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Australian Transport Safety Bureau

Reduced braking effectiveness during landing involving Boeing 737-800, VH-VOP

Christchurch, New Zealand | 11 May 2015



Investigation

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Addendum

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Safety summary

What happened

On 11 May 2015, a Boeing 737 aircraft, registered VH-VOP and operated by Virgin Australia International, conducted a scheduled passenger service from Sydney, New South Wales to Christchurch, New Zealand.

Shortly after midnight, the aircraft landed on runway 29 at Christchurch. Runway 29 was shorter than the main runway at Christchurch. The aircraft landed within the required touchdown zone, using full reverse thrust, speedbrakes, and the autobrake system engaged the wheel brakes. Recorded flight data showed that the aircraft initially achieved, and at times exceeded the selected AUTOBRAKE 3 target deceleration rate. However, after crossing the runway intersection, the aircraft did not continue to decelerate as expected and the crew believed the aircraft appeared to slide or skid. In response, the crew overrode the autobrakes and applied hard manual braking while retaining full reverse thrust for longer than used in normal operations. The crew also corrected a minor directional deviation. The aircraft came to a stop about 5 m from the runway end. There were nil recorded injuries or aircraft damage.

What the ATSB found

The ATSB found that, due to increased workload, the crew misperceived the runway surface conditions and believed it was damp when in fact it was wet. As there was no regulatory direction on how a damp runway was to be considered for aircraft landing performance purposes, the operator's policy was to treat a damp runway the same as a dry runway. As a result, the crew established the aircraft's landing performance based on a dry rather than a wet runway and the expected runway 29 landing performance was not achieved.

The ATSB also found that, several months prior, the operator had changed its policy whereby damp runways had previously been treated as wet runways.

Based on the crew's observations and a review of the available recorded data, it was very likely that the surface conditions on the later part of the runway had degraded to the extent that they adversely affected the aircraft's braking capability. It was also possible that the aircraft experienced viscous aquaplaning. However, the initial exceedance of the target deceleration rate, combined with the crew's actions, likely prevented a runway overrun.

Further, a post-incident analysis of the flight data recorder by the aircraft manufacturer found that a 5 kt tailwind existed on final approach and landing. This also significantly affected the aircraft's landing performance and further reduced safety margins.

Additionally, and along with the United States Federal Aviation Administration, the ATSB found that the 15 per cent in-flight safety margin applied to actual landing distances during landing performance calculations may be inadequate under certain runway conditions. In these conditions, additional conservatism is encouraged.

Safety message

This incident highlights the adverse consequences of crew experiencing a high workload during critical phases of flight, including missing important information needed to determine an accurate landing performance.

In addition, runway surface condition and braking action reports (intended for the benefit of other pilots landing aircraft after them) can be subjective, and the terminology used to describe these can be inconsistent. Considerable efforts have been made by organisations such as the United States Federal Aviation Administration to address this issue with the introduction of the runway condition assessment matrix.

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The occurrence

Sequence of events

On 12 May 2015, shortly after midnight local time, a Boeing 737-800 aircraft, registered VH-VOP (VOP) and operated by Virgin Australia International as Velocity 134, touched down on runway 29 at Christchurch, New Zealand. During the landing roll, the aircraft did not decelerate as expected and the crew believed it appeared to slide or skid. The crew responded to the situation and the aircraft came to a stop about 5 m from the runway end.

Pre-flight preparations

Earlier in the evening of 11 May 2015, the crew arrived at Sydney, New South Wales for the scheduled passenger service to Christchurch. During flight preparations in Sydney, the crew reviewed the notice to airmen (NOTAM)¹ and applicable weather forecasts. The NOTAMs indicated that works in progress would be occurring on the northern end of runway 02 at Christchurch, resulting in a reduced runway length on the main runway. The NOTAM also stated that runway 20 was closed for landing. There was no significant weather forecast for their arrival, but rain was expected later the next morning (after the scheduled arrival time), and at that time, the conditions were favourable to runway 02. The operator's flight dispatch notes indicated that there were no landing performance weight restrictions for their arrival with the forecast weather conditions.

At 0941 Coordinated Universal Time (UTC),² VOP departed Sydney and climbed to flight level (FL)³ 390. The first officer (FO) was designated as the pilot flying and the captain was the pilot monitoring.⁴

First contact with Christchurch air traffic control

The captain reported that, at about 1135, he contacted air traffic control (ATC) on the Christchurch Information frequency and requested the automatic terminal information service (ATIS)⁵ for Christchurch Airport. The crew received the ATIS 'X-ray' (X) details, which advised that the runway surface conditions were dry and to expect an approach to runway 02. These details were consistent with the crew's pre-flight assessment of the forecast conditions. The crew recorded these details on the take-off data card⁶ and then prepared for the approach. Due to forecast turbulence over the Southern Alps, the crew had previously briefed the cabin crew on the need to prepare the cabin for the approach earlier than normal.

¹ A notice distributed by means of telecommunication containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

² Australian Eastern Standard Time (EST) was Coordinated Universal Time (UTC) + 10 hours and New Zealand Standard Time (NZST) was Coordinated Universal Time (UTC) + 12 hours. Times herein are in UTC unless stated otherwise.

³ At altitudes above 10,000 ft in Australia (transition altitude), an aircraft's height above mean sea level is referred to as a flight level (FL). FL 390 equates to 39,000 ft.

⁴ Pilot flying (PF) and pilot monitoring (PM) are procedurally assigned roles with specifically assigned duties at specific stages of a flight. The PF flies the aircraft. The PM carries out support duties and monitors the PF's actions and aircraft flight path.

⁵ ATIS: An automated pre-recorded transmission indicating the prevailing weather conditions at the aerodrome and other relevant operational information for arriving and departing aircraft.

⁶ A take-off data card is used to record essential take-off performance and airport information, including the ATIS. Some operators also have a dedicated landing card for recording similar information for landing. In other cases, as was for VOP, the take-off data card was used for recording landing information.

At around the same time, the crew of an Airbus A320 (A320) aircraft inbound to Christchurch and ahead of VOP, were in contact with Christchurch Area ATC. ATC advised the A320 crew that it was now raining at Christchurch Airport and the runway-in-use was about to change due to a variation in the surface wind conditions.

At 1136, ATIS ‘Yankee’ (Y) was issued, indicating that runway 29 was now in-use and the surface conditions were dry.

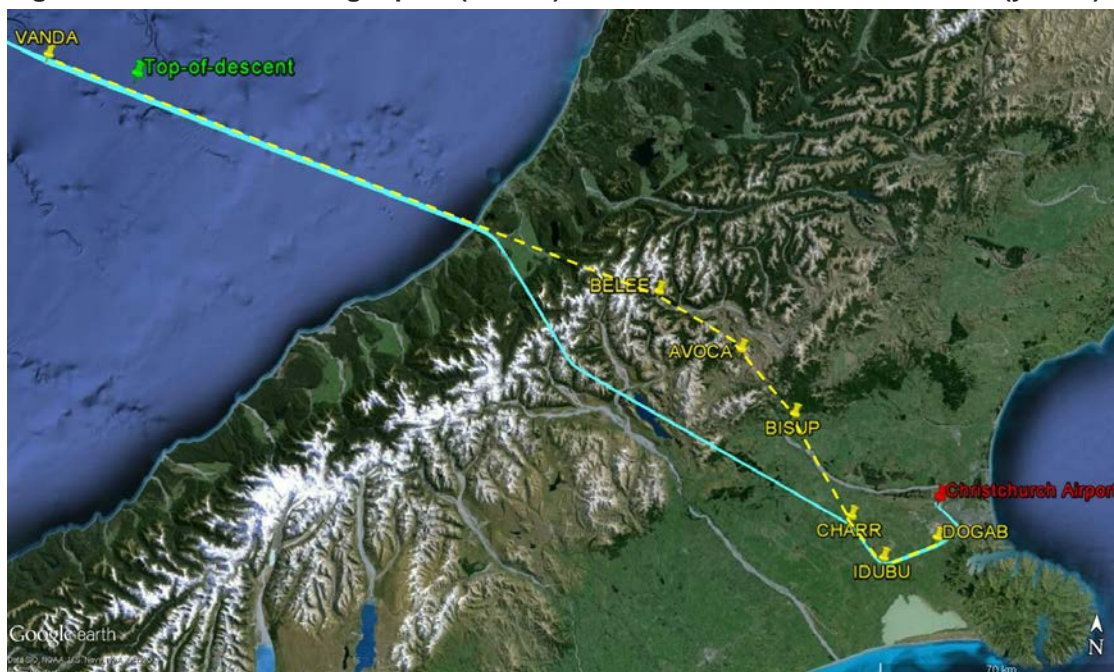
The A320 crew continued discussions with ATC regarding the changing weather conditions at Christchurch. The crew determined that, rain on the reported dry runway rendered it wet, therefore, they were unable to land at Christchurch due to performance restrictions and elected to divert to Wellington.

Change in ATIS and approach

At 1146, the crew of VOP established contact with Christchurch Area ATC on a different frequency from the A320 crew. The crew advised ATC that they were at waypoint ‘VANDA’ (Figure 1) maintaining FL 390 and were in receipt of ATIS X. ATC began to clear the crew to descend for the ‘BELEE 1’ arrival but then asked them to standby. Shortly after, ATC advised the crew that ATIS Y was now available with a visual approach to runway 29 and that there were ‘quite a few changes from the previous, you want to have a listen’. About 1 minute later ATC contacted the crew and advised they were cleared to descend to FL 160 for the ‘BELEE 1 Charlie’ standard arrival route for runway 29 (Figure 1). The crew acknowledged the clearance and responded ‘Velocity 160’, inadvertently transposing their cleared flight level for their call sign. ATC then confirmed their call sign as ‘Velocity 134’ and advised that ATIS Y was current with a QNH⁷ of ‘993’. The crew acknowledged the QNH and requested the surface wind, which was reported as 250° at 12 kt, maximum 18 kt. The crew recorded these details on the take-off data card.

Having been notified of the change in runway-in-use, the crew commenced their preparations for the revised approach. Also around this time, the crew noted weather ahead on the aircraft’s weather radar at waypoint ‘BELEE’, requiring a track deviation.

Figure 1: VH-VOP actual flight path (in blue) and BELEE 1 Charlie arrival route (yellow)



Source: Google earth and operator, annotated by the ATSB

⁷ Altimeter barometric pressure subscale setting to provide altimeter indication of height above mean sea level in that area.

The crew reported that, in order to manage an increased workload associated with the revised approach, they divided the duties. The captain focussed on entering the approach into the flight management system and assessed the aircraft's landing performance to determine the suitability of runway 29 (which was shorter than the expected runway 02). The FO managed the weather deviation and focussed on the implications of landing on a shorter runway. The crew also discussed holding at waypoint 'CHARR' if additional time was needed to prepare for the approach. Due to the higher than normal workload, the captain reported that they did not get the opportunity to listen to ATIS Y.⁸

At 1149, the crew commenced their descent. Shortly after, the crew made a public address for the cabin crew to prepare for the approach.

At 1150, ATIS 'Zulu' (Z) was issued. At 1151, ATC advised the crew that it had been issued and that the runway was now wet with light rain. The crew acknowledged the call by responding 'Velocity 134'. The crew did not listen to the ATIS as the details had been passed on by ATC. The details were not recorded on the take-off data card, but the crew specifically recalled being advised of light rain.

At 1152, the crew requested a 10 NM deviation to the right of track due to weather, which was approved by ATC.

At 1154, the A320 crew established communications with the same Christchurch Area ATC as VOP and advised they were diverting to Wellington. Shortly after, the pilot of another aircraft that had departed Christchurch at about 1146, advised the A320 crew that they considered runway 29 to be 'damp, not wet'. When questioned, the crew of the departing aircraft indicated that they had taken off from runway 29 about 5-10 minutes prior and confirmed that they considered the surface conditions to be damp not wet. ATIS Y was active at the time of that aircraft's departure and had not yet changed to ATIS Z (which indicated the runway was wet).

At 1155, the crew of VOP requested another deviation 15 NM to the right of track. ATC approved the crew to track as required around weather and then to waypoint 'BISUP' once clear. The crew then requested further clearance to track direct to 'CHARR' due to weather in the vicinity of BISUP. This was approved by ATC.

The captain, at this time, referenced the Airport Analysis Manual (refer to section titled *Airport Analysis Manual (AAM) – Landing performance limit weight*) to determine the aircraft's landing performance limit weight for runway 29 with nil wind and flap 40.⁹ Believing that the runway surface conditions had been reported as 'damp' by ATC, the captain determined that the dry limit weight would be about 68.2 t, which exceeded the aircraft's maximum certified landing weight and their expected landing weight of 60.1 t. The crew were aware that if the rain continued and the runway was then wet rather than damp, they would have been about 1 t over the limit weight. From their experience, the crew established that AUTOBRAKE 3¹⁰ was the most appropriate brake selection for landing.

At 1157, the crew of VOP advised ATC that they were clear of weather and were now tracking to CHARR. Prior to reaching CHARR, the FO provided a briefing for the revised approach, which included reviewing the arrival procedure, the runway, the aircraft configuration and performance limitations, and the identification and management of threats.

⁸ The aircraft was not fitted with an aircraft communications addressing and reporting system (ACARS), which would have provided another mechanism for obtaining the ATIS.

⁹ Flap 40 is the maximum flap extension, which results in a lower approach/touchdown speed. This reduces the required landing distance and also the possibility of aircraft tyres dynamic aquaplaning on runways affected by standing water.

¹⁰ The autobrake system has four landing settings, 1, 2, 3 and MAX, and selects the appropriate deceleration rate for landing.

Monitoring the wind conditions

The crew received further descent instructions and were transferred to the next Christchurch ATC frequency. At 1201, the crew were advised that ATIS 'Alpha' (A) was current and the QNH was 992. ATC also advised that the surface wind was easing, indicating 240° at 5 kt and that it had stopped raining at the airport. The crew replied 'understood'.

During the descent, the captain continued to monitor the wind conditions and assessed that a 5 kt tailwind on the longer runway 02 was more limiting than using the shorter runway 29 with nil wind.

At 1204, the crew requested an update on the surface wind and were advised that it was 'easing back around to the south', indicating 220° at 5 kt. Shortly after, ATC advised the crew that the surface wind had remained steady for the last 5 minutes at about 230° at 5 kt. In response, the captain questioned the availability of runway 20, to which ATC advised that it was not available for a few hours due to the works in progress, and their options were either runway 29 or runway 02 with a reduced length.

At 1208, the crew were cleared by ATC for the visual approach to runway 29 and advised that the surface wind was 200° at 3 kt, but it appeared to be changing to light and variable. Shortly after, the crew contacted Christchurch Tower ATC. During the approach, the FO focused on managing the aircraft's profile and speed to ensure the approach was stable.

At 1211, ATC advised the crew that the surface wind was now calm.¹¹ Soon after, ATC cleared the crew to land on runway 29. Around this time, the captain reported he now could see the runway surface and assessed the runway as being damp rather than wet, as the surface did not appear reflective.

Landing on runway 29

At 1214, the aircraft touched down on runway 29 within the touchdown zone. Immediately after, full reverse thrust was applied and the speedbrakes deployed.

During the landing roll, as the aircraft passed the runway 02/20 and 11/29 intersection (Figure 7), the FO reported that he did not receive the expected sensation of being restrained against the seat belt and shoulder harness and the aircraft did not decelerate as expected. The FO also indicated that it felt like the aircraft was sliding. In response, the FO made a call to the effect of 'aquaplaning' or 'skidding' and applied constant 'hard' (but not full) manual braking, overriding the autobrake system. The captain noted that there was a lot more surface water on that section of the runway than what was observed at the beginning of runway 29.

The captain assisted the FO with manual braking. Both crew reported that they could feel the rudder/brake pedals 'pulsing', which indicated the antiskid system was operating. The crew elected to keep reverse thrust deployed to assist with braking.

The FO reported that he was focusing on the red runway end lights and noticed the aircraft drift slightly right, which he then corrected to bring the aircraft back onto the centreline. The captain reported that, when reverse thrust was stowed near the runway end, there was enough surface water on the runway to create a wall of spray. The FO reported that the aircraft came 'slowly sliding' to a stop about 5 m from the runway end lights. The aircraft was then taxied to the terminal.

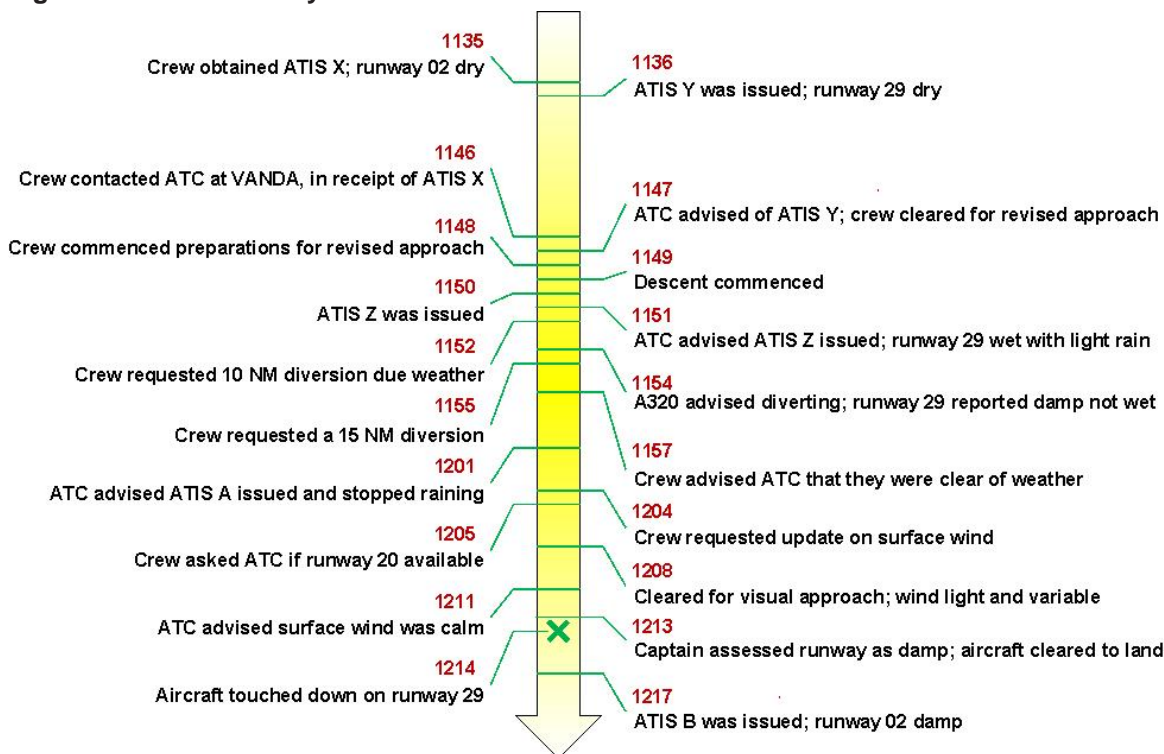
About 3 minutes after landing, ATIS 'Bravo' (B) was issued, where the runway-in-use changed to runway 02 and the reported surface conditions were changed to 'damp'.

Following engine shutdown, the crew re-checked the landing performance data for a damp (dry) runway. They also considered the amount of water spray observed at the runway end and believed the surface conditions at that time were not damp. Soon after, the captain spoke to a

¹¹ The Boeing 737 NG flight crew training manual stated that the approach speed for calm winds was the reference speed (V_{REF}) for flap 40 +5 kt.

ground engineer who had also observed the significant amount of water spray. The engineer stated that water seemed to pool in that area of the runway when it rained. The captain and FO had not previously been aware of any tendency for water to pool on that runway. The FO conducted a visual inspection of the aircraft's tyres with an engineer to see if any reverted rubber was present; none was detected. Figure 2 provides a timeline of the key events leading up to the incident.

Figure 2: Timeline of key events¹²



Source: ATSB

Cabin crew observations

A cabin crew member recalled that, during the landing, she heard the brakes ‘squealing’, but the aircraft did not slow down. She could also smell burning rubber and was unable to see outside as there was a large amount of water spray.

Post-flight discussion with Christchurch Tower

After disembarkation, the FO visited and spoke to Christchurch Tower staff to discuss the landing. The FO advised the Tower officer that there was a lot of standing water present at the end of runway 29, which probably was not visible from the Tower position. The officer agreed that the water was not visible. The officer also indicated they did observe the aircraft stop at the runway end for some time. The FO stated that they had planned on a damp runway as reported, however, the amount of water spray observed suggested otherwise. The FO further indicated that they noticed the standing water after crossing the runway intersection. The officer replied that another operator would reportedly not use runway 29 after they ran off the end in March 2015.¹³

¹² Refer to sections titled *Meteorological information – Automatic terminal information service (ATIS) and Air traffic services information – Summary of radio calls*.

¹³ On 6 March 2015, a Boeing 737 landed on runway 29 at Christchurch when it was raining heavily. After touchdown, braking effectiveness was initially achieved. However, when exiting the runway, the nose wheel skidded on a painted area of the runway. The aircraft crossed an area of grass for a short period time before continuing to the terminal. The operator issued a notice to alert their crews to exercise caution when initiating a turn off the runway end onto the taxiway in wet conditions.

The FO commented that they mainly used runway 02 and rarely used runway 29. The Tower officer noted that runway 29 was only used when there was a 'screaming north-wester' and they believed it was only the second time they had seen it used when wet.

Context

Personnel information

Captain

The captain held a valid Air Transport Pilot (Aeroplane) Licence and Class 1 Aviation Medical Certificate. He had a total flying experience of 8,912 hours, of which 4,978 hours were in the Boeing 737 aircraft. The captain had been operating from Christchurch for the previous 7 years.

This was the fifth day of duties on the captain's roster, which included both domestic and international flights. While the captain reported that the flight conducted the previous day was 'fatiguing', he felt well rested and in good health for the incident flight. There was no evidence to indicate a level of fatigue known to affect performance beyond what would reasonably be experienced towards the end of a duty late in the evening.

First officer

The first officer (FO) held a valid Air Transport Pilot (Aeroplane) and Class 1 Aviation Medical Certificate. He had a total flying experience of 8,229 hours, of which 2,786 hours were in the Boeing 737 aircraft. The FO had been operating from Christchurch for the previous 5 years.

This was the FO's third day on roster and he reported feeling well rested and in good health. Although the FO reported feeling tired after the incident flight, there was no additional evidence to indicate a level of fatigue known to affect performance beyond what would reasonably be experienced towards the end of a duty late in the evening.

Aircraft information

Post-flight inspection

Following the incident, an engineer inspected VH-VOP's (VOP) tyres and reported nil evidence of abnormal wear or damage indicative of reverted rubber aquaplaning (refer to section titled *Aquaplaning*). The tyre pressures were also normal and the aircraft's maintenance logs showed no pre-existing defects with the brake system. However, the engineer noted that the engines and fuselage were covered in dirty water, consistent with reverse thrust being used at high power settings.

Several days following the incident, the number 3 and 4 tyres were replaced as canvas was showing through the tread face. The exact condition of the tyres prior to the incident flight and whether this contributed to reduced braking effectiveness during landing was unknown. However, it was likely that the aircraft was flown in this period and the tyres inspected during normal daily checks.

Autobrake system

Once selected by the crew, the autobrake system supplies metered brake pressure during the landing roll to maintain a specified deceleration rate until the aircraft comes to a stop. The system has four landing selections (1, 2, 3 and MAX) that correspond to a target deceleration rate. For AUTOBRAKE 3, as selected by the crew of VOP, the target deceleration rate was 7.2 ft/sec/sec (0.224 g). If, during autobrake application, the crew applies a manual input of over 750 psi, the autobrake system will disconnect and disarm.

Antiskid system

During brake application, the antiskid system automatically controls the brake system to prevent the wheels from skidding. The system compares the aircraft's speed with the rotational speed of each main wheel. If the wheel speed is too slow, the brake on that wheel will momentarily release. This allows the wheel speed to increase and prevents skidding.

Boeing advised that the operation of the antiskid system would not normally be felt by the crew through the brake pedals. However, if many wheels experienced a skid concurrently, for example, if all of the wheels contacted a slippery section on the runway, the crew may feel ‘bumps’ or ‘pulses’ in the pedals. This would occur due to large changes in brake pressure as the antiskid system responds to sudden variations in runway friction.

The United States Federal Aviation Administration (FAA)¹⁴ also stated that the brakes should be applied firmly throughout the deceleration process. Specifically, when maximum braking is required, maintain maximum brake pressure and allow the antiskid system to operate. The antiskid system pulsing is caused by the modulation of the brake pressure and indicates that the system is operating normally, though this may be disconcerting to the pilot.

Main landing gear brake pressure recording switch

A review of the recorded data for the flight (refer to section titled *Recorded information - Flight data recorder (FDR) analysis*) identified no system failures. However, the brake pressure applied during the landing could not be determined due to an anomaly with a switch that controlled what brake pressures (main or alternate) were recorded on the flight data recorder (FDR). This resulted in the alternate,¹⁵ rather than the main brake pressures being recorded for the incident flight. After being made aware of the anomaly, the operator identified four other aircraft with a similar defect. The defective switch on these aircraft and VOP were replaced.

Meteorological information

Forecast weather at Christchurch

An aerodrome forecast (TAF) for Christchurch was issued at 0629 on 11 May 2015, valid between 0600 on 11 May 2015 and 0600 on 12 May 2015. The TAF predicted light and heavy rain from 2200, after the aircraft’s arrival at Christchurch. This forecast was viewed by the crew prior to departing Sydney. After departing at 0941, a subsequent TAF was issued at 1102, which forecast light rain for the aircraft’s arrival and heavy rain expected later the next day (refer to *Appendix A – Christchurch aerodrome forecasts (TAFs) and automatic terminal information service (ATIS)*).

Actual weather at Christchurch

Weather radar imagery showed that light to moderate rain passed through the Christchurch area between 1130 and 1207 (Figure 3), prior to the aircraft landing at 1214. MetService reported that a small amount of rain was recorded, but they considered it unlikely that this resulted in standing water on the runway.

¹⁴ Federal Aviation Administration. (2007). *Runway Overrun Prevention* (Advisory Circular AC 91-79 cancelled).

¹⁵ The alternate brake system should only be active during landing gear retraction or if there is a failure in the main brake system.

Figure 3: Weather radar showing rain passing overhead Christchurch Airport

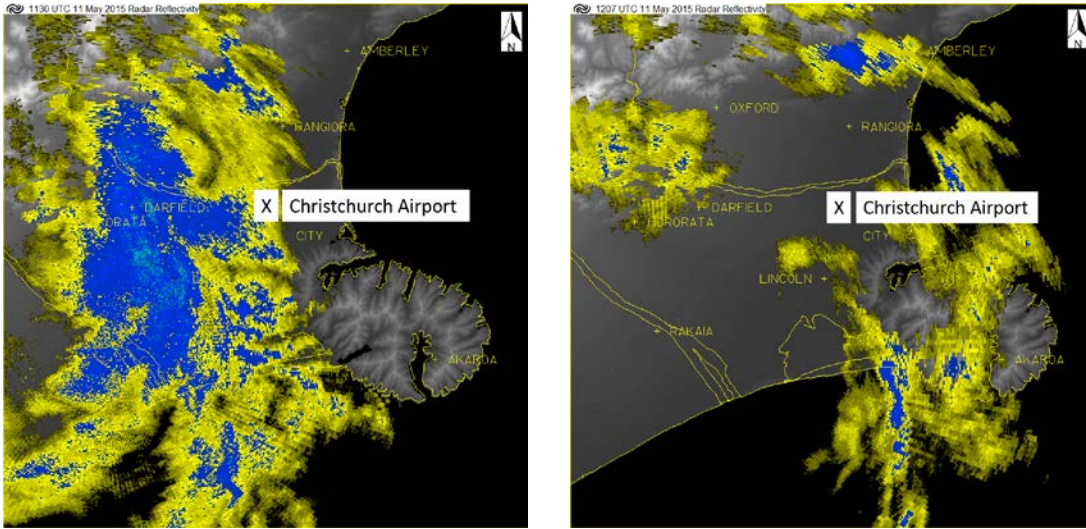
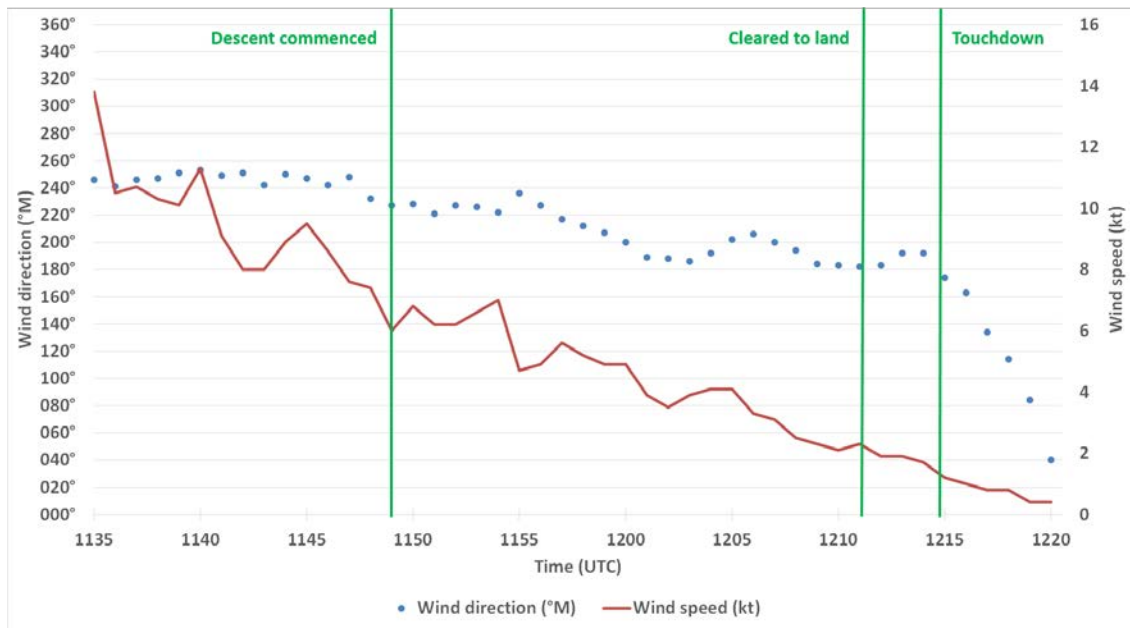


Image shows light (yellow) to moderate (blue) rain passing overhead Christchurch Airport between 1130 (left) and 1207 (right); VOP touchdown was at 1214. Source: MetService, annotated by the ATSB

Christchurch Airport had four anemometer (wind) sensors located 1,000 ft from each runway end. MetService provided the ATSB with one-minute interval data recorded by the automatic weather station, which captured temperature and wind data. The temperature at the time of landing was 12 °C. A graphical depiction of the changing wind (° Magnetic)¹⁶ between 1135 and 1220 is shown in Figure 4.

Figure 4: Christchurch Airport one-minute interval wind data between 1135 and 1220



Images shows the changing wind speed (in red) and direction (in blue). Source: MetService, modified by the ATSB

¹⁶ Wind direction data provided by the automatic weather station is in degrees True (°T). However, for the purposes of comparison with other wind information, the wind direction was converted to degrees Magnetic (°M).

Automatic terminal information service (ATIS)

Throughout the aircraft's flight and arrival, multiple changes to the Christchurch Airport automatic terminal information service (ATIS) reports were issued. Relevant aspects of the ATIS reports from the time the crew first obtained the ATIS until 3 minutes after landing is shown in Table 5.¹⁷

Table 5: Summary of ATIS issued

ATIS	Issue time	Runway-in-use	Runway surface	Wind (°M)	Weather	QNH	Temperature (°C)
<i>VOP departed Sydney at 0941</i>							
X	1018	02	Dry	010° at 8 kt	Nil	992	16
<i>Crew obtained ATIS X</i>							
Y	1136	29	Dry	250° at 12 kt, maximum 18 kt	Rain	993	14
<i>Aircraft at top-of-descent</i>							
Z	1150	29	Wet	250° at 10 kt, maximum 15 kt	Light rain	993	13
A	1157	29	Wet	220° at 7 kt	Nil	993	13
<i>Aircraft landed at 1214</i>							
B	1217	02	Damp	Variable at 3 kt ¹⁸	Nil	991	12

Air traffic services information

Summary of radio calls

Table 6 provides a summary of the key radio calls made between Christchurch air traffic control (ATC), the crew of VOP, the A320 crew, and the pilot of the departing aircraft.

Table 6: Summary of the key radio calls made on the Christchurch ATC frequencies

Time (UTC)	Summary of radio calls
1134:03	ATC advised the A320 crew that the surface wind had changed and it was raining at Christchurch. Shortly after, ATC further advised the crew that the runway-in-use was about to change to runway 29.
1139:41	The A320 crew advised ATC that they were unable to land on runway 29.
1143:00	The A320 crew advised ATC that they were diverting to Wellington.
<i>The above radio calls were made on a different ATC frequency to those made below.</i>	
1146:01	The crew of VOP advised ATC that they were at waypoint 'VANDA' at FL 390 and were in receipt of ATIS X-ray with a QNH of 992.
1146:02	ATC instructed the crew to descend to FL 160 and advised that they were cleared for the BELEE 1 arrival. ATC then advised the crew to standby.
1146:24	ATC advised the crew that, prior to providing the arrival clearance, ATIS 'Y' was now current with runway 29 in-use, visual approaches and 'quite a few changes from the previous, you want to have a listen'.
1147:37	ATC instructed the crew to descend to FL 160 when ready and that they were cleared for the BELEE 1 Charlie arrival to runway 29.
1147:51	The crew read back the clearance but replied 'Velocity 160'. ATC confirmed their call sign as 'Velocity 134' and advised that ATIS Yankee was current with a QNH of 993.

¹⁷ The original ATIS is shown in Appendix A.

¹⁸ The term 'variable' is used when the reporting of a mean wind direction is not possible such as, in light wind conditions (3 kt or less) or if the wind is veering or backing by 180° or more.

Time (UTC)	Summary of radio calls cont...
1148:12	The crew confirmed their call sign and the QNH. The crew then requested the surface wind at Christchurch to which ATC advised it was 250° at 12 kt maximum 18 kt.
1151:17	ATC advised the crew that ATIS Zulu had been issued; the runway was wet with light rain, visibility had reduced to 20 km and the cloud was broken ¹⁹ at 6,000 ft. The crew replied 'Velocity 134'.
1152:52	The crew requested a 10 NM diversion right of track. ATC approved the diversion and once clear of weather to track direct to 'BISUP'.
1154:12	The crew of an A320 aircraft initially for Christchurch contacted ATC and confirmed they were diverting to Wellington.
1154:45	The pilot of an aircraft that had departed Christchurch advised the A320 crew that they 'would call the runway 29 take-off damp not wet'.
1154:57	The pilot of the departing aircraft repeated that they had taken off from runway 29 about 5-10 minutes prior and they considered the runway to be damp.
1155:14	The crew of VOP requested a 15 NM diversion right of track. ATC advised the crew that they could track as required around the weather and then to BISUP once clear.
1155:26	The crew advised ATC that the weather was bordering BISUP and requested direct to 'CHARR' once clear of the weather. The revised clearance was approved by ATC.
1157:16	The crew advised ATC that they were clear of weather and tracking to CHARR. ATC acknowledged the crew and provided descent instructions.
1201:29	ATC provided the crew with further descent instructions and advised the 'weather is Alpha' and the QNH was 992. The crew read back the descent instruction and QNH.
1201:46	ATC also advised the crew that the surface wind was 'easing off a bit', indicating 240° at 5 kt and that it had stopped raining at the field. The crew replied 'understood'.
1203-1204	The crew received several descent instructions from ATC, which were read back.
1204:54	The crew asked ATC for an update on the wind. ATC advised that it was 'easing back around to the south but indicating 220° at 5 kt'. The crew received further descent instructions.
1205:28	ATC advised the crew that the surface wind for the last 5 minutes had remained steady at 230° at 5 kt and the wind at 2,000 ft was 350° at 26 kt.
1205:42	The crew asked ATC if runway 20 was available. ATC advised that it wasn't available due to the works in progress at the northern end. Excavations were being conducted on that end and it wouldn't be available for a few hours 'so it's runway 29 or 02 with reduced length at the moment'.
1209:05	After receiving further descent instructions, ATC advised the crew that the surface wind was 200° at 3 kt and that it 'looks like it is going to light and variable'.
1211:12	ATC advised that the surface winds were now calm.
1213:23	ATC cleared the aircraft to land on runway 29.
1257:30	<i>The FO went to the Christchurch Control Tower and advised of the standing water at the end of runway 29.</i>

Air traffic control assessing runway surface conditions

The New Zealand Airways Manual of Air Traffic Services stated that, when information was not available from the aerodrome (airport) operator, air traffic service personnel should use their best judgement to describe the runway surface conditions. This included the centre half of the width of paved runways, and should be described as either of the following:

- damp: the surface shows a change of colour due to moisture

¹⁹ Cloud cover: in aviation, cloud cover is reported using words that denote the extent of the cover – 'broken' indicates that more than half to almost all the sky is covered.

- wet: the surface is soaked but there is no standing water
- water patches: significant patches of standing water are visible
- flooded: extensive standing water is visible.

The Manual further indicated that braking action reports²⁰ were only to be provided by the airport operator and/or pilots, and should include the type of aircraft reporting if known.

The operator of VOP established that ATC personnel at Christchurch would regularly seek advice from the airport operator regarding the runway surface conditions. It was unknown if such information was obtained by ATC prior to VOP landing.

Runway-in-use selection

The runway-in-use indicates the runway considered by ATC to be the most suitable for the aircraft types expected to be taking off and landing at that location. The Manual of Air Traffic Services specified that, when selecting the runway-in-use, controllers should take into account the traffic circuit patterns, the available runway length, position of the sun, the approach and landing aids available, and noise considerations.

When the winds were calm or light (less than 5 kt), the main prepared runway should normally be the runway-in-use. However, where doubt existed, the prevailing local wind conditions should be taken into account when establishing the preferred runway. If the runway-in-use was not considered suitable, a pilot may request an alternative.

Christchurch Airport information

Christchurch International Airport has two runways – runway 02/20 and 11/29 (Figure 7). Runway 02/20 was used for 93 per cent of all operations, while runway 11/29 was generally only used in north-westerly wind conditions. The captain, FO and Christchurch Tower controller also reported that runway 29 was infrequently used.

Runway 02/20, the main runway, was 3,288 m in length and had a grooved²¹ surface. A notice to airmen (NOTAM), valid for the aircraft's time of arrival, indicated works in progress (WIP) on the northern end of runway 02/20. This resulted in a reduced length of 1,920 m on runway 02, however, the full length was available with 60 minutes' prior notice to ATC. Runway 20 was closed for landing.

At the time of the incident, runway 29 was the runway-in-use. It was 1,703 m in length, had a 60 m clearway at the end, and was not grooved. The National Aeronautics Space Administration conducted a [comparative analysis of braking performance](#) for various aircraft types on grooved and non-grooved runway pavements. That testing showed that grooved runways provided substantially increased aircraft braking capability and directional control, improved runway surface water drainage and more rapid wheel spin-up rates. The runway has since been grooved and the length extended to 1,741 m, with a 60 m clearway.²²

The operator's supplementary port information for Christchurch highlighted that a portion of the manoeuvring²³ and apron²⁴ areas were not visible from the ATC tower.

²⁰ Braking action: a term used by pilots to characterise the deceleration associated with the wheel braking effort and directional controllability of the aircraft.

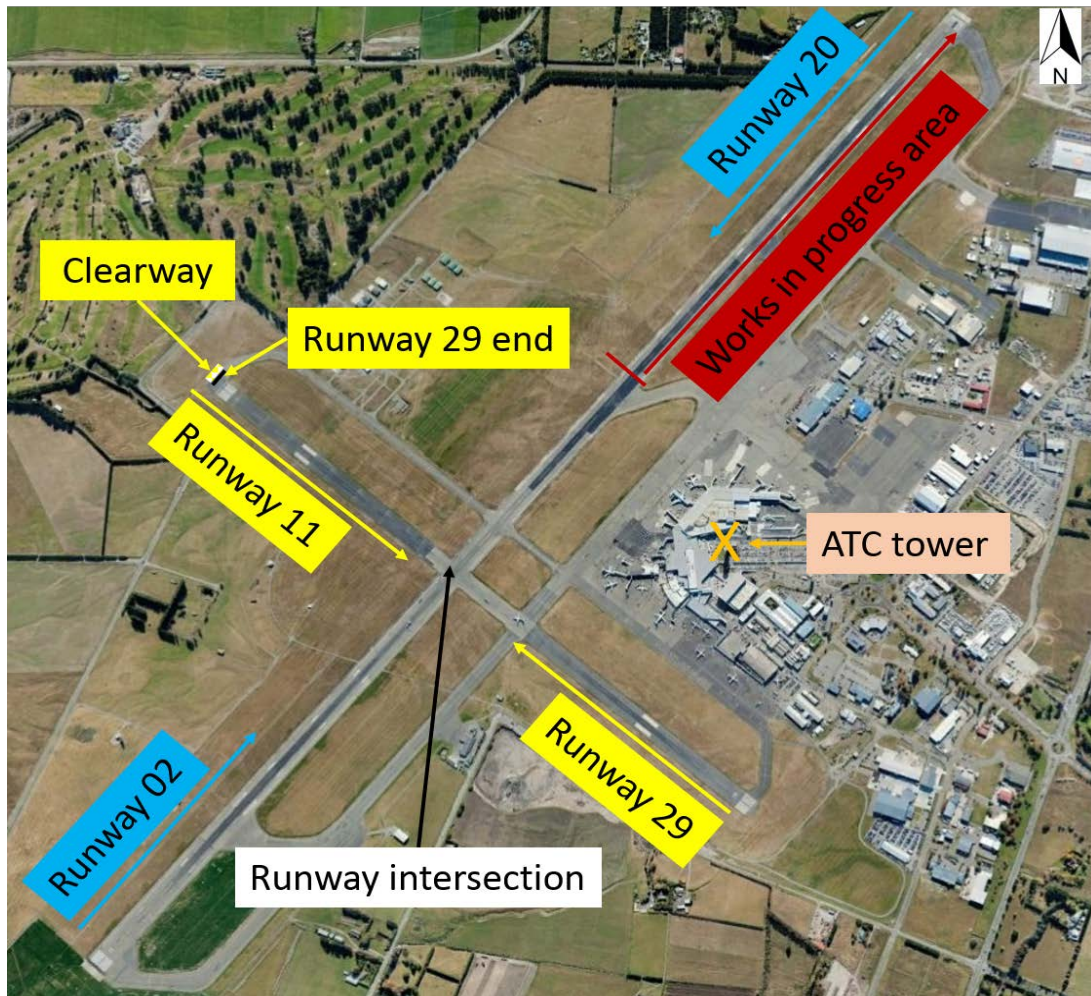
²¹ Lateral grooving is used to improve braking characteristics when wet.

²² Prior to the incident, the airport operator had scheduled to groove the runway later that year.

²³ Manoeuvring area: that part of an airport to be used for take-off, landing and taxiing of aircraft, excluding aprons.

²⁴ Apron area: a defined area on a land airport, intended to accommodate aircraft for purposes of loading or unloading passengers, mail, cargo, fuelling, parking or maintenance.

Figure 7: Christchurch Airport showing the runway directions and works in progress

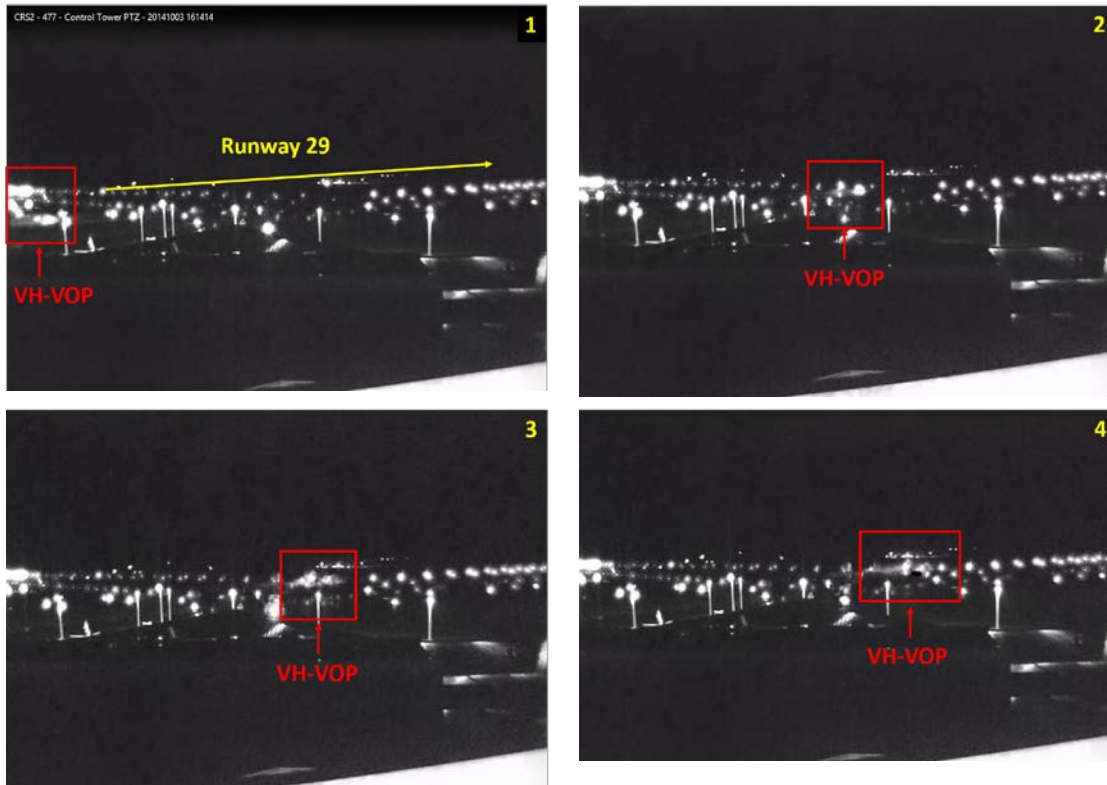


Source: Google earth, annotated by the ATSB

Closed-circuit television footage

Closed-circuit television (CCTV) from the terminal showed the aircraft landing on runway 29 (Figure 8 – frames 1 and 2). While the quality of that footage was limited, around or shortly after crossing the runway 02/20 and 11/29 intersection, there was a spray of water observed coming from the aircraft (Figure 8 - frames 3 and 4).

Figure 8: Screenshots of footage showing VH-VOP landing on runway 29



Images show the spray of water first visible in frame 3 and then more apparent in frame 4. Source: Christchurch International Airport Limited, annotated by the ATSB

CCTV footage of the apron area showed a reflective surface indicative of a ‘wet’ surface. The drainage characteristics of the apron were unknown, but they were unlikely to be the same as that for a runway. Therefore, it was not possible to establish if these conditions were representative of that present on runway 29 at the time.

Post-incident runway inspection

While an assessment of the runway condition was not done immediately following the incident, an inspection was conducted several days later. That inspection found that the runway intersection was relatively flat with a slight camber out from the centreline to the runway edges. There did not appear to be any wheel rutting or deformations in the runway surface that were conducive to the formation of standing water.

Rubber removal and Gilsonite application

In October 2014, rubber removal on runway 11/29 had been undertaken followed by the application of Gilsonite. At Christchurch Airport, about 66 per cent of the airside pavement surface is asphalt that rarely receives aircraft traffic loadings. This pavement deteriorates from environmental factors and is replaced about every 12-15 years due to embrittlement and cracking, which creates foreign object debris. The application of Gilsonite is a preservation agent that extends the life of the pavement surface. Upon application, there is an initial reduction in pavement friction before undergoing a curing process, which allows the friction values to progressively return to status quo.

Runway surface friction testing

New Zealand Civil Aviation Authority [Advisory Circular AC139-13](#) stated that the runway surface condition has a major impact on the safety of aircraft operations, particularly relating to landing performance. Airport operators are required to closely monitor runway friction levels to ensure they are kept at an acceptable level. To do this, operators should regularly conduct friction testing to build up an overview of the runway condition over a period of time to identify any deterioration.

The results of such testing are assessed based on the following levels, which determine the action to be taken.

- Design objective level - DOL: The friction level to be achieved or exceeded on a new or resurfaced runway within one year.
- Maintenance planning level - MPL: The friction level below which corrective maintenance action should be initiated.
- Minimum friction level - MFL: If the friction level is below the minimum friction level, maintenance should be arranged to restore the friction level and a NOTAM issued advising that the runway may be slippery when wet. If the friction level is significantly below, the airport operator should consider withdrawing the runway from use when wet.

Christchurch Airport tested both runways every 3 months using continuous friction measuring equipment²⁵ (GripTester).²⁶ This testing was conducted at both 3 m and 6 m from the runway centreline and at speeds of 65 km/h (35 kt) and 95 km/h (51 kt). The lower speed determines the overall mix of macro-texture and micro-texture/contaminant/drainage condition of the runway surface.²⁷ The higher speed provides a further indication of the surface's macro-texture.

Following the application of Gilsonite in October 2014, the friction testing results showed that a considerable portion of runway 11/29 was below the MPL. Follow-up testing conducted on 9 March 2015 showed a marked improvement. However, the last third of runway 29 (western end), from about 1,100 m onwards, was mostly below the MPL at both speeds. In response, the airport operator reported that they undertook a light water cut²⁸ of the centre section (16 m) of the last third (western) of runway 29 in June 2015. Despite this, there was no appreciable improvement in the runway friction levels. The operator of VOP reported that they were not aware of these results prior to the incident, although there was no requirement for airport operators to advise of such.

Although not applicable to these results, a NOTAM was issued after this incident for 26 June - 29 August 2015 stating that the eastern third of runway 11/29 may be slippery when wet. Subsequent to runway 11/29 being grooved in August-September 2015, testing showed that the majority of the runway was above the MPL and exceeded the design objective level in some areas.

Recorded information

Flight data recorder (FDR) analysis

The aircraft was fitted with a FDR and following the incident, the data was downloaded by the operator and provided to the ATSB. The aircraft's recorded data was also analysed by Boeing. The data showed the following (Figure 9):

- A stable approach²⁹ with flaps 40 was performed.
- There was a 5 kt tailwind and essentially zero crosswind just prior to touchdown.
- The flare³⁰ was initiated at a radio altitude of about 30 ft.
- The aircraft settled onto the right main landing gear immediately followed by the left main landing gear.

²⁵ A device designed to produce continuous measurement of runway friction values.

²⁶ www.findlayirvine.com/capabilities/skid/griptester.php

²⁷ Microtexture is the texture of the individual stones while macrotexture is the texture between the individual stones.

²⁸ The water cutting process involves the use of a very fine, concentrated stream of ultra-high pressure water to gently cut away any excess from the runway surface. With the excess removed, both surface texture and skid resistance are improved.

²⁹ Maintaining a stable speed, descent rate and vertical/lateral flight path in the landing configuration is commonly referred to as a stabilised approach.

³⁰ The final nose-up pitch of a landing aircraft used to reduce the rate of descent to about zero at touchdown.

- Initial touchdown occurred at a computed airspeed of 138 kt, which was 3 kt above the flap 40 landing reference speed of 135 kt (V_{REF40}).
- The aircraft's actual landing weight was 60,164 kg.
- The aircraft touched down within the touchdown zone. Based on the crew's report of the aircraft coming to rest about 5 m from the runway end, Boeing established that the aircraft touchdown point was about 920 ft (about 280 m) beyond the runway 29 threshold.
- Immediately after touchdown, the autobrakes engaged, and the speed brakes and thrust reversers deployed.
- With the autobrakes engaged, the AUTOBRAKE 3 target deceleration rate of 0.224 g was initially achieved and then exceeded to a maximum of 0.29 g.
- At a computed speed of about 79 kt, shortly after crossing the runway intersection, the autobrakes were disengaged and manual braking commenced. During the application of manual braking, the aircraft's deceleration reduced to below the AUTOBRAKE 3 target rate. The rate decreased despite the crew applying greater than AUTOBRAKE 3 pressure to override the autobrakes and the FO reported applying 'hard' braking with the captain assisting.³¹ Overall, the average deceleration from touchdown to the aircraft stopping was about 0.179 g. Refer to Appendix B for a graphical representation of the aircraft's deceleration during the landing.
- The commanded brake pressures during landing could not be verified as the alternate brake pressures were recorded instead of the main brake pressures (refer to section titled *Main landing gear brake pressure recording switch*).
- A minor directional deviation was observed during the later stages of the landing to maintain runway heading, consistent with that reported by the FO (Figure 9).
- Reverse thrust was reduced to idle when at a ground speed of about 20 kt. Reverse thrust was normally reduced when the aircraft's airspeed was about 60 kt.

Figure 9: Aircraft's ground path and recorded data after crossing the runway 11/29 and 02/20 intersection

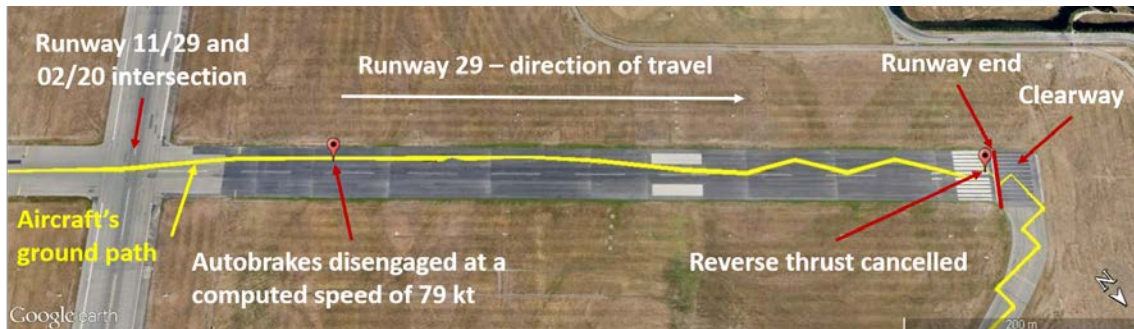


Image shows the aircraft's ground path (in yellow) and recorded data after crossing the runway 11/29 and 02/20 intersection (the zigzag yellow line on the last section of the runway was the result of flight data recording limitations). Source: Google earth, annotated by the ATSB

³¹ Boeing reported that the captain and FO brake pedals were mechanically linked and that applying force to the both sets of pedals was cumulative.

Boeing simulations

Boeing conducted simulations using the recorded data available in an attempt to characterise the amount of brake pressure applied and the runway conditions. While assumptions were made regarding the runway condition and commanded brake pressure, the results indicated that 'good' braking capability was initially achieved until the aircraft crossed the runway intersection. Between the intersection and the runway end, the aircraft's braking capability significantly reduced. Deceleration throughout the landing was initially consistent with the characteristics of a wet runway and then consistent with a flooded runway after crossing the runway intersection. Boeing further stated that, since runway 29 was not grooved, if standing water was present between the intersection and runway end, the aircraft's braking capability would have been reduced.

Operational information

Industry landing performance requirements and advice

Certified landing data and Civil Aviation Order 20.7.1B (June 2005)

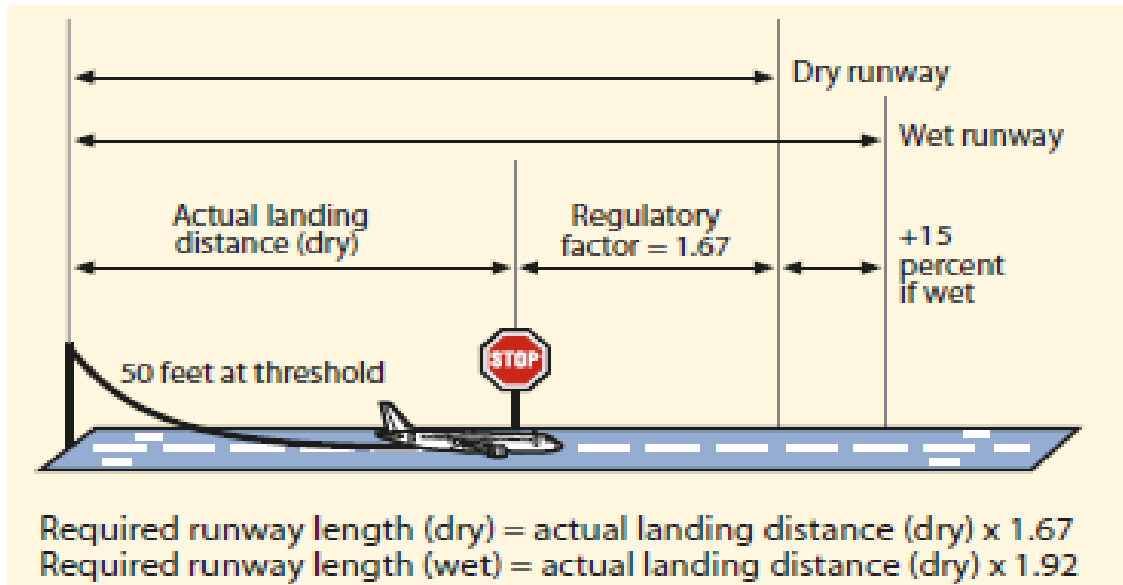
Certified landing data is used during pre-flight planning to establish the maximum take-off weight at which the aircraft can subsequently land within the available landing distance at the destination or alternate airport. This data is determined during aircraft certification under flight testing conditions and does not represent all operational situations, and excludes the use of reverse thrust. To take into account the differences between testing and normal operations, a safety margin of 1.67 and 1.92³² is applied to this data for a dry and wet runway respectively (Figure 10). The landing performance charts in the Virgin Australia Airlines (VAA) and Virgin Australia International (VAI) (collectively known as VAA VAI) Airport Analysis Manual (AAM) are derived from certified data.

Consequently, the Civil Aviation Safety Authority (CASA) Civil Aviation Order (CAO) 20.7.1B, section 11.1, issued in [June 2005](#), stipulated that the landing distance required for a jet-engine aircraft involved in regular public transport operations was either:

- when landing on a dry runway, 1.67 times the distance required to bring the aircraft to a stop on a dry runway
- when landing on a wet runway, 1.92 times the distance required to bring the aircraft to a stop on a dry runway or the distance set out in the flight manual or operations manual for operating on a wet runway.

³² The requirement for a wet runway is based on the distance computed to meet the dry requirement and then increased by a factor of 1.15.

Figure 10: Graphical representation of certified landing data and the safety margins for a dry and wet runway



Source: Flight Safety Foundation (2009b)

Southwest Airlines accident and FAA safety alert 06012

On 8 December 2005, a Southwest Airlines Boeing 737 ran off the end of runway 31 Centre after landing at Chicago Midway International Airport, Chicago, Illinois, United States (US). The US National Transportation Safety Board (NTSB) determined that the probable cause of the accident was the pilots’ failure to use available reverse thrust in a timely manner to safely slow or stop the aircraft after landing, which resulted in a runway overrun. Also found contributing was the operator’s failure to provide clear and consistent guidance on policies and procedures relating to arrival landing distance calculations, and a failure to include a safety margin in the arrival assessment to account for operational uncertainties. However, at the time, the FAA did not require or standardise arrival landing distance assessments nor specify safety margins for these assessments.

Following the accident, the FAA conducted an audit to evaluate the adequacy of the relevant regulations and guidance, which found:

- About 50 per cent of the operators surveyed did not have policies for assessing whether sufficient landing distance existed at the time of arrival, even when conditions were different and worse than those planned prior to departing.
- Not all operators who performed landing distance assessments had procedures that considered the runway surface conditions or reduced braking action reports.
- Many operators who performed landing distance assessments did not apply a safety margin to the expected actual landing distance; operators who did were inconsistent in applying an increasing safety margin as the expected actual landing distance increased.
- Some operators had developed their own contaminated runway landing performance data or were using data from third parties. In some cases, the data had been misused or was not updated with the aircraft manufacturer’s current data, or had shorter landing distances when compared with manufacturer data for the same conditions.
- Landing distances published in the Airplane Flight Manual were determined during flight testing and were not representative of normal operations (certified data). These flights were conducted by test pilots demonstrating the shortest landing distance for a given aircraft weight, with a -3.5° approach angle, high touchdown sink rates and the use of maximum manual braking. Therefore, the landing distances in the Manual were shorter than the landing distances normally achieved.

- Wet and contaminated landing distance data may not represent normal operations as it was typically computed using the dry, smooth, hard surface runway data established during certification. This, along with other factors that affect landing distances, were taken into consideration with the addition of a significant safety margin for pre-flight planning. However, the regulations did not specify a particular safety margin for arrival landing distance assessments and it was left largely to the operator and/or the crew to determine.
- Manufacturers did not provide standardised ‘advisory’ landing distance information. However, most turbojet manufacturers provided information for a range of runway or braking action conditions using varying deceleration devices and settings under a variety of meteorological conditions. This information was contained in a wide variety of documents, dependent on the manufacturer.

As a result of the NTSB’s investigation into the accident, they recommended that the FAA immediately require operators to conduct arrival landing distance assessments before every landing based on existing performance data, actual conditions, and incorporating a minimum safety margin of 15 per cent

Consequently, on 31 August 2006, the FAA issued a safety alert for operators (SAFO)³³ ([SAFO 06012 – Landing Performance Assessment at Time of Arrival \(Turbojets\)](#)). The SAFO stated:

This SAFO urgently recommends that operators of turbojet airplanes develop procedures for flightcrews to assess landing performance based on conditions actually existing at time of arrival, as distinct from conditions presumed at time of dispatch. Those conditions include weather, runway conditions, the airplane’s weight, and braking systems to be used. Once the actual landing distance is determined an additional safety margin of at least 15% should be added to that distance. Except under emergency conditions flightcrews should not attempt to land on runways that do not meet the assessment criteria and safety margins as specified in this SAFO.

The FAA indicated that the landing distance assessment should be conducted as close to the time-of-arrival, taking into consideration the crew’s workload, using the most up-to-date information. However, such an assessment did not need to be made before every landing, only when the conditions at the destination deteriorated while en route.

For the assessment, the 15 per cent safety margin should be added to the *actual landing distance*³⁴ and the resultant distance should be within the *landing distance available*.³⁵ The FAA considered this to be the minimum acceptable safety margin for normal operations. While the FAA recognised that the 15 per cent had not been substantiated, the margin was established based on historic links to the safety factor used for a wet/slippery runway for dispatch (pre-flight) landing requirements, which was already in existence.

Advisory landing data and Civil Aviation Order 20.7.1B (May 2014)

In response to the FAA SAFO 06012 recommendations, some manufacturers of jet-engine aircraft, including Boeing and Airbus, introduced actual landing distance information to assist pilots with making a more accurate in-flight assessment of the landing distance required. This information is classified as ‘advisory’ data and assumes the use of reverse thrust. It is designed to be used to determine a landing distance (actual landing distance) that can be realistically achieved taking into account the actual weather and runway conditions existing at the time-of-arrival, as distinct from the conditions prevailing during pre-flight planning. These conditions

³³ A SAFO is a safety information tool that alerts, educates, and makes recommendations. The content is particularly valuable to air carriers to assist in meeting their statutory duty to provide services with the highest possible degree of safety in the public interest.

³⁴ The landing distance for the reported meteorological and runway surface conditions, runway slope, airplane weight, airplane configuration, approach speed, use of autoland or a Head-up Guidance System, and ground deceleration devices planned to be used for the landing. It does not include any safety margin and represents the best performance the aircraft is capable of for the conditions (SAFO 06012).

³⁵ The length of the runway declared available for landing. This distance may be shorter than the full length of the runway (SAFO 06012).

include the reported braking action, braking systems to be used, aircraft weight, approach speed, altitude, runway slope, wind and temperature. Once the actual landing distance has been calculated, a safety margin of 15 per cent (1.15) is applied to determine the landing distance required.

In [May 2014](#), CASA amended CAO 20.7.1B to align the landing distance requirements for regular public transport jet-engine aircraft with a maximum take-off weight greater than 5,700 kg with international practice. This change provided a before take-off (using certified data) and in-flight landing distance determination (using either advisory or certified data):

- Before take-off: When landing on a dry runway, the landing distance required is 1.67 times the distance required to bring the aircraft to a stop on a dry runway; and when landing on a wet runway, 1.92 times the distance required, or the distance set out in the flight manual or operations manual for operating on a wet runway.
- In-flight: If actual landing distance data is supplied, the landing distance required is 1.15 times the actual landing distance. If this data is not available, the 1.67 and 1.92 before take-off safety margins apply.

At the time of the CAO change, CASA also published [Civil Aviation Advisory Publication 235-5\(0\)](#). The publication explained the amendment to the landing distance requirements and the inclusion of the 15 per cent in-flight safety margin. The purpose of the publication, similar to the FAA's SAFO, was to provide guidance and explanatory information about the meaning of the amended regulatory requirement, and describe methods to help comply with these requirements.

Boeing incorporates actual landing distance charts in the Performance In-flight section of the Quick Reference Handbook (QRH). Some operators have the 15 per cent safety margin incorporated into these charts, removing the need to manually apply the margin to the actual landing distance.

Inadequate 15 per cent safety margin and FAA SAFO 15009

In response to several landing events where the braking coefficient was found to be less than what was expected for a wet runway, the FAA issued SAFO 15009 in August 2015 (after this incident). The SAFO ([SAFO 15009](#), *Turbojet Braking Performance on Wet Runways*) warned operators and pilots of jet-engine (turbojet) aircraft that:

...advisory data for wet runway landings may not provide a safe stopping margin under all conditions.

While the FAA recognised that landing overruns on wet runways usually involved multiple contributing factors, an analysis of these events raised concerns regarding stopping performance assumptions. The cause of the underperformance was not fully understood, but the FAA cited possible factors relating to runway conditions including texture, drainage, puddling in wheel tracks and active precipitation. Specifically, the analysis showed that, 30-40 per cent of additional stopping distance may be required in certain cases where the runway was very wet, but not flooded. This indicated that:

...applying a 15% safety margin to wet runway time-of-arrival advisory data as, recommended by SAFO 06012, may be inadequate in certain wet runway conditions.

As a result of the above, the FAA suggested that operators should consider applying additional conservatism in their time-of-arrival assessment when either:

- active moderate to heavy precipitation existed on a non-grooved or non-porous friction course overlay runway
- active heavy precipitation existed on a grooved or porous friction course overlay runway.

Operator's landing performance procedures

Requirement to review landing performance

In February-March 2015, Virgin Australia New Zealand (VANZ) was incorporated into Virgin Australia International (VAI). The VAA VAI *Operating Policies and Procedures – General manual*

detailed the landing performance procedures for prior to take-off (prior to dispatch) and prior to arriving at the destination:

Prior to dispatch, the Pilot-in-Command (PIC) must ensure that the maximum performance landing weight limit is not exceeded in accordance with CAO 20.7.1B.³⁶

Prior to arrival, the PIC must review landing performance to determine that sufficient landing distance is available with adequate safety margin. This review should include consideration for:

- The runway of intended use
- The conditions existing at the estimated time of arrival
- The aircraft configuration and means of deceleration that will be used for landing.

An assessment of no change to the conditions since pre-dispatch landing weight limit calculation may constitute this review.

For diversion to an alternate, an assessment of landing weight and determination that sufficient landing distance is available with adequate safety margin shall be completed prior to arrival.

Cross-checking landing performance

For take-off, the *Operating Policies and Procedures – General* manual stated that crews must ensure that the environmental and load sheet information used to derive take-off performance data was cross-checked. Once that data was derived, the other pilot must independently cross-check the calculation by completing a full recalculation and verifying the base-line data used for the calculation and the final extracted figures. The other pilot must also independently verify the accuracy of the data entered into the flight management system. There was no such requirement for crews to independently cross-check landing performance information and the resulting calculation.

Sources to be used for landing performance

For the incident flight, the crew used the AAM to establish the aircraft's landing performance. At that time, the *VAA VAI Performance and Loading Manual (Boeing 737)* indicated that landing performance was to be determined by referencing the tabulated factored landing data prepared for each location in the AAM (Christchurch shown in Figure 11 below). However, when a non-normal condition occurred in-flight, the un-factored non-normal configuration landing distances for various runway surface conditions contained in the QRH (Figure 13 below) were to be used.

The crew of VOP had previously operated under VANZ, and indicated that during this time they had used the AAM in-flight to establish their landing performance and had used the QRH for determining non-normal landing distances in-flight and during simulator assessments. Prior to CAO 20.7.1B (May 2014), VAA and VAI crews were also using the AAM in-flight, however, the operator reported that they would also use the QRH (Figure 13 below) to plan a 'landing solution' in-flight.

Guidance regarding Civil Aviation Order 20.7.1B changes

Following the CAO 20.7.1B amendments, the operator received feedback from crews indicating the changes to in-flight landing performance requirements were ambiguous and that there were various interpretations as to how they could be applied. In response, the operator published an article (referred to as a 'Q and A') in September 2014 on the VAA and VAI intranet. The article provided guidance to crews on complying with the regulations and techniques for planning a suitable stopping solution. Specifically, the article highlighted the following:

- For pre-dispatch landing performance determination, refer to the factored figures provided in the AAM.

³⁶ Maximum performance landing weight limit: the maximum weight at which an aircraft can land on a specific runway for the given environmental conditions.

- For in-flight, the normal configuration landing distances in the QRH (Figure 13 below) should be consulted. The new requirement was to add a 15 per cent safety margin to the actual landing distance, taking into account the planned flap setting, autobrake selection and actual conditions. This equated to the landing distance required.
- If the landing distance required was in excess of the landing distance available, a higher autobrake setting should be used. If AUTOBRAKE 3 was not sufficient with the safety margin, but MAX AUTO or MAX MANUAL was, a suitable solution would be to plan to land with AUTOBRAKE 3 and override with manual braking. This was applicable if the landing distance required was ‘just outside’ the landing distance available. However, if it was ‘well above’, MAX AUTO should be used.
- The landing distances are predicated on touching down at 1,000 ft. A touch down beyond this point would rapidly compromise the 15 per cent safety margin, even if the aircraft landed within the touchdown zone.

The Q and A provided a mechanism for the operator to issue expanded standardisation guidance, in a timely manner, regarding the use of in-flight landing data under the amended CAO. This information was for educational purposes only; the techniques discussed were recommendations only and did not constitute policy. The captain and FO reported they were not aware of this particular Q and A prior to the occurrence.

The operator reported that the corresponding policy had not been updated at the time of the occurrence as they were still seeking clarification from CASA regarding the CAO requirements and waiting on additional data from Boeing.

VANZ to VAA VAI transition training on landing performance

As part of the VANZ transition to VAA VAI, the New Zealand crews were required to undergo additional training prior to operating Australian registered aircraft for VAA VAI. The crews participated in a two-day training course where they were advised of the landing performance requirements stipulated in the May 2014 version of CAO 20.7.1B. The crews were made aware of the dispatch and in-flight requirements. For dispatch, the maximum landing weight with the 1.67 and 1.92 safety margins was applied, as previously used by the crew. For in-flight, the dispatch maximum landing weight method could be used or the QRH landing distance data with a 15 per cent margin applied.

However, the training noted that using the QRH was a recent rule change and the corresponding update of the operator’s policy was still pending. Consequently, in the interim, crews were instructed to use the dispatch maximum landing weight found in the AAM (or the onboard performance tool (OPT)³⁷ when requested).

Landing performance calculations

While the crew used the AAM on the incident flight as required, a review of the aircraft’s landing performance for the flight was conducted referencing both the AAM and QRH. Each review considered the runway and weather conditions used by the crew, the conditions reported on the current ATIS (A), and the actual wind information established from the FDR (refer to section titled *Recorded information – Flight data recorder analysis*).

Airport Analysis Manual (AAM) – Landing performance limit weight

The VAA VAI AAM landing performance charts are provided for specific airports and flap settings (refer to Appendix C for an example of the AAM chart). These charts are presented in a cross-tabulation³⁸ format where, based on the runway-in-use, variables such as the wind and

³⁷ The OPT was available through the Flight Operations Department to provide crews with an accurate calculation of aircraft performance parameters. The use of the OPT was restricted to situations where payload for a specific flight was significantly affected by aircraft performance limitations or for operation at destinations not covered by the AAM (VAA VAI Performance and Loading Manual).

³⁸ Cross-tabulation allows for a comparison of the relationship between two variables.

runway surface conditions are used to establish the landing limit weight. The aircraft is only permitted to land provided the actual landing weight does not exceed the weight stipulated on the chart, unless a higher emergency exists. The crew then determine what level of braking is suitable for the landing. The Christchurch runway 29 landing chart for 40 flap was referenced by the crew (Figure 11).

Figure 11: AAM extract for runway 29 at Christchurch Airport³⁹

MAXIMUM CERTIFIED LANDING WEIGHT (MLW) = 66.3 (1000 KG)											
TEMP (C) -10 0 10 20 30 40 50											
CLIMB WT 81.9 81.8 81.6 81.3 80.8 74.0 67.6											
ANTI-ICE PENALTIES LESS THAN 10C SUBTRACT 0.2 ENG ONLY, 1.1 ENG+WING											
ANTICIPATED ICE ACCRETION CORRECTION LESS THAN 10C SUBTRACT 7.2											
RUNWAY LENGTH SLOPE	WIND kt	ANTI-SKID OPERATIONAL						ANTISKD INOP		QUICK TURN ARND	
		AUTO-SPOIL			MAN SPOIL			MAN DRY	SPOIL WET	CRTP	SUB
29 1703M 0.36%UP	TW 15	53.5	NA	43.5	49.4	NA	NA	NA	NA	MLW	
	TW 10	58.3	NA	48.9	55.0	NA	45.0	NA	NA	MLW	
	TW 5	63.0	NA	54.4	59.6	NA	50.4	NA	NA	MLW	
	0	68.2	NA	59.1	64.5	NA	55.8	NA	NA	MLW	
	HW 5	70.1	NA	60.7	66.2	NA	57.4	NA	NA	MLW	
	HW 10	72.1	NA	62.3	68.2	NA	58.9	NA	NA	MLW	

Wind information
 Dry runway landing limit weights
 Wet runway landing limit weights

Image shows the AAM extract for runway 29 at Christchurch Airport with 40 flap, highlighting (in red) the wind information and landing limit weights for a dry and wet runway. Source: Virgin Australia Airlines, annotated by the ATSB

Based on the conditions used by the crew (dry (damp) runway surface and nil wind), the resulting AAM landing limit weight was 68.2 t, which was above the aircraft’s maximum structural landing weight of 66.3 t. This was also 8.1 t above the aircraft’s actual estimated landing weight of 60.1 t, and therefore, considered suitable for landing. Similarly, with a 3 kt headwind and 5 kt tailwind determined from the ATIS (reported) and the FDR (actual) respectively, the aircraft was also able to land on a dry runway. However, for a wet runway surface, the aircraft was not certified to land under any of these conditions. With nil wind, the aircraft was about 1 T above the landing limit weight and with a 5 kt tailwind, it was about 5.7 kt too heavy (Table 12).

Table 12: Comparison of AAM landing limit weight between the conditions used by the crew, and for the reported and actual wind conditions

Runway surface	Landing limit weight (t)		
	ATIS A reported conditions (3 kt headwind) ⁴⁰	Conditions used by the crew (nil wind)	Actual conditions determined from the FDR (5 kt tailwind)
Dry	69.34	68.2	63.0
Wet	60.06	59.1	54.4

VOP’s landing weight was 60,164 kg (about 60.2 t)

The AAM provides crews with the knowledge of whether or not the aircraft can land on a particular runway in the current conditions and with the expected landing weight. However, the crew still need to determine the appropriate level of braking to ensure the aircraft can safely land on the

³⁹ Refer to section titled *Runway surface conditions and braking action reports – Runway surface conditions*.

⁴⁰ The wind in the AAM is presented in 5 kt increments (0, 5, 10, 15 kt). Therefore, the landing limit weight for the headwind component determined from ATIS A was interpolated in this case.

available runway length. This is achieved through crew experience and training. The Boeing 737 NG Flight Crew Training Manual stated that:

For normal operation of the autobrake system select a deceleration setting.

Settings include:

- MAX: Used when minimum stopping distance is required. Deceleration rate is less than that produced by full manual braking
- 3: Should be used for wet or slippery runways or when landing rollout distance is limited. If adequate rollout distance is available, autobrake setting 2 may be appropriate
- 1 or 2: These settings provide a moderate deceleration suitable for all routine operations.

Experience with various runway conditions and the related airplane handling characteristics provide initial guidance for the level of deceleration to be selected...

...If stopping distance is not assured with autobrakes engaged, the PF [pilot flying] should immediately apply manual braking sufficient to assure deceleration to a safe taxi speed within the remaining runway.

Quick Reference Handbook (QRH) – Actual landing distance

The QRH normal configuration landing distance chart (Figure 13 and Appendix D) is used to calculate the aircraft's (predicted) actual landing distance based on a level of reported braking action and autobrake setting. To do this, crews calculate an adjustment for up to seven variables (aircraft weight (WT ADJ), altitude (ALT ADJ), wind (WIND ADJ), runway slope (SLOPE ADJ), temperature (TEMP ADJ), approach speed (APP SPD ADJ) and partial/nil reverse thrust if applicable (REVERSE THRUST ADJ). Each adjustment is then added or subtracted to a baseline reference distance (REF DIST – this distance includes an air distance allowance of 305 m (1,000 ft).⁴¹ The resulting calculation predicts the actual landing distance. Effectively, the QRH provides what is considered a 'landing solution' as it takes into account all the necessary variables to determine an aircraft's landing performance.

In some cases, the 15 per cent in-flight safety margin is incorporated into this chart. However, if this is not the case, the safety margin is then added to the calculated actual landing distance to establish the landing distance required. At the time of the incident, the operator's QRH chart did not include the safety margin and no such guidance was included on the version of the chart used by the VAA VAI crews.

In addition, there was no specific guidance provided to the operator's crews on whether the adjustments were to be exact (interpolated) or rounded to the nearest conservative value. Boeing indicated to the ATSB that they did not promote any particular calculation technique, allowing operators to make that determination based on the knowledge of their crews and operating environment. While Boeing considered interpolation acceptable, they would suggest rounding up in terms of weights and speeds, and being conservative, so not to induce errors.

⁴¹ Air distance: The distance from when an aircraft is 50 ft above the runway threshold to touchdown.

Figure 13: QRH normal configuration landing distances with 40 flap for ‘good’ reported braking action

ADVISORY INFORMATION

**Normal Configuration Landing Distance
Flaps 40**

	LANDING DISTANCE AND ADJUSTMENTS (M)								
	REF DIST	WT ADJ	ALT ADJ	WIND ADJ	SLOPE ADJ	TEMP ADJ	APP SPD ADJ	REVERSE THRUST ADJ	
BRAKING CONFIGURATION	65000 KG LANDING WEIGHT	PER 5000 KG ABV/BLW 65000 KG	PER 1000 FT STD/HIGH*	PER 10 KTS HEAD/ TAIL WIND	PER 1% DOWN/ UP HILL	PER 10°C ABV/ BLW ISA	PER 5 KTS ABOVE VREF40	ONE REV	NO REV

Good Reported Braking Action

MAX MANUAL	1270	70/-75	35/45	-55/200	35/-30	30/-30	50	65	140
AUTOBRAKE MAX	1350	75/-80	35/45	-60/205	30/-25	35/-35	60	70	150
AUTOBRAKE 3	1600	85/-100	40/55	-70/240	10/-5	45/-45	95	5	15
AUTOBRAKE 2	2030	125/-140	60/80	-95/330	20/-35	60/-60	95	35	35
AUTOBRAKE 1	2260	150/-165	75/95	-115/390	55/-65	65/-65	85	155	220

Source: Virgin Australia Airlines

The ATSB used the normal configuration QRH landing distance chart for flaps 40 to calculate the predicted *actual* landing distance (without a 15 per cent safety margin) and the landing distance *required* (incorporating a 15 per cent safety margin) for VOP (Table 14). The calculations took into account varying autobrake configurations, approach speed additives, and the surface wind conditions used by the crew, and the reported (ATIS) and actual (FDR) wind conditions. Table 14 shows the landing performance calculations for both dry and wet runways. While there were no reports of braking action, ‘good’ reported braking action⁴² reported braking action was used for the wet runway calculations. To establish the most precise distances, the adjustments were interpolated. Specifically, the calculations showed:

- **Conditions used by the crew (orange):** The crew planned the landing using a dry runway, AUTOBRAKE 3, nil wind and $V_{REF} + 5$ kt (approach speed). The QRH calculated actual landing distance using these conditions was about 123 m shorter than the landing distance that was available for runway 29. However, if the 15 per cent safety margin was applied, the landing distance required would have exceeded the landing distance available, requiring the use of a higher braking selection. If the wet (‘good’ reported braking action) data was used, the landing distance required increased by about 15 m.
- **Reported conditions (green):** For a wet (‘good’ reported braking action) runway with AUTOBRAKE 3, $V_{REF} + 5$ kt and the 3 kt headwind reported by the ATIS the calculated actual landing distance was about 131 m shorter than the landing distance available. If the 15 per cent safety margin was applied, the landing distance required exceeded the landing distance available by about 104 m.
- **Actual conditions (blue):** For a wet (‘good’ reported braking action) runway with AUTOBRAKE 3, $V_{REF} + 5$ kt, and the unreported 5 kt tailwind (later determined from the FDR), the calculated actual landing distance was about 5 m greater than the landing distance available. If the 15 per cent safety margin was applied, the landing distance required exceeded the landing distance available by about 261 m.

⁴² ‘Good’ reported braking action is comparative and is intended to mean that aircraft should not experience braking or directional difficulties when landing. The performance level used to calculate the ‘good’ data is consistent with wet runway testing done on early Boeing aircraft (Boeing 737, Flight Crew Operations Manual – Performance inflight – Advisory information – Normal configuration landing distance).

The FDR analysis determined that the aircraft landed with an airspeed of $V_{REF} + 3$ kt and an actual air distance of about 280 m (2 kt slower and 25 m less than the QRH assumptions respectively). For the actual conditions, these should have resulted in an actual landing distance about 58 m less than the landing distance available. However, the average deceleration achieved from 138 kt at touchdown to the aircraft being stopped about 1,418 m later was about 0.179 g. AUTOBRAKE 3 performance is predicated on 0.224 g deceleration. Therefore, despite initially exceed AUTOBRAKE 3 performance and the later application of firm manual braking, the overall landing performance achieved on the wet runway was less than what would have normally been achieved with AUTOBRAKE 3. If the 15 per cent safety margin was applied, the calculated landing distance required would have exceeded the landing distance available by about 189 m.

Overall, under all of the above conditions, to meet the landing distance requirements stipulated in CAO 20.7.1B, AUTOBRAKE MAX or MAX MANUAL braking would have been required. As shown in Table 14 (black text), the landing distance required was within the runway length available on either a wet (with good reported braking action) or dry runway.

Table 14: Comparison of QRH actual landing distances for a dry and wet ('good' reported braking action) runway

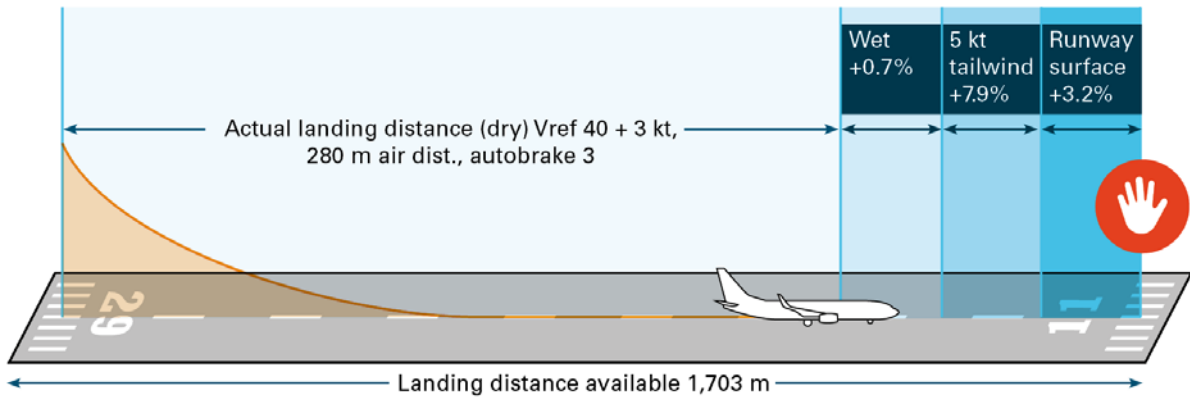
Brake configuration	Wind (kt)	Speed above V_{REF40} (kt)	Actual landing distance (m)	Safety margin	Landing distance required (m)
Dry reported braking action					
AUTOBRAKE 3	0 kt	+5	1,579.20	15%	1,816.08
AUTOBRAKE MAX	0 kt	+5	1,130.04	15%	1,229.55
MAX MANUAL	0 kt	+5	896.60	15%	1,031.09
Wet runway with good reported braking action					
AUTOBRAKE 3	3 kt head	+5	1,571.45	15%	1,807.17
	0 kt	+5	1,592.45	15%	1,831.32
	5 kt tail	+5	1,707.95	15%	1,964.14
(actual air distance of 280 m)	5 kt tail	+3	1,644.95	15%	1,891.69
AUTOBRAKE MAX	3 kt head	+5	1,303.18	15%	1,498.66
	5 kt tail	+5	1,424.18	15%	1,637.81
MAX MANUAL	3 kt head	+5	1,218.77	15%	1,401.58
	5 kt tail	+5	1,335.27	15%	1,535.55
Runway 29 landing distance available was 1,703 m					

Table shows a comparison of the QRH actual landing distances for a dry and wet ('good' reported braking action) runway with varying brake selections for the conditions used by the crew (nil wind), and the reported (3 kt headwind) and actual (5 kt tailwind) conditions, and the corresponding landing distance required.

Environmental effects on the actual landing distance

As previously discussed, the crew were of the understanding that there was nil wind and the runway was damp (dry). The ATIS current at the time of landing indicated that the runway was wet and there was a 3 kt headwind, but Boeing later determined that there was a 5 kt tailwind. While the difference in wind component between the ATIS and that established by Boeing could not be resolved, environmental factors can have a significant effect on aircraft landing performance. In this case, as shown in Figure 15, the wet runway and 5 kt tailwind accounted for a 0.7 and 7.9 per cent increase respectively in the actual landing distance. The remaining distance between this, and when VOP was stopped, was attributable to the additional effects of the runway surface conditions (3.2 per cent). Combined, these environmental conditions resulted in about a 12 per cent increase to the actual landing distance.

Figure 15: Effect of environmental conditions on the actual landing distance (not to scale)



Source: ATSB

Underestimated conditions and effect on safety margins

The International Civil Aviation Organization (ICAO) has recognised that information provided by personnel assessing and reporting runway surface conditions is crucial to the effectiveness of runway condition reporting.

A misreported runway condition alone should not lead to an accident or incident. Operational margins should cover for a reasonable error in the assessment, including unreported changes in the runway condition. But a misreported runway condition can mean that the margins are no longer available to cover for other operational variance (such as unexpected tailwind, high and fast approach above threshold or long flare).⁴³

To gain an appreciation of when the 15 per cent in-flight safety margin may be inadequate, the ATSB compared the QRH landing distances for varying brake settings. Specifically, this was done to examine the potential reduction in the safety margin when the runway condition (reported braking action) was underestimated.

If the runway conditions were reported ‘dry’ and this was used to calculate the QRH landing distance, when in fact the conditions were wet ‘good’ reported braking action,⁴⁴ for AUTOBRAKE 3, the difference would be negligible (less than 1 per cent). However, if AUTOBRAKE MAX or MAX MANUAL braking were used, the landing distance for the actual conditions would be 18 per cent or 38 per cent (respectively) greater than the landing distance calculated for the reported conditions (Figure 16). Similarly, if the conditions were reported wet ‘good’ reported braking action but were actually wet ‘medium’ reported braking action, for AUTOBRAKE 3, the difference would be about a 12 per cent increase. For AUTOBRAKE MAX and MAX MANUAL braking, the difference would be an increase of at least 27 per cent and 34 per cent respectively.

⁴³ Letter to signatory States dated 5 April 2016, regarding the adoption of amendment 13 to Annex 14, *International Standards and Recommended Practices, Aerodromes — Aerodrome Design and Operations*.

⁴⁴ Refer to Appendix E for the assessment criteria and definitions for the varying runway surface conditions and pilot braking action reports.

Figure 16: Comparison of QRH landing distances when the runway conditions are underestimated

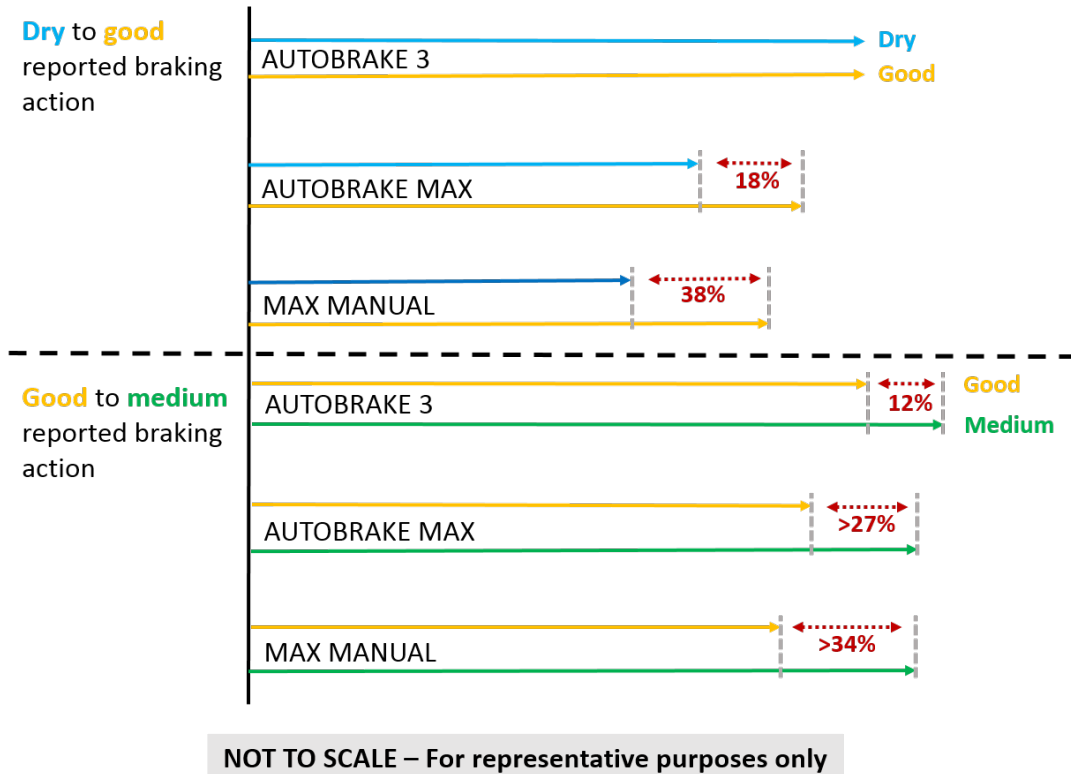


Image shows a comparison of QRH landing distances when the runway conditions are underestimated between 'dry' to 'good' and 'good' to 'medium' reported braking action. Source: ATSB

Electronic devices for performance calculations

Boeing recognised that using charts (AAM and QRH) to establish landing performance continue to be a viable option. However, the use of electronic devices such as the Boeing OPT was encouraged. A tool such as OPT allows crews to perform real-time, precise extraction of data based on current weather and runway conditions, without the need for complex calculations and extensive guidance.

Similarly, the International Air Transport Association has also recognised that operators must provide performance data to enable crews to operate aircraft safely, economically and in accordance with applicable rules and practices. To assist with this, the International Air Transport Association has developed the standardised computerised aircraft performance tool, which allows performance calculations to be generated electronically using an iPad.

Runway surface conditions and braking action reports

Information regarding runway conditions are normally available from three sources:

- a description of the runway surface condition by either air traffic control, pilots and/or airport personnel
- pilot braking action reports
- readings from runway friction measuring devices as used by airport personnel.

While extensive research has been conducted to establish a correlation between runway friction measuring device readings and aircraft braking friction capability, the results have been inconclusive (FAA, 2016). Consequently, the following will focus on the first two sources of information.

Runway surface conditions

The VAA VAI Performance and Loading Manual (Boeing 737), effective from February 2015, defined runway surface conditions as either dry, damp, wet or contaminated. Specifically, a damp runway was:

A runway surface that is not dry, but has insufficient moisture to make it appear reflective. A damp runway shall be considered a wet runway.

However, during the incorporation of VANZ into VAI, this definition was changed due to operational requirements with flying into some locations in New Zealand. Further, the operator indicated that there was no guidance on damp runways in CAO 20.7.1B, but the change was consistent with the European Aviation Safety Agency (EASA) definition detail below. Subsequently, a flight crew operating notice was also issued in February 2015 and stated that:

A runway is considered damp when the surface is not dry, but when moisture on it does not give it a shiny appearance. For performance purposes, a damp runway may be considered to be dry.

The amended definition was consistent with the crew's understanding of how a damp runway was classified and treated for performance purposes at the time of the incident. The Manual was later amended to reflect this change.

Broadly, the term 'damp' to describe runway surface conditions is used inconsistently. In Australia, CASA considers a runway to be either, dry, wet or contaminated; they do not use the term damp. However, Airservices Australia use the terms, damp, wet, water patches and flooded. Internationally, ICAO defines runway surface conditions as:

- dry, wet or contaminated (Annex 6 – Operation of Aircraft)
- damp, wet or standing water (Doc 4444 – Air Traffic Management; Annex 14 – Aerodromes)
- damp, wet, water patches or flooded (Doc 9137 – Airport Services Manual)

Larger aircraft manufacturers provide performance and limitation data for dry and wet runway surface conditions, but not damp. Consequently, and unless otherwise directed, operators determine how a damp runway should be treated for performance purposes. As detailed above for VAA VAI, prior to the VANZ transition, a damp runway was considered wet, but after, it was considered dry. At the time of the incident, the EASA also stated that a damp runway, other than a grass runway, may be considered to be dry. An informal review of other Australian operators found that the term damp was applied inconsistently.

A CASA subject matter expert indicated to the ATSB that they would consider a damp runway to be wet for performance purposes. Similarly, Boeing and the FAA (refer to section titled *Operational information - Runway surface conditions and braking action reports - Achieving standardisation*) also considered a damp runway to be wet. The International Federation of Air Line Pilots' Association [Runway Safety Manual](#) quoted the Joint Aviation Authorities, which stated that evidence had become available, which established that a damp runway did not provide an equivalent braking surface as a dry runway. This was further highlighted by the United Kingdom Civil Aviation Authority ([Civil Aviation Publication 789 Requirements and Guidance Material for Operators – The Use of Performance Data Appropriate to the Existing Runway Conditions](#)):

Operators should be aware of the importance of using the performance data appropriate to the existing runway conditions...It is not sufficient for a runway to be considered, for performance purposes, as dry when it is wet solely on the basis that it is constructed with, for example, grooves or porous friction course pavement...Although a runway may have a grooved or porous surface, it may not be possible to demonstrate that it retains an 'effectively dry' braking action when wet. This may be because the type of surface is inherently not physically capable of retaining dry braking friction characteristics in the presence of sufficient moisture to be termed 'wet'.

Braking action reports

Similar to that observed with runway surface conditions, the terminology used by pilots to describe the braking characteristics of an aircraft varies amongst organisations. For example, the Airservices Australia Aeronautical Information Package and Boeing 737 flight crew operating

manual use the terms ‘good, medium or poor’, while ICAO use the terms ‘good, medium-good, medium, medium-good and poor’. Until recently, the FAA also used the term ‘fair’.

Subjective assessment and inconsistent terminology

A BMT Fleet Technology presentation to the European Aviation Safety Agency *Runway Friction and Aircraft Braking – The way forward* Workshop in March 2010 highlighted the limitations associated with assessing runway surface conditions. Specifically, the visibility of the surface conditions may be affected by visual field of range, ambient visibility (precipitation, illumination of the surface at night, fog/freezing fog), depth perception, contaminant feature contrast (low light reducing shadows, bright sunlight creating glare, contaminant reflectivity), and eyesight.

Similarly, the FAA SAFO 06012 highlighted that runway surface conditions may be reported using several types of descriptive terms and that pilot braking action reports were subjective.

Specifically, the possibility of two pilots operating identical aircraft under the same conditions reporting a different level of braking action. This may be attributed to specific differences between the aircraft, the aircraft’s weight, pilot technique used for landing, or the pilot’s experience and expectations. The assessment of an aircraft’s braking capability relies on pilot judgement.

The subjective nature and inconsistent terminology used to describe runway surface conditions and reported braking assessments has been widely recognised by industry.

Firstly, the [FAA](#) (2015b) outlined the reliance on pilots for assessing conditions:

Pilot-reported braking action is a subjective assessment of runway slipperiness. The pilot bases the assessment on observations of braking deceleration and directional controllability during landing rollout.

The [International Air Transport Association](#) (2011) highlighted the lack of standard definitions and practices:

The runway surface condition at airports is a critical safety concern...water on runways can have a significant impact on aircraft performance...braking action is an area where there is little standardization between pilots, industry and regulators...There are many different definitions of these terms, and their use may lead flight crews into believing that a runway is safe to use for their aircraft when it may not actually be safe; miscalculating the landing rollout length; or configuring the aircraft incorrectly for landing.

[Comfort and others](#) (2010) outlined some of the inherent challenges in assessing conditions:

...challenges with the accuracy of friction measurement...surface contaminants are visually assessed, not measured...human factors affect RCR [runway condition reporting] accuracy... terminology used to describe runway conditions by RIs [runway inspectors] is not standardised...runway state (dry, wet, contaminated) and condition descriptions used to describe aeroplane TaLP [take-off and landing performance] are not standardized or harmonized...

The [International Federation of Air Line Pilots’ Association](#) (2009) emphasised the need for standardised runway condition reporting:

To enhance the safety of operations it is clear that crews of arriving aircraft have an understanding of the prevailing conditions at an airport and more importantly can gain an expectation of how their aircraft is likely to handle. For this to happen there must be a harmonised system of runway condition reporting. At present there is a lack of harmonisation of the runway state definitions of the various regulatory bodies...Specifically, there is a disconnect between the treatment of grooved/PFC [porous friction course overlay] runways in JAR-OPS and scientific research into dry, damp and wet runway states.

In a previous research report, the [ATSB](#) (2009) highlighted the lack of standardisation in defining braking conditions:

Definitions of braking actions are another area where there is little standardisation between pilots, industry and regulators...Less than adequate runway condition information in heavy precipitation is a safety issue and a potential contributing factor to runway excursion accidents. Where this information does exist, it is often conflicting (reported by multiple sources), generic (uses general terms), misleading (only applicable to certain aircraft types), or outdated (due to the dynamic nature of

weather)...On wet runways, there is generally little information available to flight crews on the depth of any standing water on the runway.

The [National Academies of Sciences, Engineering, and Medicine](#) (2008) also highlighted the ambiguity of runway condition reporting and lack of industry standardisation:

The measurement of certain parameters suffer from inherent ambiguity in the aviation industry. A prime example is runway condition. There simply has not been an agreed industry standard on reporting runway conditions and determining its relationship with runway friction and aircraft braking performance...The current industry approach is to measure and report runway friction periodically using standard equipment and wet surface conditions. However, it also is common practice to rely on pilots' subjective reporting, particularly for contaminated runways.

[Johnsen](#) (2007) emphasised the risks of basing braking action on pilot assessments alone:

The pilot's assessment of braking action is a personal judgment that is influenced by a number of factors; given the same conditions and aircraft, two pilots likely will judge the conditions differently. Various factors affect the pilot's perception. Braking action on a long runway, for example, might be perceived as better than braking action on a shorter, marginal runway where the end seems to approach substantially faster.

[Giesman](#) (2005) specifically highlighted the subjectiveness of the term 'damp':

Damp runway...friction was reduced compared to dry...friction may be better than wet...subjective term...

The [Flight Safety Foundation](#) (date unknown) also outlined the risks posed by pilot subjectivity and other factors:

Pilot braking action reports can be affected by the reporting crew's experience and the equipment they are operating...Pilot braking action reports generally are the most recent information available and therefore provide information about changing runway conditions. However, pilot reports are subjective. The pilot of a small airplane may perceive different braking conditions than the pilot of a large airplane. The braking action assessment also can be influenced by the airplane's weight, approach speed, amount of wheel braking applied and the location on the runway where the highest amount of wheel braking is used.

The CASA subject matter expert, who was also a member of the ICAO Flight Operations Panel, advised the ATSB that the terminologies used to describe braking action were not standardised. It would be difficult to achieve standard reporting as it was reliant on how the pilot assessed the landing and the technique used, which was subjective. However, the officer indicated that, in the future, ICAO will require pilots to make braking action reports and they will be provided with guidance material to assist with reporting. Further, if an aircraft had not recently landed, air traffic control would be required to make a subjective assessment of whether the runway was dry, damp or wet.

The deficiencies and limitations for assessing and reporting runway surface conditions using the existing methods were also highlighted in the FAA report (Subbotin and Gardner, 2013) [Takeoff and Landing Performance Assessment Validation Effort of the Runway Condition Assessment Matrix](#) (refer to section titled *Operational information - Runway surface conditions and braking action reports - Achieving standardisation*). These included:

- pilot reports were too subjective in nature
- standard definitions of pilot report terms did not exist
- training and guidance was not given to pilots on how or when to report braking action
- there was no correlation between pilot reports from different aircraft types
- most aircraft manufacturers did not provide performance data in terms of braking action
- friction-measuring devices could only be operated on certain runway surface conditions and there was a lack of repeatable readings on consecutive measurements

- there was no correlation between runway coefficient of friction (μ)⁴⁵ and aircraft braking performance
- there were various terms and definitions used to describe runway surface contaminants
- inconsistent or lack of reporting accurate contaminant depth on a runway made it difficult to determine aircraft performance degradation.

Achieving standardisation

Following the 2005 Southwest Airlines overrun accident, the FAA found that industry practices did not have adequate guidance and regulations addressing operations on non-dry, non-wet runways. As a result, the FAA formed the takeoff and landing performance assessment aviation rulemaking committee (known as [TALPA ARC](#)) to make recommendations on improving the safety of operations on wet or contaminated runways. Most notably, the committee found that (Subbotin & Gardner, 2013):

...there was a lack of a standard means to assess and communicate actual runway conditions at the time of arrival, particularly when conditions have changed, in terms that directly relate to aircraft landing performance.

The committee’s primary recommendations were to use a runway condition assessment matrix (RCAM – Figure 17 and Appendix E) and to ensure the use of common terminology by those involved in the process of determining and reporting runway surface conditions and their effect on aircraft performance. The matrix provided a methodology for communicating actual runway conditions to pilots based on expected aircraft performance. Of note, the matrix considered a damp runway to be wet.

The matrix also provided criteria relating to control and braking. For example, ‘good’ reported braking action was defined as, braking deceleration was normal for the amount of braking applied and directional control was normal. For ‘medium’ reported braking action, braking deceleration was noticeably reduced for the amount of braking applied and directional control was also noticeably reduced.

⁴⁵ Coefficient of friction: a dimensionless ratio of the friction force between two bodies to the normal force pressing these two bodies together.

Figure 17: RCAM extract

Assessment Criteria		Control/Braking Assessment Criteria	
Runway Condition Description	RwyCC	Deceleration or Directional Control Observation	Pilot Reported Braking Action
<ul style="list-style-type: none"> Dry 	6	---	---
<ul style="list-style-type: none"> Frost Wet (Includes damp and 1/8 inch depth or less of water) <p>1/8 inch (3mm) depth or less of:</p> <ul style="list-style-type: none"> Slush Dry Snow Wet Snow 	5	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
<p>-15°C and Colder outside air temperature:</p> <ul style="list-style-type: none"> Compacted Snow 	4	Braking deceleration OR directional control is between Good and Medium.	Good to Medium
<ul style="list-style-type: none"> Slippery When Wet (wet runway) Dry Snow or Wet Snow (any depth) over Compacted Snow <p>Greater than 1/8 inch (3 mm) depth of:</p> <ul style="list-style-type: none"> Dry Snow Wet Snow <p>Warmer than -15°C outside air temperature:</p> <ul style="list-style-type: none"> Compacted Snow 	3	Braking deceleration is noticeably reduced for the wheel braking effort applied OR directional control is noticeably reduced.	Medium

Source: FAA

In 2009, a validation effort to assess the RCAM was commenced and the results were documented in the report [Takeoff and Landing Performance Assessment Validation Effort of the Runway Condition Assessment Matrix](#). This process involved validating the correlation between the matrix surface condition descriptions and pilot braking action reports, and determining the useability of the matrix for airport operators and pilots. Based on the results of the validation efforts, it was recommended that the FAA implement the RCAM.

In August 2016, the FAA notified operators, pilots, training providers and other personnel that they would be implementing the RCAM in the US, effective from 1 October 2016 ([SAFO 16009 – Runway assessment and condition reporting](#)). The matrix would be used by airport operators to perform assessments of runway conditions and by pilots to interpret the reported runway conditions. The SAFO highlighted that:

The RCAM is presented in a standardized format, based on airplane performance data supplied by airplane manufacturers, for each of the stated contaminant types and depths. The RCAM replaces subjective judgments of runway surface conditions with objective assessments tied directly to contaminant type and depth categories.

Further to the FAA’s efforts to achieve harmonisation with runway condition reporting, ICAO also intend to standardise the reporting of runway conditions in an attempt to reduce runway excursion events. Becoming applicable on 5 November 2020, ICAO will be adopting the RCAM, which will allow crews to more accurately determine aircraft take-off and landing performance. ICAO highlighted that this will provide a solution to a long outstanding problem with correlating aircraft performance to runway state information in a more objective manner.

In September 2016, EASA issued a notice of proposed amendment ([2016-11](#)) regarding aircraft performance requirements for commercial air transport operations. The purpose of the amendment was to increase the current level of safety in relation to aircraft performance, to improve harmonisation with the FAA, and to align with ICAO. Specifically, EASA stated their intention to delete the ‘damp’ runway definition as this condition would be included in their definition of a ‘wet’ runway.

Flight following services

The operator's Flight Dispatch Policy Manual stated that flight following services were provided to all Virgin Australia aircraft⁴⁶ to primarily enhance and contribute to the safety of a flight. This service was the responsibility of the flight dispatcher and commenced from the time a flight plan was submitted to air traffic services until confirmation of a safe landing. It included the advice and provision of operationally critical information (OCI), and other information relevant to the safe and efficient operation of that flight. While the Manual detailed what was considered OCI, of most relevance to this incident was:

Any other operational requirements assessed by the dispatcher to be relevant to the operation of the flight.

The manual also noted that, due to operational constraints with high frequency radios and a short sector length of less than 3 hours, the transmission of OCI could not be assured. However, it was a dispatcher's duty of care to attempt to contact the crew by radio or to relay OCI advice via ATC, which may affect the safe continuation of the flight.

During pre-flight planning, the crew were provided with the Christchurch TAF issued at 0629 and were aware of rain forecast for later in the morning. The operator's investigation found that the revised TAF issued at 1102 was not transmitted to the crew in-flight. They assessed that the change in weather conditions was not considered OCI and had no operational significance to the aircraft en route to Christchurch.

Aquaplaning⁴⁷

An aircraft's brakes provide the primary means for stopping, but their contribution to the total stopping force varies significantly with the runway conditions and groundspeed. The amount of braking force on the tyre depends on the tyre to runway surface friction and the weight on the wheel. The presence of contaminants such as water, ice or slush can lift the tyre above the runway surface on a layer of water. This phenomenon is known as 'aquaplaning' or 'hydroplaning'.

The presence of a layer of water can reduce the coefficient of friction between the tyres and the runway in three ways: viscous, dynamic and reverted rubber aquaplaning. All three can degrade both the braking and cornering capability of the aircraft, thereby affecting deceleration and directional control.

- Reverted rubber aquaplaning: This occurs when the heat from a locked-wheel being dragged across a wet surface generates steam. The pressure of the steam is sufficient to raise the centre of the tyre off the runway surface while the edges remain in contact. Heat from the steam reverts the rubber to its natural state, leaving a black, gummy deposit of reverted rubber on the tyre. It will also typically leave distinctive marks on the runway.
- Dynamic aquaplaning: This occurs when a build-up of hydrodynamic pressure at the tyre-runway surface area creates an upward force that lifts part or all of the tyre off the surface. Total aquaplaning will occur when there is complete separation between the tyre and surface, and wheel rotation stops. The depth of water required to support dynamic aquaplaning varies from 0.1 inch (2.54 mm) for a well-worn tyre to 0.3 inches (7.62 mm) for new tyres with full tread depth. The speed required to generate sufficient water pressure to raise the tyre off the runway depends on the tyre pressure and if the wheel is rotating as it moves through the water. If the tyre is rotating, the minimum speed will be nine times the square root of the tyre pressure. If the tyre is not rotating, the minimum speed will be 7.7 times the square root of the tyre pressure. In this case, this equated to 129 kt and 110 kt respectively. This was about 35 kt and 16 kt above VOP's recorded computed speed after crossing the runway 11/29 and 02/20 intersection.

⁴⁶ This excludes Virgin Australia Regional Airlines flights.

⁴⁷ ATSB (1999), Wood and Sweginnis (2006), International Civil Aviation Organization (n.d.).

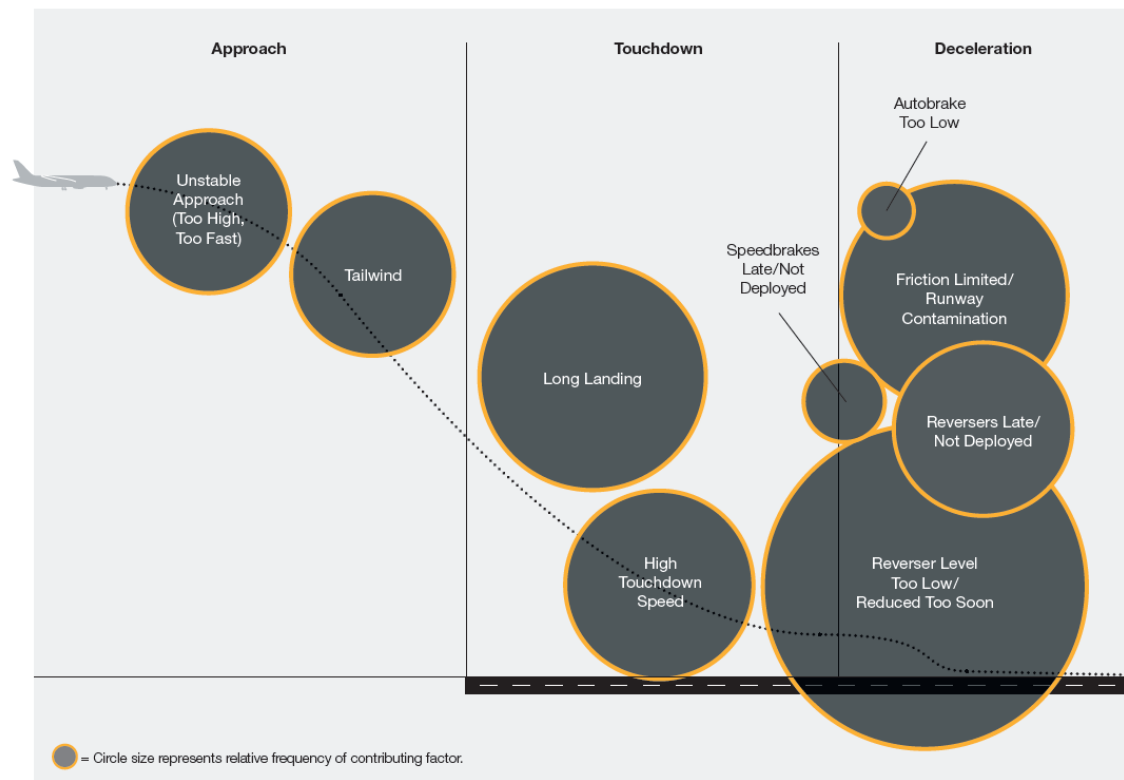
- Viscous aquaplaning: This occurs when the runway surface is lubricated by a thin film of water, reducing the coefficient of friction. The tyre is unable to penetrate this film and contact with the surface is partially lost. Essentially, it makes the runway slippery. When operating on damp or wet runways, a loss of tyre braking and cornering ability is mainly attributable to this type of aquaplaning. However, it is most severe on runways with a smooth texture, where a layer of water only 0.01 inches (0.254 mm) deep can significantly reduce the coefficient of friction. This can occur at any tyre speed. Generally, there is little or no post-event evidence available to determine if viscous aquaplaning has occurred.

Runway excursions

Runway veer-offs (when an aircraft departs the side of the runway) and overruns (when an aircraft departs the end of a runway) are collectively termed runway excursions. The international aviation community has invested a considerable amount of time and resources into reducing the risk of runway excursions. Some of the research into runway excursions has found:

- [Boeing](#) analysis of event data between 2003 and 2010 showed that 68 per cent of runway landing overruns occurred after a stable approach, 55 per cent touched down within the touchdown zone, 90 per cent landed on an other-than-dry runway and 42 per cent landed with a tailwind of 5 kt or greater. The analysis emphasised that a runway overrun was frequently the result of more than one contributing factor occurring simultaneously. Figure 18 shows the common factors in runway overruns during landing. The size of the circle represents the relative frequency the item was a contributing factor to the overrun.

Figure 18: Factors in landing runway overruns



Source: Jenkins & Aaron (2012)

- [ATSB](#) reviewed world-wide runway excursion accidents between 1998 and 2007 and found that there were 141 accidents involving commercial jet aircraft that resulted in 550 fatalities to passengers, crew and persons on the ground. Of these accident, 120 occurred during landing. The most common types of contributing factors were crew technique or decision-related factors, and weather-related factors.

- [Flight Safety Foundation \(2009c\)](#) ([briefing note \(2009a\)](#)) runway safety initiative found that commercial transport aircraft worldwide were involved in 417 runway excursion accidents between 1995 and March 2008. Of this, 79 per cent occurred during landing. Among these landing excursions, 47 per cent were overruns. The Foundation recognised that runway excursions were usually the result of one or more factors. Specifically, some of the following factors contribute to runway overruns:
 - incorrect assessment of landing distance for prevailing wind and runway conditions
 - unanticipated runway conditions
 - unanticipated wind shear or tail wind
 - extended flare
 - ground spoilers/speed brakes not deployed
 - brake/antiskid malfunction
 - touchdown long
 - inaccurate surface wind information
 - unstable approach
 - late braking
 - hydroplaning/aquaplaning
 - approach and touchdown fast
- [National Aerospace Laboratory NLR](#) (van Es, 2005) examined 400 landing overrun accidents between 1970 and 2004 and found that the corresponding accident rate had reduced by a factor of three over the past 35 years. This decrease was most likely due to improvements in braking devices such as antiskid and autobrakes, a better understanding of runway friction issues, and safety awareness campaigns. The study also highlighted that, often the surface condition varied along the runway. For example, only part of the runway was flooded with pools of standing water while the remainder was wet. Of the accidents examined, 48 per cent occurred on a wet/flooded runway. The research also concluded that there appeared to be a significant increase in the risk of landing overruns when one of the following factors was present:
 - non-precision approach
 - touching down far beyond the runway threshold
 - significant tailwind was present
 - snow, ice, slush covered runway
 - excessive approach speed
 - visual approach
 - high on approach
 - wet, flooded runway

Similar occurrences

ATSB investigation [AO-2010-099](#)

On 24 November 2010, the crew of a Boeing 737 aircraft were preparing to land on runway 12 at Hobart, Tasmania. The crew were informed that the runway was wet, but understood that the braking was 'good'. Based on the reported weather, aircraft weight and airport conditions, the FO determined that a flap setting of 30° and the use of AUTOBRAKE 3 would provide sufficient braking for the landing. When at about 1,000 ft, the crew were advised by ATC that the wind was tending more northerly and they were offered the option of landing on runway 30. For various reasons, the crew elected to continue the approach to runway 12.

The touchdown and initial deceleration was reported to be normal. When at about 60 kt and three quarters of the way through the landing roll with reverse thrust stowed and autobrakes disengaged, the captain assumed control of the landing and braking. Soon after, the braking response was not as expected and the captain increased braking pressure until no further braking

could be applied. The FO reported that it felt like the aircraft was sliding or aquaplaning. The cabin crew also reported that the deceleration did not feel normal in the last portion of the landing.

The captain re-introduced reverse thrust. The FO noted that once the aircraft reached the runway threshold markings at the southern end, the aircraft's speed decreased significantly. The aircraft overran the runway onto the sealed stopway and came to a stop about 4 m beyond the runway end.

To lengthen the life and prevent the surface from breaking up, the runway had been resealed in February 2010. Some sections of the runway had broken up and required patching, and the patching was not grooved. After the incident, the runway and stopway area were inspected. While no damage was found it was noted that there was rubber build-up around the runway 30 touchdown area; runway patching in this area had not been re-grooved.

Safety analysis

Introduction

After touching down on runway 29 at Christchurch Airport, New Zealand, the aircraft did not decelerate as expected during the later stages of the landing roll. In response, the crew overrode the autobrakes, applied hard manual braking and retained the use of reverse thrust until near the runway end. The aircraft stopped about 5 m from the runway end.

A review of the recorded flight data confirmed that the approach was stable, the approach speed was normal, the aircraft landed within the touchdown zone and in proximity to the required touchdown point. Deceleration devices (speedbrakes and autobrakes) were deployed in a timely manner.

The runway was not inspected immediately following the incident. Therefore, the amount of water present during the landing was unknown. However, a later runway inspection found no indications that the later part of runway 29 was predisposed to the formation of standing water. Further, along with the brake pressures not being recorded, the ATSB was unable to establish if the runway surface friction, including the application of Gilsonite, contributed to the reduced braking capability.

This analysis will examine why the crew misperceived the runway surface conditions and how this affected the aircraft's landing performance. It considers runway surface conditions and the terminology used to report on this. Further, the requirements and adequacy of landing distance calculations is discussed along with the operator's policy and procedures for this. The analysis also explores the provision of weather information to crews in-flight.

Misperceived critical landing information

Citing Hart (n.d.), Orlady and Orlady (1999) defined workload as:

...a hypothetical construct that reflects the interaction between a specific individual and the demands imposed by a particular task. Workload represents the cost incurred by the human operator in achieving a particular level of performance

A person experiences workload differently based on their individual capabilities and the local conditions at the time. Kantowitz and Casper in Wiener and Nagel (1988) indicated that people are most reliable under levels of moderate workload. However, extremes of workload increases the possibility of error. It was further acknowledged that workload may be affected by factors not under the crew's control, such as weather and communication requirements

Both crew reported experiencing a higher-than-normal workload during the later stages of the flight. Prior to the descent, the crew were of the understanding that runway 02 was in-use and they had completed their preparations for this approach. However, due to shifting wind conditions, the runway-in-use changed to runway 29. The crew were advised of this change and they subsequently commenced preparations for the revised approach. Also around this time, the crew made several track deviations due to weather. The crew's workload increased considerably having to manage the runway change and weather deviations.

Green and others (1996) also recognised that:

As the demands of the task, or the workload, are increased, the standard of our performance increases until an optimum level of workload and performance is achieved. Any increase in workload after this point leads to a degradation in performance. At extremely high levels of workload (overload), important information may be missed due to the narrowing or focusing of attention onto only one aspect of the task.

The crew's high workload coincided with the time when critical information was conveyed by air traffic control (ATC) regarding the changing reported runway surface conditions at Christchurch (from dry to wet). The crew inadvertently missed this information and based on a pilot broadcast of

the perceived runway conditions, they believed the conditions were reported as damp, rather than wet. Further, due to the higher than normal workload, the crew did not get the opportunity to listen to the automatic terminal information system reports indicating it was raining at the airport and/or the runway was wet.

Consequently, in accordance with the operator's procedures for a damp runway, the crew determined if the aircraft could land on runway 29 based on a dry runway from the operator's Airport Analysis Manual (AAM). If the crew had used a wet runway as a reference, the AAM would have indicated a safe landing was not possible.

Runway 29 landing performance exceeded

According to the AAM, with a wet runway surface, the aircraft's actual landing weight was above the landing performance limit weight for both the reported and actual wind conditions by about 100 kg and 5.7 T respectively. Therefore, at the time of landing, the aircraft exceeded the AAM landing performance limitations for runway 29.

The captain assessed that the initial part of runway 29 was damp. A pilot who departed Christchurch about 30 minutes prior to VH-VOP (VOP) landing had also reported that the runway surface was damp rather than wet. However, the surface conditions were reported wet by ATC and the amount of water spray observed during the later stages of the landing indicated that this section of the runway at least was wet.

At the time of landing, the reported wind conditions from the automatic terminal information service indicated a 3 kt headwind, while the actual wind determined by the flight data recorder showed a 5 kt tailwind. Notably, the automatic weather station data was showing a change in the wind direction around this time and the automatic terminal information service issued shortly after landing indicated the wind was now variable.

The Quick Reference Handbook (QRH) landing distance charts provide a landing solution by taking into account braking selections. With AUTOBRAKE 3, as selected by the crew, for a wet runway ('good' reported braking action):

- For the reported wind conditions, the calculated actual landing distance was within the landing distance available. However, when the 15 per cent in-flight safety margin stipulated in the Civil Aviation Safety Authority (CASA) Civil Aviation Order (CAO) 20.7.1B was applied, the landing distance required exceeded the landing distance available.
- For the actual wind conditions, both the calculated actual landing distance and landing distance required exceeded the landing distance available (air distance of 305 m and reference speed plus 5 kt). However, when taking into account the reduced air distance and speed at touchdown established from the flight data recorder, the calculated actual landing distance was within the landing distance available, but the landing distance required exceeded it.

Therefore, to meet the CASA in-flight landing distance requirements, a setting of AUTOBRAKE MAX or MAX MANUAL would have been required. Landing performance calculations are designed to ensure the aircraft stops within the confines of the runway. By exceeding these requirements, the risk of an overrun event is increased.

Of significance, the QRH calculations also showed that the wet runway, 5 kt tailwind and additional effects from the runway surface conditions combined, increased the aircraft's expected actual landing distance by about 12 per cent.

Determining brake configuration for landing

The operator's AAM could be used both pre-dispatch and in-flight to determine if the aircraft's expected landing weight was below the landing limit weight for each runway with the given wind and runway surface conditions. In this case, for a dry runway, the AAM indicated that the aircraft could land on runway 29.

However, unlike the QRH, the AAM does not provide a landing solution. Therefore, the crew, based on their judgement and training, determine the braking configuration required. While the crew had minimal experience landing on runway 29, their decision to use AUTOBRAKE 3 was based on their experience from operating at airports with similar runway lengths. This judgement was consistent with the guidance in the Boeing 737 flight crew training manual.

During transition training the crew were instructed to use the AAM rather than the QRH for in-flight landing performance. If the QRH had been referenced and the CAO 20.7.1B 15 per cent in-flight safety margin applied, the crew would have determined that they were unable to land on runway 29 when both dry and wet, using AUTOBRAKE 3 and with the given environmental conditions. Consequently, MAX AUTO or MAX MANUAL braking would have been required to safely land.

If a higher level of braking had been used, the aircraft would have initially decelerated at a greater rate. The aircraft would have then entered the standing water at a slower speed and likely stopped sooner.

Runway 29 surface conditions and reduced braking

A small amount of rain had passed through the Christchurch area shortly before the aircraft's arrival. Around this time, the pilot of a departing aircraft reported the runway 29 surface conditions as 'damp', though the automatic terminal information service issued shortly afterwards indicated the runway was 'wet', equating to 'good' reported braking action.

After passing the runway intersection during landing, the aircraft did not decelerate as expected, and closed-circuit television footage showed a spray of water coming from the aircraft. Similarly, water spray was also observed when stowing reverse thrust. There was no runway inspection conducted immediately after the landing. Therefore, it was not possible to assess the amount of water present at the time of landing or if any tyre marks were visible. A later inspection did not detect any irregularities, although water was said to sometimes pool on the later part of the runway.

Despite the first officer (FO) applying manual braking in excess of the AUTOBRAKE 3 selection and the captain assisting, the aircraft's deceleration reduced rather than increased. This was consistent with Boeing's assessment via simulations that the runway conditions were initially likened to a wet runway and then with a flooded runway after the intersection.

Further, the crew indicated that, when sensing the antiskid operating they were applying close to or maximum manual braking effort. This, combined with the minor directional deviation, showed that there were variations in the runway surface friction. Also, runway 11/29 was not grooved at the time, which was known to reduce aircraft braking capability and affect directional control.

When referencing the United States Federal Aviation Administration (FAA) runway condition assessment matrix, the noticeably reduced braking capability of the aircraft with near to maximum manual braking being applied and the minor directional deviation would indicate that the braking action was 'good to medium' or 'medium' during the later stages of the landing. Therefore, it was very likely that the amount of water on the later part of runway 29 did exceed the limits that would achieve a 'good' braking action.

Although there was no physical evidence of reverted rubber aquaplaning and the aircraft's speed after passing the runway intersection was below the minimum speeds required for dynamic aquaplaning, viscous aquaplaning could not be discounted.

Therefore, despite the crew applying hard braking, the amount of water on the runway along with the possibility of viscous aquaplaning resulted in a reduced braking capability of the aircraft.

Operator's change in damp runway definition

Several months prior to the incident, the Virgin Australia Airlines/Virgin Australia International's policy on calculating performance for a damp runway changed. The policy changed from a damp runway being considered wet to now being treated as dry. The crew were aware of the change in definition, and believing the runway surface conditions were damp, they determined if the aircraft was able to land based on a dry runway. This established that they could land on runway 29. The crew were also aware that they could not land if the runway was wet.

Irrespective of the crew's incorrect understanding of the runway condition, if the operator's previous definition had applied at the time, the crew would have used wet instead of dry landing performance data. This would have likely resulted in the crew seeking an alternative landing solution such as changing runways (if available), holding to burn off fuel or diverting to another airport.

Regulatory direction regarding damp runways

While the term 'damp' was used by air traffic service providers and airport operators internationally to describe runway surface conditions, it was not used by CASA or by major aircraft manufacturers for providing performance data. Consequently, there was no regulatory direction from CASA to operators on how a damp runway was to be considered for performance purposes. Instead, it was the operator who determined if a damp runway was treated as dry or wet. In this case, the definition adopted by Virgin Australia Airlines/Virgin Australia International was based on operational requirements and that used the by European Aviation Safety Agency.

In addition, the term has been applied inconsistently among Australian operators. This is of particular concern since research has shown that a damp runway may not provide an equivalent braking surface as a dry runway. This increases the risk of an excursion as a result of overestimating an aircraft's braking efficiency.

Cross-checking environmental information and landing performance

Cross-checking is a fundamental element in all multi-crew operations, and is a vital mechanism for detecting errors. For example, when one crew member calculates aircraft performance, the other cross-checks the base-line data (including the environmental information) and calculation, or duplicates the calculation. The absence of a cross-check removes an opportunity for crews to identify errors before they lead to consequences.

At the time of the incident, Virgin Australia Airlines/Virgin Australia International had a policy requiring crews to cross-check take-off performance data. However, there was no such requirement for cross-checking in-flight environmental information and landing performance calculations. An informal review of other Australian operators found that one or both of these were to be cross-checked. For example, one operator requires the automatic terminal information service details, in particular the QNH, to be verified and viewed by more than one crew member.

An exploratory study of error detection processes during normal line operations conducted by Thomas and others (2004) found that 57 per cent of all errors observed remained undetected by the crew. The study also identified that cross-checking and monitoring of other crew actions was the most frequently observed error detection process. Overall, the authors concluded:

With reference to the errors that were detected, the result of this study suggest that error detection is more easily accomplished by the crew-member who was not responsible for the error. Accordingly, this study emphasised the importance of crew cooperation in the multi-crew environment and highlights the essential role of monitoring and cross-checking in maintaining safety.

When the captain, as the pilot monitoring, obtained the environmental information (automatic terminal information service) from ATC, the FO was focusing on his pilot flying duties and was not as attentive to the details provided. Therefore, cross-checking the landing performance calculations alone would not have identified the misperceived runway conditions as the FO was also of the understanding that the runway conditions were damp. However, in-line with the research above, if the FO had to independently cross-check the environmental information, it was likely that he would have identified that the runway conditions were in fact wet. The subsequent cross-check of the landing performance calculations using this information would have established that they could not land on runway 29 at that time.

Guidance provided through an uncontrolled mechanism

While it was recognised that the operator was providing crews with clarification on the CAO 20.7.1B changes, the 'Q and A' guidance contained critical information regarding landing performance determination. As this guidance was only accessible on the operator's intranet, there was no mechanism for knowing who had read the information. Therefore, the operator could not be assured that the critical information contained in the Q and A had been read, understood and uniformly applied by crews.

Flight following

Crews should be made aware of changing weather conditions that potentially reduce their landing options available at the intended destination. This would assist crews with deciding whether to continue to their destination, hold until the conditions improve or to burn off fuel (to decrease landing weight), or divert to another airport.

After reviewing the Christchurch aerodrome forecast prior to departing Sydney, the crew were expecting rain later in the morning. However, an amended forecast was issued while the aircraft was en route, indicating light rain for their arrival. The operator assessed that this change in conditions was not operationally critical and therefore, the information was not passed to the crew. While the crew could obtain the weather in-flight by other means and were later advised by ATC of rain at the airport, the forecast rain reduced their landing options at Christchurch. The aircraft was unable to land on runway 29 when wet, runway 20 was closed due to the works in progress and the wind conditions were least favourable for runway 02 at the time.

If the above weather information had been provided to the crew earlier in the flight through flight following services, particularly during a period of low workload, this would have allowed them more time to consider the implications and assess alternatives. An increased awareness of the changing conditions may have also acted as a primer for the information later provided by ATC regarding the runway surface conditions.

Subjective assessment of runway conditions

It has been widely recognised by industry that runway surface conditions and pilot braking action reports are subjective and the terminology used to describe these are inconsistent. In this incident, this issue was highlighted by the differences in how the runway conditions were assessed by the pilot of the previously departing aircraft, the crew of VOP, the aircraft's actual performance as recorded by the flight data recorder, and what was recorded by the automatic terminal information service.

Various organisations have highlighted that ambiguous braking action reports may result in a miscalculation of the landing rollout length. This was confirmed by the ATSB's calculations utilising the QRH for the Boeing 737. These calculations showed that, in some circumstances, if the runway surface conditions and braking action were under-reported, the landing performance would also be underestimated. This subsequently reduces, and in some cases exceeds safety margins.

The Southwest Airlines overrun accident led to the FAA instigating the development and implementation of a runway condition assessment matrix. This matrix will assist in achieving a harmonised, consistent approach to assessing runway conditions.

In-flight landing distance safety margin

As highlighted by the International Civil Aviation Organization, operational margins should cover for a reasonable error in runway condition assessment. However, a misreported condition may mean that margins are no longer available to account for other operational variances.

The FAA recommended that ‘at least’ or ‘a minimum’ of a 15 per cent safety margin should be added to actual landing distance calculations as a minimum acceptable margin for normal operations. However, in response to several landing events, in late 2015 (after this incident), the FAA recognised that 15 per cent may be inadequate under certain wet runway conditions and subsequently encouraged operators to apply additional conservatism.

While the FAA has recognised that the margin had not been substantiated, they, combined with the ATSB’s calculations, show that the safety margin may be inadequate under certain conditions. Specifically, the ATSB found that underestimating these conditions may diminish, and in some circumstances, exceed the 15 per cent safety margin applied to the landing performance data.

CASA introduced the 15 per cent in-flight safety margin for landing distance requirements in the 2014 amendment to CAO 20.7.1B based on the FAA recommendation, but did not include the provision of ‘at least’ or ‘a minimum of...’. CASA advised the ATSB that the CAO is a document that contains legal requirements and as such, is not expressed in terms of ‘at least the following...’ or ‘a minimum of...’. Further, CASA indicated that regulatory requirements represent the absolute minimum required by law and it is incumbent on the operator to determine if they need to operate, or if circumstances dictate they should operate, above the regulatory minimum. The corresponding Civil Aviation Advisory Publication (235-5(0)) to the CAO 20.7.1B amendment provided guidance and explanatory information about the changes made. This publication also stipulated a 15 per cent in-flight safety margin.

Although not considered to have contributed to this incident, in some circumstances there is an increased risk of a runway excursion by only using the 15 per cent in-flight safety margin instead of ‘a minimum of...’ or ‘at least’ 15 per cent. Civil Aviation Advisory Publication 235-5(0) would provide a suitable mechanism for highlighting the FAA’s observations and encouraging additional conservatism above the minimum regulatory requirement of 15 per cent.

Operator’s quick reference handbook charts complex

When compared with other methods for establishing landing performance, such as the AAM and electronic devices, the operator’s QRH is more complex. To determine the actual landing distance using the QRH, seven adjustments are required to be calculated by the crew: weight, altitude, wind, runway slope, temperature, approach speed and use of reverse thrust. These adjustments are added/subtracted from a reference distance to determine the aircraft’s actual landing distance. The CAO 20.7.1B 15 per cent safety margin is then added onto the resultant actual landing distance to establish the landing distance required. This complexity may increase if the adjustments are to be interpolated rather than rounded to the nearest conservative value.

The QRH normal configuration landing distance charts would generally be referenced by crews in-flight when there was a change from the pre-dispatch conditions, such as the runway surface conditions, the runway-in-use or diverting to another airport. A change in conditions would typically increase workload experienced by crew. As shown in this incident, the change in runway-in-use, combined with the weather deviations, increased the crew’s workload. It is well-known that crew experiencing a high workload will be more likely to make errors. As previously discussed, effective cross-checking can assist with error detection and may provide the last line of defence against an

occurrence. However, measures to prevent errors in the first place should be implemented when possible.

Operator's landing performance policy and guidance inconsistent

At the time of the incident, the operator's policy stipulated that the AAM was to be used for determining landing performance. While it was recognised that the operator was in discussions with CASA regarding the CAO 20.7.1B changes, the policy differed from the guidance provided in the Virgin Australia Q and A. The Q and A indicated that the AAM was to be used pre-dispatch and the QRH used in-flight. However, it was not known if the inconsistency between the policy and guidance resulted in confusion among crews. Irrespective, CAO 20.7.1B allowed both the AAM (certified data) and QRH (advisory data) to be used to establish landing performance in-flight.

Further, during transition training for the incorporation of Virgin Australia New Zealand into Virgin Australia International, the New Zealand crews were instructed to use the AAM to determine their in-flight landing performance. This was considered an interim measure until the operator's policy had been updated to reflect the CAO 20.7.1B changes. However, the Q and A guidance advised crews to use the QRH in-flight. While the crew of VOP were not aware of the Q and A prior to the incident, their transition training was consistent with the policy but contradicted the guidance.

Crew's actions prevented a runway excursion

According to the AAM, the aircraft was unable to land on runway 29 when wet. The QRH indicated that, for a wet runway with 'good' reported braking action, the actual landing distance was marginally less than the landing distance available with the actual reduced air distance and reference speed. However, the surface conditions on the later part of the runway likely resulted in less than 'good' reported braking action, which reduced the aircraft's braking capability. Consequently, the aircraft was stopped about 5 m from the runway end. It was likely that the initial exceedance of the AUTOBRAKE 3 deceleration rate, combined with the crew's application of hard manual braking and retaining reverse thrust prevented a runway excursion.

Findings

From the evidence available, the following findings are made with respect to the reduced braking effectiveness during landing involving a Virgin Australia International Airlines Boeing 737-800, registered VH-VOP that occurred at Christchurch Airport, New Zealand on 11 May 2015. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Safety issues, or system problems, are highlighted in bold to emphasise their importance.

A safety issue is an event or condition that increases safety risk and (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

Definitions of the following headings are provided in the section titled *Terminology used in this report*.

Contributing factors

- Due to the crew experiencing increased workload, the crew misperceived critical landing information, which resulted in the aircraft's landing performance being determined based on a damp (dry) runway rather than a wet runway.
- The runway surface conditions combined with the autobrake selection resulted in the aircraft exceeding the landing performance limitations for runway 29 for both the reported and actual wind conditions.
- Using the operator's Airport Analysis Manual to establish that the aircraft could land safely on runway 29 relied on the crew's judgement to determine the braking level required. While that judgement was consistent with the flight crew training manual, the Quick Reference Handbook indicated that a higher braking level than chosen was needed to meet the landing distance safety margin requirements.
- It was very likely that the amount of water on the later part of runway 29 resulted in less than 'good' braking action. Along with the possibility of viscous aquaplaning and despite the crew applying hard braking, this water resulted in a reduced braking capability.
- **Several months prior to the incident, Virgin Australia Airlines/Virgin Australia International changed their policy on calculating landing performance for damp runways from referencing a wet runway to a dry runway. [Safety issue]**
- **There was no regulatory direction from the Civil Aviation Safety Authority on how a damp runway was to be considered for aircraft landing performance. [Safety issue]**
- **Virgin Australia Airlines/Virgin Australia International did not have a policy requiring crews to independently cross-check environmental information and landing performance calculations in-flight, removing an opportunity to detect crew errors. [Safety issue]**

Other factors that increased risk

- The operator provided guidance on landing performance through an uncontrolled mechanism, which did not provide assurance that crews had read, understood and applied the critical information contained within that guidance.
- The flight following department did not highlight to the crew the changing weather conditions, which had the effect of minimising their landing options for Christchurch.
- The subjective nature of assessing runway surface conditions and braking action, increases the risk of incorrect landing performance determination.

- **Civil Aviation Order 20.7.1B stipulated that a 1.15 (15 per cent) safety margin was to be applied to the actual landing distance for jet-engine aircraft with a maximum take-off weight greater than 5,700 kg. This safety margin may be inadequate under certain runway conditions, which increases the risk of a runway excursion. The corresponding guidance in Civil Aviation Advisory Publication 235-5(0) had not been updated to account for this. [Safety issue]**
- The inherent complexity of re-calculating landing performance data in-flight using the operator's Quick Reference Handbook increases the risk of errors, especially during times of elevated crew workload.

Other findings

- The operator's guidance was inconsistent with its policy for determining in-flight landing performance.
- Initial aircraft autobraking above the required deceleration rate, combined with the crew's application of hard manual braking and delayed stowage of reverse thrust, likely reduced the risk of a runway excursion.
- The main landing gear brake pressure recording switch was faulty, therefore, the amount of brake pressure applied during landing was not recorded by the flight data recorder.

Safety issues and actions

The safety issues identified during this investigation are listed in the Findings and Safety issues and actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

Depending on the level of risk of the safety issue, the extent of corrective action taken by the relevant organisation, or the desirability of directing a broad safety message to the aviation industry, the ATSB may issue safety recommendations or safety advisory notices as part of the final report.

The initial public version of these safety issues and actions are repeated separately on the ATSB website to facilitate monitoring by interested parties. Where relevant the safety issues and actions will be updated on the ATSB website as information comes to hand.

Change in ‘damp’ definition for performance purposes

Number:	AO-2015-046-SI-01
Issue owner:	Virgin Australia Airlines/Virgin Australia International
Operation affected:	Aviation: Air transport
Who it affects:	Virgin Australia Airlines/Virgin Australia International crews

Safety issue description:

Several months prior to the incident, Virgin Australia Airlines/Virgin Australia International changed their policy on calculating landing performance for damp runways from referencing a wet runway to a dry runway.

Proactive safety action taken by Virgin Australia/Virgin Australia International

Action number: AO-2015-046-NSA-008

In response to a preliminary analysis of this incident, Virgin Australia/Virgin Australia International conducted an initial post-implementation review of the change to their policy that permitted a damp runway to be considered dry for performance purposes. A further review of this change is currently underway in response to the ATSB’s investigation report. This review is examining change objectives, proposed and realised risk profile, current regulatory direction and industry guidance, and operational outcomes from the policy change. Findings from this review will be used by Virgin Australia/Virgin Australia International to determine whether further changes to the aircraft performance policy are required. Any policy changes will be incorporated into the aircraft performance training course.

Current status of the safety issue

Issue status: Monitor

Justification: The ATSB notes that Virgin Australia/Virgin Australia International is currently reviewing their internal policy on the classification of damp runways for performance purposes. The ATSB will monitor the operator’s progress and assess the safety issue on completion of that review.

Regulatory direction regarding damp runways

Number:	AO-2015-046-SI-02
Issue owner:	Civil Aviation Safety Authority
Operation affected:	Aviation: Air transport
Who it affects:	Operators and pilots of aircraft where landing performance data is not available for damp runway surface conditions

Safety issue description:

There was no regulatory direction from the Civil Aviation Safety Authority on how a damp runway was to be considered for aircraft landing performance.

Proactive safety action taken by the Civil Aviation Safety Authority

Action number: AO-2015-046-NSA-009

In response to this safety issue, the Civil Aviation Safety Authority advised that the International Civil Aviation Organization has already harmonised its runway condition definitions across all relevant Annexes and Documents (Docs) for the pending implementation of a globally harmonised methodology for runway surface condition assessment and reporting. The new methodology is scheduled to become effective in 2020. The new definitions remove any reference to damp as a separate runway condition, and explicitly introduce 'dampness' under the 'wet' runway condition.

The Civil Aviation Safety Authority is committed to closely harmonising its regulations with the International Civil Aviation Organization. Considering the regulatory development process the Civil Aviation Safety Authority is currently undertaking, it is their preference to align the relevant runway condition definitions with International Civil Aviation Organization, and at which time they will consult industry accordingly.

Current status of the safety issue

Issue status: Monitor

Justification: The ATSB notes the Australian Civil Aviation Safety Authority's recognition of the importance of harmonising runway condition definitions. The ATSB will monitor the Civil Aviation Safety Authority's progress and assess the safety issue on completion of changes made to the definitions.

Cross-checking environmental information and landing performance

Number:	AO-2015-046-SI-03
Issue owner:	Virgin Australia Airlines/Virgin Australia International
Operation affected:	Aviation: Air transport
Who it affects:	Virgin Australia Airlines/Virgin Australia International crews

Safety issue description:

Virgin Australia Airlines/Virgin Australia International did not have a policy requiring crews to independently cross-check environmental information and landing performance calculations in-flight, removing an opportunity to detect crew errors.

Proactive safety action taken by Virgin Australia/Virgin Australia International

Action number: AO-2015-046-NSA-010

Virgin Australia/Virgin Australia International are reviewing cross-checking mechanisms within their existing aircraft performance standard operating procedures. The intention of this is to further strengthen error-detection and monitoring within the in-flight landing performance procedure.

Current status of the safety issue

Issue status: Monitor

Justification: The ATSB notes that Virgin Australia/Virgin Australia International is currently reviewing their internal policy on cross-checking aircraft performance calculations. The ATSB will monitor the operator’s progress and assess the safety issue on completion of that review.

In-flight landing distance safety margin may be inadequate

Number:	AO-2015-046-SI-05
Issue owner:	Civil Aviation Safety Authority
Operation affected:	Aviation: Air transport
Who it affects:	Operators of jet-engine aircraft with a maximum take-off weight above 5,700 kg

Safety issue description:

Civil Aviation Order 20.7.1B stipulated that a 1.15 (15 per cent) safety margin was to be applied to the actual landing distance for jet-engine aircraft with a maximum take-off weight greater than 5,700 kg. This safety margin may be inadequate under certain runway conditions, which increases the risk of a runway excursion. The corresponding guidance in Civil Aviation Advisory Publication 235-5(0) had not been updated to account for this.

Proactive safety action taken by the Australian Civil Aviation Safety Authority

Action number: AO-2015-046-NSA-011

In response to this safety issue, the Civil Aviation Safety Authority advised that the advisory guidance material, Civil Aviation Advisory Publication 235-5(0) - *New performance provisions for Civil Aviation Order 20.7.1B and Civil Aviation Order 20.7.4* was published to accompany the May 2014 amendment to Civil Aviation Order 20.7.1B. The subsequent August 2015 United States Federal Aviation Administration advisory safety alert (15009), which warns aircraft operators and pilots that the advisory data for wet runway landings may not provide a safe stopping margin under certain conditions will be evaluated for incorporation into the advisory material contained in Civil Aviation Advisory Publication 235-5(0), with an aim to incorporate any changes prior to the end of March 2019.

Current status of the safety issue

Issue status: Monitor

Justification: The ATSB notes the Civil Aviation Safety Authority’s intention of incorporating additional safety information regarding the in-flight safety margin into Civil Aviation Advisory Publication 235-5(0). The ATSB will monitor the Civil Aviation Safety Authority’s progress and assess the safety issue on completion of amendments made to this publication.

Additional safety action

Whether or not the ATSB identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk. The ATSB has been advised of the following proactive safety action in response to this occurrence.

Operational restrictions at Christchurch

The operator issued a flight crew operational notice, effective from 12 May 2015 and valid until 23 July 2015, indicating that runway 11/29 at Christchurch was not be used when the runway surface conditions were reported 'damp' or 'wet', unless an overriding emergency dictated otherwise. The availability of the runway under those conditions would be reviewed once their internal investigation had been completed. This restriction was later removed after runway 29 was grooved and the operator's internal investigation had been completed.

Simulator training

As a result of this incident, the operator incorporated crew training on landing distance calculations, touchdown points, and manual braking techniques following autobrake disconnection into their recurrent simulator sessions.

Safety margin incorporated into the actual landing distance charts

Subsequent to the incident, the operator has advised the ATSB that they are in the process of having the 15 per cent safety margin incorporated into the actual landing distance charts in the Performance In-flight section of the Quick Reference Handbook (QRH).

Civil Aviation Authority of New Zealand

The Civil Aviation Authority of New Zealand highlighted that any braking action report from the airport operator would need to be standardised, although previous efforts to do this via friction testing has had limited acceptance worldwide. However, the United States Federal Aviation Administration runway condition assessment matrix, in real-time, provides standardised information. This, along with using the associated takeoff and landing performance assessment procedures, which have already been accepted by aircraft manufacturers, can provide reliable and repeatable certified landing performance data. Standardised pilot braking action reports combined with the use of the matrix can potentially provide useful guidance. As of 31 July 2018, the Civil Aviation Authority of New Zealand Civil Aviation Rules Part 139.103 (b) (3) states that an aerodrome maintenance program must:

...provide for the measurement and provision of real-time surface condition reporting when a runway is contaminated using standardised reporting methods.

The above rule will allow guidance on braking action reporting to be more readily incorporated into operational procedures.

General details

Occurrence details

Date and time:	11 May 2015 – 1215 UTC	
Occurrence category:	Incident	
Primary occurrence type:	Reduced braking efficiency	
Location:	Christchurch Airport, New Zealand	
	Latitude: 43° 30.00' S	Longitude: 172° 30.90' E

Aircraft details

Manufacturer and model:	The Boeing Company, 737-800	
Year of manufacture:	2003	
Registration:	VH-VOP	
Operator:	Virgin Australia International Airlines	
Serial number:	33797	
Type of operation:	Air transport – high capacity	
Persons on board:	Crew – 6	Passengers – 111
Injuries:	Crew – Nil	Passengers – Nil
Damage:	Nil	

Sources and submissions

Sources of information

The sources of information during the investigation included:

- the crew of VH-VOP
- Virgin Australia Airlines/Virgin Australia International
- New Zealand Transport Accident Investigation Commission
- New Zealand Airways
- New Zealand MetService
- The Boeing Company
- The Civil Aviation Safety Authority.

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Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the crew of VH-VOP, Virgin Australia Airlines/Virgin Australia International, the Civil Aviation Safety Authority, the Civil Aviation Authority of New Zealand, the New Zealand Transport Accident Investigation Commission, The Boeing Company, and the National Transportation Safety Board.

Submissions were received from the crew of VH-VOP, Virgin Australia Airlines/Virgin Australia International, the Civil Aviation Safety Authority, the Civil Aviation Authority of New Zealand, and The Boeing Company. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

Terminology used in this report

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing factor would probably not have occurred or existed.

Other factors that increased risk: a safety factor identified during an occurrence investigation, which did not meet the definition of contributing factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other findings: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which ‘saved the day’ or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

Appendices

Appendix A – Christchurch aerodrome forecasts (TAFs) and automatic terminal information service (ATIS)

Christchurch aerodrome forecasts (TAFs)

TAF AMD NZCH 110629Z 1106/1206 31012G25KT CAVOK

BECMG 1108/1110 03012KT

FM112200 24020G35KT 9999 –RA BKN 025

TEMPO 1122/1200 4000 +RA BKN012

2000FT WIND 360025KT

BECMG 1122/1200 24040KT

QNH MNM 983 MAX 992

TAF NZCH 111102Z 1112/1212 03012KT 9999 –RA BKN065

TEMPO 1123/1208 4000 +RA BKN012 FEW020TCU

FM120100 24020G35KT 9999 –RA BKN025

FM120800 24010KT 9999 FEW030

Automatic terminal information service (ATIS)

ATIS X

ATIS NZCH X 1018

APCH: EXPECT RNAV NOVEMBER APPROACH

RWY: 02

SFC COND: DRY

OPR INFO: RUNWAY 02 REDUCED LENGTH DUE WORK IN PROGRESS NORTH REFER
NOTAM BRAVO 2400 AND YELLOW PAGES

WIND: 010/08

VIS: 40KM

CLD: NSC

TEMPERATURE: 16

DEW POINT: 06

QNH: 992

2000FT WIND: REPORTED 350/26

ATIS Y

ATISNZ NZCH Y 1136

APCH: VA

RWY: 29

SFC: DRY

OPR: RWY02 RED LEN DUE WIP N REF B2400 AND YEL PGS

WIND: 250/12 MAX18

VIS: 40KM

PWX: RA

CLD: SCT060

TT: 14

DP: 08

QNH: 993

2000FT: R350/26

PAC: IAB

ATIS Z

ATISNZ NZCH Z 1150

APCH: VA

RWY: 29

SFC: WET

OPR: RWY02 RED LEN DUE WIP N REF B2400 AND YEL PGS

WIND: 250/10 MAX15

VIS: 20KM

PWX: -RA

CLD: BKN060

TT: 13

DP: 09

QNH: 993

2000FT: R350/26

PAC: IAB

ATIS A

ATISNZ NZCH A 1157

APCH: VA

RWY: 29

SFC: WET

OPR: RWY02 RED LEN DUE WIP N REF B2400 AND YEL PGS

WIND: 220/07

VIS: 20KM

PWX:

CLD: BKN070

TT: 13

DP: 09

QNH: 993

2000FT: R350/26

PAC: IAB

ATIS B

ATISNZ NZCH B 1217

APCH: RNAV

RWY: 02

SFC: DAMP

OPR: RWY02 RED LEN DUE WIP N REF B2400 AND YEL PGS

WIND: VRB03

VIS: 30KM

PWX:

CLD: NSC

TT: 12

DP: 09

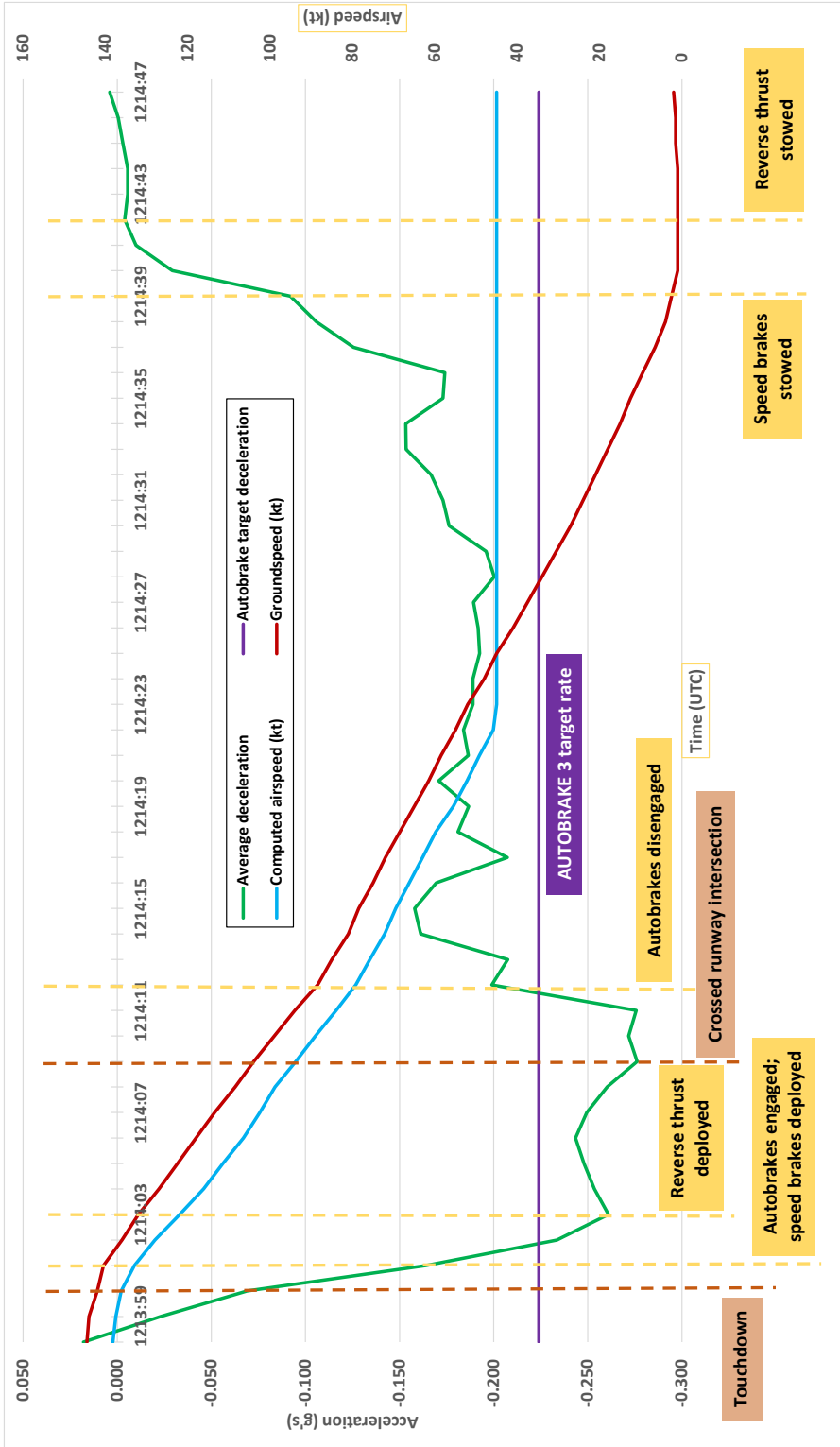
QNH: 991

2000FT: R280/20

PAC: IAB

Appendix B – VH-VOP deceleration during landing

The AUTOBRAKE 3 target deceleration rate compared with the average deceleration for VH-VOP measured in g's, where negative values indicate deceleration (left axis), and the computed airspeed and groundspeed (right axis) from just prior to touchdown on runway 29 .



Source: ATSB

Appendix C – Airport Analysis Manual landing performance chart for flap 40

B737-800W 26K

LAND 40

CHRISTCHURCH

Air Cond: **AUTO**

APP 15

NZCH (123ft)

MAXIMUM CERTIFIED LANDING WEIGHT (MLW) = 66.3 (1000 KG) TEMP (C) -10 0 10 20 30 40 50 CLIMB WT 82.0 81.8 81.6 81.3 80.8 74.0 67.6 ANTI-ICE PENALTIES LESS THAN 10C SUBTRACT 0.2 ENG ONLY, 1.1 ENG+WING ANTICIPATED ICE ACCRETION CORRECTION LESS THAN 10C SUBTRACT 7.2										
RUNWAY LENGTH SLOPE	WIND kt	ANTI-SKID OPERATIONAL						ANTISKD INOP		QUICK TURN ARND CRTP SUB
		AUTO-SPOIL			MAN SPOIL			MAN	SPOIL	
		DRY	WSR	WBT	DRY	WSR	WBT	DRY	WBT	
02 WIPN 1920M 0.28%DN	TW 15	61.4	61.4	52.0	58.0	58.0	48.0	NA	NA	MLW
	TW 10	66.2	66.2	57.0	62.7	62.7	53.5	NA	NA	MLW
	TW 5	71.9	71.9	61.7	68.0	68.0	58.3	NA	NA	MLW
	0	77.9	77.9	66.7	73.9	73.9	63.2	NA	NA	MLW
	HW 5	80.0	80.0	68.6	75.9	75.9	64.8	NA	NA	MLW
HW 10	82.2	82.2	70.6	78.0	78.0	66.7	NA	NA	MLW	
02 WIPS 1750M 0.28%DN	TW 15	55.4	55.4	45.3	51.5	51.5	41.5	NA	NA	MLW
	TW 10	60.0	60.0	50.8	56.7	56.7	46.8	NA	NA	MLW
	TW 5	64.7	64.7	56.1	61.3	61.3	52.3	NA	NA	MLW
	0	70.3	70.3	60.7	66.4	66.4	57.4	NA	NA	MLW
	HW 5	72.3	72.3	62.3	68.3	68.3	59.0	NA	NA	MLW
HW 10	74.3	74.3	64.0	70.3	70.3	60.6	NA	NA	MLW	
20 WIPS 1750M 0.28%UP	TW 15	55.4	55.4	45.3	51.5	51.5	41.5	NA	NA	MLW
	TW 10	60.0	60.0	50.8	56.7	56.7	46.8	NA	NA	MLW
	TW 5	64.7	64.7	56.1	61.3	61.3	52.3	NA	NA	MLW
	0	70.3	70.3	60.7	66.4	66.4	57.4	NA	NA	MLW
	HW 5	72.3	72.3	62.3	68.3	68.3	59.0	NA	NA	MLW
HW 10	74.3	74.3	64.0	70.3	70.3	60.6	NA	NA	MLW	

QNH = 1013.25 mb
 WSR = WET LANDING PERFORMANCE FOR SKID RESISTANT RUNWAYS
 CRTP = QUICK TURN AROUND NOT LIMITING BELOW THIS TEMP (C)
 SUB = SUBTRACT 'SUB' FROM 66.3 FOR EACH DEG C HOTTER THAN TEMP
 CHECK = QUICK TURN AROUND CHART/THERMAL PLUGS, NA = NOT ALLOWED

Source: Virgin Australia Airlines

Appendix D –Quick Reference Handbook normal configuration landing distance chart for flap 40

737-800W/CFM56-7B26
 FAA
 Category C Brakes

Performance Inflight - QRH
 Advisory Information

737 Flight Crew Operations Manual

ADVISORY INFORMATION

Normal Configuration Landing Distance

Flaps 40

	LANDING DISTANCE AND ADJUSTMENTS (M)								
	REF DIST	WT ADJ	ALT ADJ	WIND ADJ	SLOPE ADJ	TEMP ADJ	APP SPD ADJ	REVERSE THRUST ADJ	
BRAKING CONFIGURATION	65000 KG LANDING WEIGHT	PER 5000 KG ABV/BLW 65000 KG	PER 1000 FT STD/HIGH*	PER 10 KTS HEAD/ TAIL WIND	PER 1% DOWN/ UP HILL	PER 10°C ABV/ BLW ISA	PER 5 KTS ABOVE VREF40	ONE REV	NO REV

Dry Runway

MAX MANUAL	915	55/-50	20/25	-35/115	10/-10	20/-20	35	15	35
AUTOBRAKE MAX	1135	55/-60	25/35	-40/140	0/0	25/-25	55	0	0
AUTOBRAKE 3	1590	85/-100	40/55	-70/235	0/0	45/-45	90	0	0
AUTOBRAKE 2	2030	125/-140	60/80	-95/330	20/-35	60/-60	95	35	35
AUTOBRAKE 1	2260	150/-165	75/95	-115/390	55/-65	65/-65	85	155	220

Good Reported Braking Action

MAX MANUAL	1270	70/-75	35/45	-55/200	35/-30	30/-30	50	65	140
AUTOBRAKE MAX	1350	75/-80	35/45	-60/205	30/-25	35/-35	60	70	150
AUTOBRAKE 3	1600	85/-100	40/55	-70/240	10/-5	45/-45	95	5	15
AUTOBRAKE 2	2030	125/-140	60/80	-95/330	20/-35	60/-60	95	35	35
AUTOBRAKE 1	2260	150/-165	75/95	-115/390	55/-65	65/-65	85	155	220

Medium Reported Braking Action

MAX MANUAL	1730	105/-115	50/70	-90/330	85/-65	45/-45	65	170	405
AUTOBRAKE MAX	1750	110/-120	55/70	-90/335	75/-60	45/-50	75	170	405
AUTOBRAKE 3	1800	110/-120	55/70	-95/340	70/-45	50/-50	90	150	390
AUTOBRAKE 2	2090	130/-145	60/85	-105/375	55/-55	60/-60	95	75	190
AUTOBRAKE 1	2275	150/-165	75/95	-115/405	80/-75	65/-65	85	170	275

Poor Reported Braking Action

MAX MANUAL	2245	155/-160	75/100	-140/520	200/-130	60/-65	75	360	930
AUTOBRAKE MAX	2250	155/-160	75/105	-140/520	200/-130	60/-65	75	360	930
AUTOBRAKE 3	2260	155/-165	75/105	-140/525	195/-125	60/-65	85	360	935
AUTOBRAKE 2	2370	160/-165	75/105	-140/535	185/-120	65/-70	90	290	830
AUTOBRAKE 1	2470	170/-180	80/110	-145/550	190/-130	70/-75	85	335	815

Reference distance is based on sea level, standard day, no wind or slope, VREF40 approach speed, two-engine detent No. 2 reverse thrust, and auto speedbrakes.

For max manual braking and manual speedbrakes, increase reference landing distance by 55 m.

For autobrake and manual speedbrakes, increase reference landing distance by 45 m.

Reference Distance includes an air distance allowance of 305 m from threshold to touchdown.

Actual (unfactored) distances are shown.

*For landing distance at or below 8000 ft pressure altitude, apply the STD adjustment. For altitudes higher than 8000 ft, first apply the STD adjustment to derive a new reference landing distance for 8000 ft then apply the HIGH adjustment to this new reference distance.

Source: Virgin Australia Airlines

Appendix E – Runway condition assessment matrix (RCAM)

TABLE 1-1. OPERATIONAL RUNWAY CONDITION ASSESSMENT MATRIX (RCAM) BRAKING ACTION CODES AND DEFINITIONS

Assessment Criteria		Control/Braking Assessment Criteria	
Runway Condition Description	RwyCC	Deceleration or Directional Control Observation	Pilot Reported Braking Action
<ul style="list-style-type: none"> Dry 	6	---	---
<ul style="list-style-type: none"> Frost Wet (Includes damp and 1/8 inch depth or less of water) <p>1/8 inch (3mm) depth or less of:</p> <ul style="list-style-type: none"> Slush Dry Snow Wet Snow 	5	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
<p>-15°C and Colder outside air temperature:</p> <ul style="list-style-type: none"> Compacted Snow 	4	Braking deceleration OR directional control is between Good and Medium.	Good to Medium
<ul style="list-style-type: none"> Slippery When Wet (wet runway) Dry Snow or Wet Snow (any depth) over Compacted Snow <p>Greater than 1/8 inch (3 mm) depth of:</p> <ul style="list-style-type: none"> Dry Snow Wet Snow <p>Warmer than -15°C outside air temperature:</p> <ul style="list-style-type: none"> Compacted Snow 	3	Braking deceleration is noticeably reduced for the wheel braking effort applied OR directional control is noticeably reduced.	Medium
<p>Greater than 1/8 inch(3 mm) depth of:</p> <ul style="list-style-type: none"> Water Slush 	2	Braking deceleration OR directional control is between Medium and Poor.	Medium to Poor
<ul style="list-style-type: none"> Ice 	1	Braking deceleration is significantly reduced for the wheel braking effort applied OR directional control is significantly reduced.	Poor
<ul style="list-style-type: none"> Wet Ice Slush over Ice Water over Compacted Snow Dry Snow or Wet Snow over Ice 	0	Braking deceleration is minimal to non-existent for the wheel braking effort applied OR directional control is uncertain.	Nil

Note: The unshaded portion of the RCAM is associated with how an airport operator conducts a runway condition assessment.

Note: The shaded portion of the RCAM is associated with the pilot's experience with braking action.

Note: The Operational RCAM illustration will differ from the RCAM illustration used by Airport Operators.

Note: Runway condition codes, one for each third of the landing surface, for example 4/3/3, represent the runway condition description as reported by the airport operator. The reporting of codes by runway thirds is expected to begin in October of 2016.

Source: Federal Aviation Administration

Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

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 operations involving the travelling public.

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 identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, 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 initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

Australian Transport Safety Bureau

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Linkedin [Australian Transport Safety Bureau](https://www.linkedin.com/company/atsb)

Investigation

ATSB Transport Safety Report Aviation Occurrence Investigation

Reduced braking effectiveness during landing involving
Boeing 737-800, VH-VOP, Christchurch, New Zealand on
11 May 2015

AO-2015-046

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