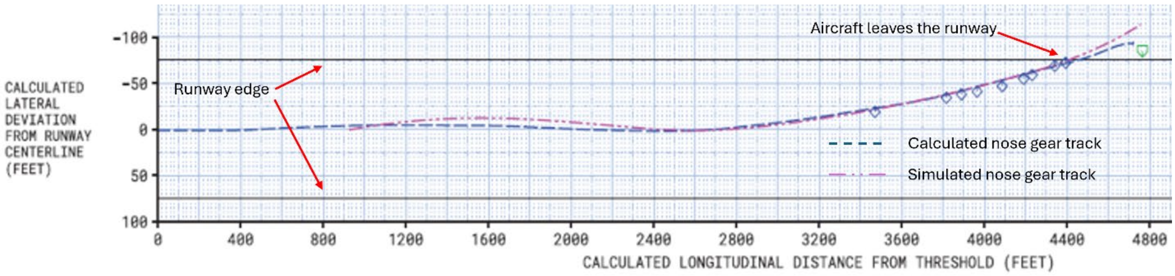

Figure 6

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.

Analysis

Approach preparation

Original text of the second paragraph:

> The landing performance was calculated and within limits to land at Leeds with a margin of 91 m[2] when using auto brake MAX. The crew referred to limiting landing performance which prevented them from commencing an approach when the wind was from 060° at 19 kt, which was the basis for the pilot's request to join the hold whilst on initial approach to Leeds. This performance landing limit could not be recreated by the investigation using the manufacturer's performance tool and the reported environmental conditions.

Amended text:

> The landing performance was calculated and within limits to land at Leeds with a margin of 91 m[3] when using auto brake max.

Runway surface

Deleted the final sentence of the first paragraph under this heading:

> The aircraft deceleration rate and braking forces applied confirms that the aircraft was not friction-limited at any point and hydroplaning was not a contributory factor in this event.

Inserted the following text between the first and last paragraphs under this heading:

> 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.

Nosewheel bearing

Original text:

> It could not be confirmed when the nosewheel bearing began to fail, but it is likely that it suffered catastrophic failure during the rollout at LBA and was contributory to the vibration through the rudder pedals as felt by the commander. The failure of the bearing did not prevent the nosewheel from rotating nor did it affect the ability to steer the nosewheels.

Footnote

2 Calculations inclusive of the required legal safety margins.
3 Calculations inclusive of the required legal safety margins.

At speeds above 60 kt the rudder is the primary method of yaw control. As the aircraft decelerates towards taxi speed the nosewheel steering becomes the primary control. There was no evidence that the bearing's failure physically reduced or restricted the pilot's ability to control the aircraft in yaw.

The PF recalled the nosewheel judder increasing as he increased the right rudder pedal, which caused him to reduce the input. Both crew members recalled the judder as being significant and unusual and the CVR recording contained a 'juddering/rattling' sound during this period. There was no evidence of a physical restriction of the rudder, rudder pedal movement or that the rudder position required to prevent the runway excursion was unobtainable.

Amended text:

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

Original text:

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, but using this technique will increase the LDR. The runway was wet but there is no evidence that the aircraft skidded at any point, nor did the aircraft drift down wind 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 which was not used. The simulation calculated by the manufacturer suggests that the available rudder would have been sufficient to correct the deviation and prevent the runway excursion without cancelling the autobrake and cancelling reverse thrust.

Based on analysis of the data from the event, the manufacturer stated: '*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.'*

Although a nosewheel judder would not necessarily be considered an 'intense stimulus', if it was perceived by the PF as such, it is possible he momentarily experienced a startle reflex. This would explain an interruption of the task of increasing the rudder input to prevent the deviation from the centreline. However, given that maintaining the aircraft's nose on the centreline is a routine, simple and instinctive task, the interruption was likely to have ranged between 100 ms to three seconds. The rollout from touchdown until the aircraft stopped lasted just under 30 seconds, whilst the deviation from the centreline occurred approximately 18 seconds before the aircraft came to a stop. Therefore, it is more likely that, if he experienced a physiological response, that it was as a result of surprise, the effects of which typically last longer than startle.

Pilots are trained to deal with non-normal and emergency events and the aircraft deviation from the runway centreline may have been considered a challenging situation by the crew. There was limited time for the crew to assess the cause of the judder and the practical impact it had on the directional control of the aircraft and surprise or startle may have been a factor. However, as the aircraft approached the side of the runway, it is not clear why the PF did not attempt to use all right rudder available, in spite of the judder, to prevent the runway excursion.

Amended text:

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.

Inserted a new paragraph heading, *Landing distance*, after *Aircraft handling*.

Landing distance

New text under *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.

Inserted a new heading, *Startle and surprise,* after *Landing distance.*

Startle and surprise

New text under *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

Original text of the second paragraph:

> The deviation from the centreline, resulting from the strong crosswind from the left, required more right rudder input than was applied, in order to correct it. Additional use of differential braking to assist was also available. There was an unusual juddering from the nosewheel reported by the crew likely resulting from the failure of a nosewheel bearing. There was no mechanical defect identified by the investigation which would have prevented the crew from applying the additional right rudder that was available to keep the aircraft on the runway. However, the crew's actions may have been influenced by the nosewheel juddering.

Amended text of the second paragraph:

> 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.

The original report was amended online on 11 February 2026.