



Australian Government
Australian Transport Safety Bureau

AVIATION SAFETY REPORT
Aviation Occurrence Investigation AO-2007-023
Final

Runway excursion
Sydney Kingsford Smith Airport, NSW
14 July 2007
ZK-PBF
Boeing Company 737-8FE



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Figure 2: Sydney Airport Corporation Limited.

Abstract

On 14 July 2007, a Boeing 737 NG, registered ZK-PBF, taxied at Sydney Airport on taxiway ‘G’ to runway 16R for a takeoff to Christchurch, New Zealand. The aircraft entered the runway with left engine N₁ at 28% RPM and right engine N₁ at 20% RPM (idle).

The flight crew commenced the takeoff by increasing both engines’ thrust and the Take Off / Go Around (TO/GA) button was pressed with the left engine N₁ at 41% RPM and the right engine N₁ at 24% RPM. As both engines accelerated, asymmetric thrust reduced directional controllability of the aircraft and it veered off the side of the runway before the crew could bring the aircraft to a halt on the crossing runway 07.

As a result of this occurrence, the aircraft operator has reviewed procedures for initial and recurrent training of flight crews.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external organisations.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

About ATSB investigation reports: How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au.

FACTUAL INFORMATION

Sequence of events

On 14 July 2007, at 1844 Eastern Standard Time¹, a Boeing 737-8FE aircraft, registered ZK-PBF, was scheduled to fly from Sydney Kingsford Smith Airport, NSW to Christchurch, New Zealand. This was the first flight of the day for the flight crew.

Following pushback, the crew taxied the aircraft via taxiway 'G', planning a 90 degree right turn onto runway 16 Right (16R) to take off from that intersection. The takeoff was planned as a rolling takeoff with reduced thrust². The pilot in command (PIC) handled the aircraft during the taxi, using the nose-wheel steering wheel³ for directional control, and also planned to handle the aircraft during the takeoff.

Approximately 20 seconds before the aircraft entered runway 16R, as the aircraft crossed taxiway 'A' (Figure 1), a take-off clearance was issued by air traffic control.

Recorded data from the flight data recorder (FDR) showed that, at about this position, both the engine thrust levers were advanced together, the left engine N₁⁴ increased to 28% RPM, while the right engine N₁ remained steady at 20% RPM (idle).

The aircraft entered runway 16R at a groundspeed of 16 kts, and the PIC advanced the thrust levers as the aircraft turned right onto the runway heading. The PIC pressed the TO/GA⁵ (Take Off / Go Around) button to set take-off power when the aircraft was turning onto the runway and still 30 degrees short of the runway heading. The left engine N₁ was at 41% RPM and the right engine N₁ was at 24% RPM at this time with no stabilisation in engine acceleration at 40%. During this period, the copilot was setting his clock to measure elapsed flight time and he did not observe the engine settings.

The thrust levers then moved forward equally toward the take-off thrust setting. However, engine thrust increased more rapidly on the left engine as it had the higher initial N₁, and the aircraft continued turning to the right. The PIC applied

1 The 24 hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) + 10 hours.

2 If an aircraft's performance-limited weight using full take-off thrust exceeds the actual weight of the aircraft, the possibility may exist that the takeoff can still be performed within the certified limitations, but at a lower thrust setting.

3 'Nosewheel steering wheel' is a handle that is accessible to the Captain. It is used for controlling large nosewheel steering deflections for manoeuvring when taxiing. It is commonly referred to as a 'tiller'.

4 N₁ is the low pressure compressor rotor speed, normally used as a primary indication of engine thrust.

5 TO/GA (Take Off / Go Around) is an auto throttle system to set the engine power to preset take-off or go-around power.

maximum left rudder input, but was unable to prevent the aircraft from turning past the runway heading.

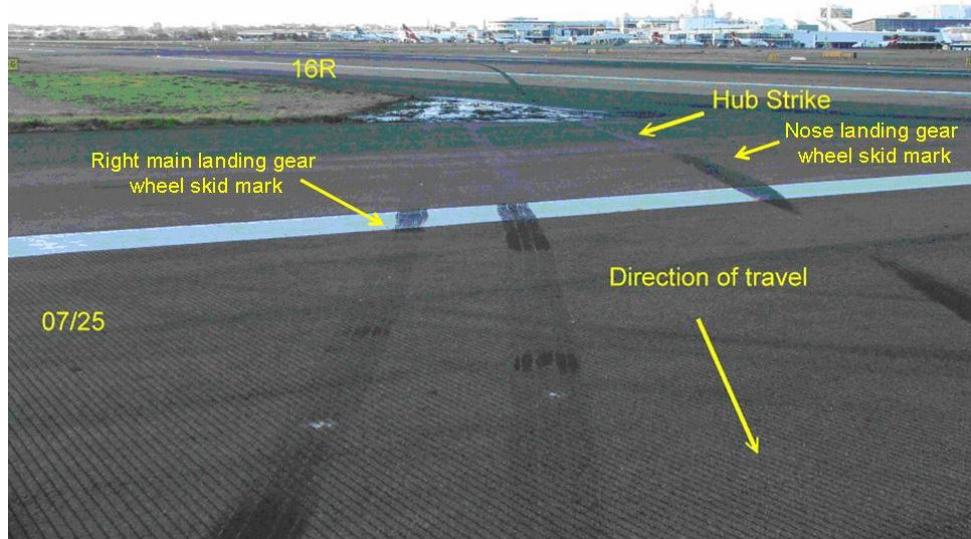
Figure 1: Aircraft path from commencement of taxi to stop



The PIC retarded the thrust levers to the idle position. Just prior to this, the left engine N₁ had reached the take-off setting of 98% RPM and the right engine N₁ a maximum of 64% RPM. The aircraft reached a maximum groundspeed of 30 kts before slowing. The aircraft departed runway 16R and came to rest on crossing runway 07.

The PIC reported that he was not aware of an increasing thrust asymmetry at this time and considered that his difficulty in maintaining directional control was a problem with the nose-wheel steering. An increasing left nosewheel steering wheel input, was therefore applied when trying to maintain directional control as the aircraft decelerated. The nosewheel steering wheel provided greater nosewheel steering authority (78 degrees nosewheel turn) than the rudder pedal nosewheel input (8 degrees nosewheel turn). Full left nosewheel steering wheel control input was applied before the aircraft stopped. A skid mark from the nosewheel was found from the centreline of runway 16R to the position of the stopped aircraft (Figure 2). This skid mark was consistent with a large nosewheel steering direction change to the left from the time the engine thrust levers were retarded to idle.

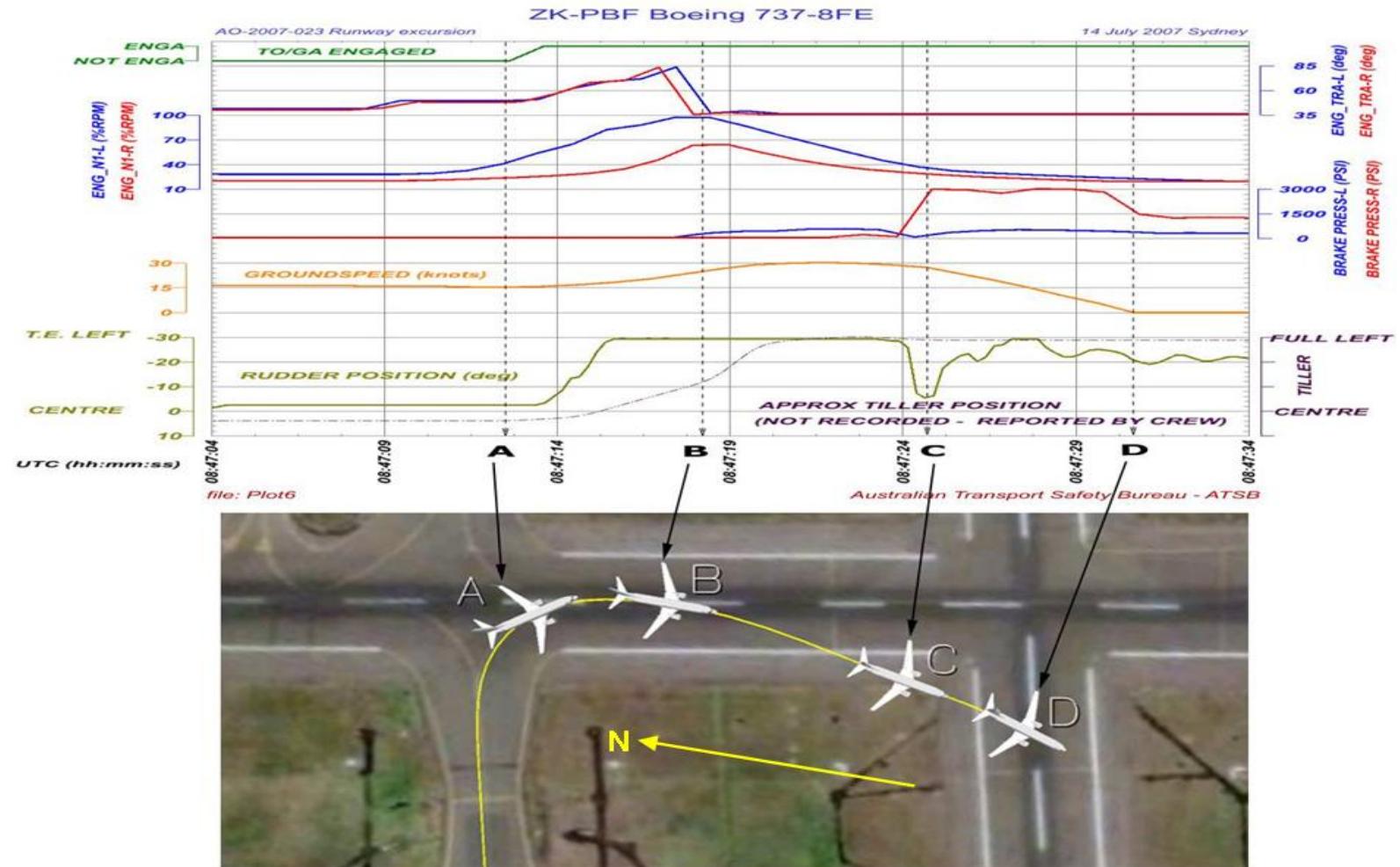
Figure 2: Skid and tyre marks from the aircraft nose and main tyres



The aircraft decelerated in a direction approximately 25 degrees to the right of the runway 16R heading. The right main landing gear and the nose landing gear departed runway 16R to the right onto grass near the intersection of runway 07, and then returned from the grass onto tarmac and stopped on runway 07. The left wheel brake was applied at approximately 20% from the time the thrust levers were retarded. However, the right wheel brake was applied at 95% to 100% from the time the aircraft nose wheel departed the runway onto the grass. The right main landing gear passed over the muddy surface on the corner between runway 16R and runway 07 as the aircraft decelerated.

The aircraft stopped on runway 07 on a heading of 186°M and with the nosewheel deflected 78 degrees to the left. Figure 3 shows the FDR data from the time the aircraft taxied from taxiway 'G' onto the runway until the aircraft came to rest on runway 07.

Figure 3: FDR readout from taxi on taxiway 'G' until the aircraft stopped



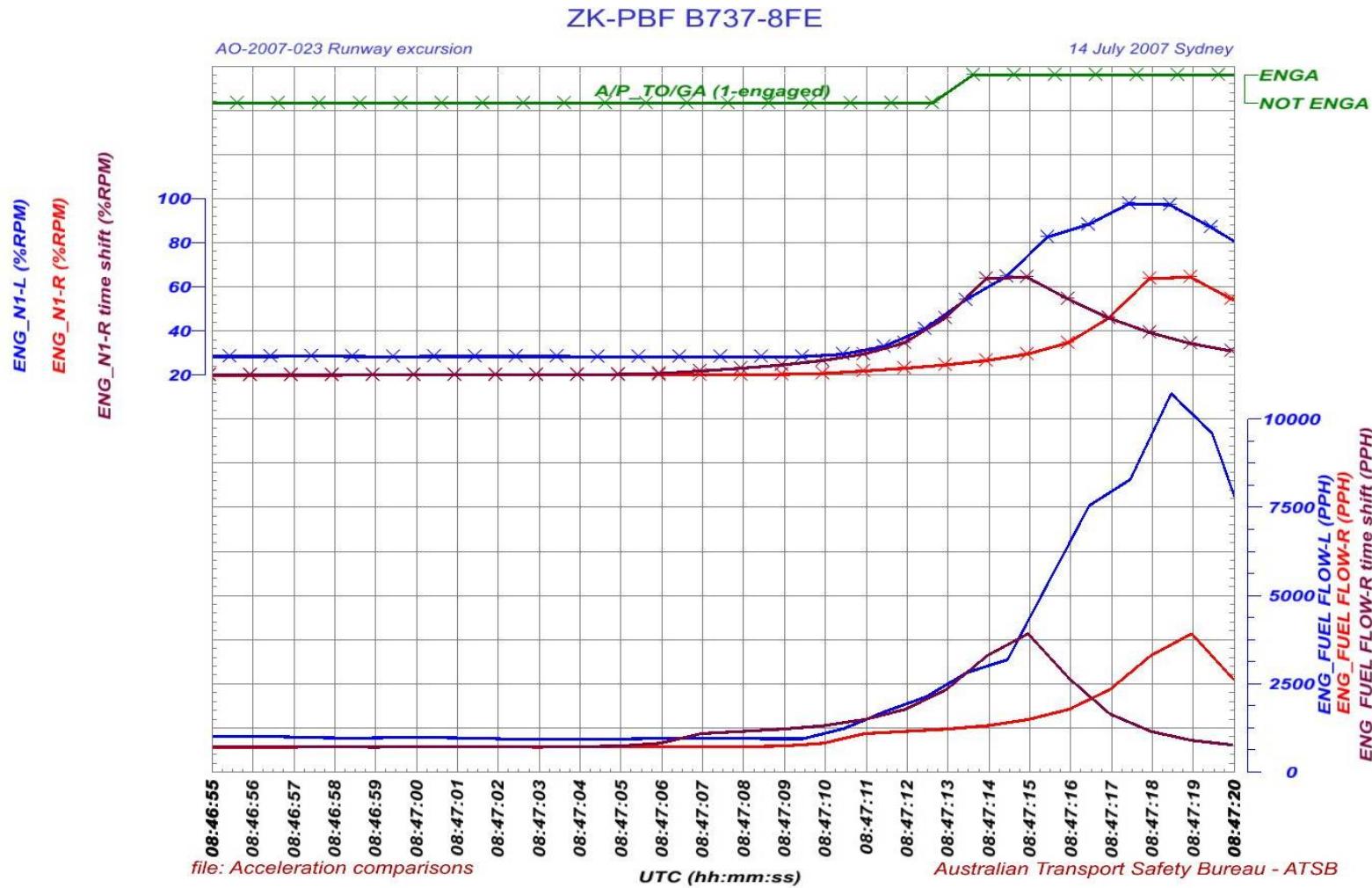
Turbo-fan engine acceleration

High bypass turbo-fan engines of the type found on modern Boeing 737 aircraft do not accelerate in a linear manner when thrust is increased. The rate of acceleration increases as N_1 increases (Figure 4), which was demonstrated by the characteristics of the engines during the acceleration sequence in this incident. The FDR readout depicts an expanded 25-second period across the engines' thrust changes, showing recorded values of engine fuel flow and fan speeds, comparing the acceleration characteristics of the engines from idle. The red lines depict the characteristics of the right engine that commenced accelerating from an idle N_1 setting. The blue lines depict the characteristics of the left engine that commenced accelerating from a higher initial N_1 setting. The brown lines represent the acceleration of the right engine, moved 4 seconds earlier in the sequence, so that they overlay the acceleration phase of the left engine, to assist in making a comparison between the individual engines' performance characteristics while accelerating.

The slopes of the blue and brown lines during the acceleration phase depicted in Figure 4 are approximately the same. This indicates that, if both engines had accelerated from the same N_1 setting, their thrust would have remained symmetrical.

Just prior to the thrust on both engines being reduced, when N_1 for each engine was 64% and 98% respectively, the left engine's thrust would be about three times the right engine's thrust, which can also be seen from the respective engine fuel flows depicted in Figure 4.

Figure 4: FDR readout of the 25 second period during the engine acceleration period showing recorded values of engine fuel flow and fan speeds, comparing the different engines' acceleration characteristics



Rejected takeoff under asymmetric power

The aircraft operator had identified two separate risks related to high and low-speed rejected takeoffs associated with thrust loss from a single engine. The primary risk in a high-speed rejected takeoff was considered to be whether the crew should continue to fly or attempt to stop in the runway distance remaining. Maintaining initial directional control during a rejected takeoff at a higher speed was considered to be less of an issue because the rudder had sufficient aerodynamic authority to maintain directional control. In contrast, it was considered to be harder to maintain directional control at low speed, with the resultant lower rudder authority. In those circumstances, available alternatives for maintaining directional control included the use of nose-wheel steering or the use of asymmetric wheel braking. The documented standard procedure for maintaining directional control in those circumstances was to maintain powerful, symmetrical wheel braking at the same time as applying immediate thrust reduction, and using nose-wheel steering inputs where it was necessary to maintain directional control. The operator's training procedures included practical training for all pilots in a flight simulator, including high and low-speed rejected takeoffs initiated following the loss of power from one engine. The simulator training modules were scheduled during the company's induction and 6-month recurrent simulator sessions.

Documented procedures

The aircraft operator provided its pilots with a company Operations Manual in addition to Boeing aircraft manuals. The company Operations Manual was primarily designed to address company procedures. In the case of any discrepancy between documents, the order of priority was:

- aircraft operator's Operations Manual
- Boeing B737 Flight Crew Operation Manual (FCOM)
- Boeing B737 Flight Crew Training Manual (FCTM)

Taxi and take-off procedure

The taxi and take-off procedures for the Boeing 737 NG contained in the Boeing Flight Crew Training Manual (FCTM) were as follows:

Taxi Speed and Braking

Normal taxi speed is approximately 20 Knots. On long straight taxi routes, speeds up to 30 knots are acceptable, however at speed greater than 20 Knots use caution when using the nose wheel steering wheel to avoid over-controlling the nose wheel. When approaching a turn, speed should be slowed up to an appropriate speed for condition. On a dry surface, use approximately 10 Knots for turn angles greater than those typically required for high speed runway turnoffs.

Thrust Management (Take Off)

The Electronic Engine Control (EEC)⁶ simplifies thrust management procedures. Having the EEC (Electronic Engine Control) functioning does not relieve the pilots from monitoring the engine parameters and verifying proper thrust is obtained.

Initiating Takeoff Roll

A rolling take off procedure is recommended for setting take off thrust. It expedites the take off and reduces the risk of foreign object damage or engine surge / stall in a tail wind or cross wind.

Rolling take offs are accomplished in two ways:

- If cleared for take off prior to or while entering the runway, maintain normal taxi speed. When the airplane is aligned with the runway centre line ensure the nose wheel steering wheel is released and apply take off thrust by advancing the thrust levers to just above idle (40% N_1). Allow the engines to stabilise⁷ momentarily then promptly advance the thrust levers to take off thrust (auto throttle to TOGA). There is no need to stop the airplane prior to adding thrust.
- If holding in position on the runway, ensure the nose wheel steering wheel is released, release brake, then apply take off thrust as described above.

Allowing the engines to stabilise will provide uniform engine acceleration to take off thrust and minimises any directional control problem. This is particularly important if a crosswind exists or the runway surface is slippery. The exact initial setting is not as important as setting symmetrical thrust.

Note: Allowing the engines to stabilize for more than approximately 2 seconds before advancing the thrust levers to take off thrust may affect take off distance.

After thrust is set, a small deviation in N_1 between engines should not warrant a decision to reject the take off unless this deviation is accompanied by a more serious event.

Use of the nose wheel steering wheel is not recommended above 30 Knots. However, pilots must use caution when using the nose wheel steering wheel above 20 Knots to avoid over-controlling the nose wheel resulting in a possible loss of directional control.

Regardless of which pilot is making the take off, the captain should keep one hand on the thrust lever until V_1 in order to respond quickly to a rejected take off condition.

The PM (Pilot Monitoring) should monitor engine instruments and airspeed indications during the take off roll and announce any abnormalities.

⁶ EEC (Electronic Engine Control) is an engine control system that calculates the correct N_1 thrust setting and uses inputs from various sources. The EEC compares commanded N_1 to actual N_1 and adjusts the fuel flow to achieve the commanded N_1 .

⁷ Stabilised engines are established when the commanded N_1 from the thrust lever position and the actual N_1 are equal.

The Boeing 737 NG procedures for taxi and takeoff are documented in the Boeing Flight Crew Operation Manual (FCOM) below. They provide expanded flight crew procedures for the flying pilot and the non-flying pilot:

Pilot Flying	Pilot Monitoring
	Enter the runway offset on the CDU TAKE OFF REF page
	When entering the departure runway, set the strobe light switch to ON. Use other lights as needed
	When cleared for take off, set the FIXED LANDING light switches to ON. Set the transponder mode selector to TA/RA
Advance the thrust lever to approximately 40% N ₁ . Allow the engines to stabilise. Push the TOGA switch. Verify that the take off thrust is set.	
	Monitor the engine instruments during the take off. Call out any abnormal indications. Adjust take off thrust before 60 Knots as needed. During strong headwind, if the thrust levers do not advance to the planned take off thrust by 60 knots, manually advance the thrust levers.

Rejected take-off procedure

The FCTM also provided procedures that should be followed in the event of a rejected takeoff:

If the decision is made to reject, the captain must, without delay:

- Rapidly and simultaneously retard the thrust levers to idle and apply maximum manual braking, or verify proper operation of RTO⁸ auto-brakes.
- Immediately extend the speed brakes and initiate maximum reverse thrust consistent with the condition;
- Maintain maximum braking and reverse thrust as required, transitioning to the normal landing roll procedure after determining that stopping on the remaining runway is assured.

⁸ RTO is a selection in the auto-brake system. If RTO is selected, wheel braking will activate automatically in the case of a rejected takeoff, but it will only activate if the wheel speed is above 90 kts at the start of the rejected takeoff.

The FCTM procedure did not stipulate which pilot should be involved in the decision to reject a takeoff, but it was specific in stating that the captain [pilot in command] shall carry out the actions associated with a rejected takeoff.

ANALYSIS

Operational procedures for controlling direction during the start of the takeoff

During the taxi to takeoff, the engine thrust levers had been moved to a higher thrust setting as the aircraft approached the runway, but the left engine had a higher thrust setting immediately before take-off thrust was applied to both engines. As take-off thrust was applied, the left engine thrust increased more rapidly because of its higher initial thrust setting. The increase in the difference between the engines' N_1 led to an increasing thrust asymmetry, which affected the ability of the crew to maintain directional control of the aircraft. Recorded flight data indicated that both engines' thrust settings were not stabilised at an equal setting before applying take-off thrust. Engagement of the Take Off/Go Around (TO/GA) button before thrust stabilisation then led to a further increase in asymmetric engine acceleration, despite both thrust levers being moved equally.

The higher thrust from the left engine would have produced a torque about the aircraft's normal axis that led to the loss of directional control to the right. The nose wheel was already deflected to the right for the right turn onto the runway, and the thrust asymmetry would have increased the aircraft's right turn past the runway heading.

Before starting to apply take-off thrust, the aircraft operator's procedures required the crew to:

- align the aircraft with the runway heading
- release the nose-wheel steering wheel
- stabilise both engines at an equal thrust of approximately 40% N_1 .

In this occurrence, the TO/GA button was pressed to initiate take-off thrust without first stabilising both engines' thrust, and when the aircraft was still turning with 30 degrees to go before reaching the runway heading. The pilot in command's (PIC) attention needed to be simultaneously directed to the tasks described in the procedures. At the same time, the copilot's attention was directed to another task as he set a clock, which would have diverted his attention away from monitoring the PIC's actions. It was therefore possible that neither pilot had the necessary awareness of the engine thrust indications as take-off thrust was applied to ensure that they had been stabilised.

This diversion of attention could be why the PIC was not aware of any thrust asymmetry during the start of the takeoff and therefore was not aware of the reason for the difficulty in maintaining directional control of the aircraft. Instead, the PIC had believed the difficulty was based on problems with the nosewheel steering. This led to the application of excessive nosewheel steering.

Adherence to the operator's procedures would have established an aircraft configuration that would have made it easier for the crew to maintain directional control as the takeoff was initiated.

Controlling direction during low speed rejected takeoff

Nosewheel steering

The turn from the taxiway to the runway was too sharp to have been accomplished with only the 8 degree nosewheel steering authority that was available from using the rudder pedals alone. It was therefore necessary for the pilot to have used the nosewheel steering wheel for greater directional authority until the aircraft had been aligned with the runway centreline. The application of take-off thrust before reaching the runway heading meant that the nosewheel steering wheel was still being used for directional control during the initiation of the takeoff.

Steering input from a tyre is effective if the steering wheel's rolling direction is close to the vehicle's travelling direction, but steering forces from the nosewheel are reduced once a steering tyre starts to skid. The large nosewheel deflection (up to 78 degrees) possible through the use of the nosewheel steering wheel, combined with the direction of travel of the aircraft as a result of the asymmetric thrust from the engines, led to the nosewheel skidding and directional control of the aircraft being lost.

Wheel braking

Light left-wheel braking was applied consistently throughout the deceleration manoeuvre, which would have exerted a left yawing moment. The wheel braking input changed as the nosewheel left the runway onto rougher terrain, with the application of maximum right-wheel braking, which would normally create a strong right yaw input. However, the aircraft continued in a straight line, which indicated that the powerful right-wheel braking input was acting on a relatively slippery surface and was comparable in effect with the decelerating force from the light braking from the left wheel on the high friction runway surface. The yawing moment from the skidding nosewheel would have been insignificant in comparison with effective powerful braking from one main wheel.

At the time that the rejected takeoff was initiated, the aircraft was moving at less than 30 kts and there was still a significant length of runway remaining. These circumstances could lead a pilot to initiate a gentle deceleration, under the premise that there was little need to brake hard and apply more wear to the aircraft or increase passenger concern. However, rejected takeoff (RTO) procedures called for the initial application of powerful decelerating forces and for those forces to be reduced only after the pilot had determined that stopping on the remaining runway was assured. If powerful, symmetrical, wheel braking had been applied to both main wheels from the start of the RTO, the aircraft would have travelled a shorter distance overall, including less sideways deviation from the runway centreline. This action would have also reduced the likelihood of inadvertent application of asymmetric wheel braking, particularly if the pilot was familiar with the procedure from simulator training.

The combined use of correct wheel brake application and appropriate nosewheel steering input could increase the chance of recovery from a low speed rejected takeoff where directional control was impaired.

FINDINGS

From the evidence available, the following findings are made with respect to the runway excursion at Sydney Kingsford-Smith Airport, NSW, 14 July 2007; and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The engine thrust on both engines was not stabilised and the stabilised engines checks were not done before the Take Off/Go Around (TO/GA) button was pressed.
- The nosewheel steering wheel (tiller) was not released before thrust was increased.
- The aircraft was still turning toward the runway heading as thrust was increased and the pilot in command was focussing his attention on aligning the aircraft to the runway centreline at that time.
- The copilot was not monitoring engine conditions as thrust was increased.
- The pilot in command thought that the directional control difficulty was based on a problem from the nosewheel steering (tiller) and not from any engine thrust asymmetry.
- The rejected takeoff was not initiated with the application of maximum wheel braking.
- There was significant nosewheel steering input, which was ineffective due to the large nosewheel deflection and resultant skid.

Other safety factors

- After TO/GA was engaged, the left engine accelerated more rapidly than the right engine, resulting in asymmetric thrust. The left engine then reached 98% N₁ as the right engine reached 64% N₁.

Other key findings

- The aircraft flight recorder data showed that both thrust levers had moved equally after the TO/GA button was pressed, which indicated that the auto throttle system had worked normally.
- Full right-wheel braking was applied when the wheel was on a relatively slippery surface, reducing the effectiveness of the wheel brake.

SAFETY ACTIONS

Aircraft operator

Following this incident, the aircraft operator initiated safety actions relating to a review of procedures for the training syllabus for recurrent and induction training. The review included briefing and assessment on the correct procedure for commencing a take-off roll. The briefing now includes:

1. The correct procedures to be followed when commencing the take-off roll, including runway alignment prior to thrust application, engine stabilisation with symmetrical thrust prior to advancing thrust levers to take-off thrust (selecting TO/GA) and the use of the nose-wheel steering wheel during the take-off roll.
2. Ensuring thrust is symmetrical and stabilised, and the aircraft aligned with the runway centreline before selecting TO/GA.

In addition, a low-speed rejected takeoff is to be completed during recurrent training.

The correct take-off thrust setting procedures have been incorporated in induction training.

SOURCES AND SUBMISSIONS

Sources of information

Flight crew of ZK-PBF
Aircraft operator
Sydney Airports Corporation Limited
The Boeing Company

Submissions

A draft of this report was provided to the flight crew, aircraft operator and the Civil Aviation Safety Authority. Submissions were received from the pilot in command and the aircraft operator. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.